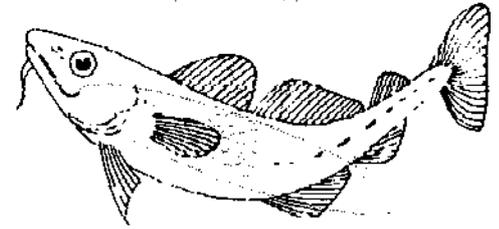


# AQUATIC ENVIRONMENT MONITORING REPORT

Number 45



## **Radioactivity in Surface and Coastal Waters of the British Isles, 1994**



**Directorate of Fisheries Research**  
Lowestoft, 1995



MINISTRY OF AGRICULTURE, FISHERIES AND FOOD  
DIRECTORATE OF FISHERIES RESEARCH

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Number 45

**Radioactivity in Surface and Coastal Waters  
of the British Isles, 1994**

LOWESTOFT  
1995

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## SUMMARY

1. Discharges of liquid radioactive wastes from major nuclear sites in the United Kingdom are controlled by enforcement authorities using powers in the Radioactive Substances Act, 1993. Discharges from all sites in 1994 were within the limits set by the authorities.
2. The Directorate of Fisheries Research operates a radioactivity monitoring programme throughout waters of the United Kingdom and adjacent seas to check the safety of these discharges. The programme is supported by the Ministry of Agriculture, Fisheries and Food, the Scottish Office, the Welsh Office, the Department of the Environment for Northern Ireland and the Channel Island States. The programme is a key component of the Government's strategy to protect the safety of the aquatic food chain, fisheries and the marine environment. A substantial part of the cost of the programme is recouped from industries discharging wastes from licensed nuclear sites, in accordance with the 'polluter pays' principle.
3. Measurements in 1994 included detection of beta and gamma dose rates in the environment and the analysis of samples of seafood and other materials from the environment. The results showed that radiation dose rates and radionuclide concentrations were generally similar to those in 1993. However, superimposed on the general downward trend in radionuclide concentrations due to Sellafield discharges, there were some changes in concentrations of particular radionuclides in the marine environment near Sellafield reflecting developments in operations at the site in 1994. These developments included processing of stored wastes, re-routing of activity from a gaseous waste stream and the operation of the Enhanced Actinide Removal Plant (EARP). The Thermal Oxide Reprocessing Plant (THORP) was being commissioned in 1994 and had little effect on discharges to sea and on the marine environment. The results of our monitoring have been interpreted in terms of public radiation exposures using data from habits surveys to establish 'critical groups' of people likely to be most exposed.
4. Public radiation exposures from discharges of liquid radioactive waste in 1994 are presented in the Summary Table. The exposures are expressed on two bases. For each exposed group, the 'committed effective dose equivalent' is given using the methodology of ICRP-26 and, when it is different, compared with results for 'committed effective dose' calculated on the basis of the more recently recommended methodology in ICRP-60. Where appropriate, doses to skin are also given. Both methods incorporate accepted values for gut transfer factors of transuranics, i.e. 0.0002 for winkles near Sellafield, 0.0005 in other cases. Exposures were all within the dose limit of 1 mSv for members of the public or the skin dose limit of 50 mSv as appropriate.
5. Exposures of high-rate fish and shellfish consumers due to artificial radionuclides near Sellafield decreased slightly in 1994, as compared with 1993, due to changes in radionuclide concentrations and seafood consumption rates. Exposures of people associated with fisheries at Whitehaven, Morecambe Bay and Fleetwood were similar in 1994 to exposures in 1993. Those associated with fisheries at Dumfries and Galloway reduced because of a reduction in the availability and consumption of molluscs.
6. Those most exposed to external radiation in connection with discharges from Sellafield continued to be a small group of houseboat dwellers in the Ribble estuary. Their dose in 1994 was 0.14 mSv, a reduction from 0.26 for 1993 due to reduced gamma dose rates on the boat in the estuary. In the Sellafield vicinity, a group of anglers who also dig for bait received a dose of 0.11 mSv in 1994. All external exposures were well within the dose limit of 1 mSv.
7. Concentrations in seafood of the key radionuclides discharged from Whitehaven Works (Albright and Wilson Ltd) have reduced in 1994, as expected, due to reductions in discharges. As a consequence, exposures of the critical group of fish and shellfish consumers due to the enhancement of concentrations of natural radionuclides have reduced substantially. On the basis of ICRP-26 methodology and taking an upper estimate of the gut transfer of polonium, the dose in 1994 was cautiously estimated to be 0.64 mSv compared with 0.93 mSv in 1993 (ICRP-60: 0.34 mSv and 0.48 mSv respectively). Further reductions in concentrations of radionuclides in shellfish are expected in 1995.

8. The collective dose to the UK and other European populations in 1994 was 5 and 22 man-Sv respectively, similar to the values for 1993. These data exclude the effects of Chernobyl on Baltic Sea fish. The most significant waste discharges giving rise to collective dose were those of radiocaesium from Sellafield. The effects of the Chernobyl accident on Baltic Sea fish on the UK population was small, but they would have added a further 60 man-Sv to the collective dose to other European countries.
-

**Summary Table: Estimates of public radiation exposure from discharges of liquid radioactive waste in the UK, 1994**

Establishment	Radiation exposure pathway	Critical group	Exposure, mSv	
			ICRP-26 <sup>e</sup>	ICRP-60 <sup>+</sup>
<b>British Nuclear Fuels plc</b>				
Sellafield and Drigg <sup>x</sup>	Fish and shellfish consumption	Local fishing community	0.14	0.08
	External	Houseboat dwellers (River Ribble)	0.14	0.14
	External <sup>d</sup>	Fishermen (Whitehaven)	0.10	0.10
	"	Anglers	0.11	0.11
	External	"	0.60 <sup>#</sup>	0.60 <sup>#</sup>
Springfields	Handling of fishing gear	Local fishing community	0.34 <sup>#</sup>	0.34 <sup>#</sup>
	Porphyra/laverbread consumption	Consumers in South Wales	<0.005	<0.005
Capenhurst	External	Houseboat dwellers (River Ribble)	0.14 <sup>a</sup>	0.14 <sup>a</sup>
	" (skin)	Wildfowling	0.02 <sup>b</sup>	0.03 <sup>b</sup>
Chapelcross	External	Anglers	1.8 <sup>#</sup>	1.8 <sup>#</sup>
	Inadvertent ingestion of sediment	Local community	<0.005	<0.005
" )	Fish and shellfish consumption	Local fishermen	0.03 <sup>a</sup>	0.03 <sup>a</sup>
	External			
	Wildfowling	Local fishermen	0.02 <sup>a</sup>	0.02 <sup>a</sup>
" )	Handling of fishing gear		0.05 <sup>a</sup>	0.05 <sup>a</sup>
<b>United Kingdom Atomic Energy Authority</b>				
Harwell )	Fish consumption	Anglers	0.009	0.009
	External			
Winfrith	Fish and shellfish consumption	Local fishing community	<0.005 <sup>b</sup>	<0.005 <sup>b</sup>
Dounreay )	Handling of fishing gear	Local fishermen	0.16 <sup>#b</sup>	0.16 <sup>#b</sup>
	External	Local community	0.008 <sup>b</sup>	0.008 <sup>b</sup>
	Fish and shellfish consumption	Local fishing community	<0.005 <sup>b</sup>	<0.005 <sup>b</sup>
	Mollusc consumption	Mollusc collectors	0.03 <sup>b</sup>	0.03 <sup>b</sup>
	External			
<b>Nuclear Power Stations Operated by the Electricity Companies</b>				
Berkeley and Oldbury )	Fish and shellfish consumption	Local fishing community	<0.005 <sup>b</sup>	<0.005 <sup>b</sup>
	External			
Bradwell )	Fish and shellfish consumption	Houseboat dwellers	0.01 <sup>b</sup>	0.01 <sup>b</sup>
	External			
Dungeness )	External	Bait diggers	<0.005 <sup>b</sup>	<0.005 <sup>b</sup>
	Fish and shellfish consumption			
Hartlepool	Fish and shellfish consumption	Local fishing community	<0.005 <sup>b</sup>	<0.005 <sup>b</sup>
Heysham )	Fish and shellfish consumption	Local fishermen	0.13 <sup>a</sup>	0.08 <sup>a</sup>
	External			
Hinkley Point )	Fish and shellfish consumption	Local fishing community	0.007 <sup>b,e</sup>	0.007 <sup>b,e</sup>
	External			
Hunterston )	Fish and shellfish consumption	Local fishing community	0.02 <sup>a</sup>	0.01 <sup>a</sup>
	External			
Sizewell )	Fish and shellfish consumption	Local fishing community	<0.005 <sup>b</sup>	<0.005 <sup>b</sup>
	External			
Torness	Fish and shellfish consumption	Local fishing community	<0.005 <sup>a</sup>	<0.005 <sup>a</sup>
	External	Shellfish collectors	<0.005 <sup>a</sup>	<0.005 <sup>a</sup>
Trawsfynydd )	Fish consumption	Local fishing community	0.03	0.03
	External			
Wylfa )	Fish and shellfish consumption	Local fishing community	0.01 <sup>a</sup>	0.009 <sup>a</sup>
	External			
<b>Defence Establishments</b>				
Aldermaston )	Fish consumption	Anglers	<0.005	<0.005
	External			
Barrow	External	Local community	0.03 <sup>a</sup>	0.03 <sup>a</sup>
Chatham	External	Houseboat dwellers	0.006 <sup>b</sup>	0.006 <sup>b</sup>
Devonport )	Fish and shellfish consumption	Local community	0.01 <sup>b</sup>	0.01 <sup>b</sup>
	External			
Faslane	External	Boatyard workers	0.007 <sup>b</sup>	0.007 <sup>b</sup>
Rosyth	External	Dredgermen	0.02 <sup>a</sup>	0.02 <sup>a</sup>
Holy Loch	External	Local community	<0.005 <sup>a</sup>	<0.005 <sup>a</sup>
<b>Amersham International plc</b>				
Amersham )	Fish consumption	Anglers	<0.005	<0.005
	External			
Cardiff )	Fish and shellfish consumption	Local fishing community	0.01 <sup>b</sup>	0.01 <sup>b</sup>
	External			
<b>Albright and Wilson Ltd</b>				
Whitehaven <sup>c</sup>	Fish and shellfish consumption	Local fishing community	0.64	0.34

<sup>e</sup> Unless otherwise stated, represents the committed effective dose equivalent calculated using the methodology of ICRP-26, to be compared with the dose limit of 1 mSv. (see sub-section 3.3)

<sup>#</sup> Exposure to skin including a component due to natural sources of beta radiation, to be compared with the dose limit of 50 mSv (see sub-section 3.3)

<sup>a</sup> Mainly due to discharges from Sellafield

<sup>b</sup> Partly due to discharges from Sellafield

<sup>+</sup> Unless otherwise stated, represents committed effective dose calculated using methodology of ICRP-60 to be compared with the dose limit of 1mSv (see sub-section 3.3)

<sup>x</sup> These estimates include the effects of discharges from Drigg, but exclude the effects of natural radionuclides. The contribution due to Drigg is negligible. The exposure due to enhanced concentrations of natural radionuclides in 1994 was 0.63 mSv (on the basis of ICRP-60: 0.34 mSv)

<sup>c</sup> These estimates include the effects of enhanced concentrations of natural radionuclides but exclude a small contribution from the effects of artificial radionuclides from other sites. They assume a gut uptake factor of 0.8 for polonium which is based on studies at this laboratory (see Section 11). The exposure due to artificial radionuclides in 1994 was 0.04 mSv (on the basis of ICRP-60: 0.03 mSv)

<sup>d</sup> Includes a small contribution due to consumption

<sup>e</sup> Excludes the effects of direct radiation from the reactors



# 1. INTRODUCTION

This report presents the results of the environmental monitoring programme carried out during 1994 by staff of the Ministry of Agriculture, Fisheries and Food's (MAFF's) Directorate of Fisheries Research (DFR), Lowestoft. This programme, together with the Terrestrial Radioactivity Monitoring Programme (TRAMP) (MAFF, 1994) and the programme operated by Her Majesty's Inspectorate of Pollution (HMIP, 1994) supports statutory functions under the Radioactive Substances Act, 1993 (United Kingdom – Parliament, 1993) (replacing the Radioactive Substances Act, 1960 (United Kingdom – Parliament, 1960)). The DFR programme is set up to verify the satisfactory control of liquid radioactive waste discharges to the aquatic environment, and to ensure that the resulting public radiation exposure is within nationally-accepted limits. The monitoring is independent of similar programmes carried out by nuclear site operators as a condition of their authorisations to discharge radioactive wastes. This report includes results of monitoring carried out on behalf of the Scottish Office, the Welsh Office, the Department of the Environment for Northern Ireland, and the Channel Islands States. Where appropriate, the monitoring data are supplemented by results from our programme of research into the behaviour of radioactivity in the aquatic environment.

To set the monitoring results from our regular programme in context, liquid radioactive discharges from UK nuclear establishments to the aquatic environment in 1994 are first summarised. Before the results are presented, an explanatory section gives details of methods of analysis and presentation and a sub-section explains how results are interpreted in terms of public radiation exposures.

## 2. DISCHARGES OF RADIOACTIVE WASTE

Data on radioactive waste discharges are published annually by the Department of Environment (Department of the Environment, 1995), the latest available data being for the year 1993. Details of the 1994 discharges are not yet available, but a summary is included here. This enables the results of environmental monitoring presented in this report to be considered in the context of the relevant discharges.

### 2.1 Liquid radioactive waste

Table 1 lists the principal discharges of liquid radioactive waste from UK nuclear establishments during 1994. The locations of these establishments are shown in Figure 1. Table 1 also lists the discharge limits which are authorised or, in the case of Crown operators,

administratively agreed. In some cases, the authorisations specify limits in greater detail than can be summarised in a single table: in particular, periods shorter than one year are specified at a few sites. The authorised limits are usually very much lower than the levels of activities which could be released without exceeding the dose limits which are recommended by the International Commission on Radiological Protection (ICRP), and embodied in national policy (United Kingdom – Parliament, 1995). The percentages of the authorised (or agreed) limits taken up in 1994 are also stated in Table 1.

For completeness, it should be noted that in addition to the nuclear establishments listed in Table 1, MAFF is jointly responsible with HMIP for authorising disposals of liquid wastes from ICI, Billingham in Cleveland, Imperial College, Silwood Park in Berkshire, Rolls Royce, Derby in Derbyshire, AEA, Risley in Cheshire, MOD, Greenwich in London and MOD Burghfield in Berkshire. Data on authorised limits and quantities of waste discharged for these sites are available on request. The amounts discharged are very small and there is no requirement for routine environmental monitoring of these minor sites by DFR.

### 2.2 Solid radioactive waste

In addition to receiving most of the above liquid discharges, the marine environment has also received packaged solid waste of low specific activity, mainly disposed of in an area of the deep Atlantic Ocean. The most recent such disposal was in 1982. The environmental impact of these disposals is determined by mathematical modelling and has been shown to be negligible (OECD (NEA), 1985).

## 3. METHODS OF ANALYSIS AND OF PRESENTATION AND INTERPRETATION OF RESULTS

### 3.1 Summary of analytical methods

Although some of the analytical methods which we have used are detailed elsewhere as referenced in this sub-section, a very brief summary is given here in support of the measurements and the method of their presentation. The tables of results mostly include measurements of specific gamma-emitting nuclides. Beta emitters and alpha emitters (including transuranics) are also measured in appropriate cases.

Gamma-emitting nuclides are analysed by gamma spectrometry (Sutton, 1993). This is carried out using both NaI(Tl) and Ge detectors, calibrated using suitable reference sources. The spectra are reduced by computer-aided techniques to give radioactivity concentrations of

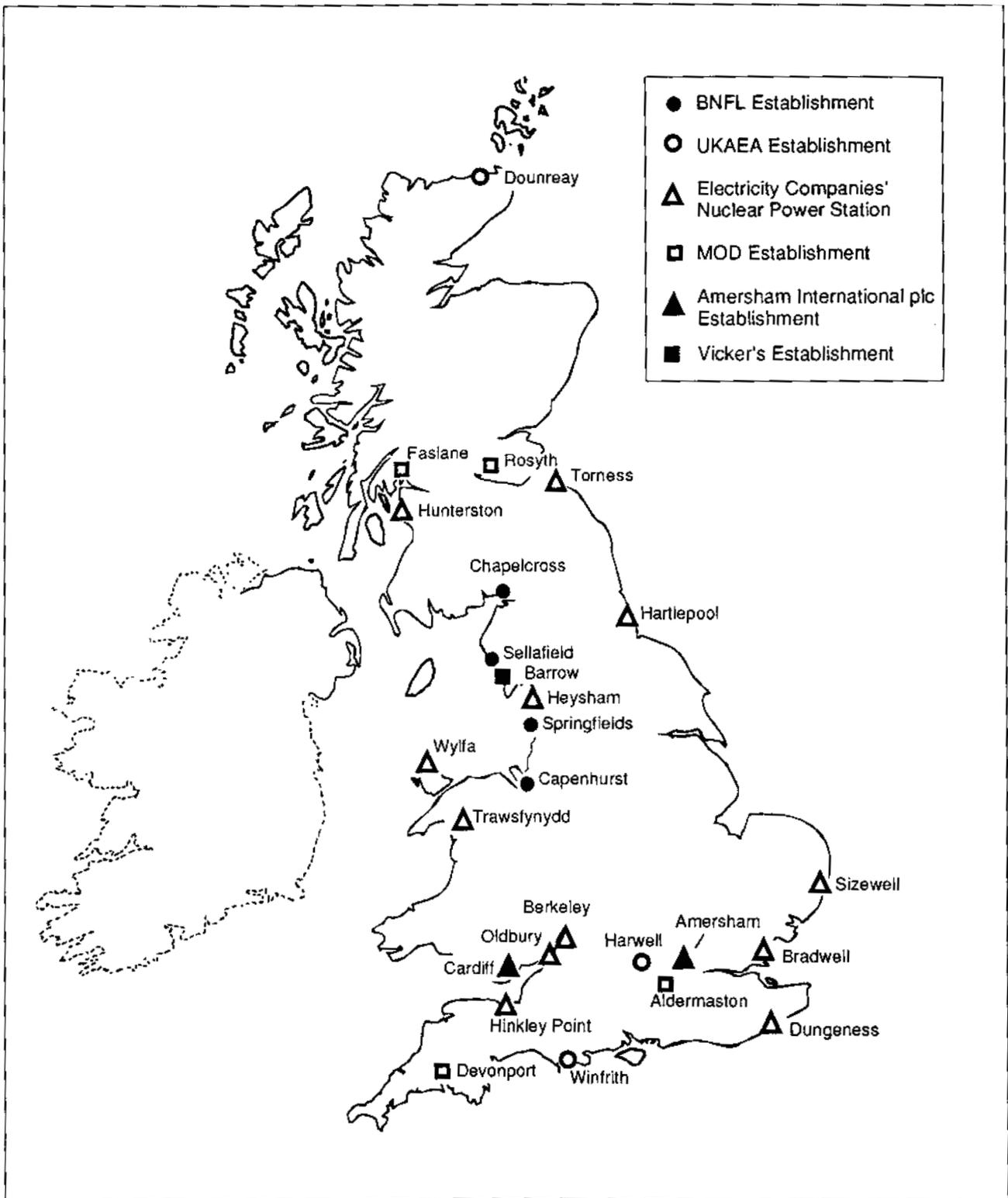


Figure 1. UK nuclear establishments giving rise to principal discharges of liquid radioactive waste

**Table 1. Principal discharges of liquid radioactive waste from UK nuclear establishments, 1994**

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1994	
			TBq <sup>(12)</sup>	% of limit <sup>(13)</sup>
<b>British Nuclear Fuels plc</b>				
Sellafield <sup>19</sup> Sea pipelines	Total alpha	4.7	1.04	22
	Total beta	400	126	31
	Tritium	31000	1680	5.4
	Carbon-14	20.8	8.16	39
	Cobalt-60	13	0.113	<1
	Strontium-90	30	28.9	96
	Zirconium-95+Niobium-95	50	3.24	6.5
	Technetium-99	200	72.0	36
	Ruthenium-106	75	6.75	9.0
	Iodine-129	2	0.157	7.8
	Caesium-134	6.6	0.611	9.3
	Caesium-137	75	13.8	18
	Cerium-144	10	0.836	8.4
	Plutonium alpha	4	0.663	17
	Plutonium-241	150	14.4	9.6
Americium-241	1.3	0.381	29	
Uranium <sup>20</sup>	2040	1388	68	
Factory sewer	Total alpha	0.0033	0.000067	2.0
	Total beta	0.0135	0.00061	4.5
	Tritium	0.132	0.0177	13
Drigg Sea pipeline	Total alpha	0.1	0.00116	1.2
	Total beta <sup>1</sup>	0.3	0.0246	8.2
	Tritium	120	2.24	1.9
Stream <sup>17</sup>	Total alpha	9 10 <sup>4</sup>	137	<1
	Total beta <sup>1</sup>	1.2 10 <sup>6</sup>	977	<1
	Tritium	6 10 <sup>8</sup>	2.1 10 <sup>5</sup>	<1
Springfields	Total alpha	4	0.158	4.0
	Total beta	240	114	47
	Technetium-99	0.6	0.0159	2.7
	Thorium-230	2	0.0902	4.5
	Thorium-232	0.2	0.0014	<1
	Neptunium-237	0.04	0.00019	<1
	Uranium	0.15	0.0553	37
Capenhurst Rivacre Brook	Uranium	0.02	0.00106	5.3
	Uranium daughters	0.02	0.0066	33
	Non-uranic alpha	0.003	0.0000461	1.5
	Technetium-99	0.1	0.00335	3.4
Meols outfall	Technetium-99	0.148	Nil	Nil
	Others	0.00148	“	“
Chapelcross	Total alpha	0.1	0.00084	<1
	Total beta <sup>1</sup>	25	0.307	1.2
	Tritium	5.5	0.485	8.9
<b>United Kingdom Atomic Energy Authority</b>				
Harwell (pipeline)	Total alpha	0.001	0.000103	10
	Total beta <sup>1</sup>	0.02	0.00467	23
	Tritium	4	0.503	13
	Cobalt-60	0.007	0.00091	13
	Caesium-137	0.007	0.00055	7.9
Harwell (Lydebank Brook)	Total alpha	0.0005	0.0000858	17
	Total beta <sup>1</sup>	0.002	0.000507	25
	Tritium	0.1	0.054	54
Winfrith (inner pipeline)	Total alpha	0.3	0.00209	<1
	Tritium	650	57.0	8.8
	Cobalt-60	10	0.00697	<1
	Zinc-65	6	0.00022	<1
	Other radionuclides	80	0.0556	<1
Winfrith (outer pipeline)	Total alpha	0.004	0.000151	3.8
	Tritium	1	0.0387	3.9
	Other radionuclides	0.01	0.000239	2.4
Dounreay	Total alpha <sup>4</sup>	0.75	0.103	14
	Total beta <sup>1</sup>	110	8.97	8.2
	Tritium	130	3.22	2.4
	Cobalt-60	1	0.010	1.0
	Strontium-90	12	1.60	13
	Zirconium-95+Niobium-95	6	0.012	<1
	Ruthenium-106	12	0.355	3.0
	Silver-110m	0.4	0.0068	1.7
	Caesium-137	50	4.70	9.4
	Cerium-144	12	0.0264	<1
	Plutonium-241	15	0.945	6.3
	Curium-242	1	0.0007	<1

**Table 1. continued**

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1994	
			TBq <sup>(12)</sup>	% of limit <sup>(13)</sup>
<b>Nuclear Electric plc</b>				
Berkeley	Tritium	8	0.0292	<1
	Caesium-137	0.2	0.0463	23
	Other radionuclides	0.4	0.0974	24
Bradwell	Tritium	30	2.17	7.2
	Caesium-137	0.75	0.316	42
	Other radionuclides	1	0.406	41
Dungeness <sup>2</sup> 'A' Station	Total activity <sup>1</sup>	7.4	0.401	11
	Tritium	74	0.0878	<1
	Tritium	35	0.0828	<1
	Caesium-137	1.2	0.185	31
	Other radionuclides	1.4	0.143	21
	'B' Station	Total activity <sup>1,5</sup>	4	0.0359
Tritium		650	342	53
Sulphur-35		25	0.738	2.9
Tritium		650	65.7	20
Hartlepool	Sulphur-35	2	0.163	16
	Cobalt-60	0.03	0.0024	16
	Other radionuclides	0.25	0.0225	18
	Tritium	1850	289	16
Heysham Station 1	Sulphur-35	8	0.446	5.6
	Other radionuclides	4	0.0104	<1
	Tritium	1850	376	20
Station 2	Sulphur-35	7.5	0.557	7.4
	Other radionuclides	4	0.00866	<1
	Tritium	1200	356	30
	Sulphur-35	7	0.0836	1.2
Hinkley Point 'A' Station	Cobalt-60	0.036	0.000777	2.2
	Other radionuclides	0.45	0.0428	9.5
	Tritium	25	0.712	2.9
	Caesium-137	1.5	0.486	32
'B' Station	Other radionuclides	1	0.237	24
	Tritium	650	336	52
	Sulphur-35	2	1.36	68
	Cobalt-60	0.035	0.00126	3.6
Oldbury	Other radionuclides	0.25	0.0201	8.1
	Tritium	25	0.263	1.1
	Caesium-137	0.7	0.045	6.4
	Other radionuclides	1.3	0.345	27
Sizewell <sup>18</sup>	Tritium	7.4	0.106	3.4
	Tritium	111	2.14	4.6
	Tritium	35	1.43	7.0
	Caesium-137	1.0	0.057	9.8
Trawsfynydd	Other radionuclides	0.7	0.129	32
	Total activity <sup>1,7,16</sup>	0.72	0.0123	1.7
	Tritium	12	0.121	1.0
	Strontium-90	0.08	0.00220	2.7
Wylfa	Caesium-137	0.05	0.0094	19
	Tritium	40	6.98	17
Other radionuclides		0.15	0.0539	36
<b>Scottish Nuclear Ltd</b>				
Hunterston 'A' Station	Total activity <sup>1</sup>	2	0.209	10
	Tritium	5	0.195	3.9
'B' Station	Total activity <sup>1,5</sup>	3.7	0.0315	<1
	Tritium	1480	423	29
	Sulphur-35	26	1.54	5.9
Torness	Total alpha	0.0045	0.0000814	<1
	Beta activity <sup>1,5,8</sup>	0.45	0.00117	<1
	Tritium	1200	220	18
	Sulphur-35	10	0.0189	<1
	Cobalt-60	0.05	0.000255	<1

**Table 1. continued**

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1994	
			TBq <sup>(12)</sup>	% of limit <sup>(13)</sup>
<b>Ministry of Defence</b>				
Aldermaston (pipeline) <sup>6</sup>	Alpha activity	0.00015	0.00000907	6.1
	Tritium	0.05	0.0284	57
	Plutonium-241	0.0006	0.0000363	6.1
	Other radionuclides	0.00015	0.00000955	6.4
Aldermaston (Silchester) <sup>6</sup>	Alpha activity	0.0001	0.0000137	14
	Beta activity	0.0003	0.0000477	16
Barrow <sup>3</sup>	Tritium	0.02	9.54 10 <sup>-4</sup>	4.8
	Manganese-54	2.5 10 <sup>-7</sup>	1.39 10 <sup>-8</sup>	5.6
	Cobalt-58	7 10 <sup>-7</sup>	1.17 10 <sup>-8</sup>	1.7
	Cobalt-60	7 10 <sup>-8</sup>	3.11 10 <sup>-8</sup>	44
	Tin-113	2.5 10 <sup>-7</sup>	1.46 10 <sup>-8</sup>	5.8
	Antimony-124	2 10 <sup>-6</sup>	8.31 10 <sup>-9</sup>	<1
	Other radionuclides	3.5 10 <sup>-6</sup>	6.38 10 <sup>-8</sup>	1.8
Devonport <sup>9,15</sup> (sewer)	Total beta		1.88 10 <sup>-6</sup>	
	Tritium		1.60 10 <sup>-6</sup>	
	Cobalt-60		5.37 10 <sup>-7</sup>	
Devonport <sup>9,15</sup> (river)	Total beta		6.38 10 <sup>-6</sup>	
	Tritium		6.58 10 <sup>-6</sup>	
	Cobalt		1.10 10 <sup>-6</sup>	
Devonport <sup>14,15</sup> (sewer)	Total activity		0.000933	
	Cobalt-60		0.000684	
Devonport <sup>14</sup> (pipeline)	Total activity <sup>1,8</sup>	0.002	0.000184	9.2
	Tritium	0.12	0.0669	56
	Cobalt-60	0.016	0.000184	1.2
Faslane	Alpha activity	0.0005	0.0000192	3.8
	Beta activity <sup>1,8</sup>	0.0002	0.000115	58
	Tritium	1	0.113	11
	Cobalt-60	0.0005	0.000064	13
Rosyth <sup>10</sup>	Total alpha	1 10 <sup>-6</sup>	4.7 10 <sup>-7</sup>	40
	Beta activity <sup>1,8</sup>	0.01	0.00029	2.9
	Tritium	0.01	0.00806	81
	Cobalt-60	0.055	0.00067	1.2
<b>Amersham International plc</b>				
Amersham	Total alpha	0.0003	0.0000725	24
	Beta >0.4 MeV	0.1	0.0103	10
	Tritium	0.2	0.0115	5.7
	Iodine-125	0.2	0.0444	22
	Caesium-137	0.005	0.0000435	<1
	Other radionuclides	0.3	0.112	37
Cardiff	Beta/gamma activity <sup>11</sup>	0.096	0.0173	18
	Tritium	1400	535	38
	Carbon-14	2	1.06	53

<sup>1</sup> Excluding tritium

<sup>2</sup> Authorisation was revised with effect from 1 July 1994. The first block of data relates to the period 1 January 1994 to 30 June 1994; the second block of data relates to the period 1 July 1994 to 31 December 1994. '% limit' refers to equivalent limit for 6 months

<sup>3</sup> Discharges from Barrow are included with those from MoD sites because they are related to submarine activities.

Discharges are made by Vickers Shipbuilding and Engineering Ltd

<sup>4</sup> Excluding curium-242

<sup>5</sup> Excluding sulphur-35

<sup>6</sup> Discharges are made by Hunting-BRAE Ltd

<sup>7</sup> Excluding caesium-137

<sup>8</sup> Excluding cobalt-60

<sup>9</sup> Discharges are made by the Ministry of Defence

<sup>10</sup> Discharges are made by Babcock Rosyth Defence Ltd

<sup>11</sup> Excluding tritium, carbon-14 and radioisotopes of calcium and strontium

<sup>12</sup> Some discharges are upper estimates because they include 'less than' data derived from analyses of effluents at limits of detection.

Data quoted to 3 significant figures except where fewer significant figures are provided in source documents.

<sup>13</sup> Data quoted to 2 significant figures except when values are less than 1%

<sup>14</sup> Discharges are made by Devonport Management Ltd

<sup>15</sup> The authorisation is a limit on concentration of total activity of 4 10<sup>-6</sup> TBq m<sup>-3</sup>. At no time did the concentration exceed the limit. The quantity discharged is expressed in TBq in 1994

<sup>16</sup> Excluding strontium-90

<sup>17</sup> Discharges and limits are expressed in terms of concentrations of activity in Bq m<sup>-3</sup>

<sup>18</sup> Authorisation was revised with effect from 1 June 1994. The first block of data relates to the period 1 January 1994

to 31 May 1994; the second block of data relates to the period 1 June 1994 to 31 December 1994. '% limit' refers to

equivalent limit for 5 and 7 months respectively

<sup>19</sup> Authorisation was revised with effect from 17 January 1994. The discharge data are those for the whole year

<sup>20</sup> The limit and discharge data are expressed in kg

detected nuclides. For samples of biota and sediments, searches are routinely made for, amongst others, the artificial gamma emitters listed in Table 2. In the tables of results for these samples, the absence of a column for any of these nuclides indicates non-detectability in each sample in that table. Otherwise, non-detectability is indicated by 'ND'. Approximate detection limits for these nuclides under typical conditions are listed in Table 2; however, these conditions may vary, sometimes significantly. Therefore, the decision on whether the radionuclide content of a sample is 'not detectable' is based on the calculated error in the result for that sample. Natural radionuclides are not normally reported in the tables unless there is reason to believe that waste discharges may have increased their levels in the environment.

Pure beta emitters, such as carbon-14, sulphur-35, strontium-90, technetium-99, promethium-147 and plutonium-241, but not tritium, are chemically separated from samples before beta counting (Harvey *et al.*, 1989, 1991, 1992). Alpha-emitting thorium, uranium and transuranic nuclides are chemically separated and analysed by alpha spectrometry using silicon surface-barrier detectors (Baker, 1984; Harvey and Thurston, 1988; Lovett *et al.*, 1990). Thorium-234 is analysed by reference to the activity of protactinium-234m using gamma spectrometry. Radiochemical procedures are generally labour-intensive and are carried out on samples in which these nuclides are of particular relevance, often on an annual bulk (sub-section 3.2). Detection limits are usually much lower for radionuclides analysed using these procedures than for gamma-emitting radionuclides.

Analyses are made of tritium and caesium isotopes in water. The method for tritium is to distil the sample twice and count the distillate by liquid scintillation. For caesium isotopes, water samples are passed through cartridges containing ammonium-duodecamolybdo-phosphate on silica gel (ASG) to absorb the caesium. The cartridges are subsequently counted using a gated NaI well crystal detector system.

Total beta radioactivity is measured using thin sources with a potassium-40 standard (Dutton, 1968). The efficiency of the method is nearly constant over a wide range of beta energies and the result gives a measure of the total radioactivity of the beta emitters present, including natural radioactivity. However, agreement with the total as derived from isotopic analysis is not expected to be exact. The number of measurements of total beta radioactivity was reduced in 1994 because the results are of limited usefulness in assessments of radiation exposure. Nevertheless, a small programme at each site was continued to provide reassurance that no beta-emitting radionuclides of significance have been neglected. In addition the total beta measurements were

**Table 2. Artificial gamma-emitting radionuclides routinely analysed and approximate limits of detection**

Radionuclide	Approximate limit of detection*, Bq kg <sup>-1</sup>
Manganese-54	0.2
Cobalt-58	0.3
Iron-59	0.5
Cobalt-60	0.2
Zinc-65	0.4
Zirconium-95	0.5
Niobium-95	0.5
Ruthenium-106	1.0
Silver-110m	0.5
Antimony-125	0.4
Caesium-134	0.1
Caesium-137	0.1
Cerium-144	1.0
Europium-154	1.0
Europium-155	1.0
Americium-241	1.0#

\* Under typical conditions of counting; these may vary in practice

# When analysed by alpha spectrometry, much lower limits are achieved

carried out quickly in order to give an early warning of any change in radioactivity concentrations which might require further investigation.

With the exception of total beta analyses, radioactive decay of radionuclides is taken into account by correcting the activity measured at the time of counting to a value representing the activity in the sample at the time of collection. A decay correction for total beta analyses is not carried out because the activity measured is due to a mixture of several radionuclides each with different half-lives and samples are generally counted soon after collection as indicated above. For the relatively short-lived radionuclides protactinium-233 and thorium-234, the ingrowth of activity from their parent radionuclides is also taken into account when deriving the activity in the sample at the time of collection. In keeping with normal practice, the concentrations of very short-lived (< 3 days) radionuclides which are supported by their parents are not reported in the tables. However, the concentrations of parents are quoted and it can be assumed that the concentrations of the daughter products are approximately equal to those of the parents. Examples of such very short-lived radionuclides are 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.

Measurements of gamma dose in air over intertidal areas are normally made at 1 m above the ground using Mini Instruments\* environmental radiation meters type 6-80 with compensated G-M tubes type MC-71. When

\* The reference to proprietary products in this report should not be construed as an official endorsement of these products, nor is any criticism implied of similar products which have not been mentioned

the human activity resulting in exposure justifies it, for example for people living on boats or for wildfowls 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 contamination monitors. These portable instruments are calibrated against recognised reference standards.

The quality of the analyses is maintained through the use of quality assurance procedures. For measurements of concentrations in materials, the procedures include (i) working to a defined scheme (Standard Operating Procedure) which is written down and used in staff training, (ii) calibration using nationally traceable standards, (iii) regular performance checks using internal standards and (iv) participation in national and international intercomparison exercises. Similar procedures are used to maintain the quality of beta and gamma dose rate measurements.

### **3.2 Methods of presentation of measurements**

The tables of monitoring results contain summarised values of observations obtained during the year under review. The data are generally quoted to two significant figures but it should be noted that values near to the limits of detection will not have the precision implied by using two significant figures. Observations of a given quantity may vary throughout the year; in general, any variations are larger than the analytical errors inherent in the observations. The variations may, for example, be due to changes in rates of discharge or to different conditions in the receiving environment. The presentation of the summarised results reflects the purpose of this monitoring which is interpretation in terms of public radiation exposures. The method of interpretation is described more fully in sub-section 3.3. The appropriate integration period for comparison with recommended limits is one year; standard practice is to combine annual rates of consumption or occupancy of the small group of people who are the most exposed (the critical group) with the arithmetic means of observed radioactivity concentrations or dose rates, respectively, during the year. The use of, for example, the highest observed (but unsustainable) radioactivity concentration with an annual consumption rate would not provide a realistic basis for comparison with the recommended limits. Therefore, the tables present the arithmetic means of observations made during the year.

The frequency of sampling reflects the resolution (which affects the accuracy) judged to be necessary in the assessment of dose and is largely governed by the radiological importance. The tables indicate the number of sampling observations carried out during the year. Observations on biota consist of the results of analysing suitably large samples of material; for fish and shell-

fish, the intent is to sample and analyse a sufficient number of individual animals for each observation so as to allow for statistical variations. The number of individuals sampled also reflects the radiological importance. Thus, as in previous years, the number of individual animals in a sample varies – from one for some fish species to several hundred for molluscs from near Sellafield. For external beta and gamma dose rates, each observation consists of the mean of a number of individual readings at a given location. The locations or materials chosen are generally those where there is likely to be occupancy or handling by persons as determined by habits surveys (see sub-section 3.3).

Analyses requiring radiochemical separation may be carried out on individual samples directly or on bulks made up of a number of individual samples collected over an extended period; in tables combining the results of gamma spectrometry and radiochemical analysis the extended period is one year.

Measurements on biota are given in terms of concentrations of activity in wet material. For sediments, whose water content is more variable, dry concentrations are given. For fish and shellfish, the concentrations apply to the edible parts, because the purpose of measurement is assessment of internal exposure of the consumer. Where our surveys of consumption habits indicate that there is a preference for one portion of the edible part, e.g. shrimp flesh rather than shrimp tails then the measurement refers to that portion. Most of our samples of fish species are not skinned. However, some species have tough skins, e.g. eels, pike and dogfish, and we remove their skin prior to analysis so as to reflect consumption habits.

Shrimps are prepared with both shell on and off depending on the location of collection. Otherwise shells of shellfish are discarded prior to analysis. Most samples of shellfish are cooked by boiling in water soon after collection in order to simulate the habits of consumers. This practice tends to avoid losses of activity from the digestive gland prior to analysis. For a few radionuclides, some activity may be lost in the cooking process. However these losses are to be expected in the normal cooking process for these species. The concentrations presented in the tables therefore represent those to be found in the diet of consumers in critical groups.

Measurements of radionuclides other than tritium in water refer to the volume of filtered water. Filtration takes place through 0.45 µm filter papers.

The results for certain measurements, particularly total beta and carbon-14 radioactivity concentrations and beta and gamma dose rates, include a contribution due to natural radioactivity. Further analysis of samples (usually by gamma spectrometry) indicates the component of total beta radioactivity which is due to artificial sources and the component due to natural radionuclides

(mainly potassium-40 and the decay products of uranium and thorium). In the case of gamma dose rates, an indication of the natural background component can be gained from measurements at similar locations which are remote from nuclear activities or from experience before these activities began. Table 3 lists representative values to be expected from natural sources of natural radioactivity. The methods used to account for natural radioactivity in dose assessments are described in sub-section 3.3.

**Table 3. Concentrations of natural radioactivity in various environmental materials and dose rates for natural background around the British Isles**

Material	Total beta radioactivity concentration (wet)*, Bq kg <sup>-1</sup>	Comments
Fish	40 to 100	Mostly <sup>40</sup> K
Shellfish	40 to 100	"
Seaweed	200 to 600	"
Sand	200 to 400	<sup>40</sup> K and decay products of U and Th
Mud	700 to 1000	"

Gamma dose rates in air over intertidal sediments: 0.03-0.1 μGy h<sup>-1</sup>

\*Except sediments for which dry concentrations apply

Tables of results in the main text of this report refer to 1994. However, tables of selected results spanning the six-year period 1989-94 are included in Appendix 3 for ease of reference when analysing the change of concentrations and dose rates in time. Where appropriate, comments on trends in environmental concentrations and dose rates are made in the main text.

### 3.3 Method of interpretation of results

The monitoring results in this report are interpreted in terms of radiation exposures of the public. The standards against which these exposures are judged are embodied in national policy on radioactive waste (United Kingdom – Parliament, 1995). The National Radiological Protection Board (NRPB) advises the UK Government on appropriate standards, including the recommendations of the ICRP. Current UK practice relevant to the general public is based on the recommendations of the ICRP as set out in ICRP Publications 26 (ICRP, 1977) and 60 (ICRP, 1991). The Euratom Directive on basic radiation safety standards (Commission of the European Communities, 1980), with which UK legislation complies, is based on the recommendations of ICRP-26, but is being revised to take account of the changes in radiological protection criteria recommended in ICRP-60; new Euratom basic safety standards will be promulgated in due course. The International Atomic Energy Agency (IAEA) and its related

inter-governmental organisations have now published their own, revised, Basic Safety Standards for Radiation Protection based on ICRP-60 (IAEA, 1994).

Both the ICRP-26 and ICRP-60 dose limitation systems for practices involving radiation include, within appropriate dose limits to individuals, the requirement that ‘all exposures shall be kept as low as reasonably achievable...’ (ALARA). This requirement involves consideration of collective, as well as individual, doses in radiological control procedures. As in previous reports in this series, collective doses from liquid radioactive waste discharges continue to be kept under review. The ICRP and the NRPB do not recommend a dose limit for populations; such a limit might be regarded as suggesting the acceptability of a higher population exposure than may be either necessary or probable. For reference purposes in this report, collective doses, averaged over the UK population and expressed on a per caput basis, are compared with the average natural background level of approximately 2.2 mSv (NRPB, 1993(a)).

The condition that doses should meet the ALARA objective is subject to compliance with appropriate individual dose limits. Control of individual exposures is intended to limit stochastic effects (i.e. those whose probability depends on the dose) to an acceptable level and to prevent non-stochastic or deterministic (threshold) effects. For stochastic effects, it is recommended that the risk should be equal whether the whole body is irradiated uniformly or non-uniformly; weighting factors proportional to the risk are defined for different organs. The weighted sum of organ doses is called the effective dose equivalent in ICRP-26, or effective dose in ICRP-60. Exposures from intakes of radioactivity can continue for a number of years, depending upon body retention time. The ICRP-26 committed effective dose equivalent (or committed effective dose in ICRP-60) represents the integrated exposure over 50 years following an intake. The ICRP-26 principal limit for the committed effective dose equivalent received by a member of the public is 1 mSv in a year (ICRP, 1985); however, it is permissible under the ICRP-26 recommendations to use a subsidiary dose limit of 5 mSv in a year for some years, provided that the average annual committed effective dose equivalent over a lifetime does not exceed 1 mSv year<sup>-1</sup>. These dose limits apply to the sum of the effective dose equivalent resulting from external exposure during one year and the committed effective dose equivalent incurred from that year’s intake of radionuclides.

ICRP-60’s dose limits are similar, that is a limit on effective dose of 1 mSv in a year and, in special circumstances, a higher value can be allowed in a single year, provided that the average over 5 years does not exceed 1 mSv year<sup>-1</sup>. A parallel additive rule applies. ICRP-60 distinguishes between ‘practices’ which add exposures, can be controlled and to which the dose limits apply, as

opposed to 'interventions' which reduce exposures from a pre-existing situation and to which the dose limits do not apply. The exposures assessed in this report are largely those from artificial radioactivity already in the environment and would be subject to intervention. However, NRPB has recently recommended (NRPB, 1993(b)) that exposures arising from past controlled releases should be included in any comparison with the dose limit to avoid any relaxation of the control of public exposure presently exercised in the UK. The ICRP continues to recommend that the dose limitation criteria for members of the public apply at each site to the mean dose of the 'critical group', which is that small group of people who, because of their habits and other aspects of behaviour which affect the doses received, are the most exposed.

Government policy for radioactive waste management is that the effective dose to members of the public should be limited to 1 mSv in a year and that the flexibility to average exposure over more than one year is unnecessary. Assessments of dose against this limit should also include the effects of past discharges (United Kingdom – Parliament, 1995). In this report, the effective doses to the critical groups in 1994 calculated from the monitoring data are therefore compared with the dose limit of 1 mSv. As regards non-stochastic (deterministic) effects due to intakes of radionuclides, the ICRP has indicated (ICRP, 1984; ICRP, 1991) that because of the limitation on lifetime exposure, described above, these effects in members of the public will be avoided. For external exposures, specific non-stochastic (deterministic) limits are appropriate. For example, the ICRP continues to recommend (ICRP, 1991) the limit for skin of 50 mSv in a year; this limit is applicable, for example, in the case of handling of fishing gear.

A new recommendation in ICRP-60 is that optimisation should be subject to appropriate constraints which apply within the overall limits. NRPB has subsequently advised (NRPB, 1993(c)) that the dose constraint for a single new source should not exceed 0.3 mSv year<sup>-1</sup> and believes that, in general, it should be possible for existing plant to be operated so that the dose from a controlled source does not exceed 0.3 mSv year<sup>-1</sup>. In cases where the 0.3 mSv dose constraint cannot be met the operator must demonstrate that the doses resulting from the continued operation of the plant are as low as reasonably achievable and within the range of tolerable risk. The Government accepts this advice and, in addition, has specified that a 'site constraint' of 0.5 mSv year<sup>-1</sup> should apply to current and future operations from a number of sources with contiguous boundaries at a single location when the site cannot be optimised as an integral whole (United Kingdom – Parliament, 1995). The use of constraints is appropriate for predictive assessments which do not include the effects of past discharges, but for those based on monitoring data, which may include the effects of several sources and

past operations, their use is limited. Nevertheless, to provide further information to help with the process of interpreting the ICRP-60 recommendations, a partial assessment of the effects of current activities at Sellafield and Springfields has been included in this report for comparison with the 0.3 mSv constraint. These sites were chosen because of the radiological significance of their discharges in relation to other sites. The assessment is based on the effect of liquid discharges from the sites in 1994. In a definitive assessment of dose for comparison with the constraint, it is necessary to consider all sources of exposure at a site.

In this report, calculations of exposures for comparison with dose limits are presented on the basis of both ICRP-26 and ICRP-60 methodologies.

For the calculations based on ICRP-26, values for committed effective dose equivalents, following intakes by members of the public, have been taken from three sources:

- (i) NRPB Documents (NRPB, 1990);
- (ii) ICRP Publication 56 (ICRP, 1989); and
- (iii) the NRPB 'RAPID' database (Greenhalgh *et al.*, 1986) as amended by changes in dosimetric factors outlined in Kendall *et al.* (1987).

Dose calculations based on ICRP-60 use committed effective doses per unit intake taken from:

- (i) ICRP Publication 67 (ICRP, 1994); and
- (ii) Phipps *et al.* (1991)

For both ICRP-26 and ICRP-60 methodologies, where there is a choice of dose coefficients in the source references, the most recent information is used. The dose coefficients used in this report are provided in Appendix 2 for ease of reference.

The dose assessments include consideration of children, where they are known to be members of critical groups, and the use of appropriate gut transfer factors. The NRPB has made recommendations on gut transfer factors for a range of radionuclides (NRPB, 1990). These recommendations include endorsement of the results of work at this Laboratory, using adult, human volunteers, which has suggested a gut transfer factor of 0.0002 in connection with 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, the NRPB considers a gut transfer factor of 0.0005 to be a reasonable best estimate (NRPB, 1990). In this report, when estimating doses to consumers of winkles from near Sellafield, a gut transfer factor of 0.0002 is used for plutonium and americium. For other foods and for winkles outside the Sellafield area, the factor of 0.0005 is used for these radioelements. The current ICRP advice is that a gut transfer factor of 0.5 for adults is appropriate for dietary

intakes of polonium (ICRP, 1994). However, a recent study at this Laboratory involving the consumption of crab meat containing natural levels of polonium-210 has suggested that the gut transfer factor could be as high as 0.8 (Hunt and Allington, 1993). Estimates of the exposures due to polonium intakes have therefore been calculated using the conservative assumption that a factor of 0.8 applies to all seafood. However, the effect of adopting the generic ICRP value of 0.5 applied to the total intake of polonium has also been considered.

In the case of external exposure to penetrating gamma radiation, uniform whole body exposure has been assumed. The measured quantity is air kerma rate. 'Kerma' is an acronym for 'kinetic energy released in matter' and for the purposes of this report is indistinguishable from absorbed dose rate in air. When interpreting this in terms of radiological effect, an air kerma rate of 1 mGy h<sup>-1</sup> has been taken as producing an effective dose equivalent rate of 0.87 mSv h<sup>-1</sup> (Spiers *et al.*, 1981). This factor does not change significantly for effective dose under ICRP-60 (NRPB, 1993(d)). For external exposure of skin, the measured quantity is contamination in Bq cm<sup>-2</sup>. In this case, dose rate factors in Sv year<sup>-1</sup> per Bq cm<sup>-2</sup> are used which are calculated for a depth in tissue of 7 mg cm<sup>-2</sup> (Kocher and Eckerman, 1987). The exposure of gonads from beta radiation is assessed using the methods described by Hunt (1992). When assessing external exposures to gamma radiation and internal exposures due to ingestion of carbon-14 and radionuclides in the uranium and thorium decay series, estimates of dose rates and concentrations, as appropriate, due to natural background levels are subtracted. The estimates of background concentrations are given in Appendix 4. The gamma dose rate backgrounds in the aquatic environment were taken to be 0.05 µGy h<sup>-1</sup> for sandy substrates, 0.07 µGy h<sup>-1</sup> for mud and salt marsh and 0.06 µGy h<sup>-1</sup> for other substrates. 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 (Hunt, 1984) has been used. Estimates of external exposures from beta radiation include a component due to natural sources because of the difficulty in distinguishing between natural and man-made contributions. Such estimates are therefore conservative when compared with the relevant dose limit which excludes natural sources of radiation.

Exposures for comparison with dose limits and the dose constraint are estimated for the critical group relevant to pathways related to discharges of liquid radioactive waste. The term 'critical group' in this report is taken to apply only to such discharges whilst, strictly, it should apply to the group of people who are most exposed to all discharges of waste and direct radiation from nuclear installations.

In order to interpret monitoring results in terms of exposures to critical groups, rates of food consumption

and/or occupancy of areas relevant to external exposure are required as appropriate. These are obtained by habits surveys specific to, and generally near, each nuclear establishment of interest. The results are kept under review and the surveys are repeated at intervals. The main purpose of the surveys is to identify, and to quantify, the relevant habits of the critical group of persons most highly exposed through a particular pathway or pathways.

It has been generally assumed, in radiological protection, that controls applied to radioactive waste disposal to provide adequate protection for man will result in sufficiently low concentrations of radionuclides in the environment that the fauna and flora are also likely to be protected (ICRP, 1977; ICRP, 1991). This assumption has been specifically addressed in the case of the aquatic environment of the British Isles, and related research programmes include a continuing study of potential radiological effects on aquatic populations. Studies of such effects on fish and shellfish (e.g. Woodhead and Pentreath, 1989) and on seabirds (Woodhead, 1986) have confirmed the applicability of the general assumption in these cases. In addition, the wider context of the work of DFR (MAFF, 1992) includes research programmes which are designed to keep the health of fish and shellfish stocks under close scrutiny.

## 4. BRITISH NUCLEAR FUELS PLC (BNFL)

BNFL is concerned mainly with the design and production of fuel for nuclear reactors and its reprocessing after irradiation. The company also operates a solid waste disposal site and nuclear power plant supplying electricity to the national grid. Regular monitoring is carried out of the environmental consequences of discharges of liquid radioactive waste from five BNFL sites, namely Sellafield, Drigg, Springfields, Capenhurst and, on behalf of the Scottish Office, Chapelcross.

### 4.1 Sellafield and Drigg, Cumbria

Liquid radioactive wastes from both Sellafield and Drigg are discharged under separate authorisations effectively to the same body of water on the Irish Sea coastline. The sites are therefore considered together for the purpose of environmental monitoring.

Operations and facilities at Sellafield include fuel element storage and decanning, the Magnox and oxide nuclear fuel reprocessing plants and the Calder Hall magnox-type nuclear power station. Liquid radioactive waste discharges include a very minor contribution from the adjoining UKAEA Windscale Laboratories. The most significant discharges are treated effluents from the BNFL fuel element storage ponds and the

reprocessing plants, through which pass irradiated Magnox and oxide fuel from the UK nuclear power programme, and some fuel from abroad. Several developments took place in 1994. The most important of these in relation to liquid effluent discharges were the processing of stored wastes through the Enhanced Actinide Removal Plant (EARP), the treatment of routine arisings through EARP and the re-routing of carbon-14 activity in the Magnox fuel dissolver off-gas scrubber stream such that all would be discharged in liquid effluents. Reprocessing of oxide fuels made little contribution to discharges in 1994 as the Thermal Oxide Reprocessing Plant (THORP) was undergoing commissioning. Most of the radioactive waste separated from the Magnox and oxide fuel is presently stored on site; relatively small quantities are discharged to the north-eastern Irish Sea through pipelines which terminate 2.1 km beyond low-water mark. The liquid radioactive discharges are the subject of a detailed authorisation which includes numerical discharge limits and a requirement on BNFL to use 'best practicable means' to limit discharges. This requirement reflects, *inter alia*, the objective of keeping radiation exposures 'as low as reasonably achievable' (ALARA) to comply with the ICRP principles as described in sub-section 3.3. It also has the effect of requiring the use of 'best available technology', as described in the recommendations of the Paris Commission (PARCOM, 1989) now the joint Oslo and Paris Commissions (OSPAR). A new authorisation took effect in January 1994 to take account of the new developments on site including THORP and EARP and to reduce limits for discharges where possible (Smith *et al.*, 1994).

Discharges from the Sellafield pipelines during 1994 are summarised in Table 1. Discharges of strontium-90 and technetium-99 increased in 1994 because of the planned treatment of stored wastes. Discharges of carbon-14 also increased due to the diversion of part of the gaseous discharges of this radionuclide to sea. However, lower concentrations of caesium-137 in the fuel element storage ponds reduced discharges of this radionuclide and the operation of EARP reduced discharges of ruthenium-106, plutonium and americium. Total alpha and beta discharges were 1.04 and 126 TBq respectively (1993: 2.59 and 97 respectively). The increase in total beta discharges was mainly caused by beta emitters in releases of treated stored wastes. All discharges were within the limits set by HMIP and MAFF.

The main function of the Drigg site is to receive solid radioactive wastes from Sellafield and other UK sites and to dispose of them in engineered trenches on land. The Authorisation for disposals allows for the discharge of leachate from the trenches through a 1 km marine pipeline. The limits for activity to be discharged through the marine pipeline and for concentrations of residual activity in the Drigg Stream are given in Table 1. Discharges in 1994 were well within these limits. These

discharges are small compared with those discharged from the Sellafield site. MAFF marine monitoring of the Drigg site is subsumed within the Sellafield programme which is described in the remainder of this sub-section. The contribution to exposures due to Drigg discharges is negligible compared with that due to Sellafield and any effects of Drigg discharges could not be detected in 1994 above those due to Sellafield. Monitoring of the Drigg Stream is carried out by HMIP (HMIP, 1994).

Regular monitoring of the marine environment near Sellafield continued during 1994. Important radiation exposure pathways were from consumption of fish and shellfish and from external exposure to gamma and beta rays from occupancy over sediments, with other pathways being kept under review. Following established practice, the largest monitoring effort was expended on these more important pathways. In 1994, as in previous recent years, there was no harvesting of *Porphyra* in west Cumbria for manufacture of laverbread, but monitoring continued because the pathway remains potentially important. Other parts of the programme served to improve knowledge of the distribution and behaviour of radionuclides in the marine environment, especially in relation to the critical exposure pathways, and also to provide a means of assessing other pathways of lower current importance, thereby assisting in keeping all exposure pathways under review. A general review of radioactivity in the Irish Sea has been compiled by Kershaw *et al.* (1992). In addition, Hunt (1995) has recently provided a reconstruction of exposures due to Sellafield liquid discharges from the beginning of operations in 1952 to 1993.

#### **4.1.1 The fish and shellfish consumption pathway**

##### **4.1.1.1 Concentrations of radioactivity**

Public radiation exposure from Sellafield discharges by consumption of fish is still predominantly due to radiocaesium. Concentrations of caesium-134 and -137 and total beta activity in fish from the vicinity of the Irish Sea and from further afield are given in Table 4(a). Data are listed by location of sampling or landing point, in approximate order of increasing distance from Sellafield. Samples taken near other nuclear establishments which reflect Sellafield discharges are given later in this report. So as to be representative of consumption by the public, samples are generally obtained from commercial sources. However, to minimise the risk of underestimating exposures, and as certain species of fish or shellfish may not be available commercially, specific surveys are also carried out. The 'Sellafield Coastal Area' extends 15 km north and south of Sellafield from St Bees Head to Selker and 11 km

**Table 4(a). Beta/gamma radioactivity in fish from the Irish Sea vicinity and further afield, 1994**

Location	Material	No. of sampling observations <sup>3</sup>	Mean radioactivity concentration (wet), Bq kg <sup>-1</sup>		
			<sup>134</sup> Cs	<sup>137</sup> Cs	Total beta
Sellafield coastal area <sup>1</sup>	Cod	4	0.27	19	170
"	Plaice	2	0.21	19	160
"	Grey mullet	1	ND	17	NA
"	Bass	1	"	31	"
Sellafield offshore area <sup>1</sup>	Cod	1	"	10	"
"	Plaice	2	0.15	11	"
"	Dab	2	0.15	14	"
Ravenglass <sup>2</sup>	Cod	7	0.02	16	"
"	Plaice	7	0.04	13	"
Whitehaven <sup>2</sup>	Cod	4	ND	10	"
"	Plaice	4	"	9.0	"
"	Ray	4	"	12	"
"	Herring	4	"	2.7	"
Parton <sup>2</sup>	Cod	4	0.13	22	"
Morecambe Bay <sup>1</sup>	Flounder	4	0.12	36	"
"	Plaice	4	ND	12	"
"	Bass	2	0.16	26	"
"	Whitebait	1	ND	11	"
River Derwent <sup>1</sup>	Sea trout	1	"	9.5	"
Fleetwood <sup>2</sup>	Cod	4	0.04	8.8	"
"	Plaice	4	ND	9.2	"
"	Fish meal <sup>4</sup>	4	"	4.4	"
"	Fish oil <sup>4</sup>	4	"	ND	"
Isle of Man <sup>2</sup>	Cod	4	0.02	5.7	"
"	Plaice	4	ND	3.5	"
"	Herring	4	"	6.0	"
Inner Solway <sup>1</sup>	Flounder	4	0.10	43	"
"	Sea trout	2	ND	7.9	"
"	Salmon	1	"	0.48	"
Kirkcudbright <sup>2</sup>	Plaice	2	"	5.4	"
"	Sole	1	"	5.0	"
North Anglesey <sup>2</sup>	Ray	4	0.03	5.2	"
"	Plaice	2	ND	2.8	"
Ribble Estuary <sup>1</sup>	Flounder	1	"	28	"
"	Salmon	1	"	0.48	"
"	Sea trout	1	"	13	"
Northern Ireland <sup>2</sup>	Cod	5	"	4.9	130
"	Whiting	9	"	6.8	170
"	Herring	1	"	1.7	NA
"	Spurdog	8	"	4.9	120
"	Saithe	2	0.08	13	140
Sound of Mull <sup>1</sup>	Salmon	1	ND	1.1	NA
Minch <sup>1</sup>	Cod	4	"	1.1	"
"	Plaice	4	"	0.90	"
"	Mackerel	2	"	0.37	"
"	Haddock	4	"	0.53	"
"	Herring	3	"	2.2	"
West of Scotland <sup>1</sup>	Mackerel	1	"	0.41	"
Shetland <sup>1</sup>	Fish meal <sup>4</sup>	4	"	1.2	"
Northern North Sea <sup>1</sup>	Cod	4	"	0.62	"
"	Plaice	4	"	0.56	"
"	Herring	4	"	0.55	"
"	Haddock	4	"	0.59	"
Mid-North Sea <sup>1</sup>	Cod	3	"	0.75	"
"	Plaice	3	"	0.38	"
"	Herring	3	"	0.51	"

**Table 4(a). continued**

Location	Material	No. of sampling observations <sup>3</sup>	Mean radioactivity concentration (wet), Bq kg <sup>-1</sup>		
			<sup>134</sup> Cs	<sup>137</sup> Cs	Total beta
Southern North Sea <sup>1</sup>	Cod	2	ND	0.64	NA
“	Plaice	2	“	0.26	“
“	Herring	2	“	0.67	“
English Channel <sup>1</sup>	Cod	4	“	0.46	“
“	Plaice	4	“	0.18	“
“	Mackerel	1	“	0.50	“
“	Herring	1	“	0.40	“
Skagerrak <sup>1</sup>	Herring	2	“	1.1	“
“	Cod	2	“	0.66	“
Norwegian Sea <sup>1</sup>	Cod	1	“	0.38	“
“	Saithe	1	“	0.48	“
Iceland area <sup>1</sup>	Cod	1	“	0.15	“
Icelandic processed <sup>2</sup>	Cod	2	“	0.25	“
Barents Sea <sup>1</sup>	Cod	1	“	0.37	“
Bear Island <sup>1</sup>	Cod	1	“	0.39	“
“	Skate	1	“	0.45	“
“	Halibut	1	“	0.52	“
“	Haddock	1	“	0.24	“
Baltic Sea <sup>1</sup>	Cod	3	0.65	16	“
“	Herring	3	0.47	11	“

NA = not analysed; ND = not detected; <sup>1</sup>Sampling area; <sup>2</sup>Landing point; <sup>3</sup>See sub-section 3.2 for definition; <sup>4</sup>Concentrations refer to weight of sample as supplied

**Table 4(b). Other beta/gamma radioactivity in fish from the Irish Sea vicinity and further afield, 1994**

Location	Material	No. of sampling observations <sup>3</sup>	Mean radioactivity concentration (wet), Bq kg <sup>-1</sup>			
			<sup>14</sup> C	<sup>90</sup> Sr	<sup>99</sup> Tc	<sup>147</sup> Pm
Sellafield offshore area <sup>1</sup>	Cod	1	98	0.16	1.9	NA
“	Plaice	2	120	0.091	3.3	0.0052
Whitehaven <sup>2</sup>	Cod	4	53	0.036	NA	NA
“	Plaice	4	NA	0.030	“	“
Morecambe Bay <sup>1</sup>	Flounder	4	58	NA	“	“
“	Whitebait	1	NA	0.16	“	“
Fleetwood <sup>2</sup>	Fish meal <sup>4</sup>	4	“	0.13	“	“
“	Cod	4	36	NA	“	“
Isle of Man <sup>2</sup>	Plaice	4	37	“	“	“
Inner Solway <sup>1</sup>	Flounder	4	54	0.028	0.67	“
North Anglesey <sup>1</sup>	Ray	4	32	NA	NA	“
“	Plaice	2	39	“	“	“
Northern Ireland <sup>2</sup>	Cod	5	31	“	“	“
Minch <sup>1</sup>	Mackerel	2	54	0.0058	“	“
Shetland <sup>1</sup>	Fish meal <sup>4</sup>	4	NA	0.0052	“	“
Northern North Sea <sup>1</sup>	Cod	4	“	0.0039	“	“
“	Haddock	4	31	NA	“	“
Mid-North Sea <sup>1</sup>	Cod	3	29	0.0028	“	“
“	Plaice	3	23	0.0021	“	“
English Channel <sup>1</sup>	Cod	4	NA	0.0054	“	“
“	Plaice	4	“	0.0055	“	“
Southern North Sea <sup>1</sup>	Cod	4	“	0.0029	“	“
“	Plaice	4	“	0.0027	“	“
Iceland area <sup>1</sup>	Cod	1	29	NA	“	“
Icelandic processed <sup>2</sup>	Cod	2	31	“	“	“

ND = not detected; NA = not analysed; <sup>1</sup>Sampling area; <sup>2</sup>Landing point; <sup>3</sup>See sub-section 3.2 for definition; <sup>4</sup>Concentrations refer to weight of sample as supplied

offshore; most of the local fish and shellfish consumed by the local critical group is taken from this Area. Specific surveys are carried out 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 wide by two nautical miles long, situated south of the pipeline with the long side parallel to the shoreline; it averages about 5 km from the pipeline outlet.

The results generally reflect the progressive dilution of radiocaesium with increasing distance from Sellafield, but the rate of decline of radiocaesium concentrations with distance is not as marked as was the case some years ago, because of the significant reductions in discharges since that time. Radiocaesium in fish from the Baltic is not due to Sellafield discharges but is substantially from the Chernobyl accident. Concentrations of radiocaesium in fish known to have been caught in Icelandic waters remained typical of those from weapons-test fallout, at a value of about 0.3 Bq kg<sup>-1</sup> for caesium-137 in cod. Data for the Barents Sea are similar. In the Irish Sea, the ratios of caesium-137 to caesium-134 were generally higher than those in recent discharges from Sellafield, even allowing for residence time in the water and uptake into fish; this suggests that a significant contribution from aged radiocaesium is present, due to remobilisation from the sediment of the Irish Sea (Hunt and Kershaw, 1990).

Variations between fish species for a given area, while not large, are mainly to be explained in terms of residence time in the area as well as in terms of feeding habits. To obtain representative results for dose estimation, samples include large numbers of individual fish (sub-section 3.2).

There were small reductions in concentrations of radiocaesium in fish from the eastern Irish Sea in 1994. Specific radionuclides, other than caesium-134 and -137 and transuranics, which were detected in fish in 1994, are listed in Table 4(b). Analyses of samples of fish for carbon-14, strontium-90, technetium-99 and promethium-147 continued to be included in the monitoring programme to enable the effects of discharges of these nuclides from Sellafield to be assessed, and for results based on measurements to be included later in consideration of critical group and collective dose. Analyses for these radionuclides are labour-intensive; thus a selection of samples was made based on potential radiological significance. Concentrations of carbon-14, strontium-90 and technetium-99 in 1994 in the eastern Irish Sea generally increased compared with 1993 coinciding with the increased discharges of these radionuclides. However, the radiological significance of these radionuclides in fish remained low.

For shellfish, a wide range of radionuclides contributes to radiation exposure of consumers owing to generally greater uptake in these organisms than in fish. Table 5

lists concentrations of beta/gamma-emitting nuclides (except plutonium-241) and total beta activity in shellfish from the Irish Sea and further afield. Results for carbon-14, strontium-90, technetium-99 and promethium-147 are included. Winkles are of particular radiological importance to the critical group near to Sellafield, as described later in this section. In addition to sampling by DFR, supplies of winkles, mussels and limpets were obtained from consumers who collected them in the Sellafield Coastal Area exploited by this critical group.

Concentrations of artificial radionuclides in shellfish, as with fish, diminish with increasing distance from Sellafield; the rate of reduction is least for nuclides which are relatively mobile in sea water, such as isotopes of caesium. There are substantial variations between species: for example, lobsters tend to concentrate more technetium-99 when compared with crabs. In addition, molluscs tend to concentrate the less mobile nuclides to a greater extent than crustaceans, which in turn tend to concentrate them more than fish. The reverse behaviour has also been true for mobile nuclides in the past. However, since the importance of caesium-137 associated with sediment has increased relative to the source of direct discharges, concentrations of this nuclide in molluscs have tended to be higher than or similar to those for crustaceans. There were both increases and decreases of concentrations of beta/gamma-emitting radionuclides in shellfish in 1994. Increases occurred for carbon-14 and technetium-99 and decreases for zirconium-95, niobium-95, ruthenium-106 and caesium-137. These changes reflected changes in discharges of these radionuclides but the magnitude of the change in discharge was not necessarily matched by an equivalent change in concentration. For example, the technetium-99 concentrations in shellfish from west Cumbria have increased on average by a factor of 7 whereas the discharges have increased by a factor of 12. Such differences are caused by several factors including the timing of sampling and the rate at which biota respond to their environment. The observed changes in environmental concentrations are in line with the predictive assessment (HMIP and MAFF, 1992) which formed the basis of the revised authorisation which came into effect in January 1994.

Analyses for transuranics are labour-intensive; as in previous years, a selection of samples of fish and shellfish chosen mainly on the basis of potential radiological significance was analysed for transuranic nuclides. Analyses were often carried out on bulked samples (sub-section 3.2). The data for 1994 are presented in Table 6. Transuranics are less mobile than radiocaesium in sea water; this is reflected in higher concentrations of transuranics in shellfish as compared with fish, and a rapid reduction with distance from Sellafield in concentrations of transuranics, particularly in shellfish. Over the past decade discharges of transuranic nuclides from Sellafield have reduced signifi-

cantly, resulting in overall decreases in concentrations of these nuclides in fish and shellfish. However, the non-mobile nature of these nuclides causes a delayed effect in the environment (Hunt, 1985) such that a contribution to present concentrations is provided by discharges in earlier years. In 1994, concentrations of transuranic nuclides in fish and shellfish were generally similar or slightly less when compared with 1993.

Concentrations of natural radionuclides in fish and shellfish in the Sellafield area are presented in section 11.

#### 4.1.1.2 Local consumption rates

The radiation dose to consumers of fish and shellfish depends upon the product of the mass of foodstuff consumed and its radioactivity concentration. Because of variations in these two variables between individual consumers, a wide range of annual doses is to be expected. The critical group approach, which is well established in the UK and recommended by the ICRP for control purposes, is based on identifying groups of individuals in exposed populations who are subject to the highest radiation exposures. Of the two main variables, radioactivity concentrations in fish and shellfish are generally highest in the Coastal Area as defined above. Hence, eaters of fish and shellfish within the local community represent one exposed population whose consumption rates have been studied and kept under review. As regards the other main variable, consumption rates, surveys have shown that, in addition to the local fishing community, the populations in south-west Scotland, Cumbria and north Lancashire, including those associated with commercial fisheries based primarily at Whitehaven, Fleetwood and in the Morecambe Bay area, also contain consumers of large quantities of fish and shellfish. These additional populations are kept under review, even though, in general, the relevant fishing grounds are further afield than the Cumbrian Coastal Area and concentrations of radioactivity in fish and shellfish landed are lower.

The consumption rates of the local fishing community described above were kept under review in 1994. Techniques used in the collection of data have continued to include the use of consumption logging sheets, particularly by members of critical groups (Leonard *et al.*, 1982; Leonard, 1984). Consumption rate data have been interpreted using techniques based upon ICRP recommendations (Hunt *et al.*, 1982) to select appropriate critical groups of higher-rate consumers. Consideration of children's consumption rates has been included in this selection process (Leonard and Hunt, 1985).

Radioactivity concentrations in fish and shellfish vary with the species involved, so in estimating doses to consumers it is not sufficient to determine only the total consumption rates of fish and shellfish together. Experience (illustrated by Tables 4-6) has shown,

however, that for a given area within each of the classes fish, crustaceans and molluscs, the concentrations of most nuclides in representative samples are relatively constant. For each of the exposed populations, therefore, sub-groups of persons were identified who were likely to have received the greatest exposures from eating each class of foodstuff, and mean consumption rates for the sub-groups were determined. For the local fishing community, there were changes in consumption rates in 1994 for all three classes of foodstuff such that rates of 26 kg year<sup>-1</sup> fish, 12 kg year<sup>-1</sup> crustaceans and 9.7 kg year<sup>-1</sup> molluscs were used in the assessment of doses to the critical group of fish and shellfish consumers. These data can be compared with rates in 1993 of 28, 15 and 7.8 kg year<sup>-1</sup> for the three classes of foodstuff respectively (Camplin, 1994).

The habits survey data show that above-average consumers in each of the component sub-groups are not consistently members of another component sub-group. However, members of more than one sub-group do exist, so to avoid underestimating the exposure of the overall critical group, this exposure is derived by adding together the exposures of each sub-group. Account is also taken of consumption of seafood from outside the Sellafield area and external radiation. In both cases the additional exposures are too small to make a significant difference to the result for their exposure due to consumption of local seafood; additions of this small order are considered to be adequately taken into account by the maximising process of summing exposures from each sub-group.

Plaice and cod are overwhelmingly the most popular fish eaten by the high-rate consumers, and the assessment of exposure of the critical group of local consumers was based upon information obtained during habits surveys which indicated the use of an equal mix of these species taken from the Sellafield Offshore Area and from landings at Ravenglass, typical sources of most of the local commercial supplies. The exposure due to consumption of crustaceans was similarly calculated on the basis of a mix of 65% crabs and 35% lobsters from the Coastal Area and landings at Ravenglass, combined equally. The exposure from consumption of molluscs was calculated on the basis of a mix of 85% winkles and 15% other molluscs from the Coastal Area, including data from both DFR sampling at specific locations within this Area and from samples collected by local consumers.

#### 4.1.1.3 Individual dose

Table 7(a) summarises exposures in 1994 from artificial radionuclides, calculated on two bases (sub-section 3.3). For each exposed group, the committed effective dose equivalent is given using the existing methodology of ICRP-26, compared with results for committed effective dose calculated using dose coefficients calculated on the

**Table 5. Beta/gamma radioactivity in shellfish from the Irish Sea vicinity and further afield, 1994**

Location	Material	No. of sampling observations <sup>3</sup>	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>										
			<sup>14</sup> C	<sup>59</sup> Fe	<sup>60</sup> Co	<sup>65</sup> Zn	<sup>90</sup> Sr	<sup>95</sup> Zr	<sup>95</sup> Nb	<sup>99</sup> Tc	<sup>103</sup> Ru	<sup>106</sup> Ru	<sup>110m</sup> Ag
Sellafield coastal area <sup>1</sup>	Crabs	9	90	ND	0.57	ND	1.3	ND	ND	21	ND	3.3	12
“	Lobsters	8	120	“	0.31	“	0.53	“	“	2400	“	0.81	19
“	Winkles <sup>4</sup>	4	83	“	2.0	“	2.0	0.30	“	56	“	27	32
“	Mussels <sup>4</sup>	4	NA	“	1.3	“	1.6	0.62	0.66	NA	“	24	0.86
“	Limpets <sup>4</sup>	4	67	“	1.1	“	9.2	0.82	0.63	400	“	32	32
“	Whelks	2	NA	“	1.3	“	NA	ND	ND	NA	“	12	28
St Bees <sup>1</sup>	Winkles	4	130	“	2.8	“	11	3.0	3.5	180	0.20	51	48
“	Mussels	4	NA	“	1.6	0.04	NA	2.0	2.1	NA	0.24	47	5.8
“	Limpets	4	“	0.50	1.5	ND	“	1.4	1.7	“	0.08	44	27
Nethertown <sup>1</sup>	Winkles	12	110	ND	2.7	“	7.1	2.5	2.2	140	0.12	47	51
“	Mussels	4	200	“	2.3	“	NA	3.2	3.5	440	0.17	65	4.6
Drigg <sup>1</sup>	Winkles	4	160	“	3.3	“	“	0.51	0.76	1200	ND	43	62
Ravenglass <sup>1</sup>	Mussels	4	NA	“	1.5	“	“	0.86	1.0	130	0.06	29	0.71
“	Cockles	4	100	“	2.9	“	1.8	0.80	0.89	15	ND	21	4.6
Ravenglass <sup>2</sup>	Crabs	4	NA	“	0.37	“	0.68	ND	ND	9.2	“	1.8	8.5
“	Lobsters	4	“	“	0.13	“	0.30	“	“	1200	“	ND	17
Tarn Bay <sup>1</sup>	Winkles	4	“	“	2.0	“	NA	0.89	1.0	NA	0.03	30	32
Saltom Bay <sup>1</sup>	“	4	“	“	1.3	“	“	0.68	0.62	“	0.10	23	11
Whitehaven <sup>2</sup>	<i>Nephrops</i>	4	53	“	ND	“	0.11	ND	ND	170	ND	ND	0.74
“	Whelks	3	56	“	0.23	“	0.066	“	“	NA	“	0.80	3.6
Parton <sup>1</sup>	Winkles	4	NA	“	1.4	“	NA	1.0	1.5	“	0.12	29	16
“	Crabs	4	“	“	0.42	“	“	ND	ND	“	ND	4.6	9.5
“	Lobsters	4	“	“	0.11	“	“	“	“	“	“	1.1	8.7
Haverigg <sup>2</sup>	Cockles	2	“	“	1.1	“	“	0.23	0.73	“	“	11	0.72
Millom <sup>1</sup>	Mussels	2	“	“	0.55	“	“	0.39	0.39	“	“	6.8	0.50
Roosebeck <sup>1</sup>	Pacific oysters	4	“	“	0.24	“	“	ND	ND	“	“	0.40	9.0
Morecambe Bay <sup>1</sup>	Shrimps	4	84	“	ND	“	0.10	“	“	1.7	“	ND	0.06
“	Mussels	4	47	“	0.22	“	NA	“	“	54	“	1.7	“
“ (Middleton Sands) <sup>1</sup>	Cockles	4	NA	“	0.58	“	“	“	“	NA	“	1.2	0.06
Fleetwood <sup>2</sup>	Squid	1	“	“	ND	“	“	“	“	“	“	ND	ND
“	Whelks	4	47	“	“	“	“	“	“	“	“	0.73	0.65
Isle of Man <sup>2</sup>	Scallops	4	NA	“	“	“	“	“	“	“	“	ND	ND
Inner Solway	Shrimps	4	“	“	“	“	0.082	“	“	“	“	“	0.37
Southernness <sup>1</sup>	Winkles	4	“	“	0.43	“	1.6	“	“	200	“	3.4	3.3
Kirkcudbright <sup>2</sup>	Scallops	4	“	“	0.15	“	NA	“	“	NA	“	ND	0.07
“	Queens	4	“	“	0.06	“	“	“	“	“	“	“	0.55
North Solway coast <sup>1</sup>	Crabs	4	70	“	0.10	“	0.42	“	“	5.6	“	“	2.6
“	Lobsters	4	52	“	0.02	“	0.083	“	“	390	“	“	2.0
“	Winkles	4	NA	“	0.48	“	NA	“	“	NA	“	3.5	3.4
“	Cockles	4	59	“	0.57	“	1.3	0.10	0.09	6.7	“	3.0	ND
“	Mussels	4	NA	“	0.37	“	NA	ND	ND	NA	“	3.6	“
Wirral <sup>1</sup>	Shrimps	2	“	“	ND	“	“	“	“	“	“	ND	“
“	Cockles	4	“	“	0.07	“	“	“	“	“	“	“	“
Conwy <sup>2</sup>	Mussels	2	“	“	ND	“	“	“	“	“	“	“	“
Northern Ireland <sup>2</sup>	<i>Nephrops</i>	8	“	“	“	“	“	“	“	12	“	“	“
“	Winkles	4	“	“	“	“	“	“	“	NA	“	“	0.07
“	Mussels	3	“	“	“	“	“	“	“	17	“	“	ND
Minch <sup>1</sup>	<i>Nephrops</i>	4	“	“	“	“	“	“	“	NA	“	“	“
Northern North Sea <sup>1</sup>	“	4	“	“	“	“	“	“	“	“	“	“	“
Mid North Sea <sup>1</sup>	Mussels <sup>5</sup>	2	“	“	“	“	“	“	“	“	“	“	“
Southern North Sea <sup>1</sup>	Cockles	2	“	“	0.66	“	“	“	“	“	“	“	“
“	“	2	“	“	0.18	“	“	“	“	“	“	“	“
“	Mussels	4	“	“	ND	“	“	“	“	“	“	“	“

**Table 5. continued**

Location	Material	No. of sampling observations <sup>3</sup>	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>								
			<sup>125</sup> Sb	<sup>129</sup> I	<sup>134</sup> Cs	<sup>137</sup> Cs	<sup>144</sup> Ce	<sup>147</sup> Pm	<sup>154</sup> Eu	<sup>155</sup> Eu	Total beta
Sellafield coastal area <sup>1</sup>	Crabs	9	0.13	ND	ND	4.3	0.11	0.63	ND	ND	110
“	Lobsters	8	0.05	NA	0.03	6.9	0.10	1.5	“	“	1600
“	Winkles <sup>4</sup>	4	0.78	“	ND	7.2	0.18	1.9	0.21	0.06	NA
“	Mussels <sup>4</sup>	4	1.6	“	“	3.6	0.26	NA	0.23	ND	“
“	Limpets <sup>4</sup>	4	5.8	“	“	12	0.30	“	0.24	0.08	“
“	Whelks	2	0.30	“	“	2.0	ND	“	ND	ND	“
St Bees <sup>1</sup>	Winkles	4	3.5	ND	0.05	23	1.8	3.9	0.43	0.40	“
“	Mussels	4	2.6	NA	ND	6.5	1.2	NA	0.40	0.06	“
“	Limpets	4	5.7	“	“	18	1.3	“	0.50	0.09	“
Nethertown <sup>1</sup>	Winkles	12	3.0	“	0.01	18	1.6	3.4	0.24	0.07	610
“	Mussels	4	3.1	“	ND	6.8	1.3	NA	0.10	ND	320
Drigg <sup>1</sup>	Winkles	4	3.1	“	“	11	0.38	3.3	0.19	“	NA
Ravenglass <sup>1</sup>	Mussels	4	1.6	“	“	3.5	0.46	NA	0.49	“	“
“	Cockles	4	1.1	“	“	7.5	1.1	“	1.1	0.27	150
Ravenglass <sup>2</sup>	Crabs	4	ND	“	“	2.9	ND	“	ND	ND	NA
“	Lobsters	4	“	“	“	5.2	“	“	“	“	“
Tarn Bay <sup>1</sup>	Winkles	4	1.5	“	“	11	0.26	“	“	“	“
Saltom Bay <sup>1</sup>	“	4	3.8	“	“	12	0.21	“	0.06	“	“
Whitehaven <sup>2</sup>	<i>Nephrops</i>	4	ND	“	“	11	ND	“	ND	“	280
“	Whelks	3	“	“	“	1.9	“	“	“	“	120
Parton <sup>1</sup>	Winkles	4	2.1	“	“	19	0.21	“	0.17	0.10	NA
“	Crabs	4	ND	“	“	4.4	ND	“	ND	ND	“
“	Lobsters	4	“	“	“	7.0	“	“	“	“	“
Haverigg <sup>2</sup>	Cockles	2	0.45	“	“	11	0.60	“	0.51	0.28	“
Millom <sup>1</sup>	Mussels	2	0.69	“	“	3.6	0.16	“	0.12	ND	“
Roosebeck <sup>1</sup>	Pacific oysters	4	0.08	“	“	2.8	ND	“	ND	“	“
Morecambe Bay <sup>1</sup>	Shrimps	4	ND	“	“	12	“	“	“	“	“
“	Mussels	4	0.4	“	“	4.1	“	“	“	“	“
(Middleton Sands) <sup>1</sup>	Cockles	4	0.30	“	“	6.1	“	“	0.12	“	“
Fleetwood <sup>2</sup>	Squid	1	ND	“	“	1.2	“	“	ND	“	“
“	Whelks	4	0.05	“	“	2.1	“	“	“	“	“
Isle of Man <sup>2</sup>	Scallops	4	ND	“	“	0.79	“	“	“	“	“
Inner Solway <sup>1</sup>	Shrimps	4	“	“	0.02	13	“	“	“	“	“
Southerness <sup>1</sup>	Winkles	4	0.90	“	0.03	12	“	“	“	“	“
Kirkcudbright <sup>2</sup>	Scallops	4	ND	“	ND	0.57	“	“	“	“	“
“	Queens	4	“	“	“	0.76	“	“	“	“	“
North Solway coast <sup>1</sup>	Crabs	4	“	“	“	2.5	“	“	“	“	“
“	Lobsters	4	“	“	“	3.7	“	“	“	“	“
“	Winkles	4	0.34	“	“	4.0	“	“	“	“	“
“	Cockles	4	0.28	“	“	7.9	“	“	0.05	“	“
“	Mussels	4	0.42	“	“	3.8	“	“	ND	“	“
Wirral <sup>1</sup>	Shrimps	2	ND	“	“	3.5	“	“	“	“	“
“	Cockles	4	0.07	“	“	2.3	“	“	“	“	“
Conwy <sup>2</sup>	Mussels	2	ND	“	“	0.55	“	“	“	“	“
Northern Ireland <sup>2</sup>	<i>Nephrops</i>	8	“	“	“	2.2	“	“	“	“	99
“	Winkles	4	“	“	“	0.63	“	“	“	“	NA
“	Mussels	3	“	“	“	0.73	“	“	“	“	“
Minch <sup>1</sup>	<i>Nephrops</i>	4	“	“	“	0.57	“	“	“	“	“
Northern North Sea <sup>1</sup>	“	4	“	“	“	0.39	“	“	“	“	“
Mid North Sea <sup>1</sup>	Mussels <sup>5</sup>	2	“	“	“	0.10	“	“	“	“	31
Southern North Sea <sup>1</sup>	Cockles	2	“	“	“	0.12	“	“	“	“	NA
“	“ <sup>6</sup>	2	“	“	“	0.14	“	“	“	“	“
“	Mussels	4	“	“	“	0.22	“	“	“	“	“

NA = not analysed; ND = not detected; <sup>1</sup>Sampling area; <sup>2</sup>Landing point; <sup>3</sup>See sub-section 3.2 for definition; <sup>4</sup>Samples collected by Consumer 116; <sup>5</sup>Landed in Denmark; <sup>6</sup>Landed in Holland

**Table 6. Transuranic radioactivity in fish and shellfish from the Irish Sea vicinity and further afield, 1994**

Location	Material	No. of sampling observations <sup>3</sup>	Mean radioactivity concentration (wet), Bq kg <sup>-1</sup>						
			<sup>237</sup> Np	<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Pu	<sup>241</sup> Am	<sup>242</sup> Cm	<sup>243</sup> Cm+ <sup>244</sup> Cm
Sellafield coastal area <sup>1</sup>	Cod	1	NA	0.0053	0.020	NA	0.033	0.00011	0.00020
“	Plaice	1	“	0.0042	0.018	“	0.032	ND	0.000064
“	Crabs	2	0.033	0.092	0.42	8.1	1.8	0.0036	0.0045
“	Lobsters	2	0.11	0.072	0.34	4.6	5.6	0.010	0.012
“	Winkles <sup>4</sup>	1	0.13	1.6	7.5	110	16	ND	0.035
“	Mussels <sup>4</sup>	1	NA	1.8	8.0	120	16	0.022	0.037
“	Limpets <sup>4</sup>	1	“	1.9	8.6	130	16	ND	0.065
“	Whelks	1	“	0.34	1.5	22	2.0	0.0021	0.0049
Sellafield offshore area <sup>1</sup>	Cod	1	“	0.0027	0.013	NA	0.021	ND	0.000046
“	Plaice	1	0.0013	0.0041	0.019	“	0.030	“	0.000063
St Bees <sup>1</sup>	Mussels	2	NA	2.5	11	180	20	0.026	0.041
“	Winkles	1	0.35	4.1	18	280	34	0.079	0.092
“	Limpets	1	NA	3.4	16	NA	26	0.053	0.058
Nethertown <sup>1</sup>	Winkles	4	0.28	3.5	16	240	29	0.0086	0.064
“	Mussels	4	NA	2.6	11	NA	22	0.027	0.050
Drigg <sup>1</sup>	Winkles	4	0.17	3.2	15	210	30	0.0027	0.059
Ravenglass <sup>1</sup>	Mussels	1	NA	1.8	8.0	120	16	0.011	0.047
“	Cockles	1	“	2.3	11	150	31	0.034	0.058
Ravenglass <sup>2</sup>	Cod <sup>5</sup>	1	“	0.0011	0.0052	NA	0.0076	ND	0.000020
“	Plaice <sup>5</sup>	1	“	0.0015	0.0069	“	0.014	“	0.000048
“	Crabs <sup>6</sup>	1	“	0.064	0.31	4.3	1.5	“	0.0013
“	Lobsters <sup>6</sup>	1	“	0.071	0.32	4.3	5.4	“	0.013
Tarn Bay <sup>1</sup>	Winkles	1	“	2.2	10	140	20	“	0.026
Whitehaven <sup>2</sup>	Cod	1	“	0.00034	0.0017	NA	0.0031	“	ND
“	Plaice	1	“	0.00050	0.0024	“	0.0047	“	0.0000073
“	Rays	1	“	0.00059	0.0029	“	0.0046	“	0.0000094
“	Herring	1	“	0.00022	0.0012	“	0.0020	“	ND
“	<i>Nephrops</i>	1	“	0.049	0.24	“	1.3	“	0.0035
“	Whelks	1	“	0.11	0.56	6.7	1.1	“	0.0031
Saltom Bay <sup>1</sup>	Winkles	4	“	NA	NA	NA	14	NA	NA
Parton <sup>1</sup>	Winkles	1	“	2.3	11	160	18	ND	0.030
“	Crabs	4	“	NA	NA	NA	1.3	NA	NA
“	Lobsters	4	“	“	“	“	2.5	“	“
Haverigg <sup>2</sup>	Cockles	1	“	2.5	12	“	28	ND	0.047
Millom <sup>1</sup>	Mussels	1	“	0.63	3.0	“	5.8	0.013	0.022
Roosebeck <sup>1</sup>	Pacific oysters	1	“	0.20	1.0	“	0.65	0.0018	0.0026
Morecambe Bay <sup>1</sup>	Flounder	1	“	0.00054	0.0029	“	0.0046	ND	0.0000082
“	Whitebait	1	“	0.041	0.21	2.8	0.32	“	0.00044
“	Shrimps	1	“	0.0056	0.028	0.29	0.043	“	0.00009
“	Mussels	1	“	0.35	1.8	NA	3.1	0.0063	0.0030
“ (Middleton Sands) <sup>1</sup>	Cockles	1	“	0.48	2.4	“	6.5	ND	0.011
Fleetwood <sup>2</sup>	Cod	1	“	0.00046	0.0021	“	0.0031	“	0.0000037
“	Plaice	1	“	0.00026	0.0020	“	0.0022	“	ND
“	Fishmeal <sup>7</sup>	1	“	0.0037	0.022	“	0.033	“	0.000094
“	Whelks	1	“	0.091	0.47	5.8	0.64	“	0.0013
Isle of Man <sup>2</sup>	Cod	1	“	0.00018	0.00093	NA	0.0013	“	0.0000039
“	Plaice	1	“	0.00021	0.0011	“	0.0016	“	ND
“	Herring	1	“	0.00097	0.0050	“	0.0072	0.0000093	0.000016
“	Scallops	1	“	0.024	0.13	“	0.048	ND	0.000085
Inner Solway <sup>1</sup>	Sea trout	1	“	0.00059	0.0027	“	0.0034	“	0.000011
“	Flounder	1	“	0.0012	0.0064	“	0.011	“	ND
“	Shrimps	1	“	0.0037	0.020	“	0.036	“	“
Southernness <sup>1</sup>	Winkles	1	“	0.63	3.4	43	5.7	0.016	0.0098

**Table 6. continued**

Location	Material	No. of sampling observations <sup>3</sup>	Mean radioactivity concentration (wet), Bq kg <sup>-1</sup>						
			<sup>237</sup> Np	<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Pu	<sup>241</sup> Am	<sup>242</sup> Cm	<sup>243</sup> Cm+ <sup>244</sup> Cm
Kirkcudbright <sup>2</sup>	Plaice	1	NA	0.00037	0.0018	NA	0.0038	ND	0.000011
“	Scallops	1	“	0.030	0.16	“	0.055	0.00011	0.00012
“	Queens	1	“	0.016	0.086	“	0.10	0.00037	0.00021
North Solway coast <sup>1</sup>	Crabs	1	“	0.037	0.18	2.3	0.77	ND	ND
“	Lobsters	1	“	0.025	0.12	1.6	0.81	“	0.0020
“	Winkles	1	“	0.41	1.9	25	3.0	“	0.0047
“	Cockles	1	0.24	0.82	4.1	54	10	“	0.032
“	Mussels	1	NA	0.68	3.1	NA	5.6	0.010	0.014
Wirral <sup>1</sup>	Cockles	1	“	0.099	0.54	“	1.5	ND	0.0027
Conwy <sup>2</sup>	Mussels	1	“	0.035	0.18	“	0.31	“	0.00046
North Anglesey <sup>2</sup>	Rays	1	“	0.00025	0.0012	“	0.0021	“	0.0000065
Northern Ireland <sup>2</sup>	Whiting	1	“	0.00043	0.0038	“	0.0044	“	ND
“	<i>Nephrops</i>	1	“	0.0049	0.028	“	0.094	“	0.00015
“	Winkles	1	“	0.037	0.18	“	0.13	“	0.0014
Minch <sup>1</sup>	Cod	1	“	0.000036	0.00018	“	0.00030	“	ND
“	Haddock	1	“	0.000087	0.00049	“	0.00060	“	“
“	Mackerel	1	“	0.000019	0.00011	“	0.00011	“	“
“	<i>Nephrops</i>	1	“	0.00071	0.0042	“	0.0063	“	0.000028
Shetland <sup>1</sup>	Fishmeal <sup>7</sup>	1	“	0.00046	0.0041	“	0.0010	“	0.000014
Northern North Sea <sup>1</sup>	Cod	1	“	0.000098	0.00043	“	0.00074	“	ND
“	Haddock	1	“	0.000057	0.00034	“	0.00038	“	“
“	<i>Nephrops</i>	1	“	0.00018	0.0014	“	0.0026	0.000016	0.000021
Mid-North Sea <sup>1</sup>	Mussels <sup>8</sup>	1	“	0.00015	0.0025	“	0.0016	ND	ND
Southern North Sea <sup>1</sup>	Cockles	1	“	0.0016	0.0067	“	0.0079	“	0.0012
“	“ <sup>9</sup>	1	“	0.0049	0.015	“	0.017	0.000069	0.0019
“	Mussels	1	“	0.0024	0.015	“	0.0057	ND	ND
Icelandic processed <sup>2</sup>	Cod	1	“	0.00028	0.0013	“	0.0022	“	“

ND = not detected

NA = not analysed

<sup>1</sup>Sampling area; <sup>2</sup>Landing point; <sup>3</sup>See sub-section 3.2 for definition; <sup>4</sup>Samples collected by Consumer 116; <sup>5</sup>Samples provided by Fisherman A; <sup>6</sup>Samples provided by Fisherman B; <sup>7</sup>Concentrations refer to weight as supplied; <sup>8</sup>Landed in Denmark; <sup>9</sup>Landed in Holland

basis of ICRP-60 methodology (Appendix 2 of this report). In both cases, the contributions of individual radionuclides are given; for simplicity, only the more important of these are listed. Hence, it is not to be expected that the sums of the listed contributions will necessarily equal the totals presented. Both methods of calculation use accepted values for gut transfer factors of transuranics (i.e. 0.0002 for winkles from the Irish Sea, 0.0005 in other cases) (Hunt *et al.*, 1990; NRPB, 1990). On the basis of ICRP-26, the committed effective dose equivalent to the local critical group of high-rate fish and shellfish consumers in 1994 was 0.14 mSv. This is a small decrease from 0.15 mSv reported on the same basis for 1993 (Camplin, 1994), and represents a balance between changing concentrations and consumption rates for particular radionuclides and species. These committed effective dose equivalents, on the basis of ICRP-26, are within the dose limit for members of the public of 1 mSv.

Exposures have also been calculated on the basis of ICRP-60 methodology. The committed effective dose to the local critical group in 1994 was 0.08 mSv (1993: 0.10 mSv). Differences for individual radionuclides, from the ICRP-26 calculation, reflect the revised tissue weighting factors and other biological data which give, for example, increased exposures for technetium-99 but reductions for the transuranic nuclides. In 1994, the committed effective dose to the local critical group was substantially less than the 1 mSv limit.

In addition, to aid consideration of ICRP-60 in relation to practices, the exposure of the local group of seafood consumers due to liquid discharges during 1994 was calculated. A predictive model, based on environmental monitoring data taking account of discharge rates, has been used (HMIP and MAFF, 1992). The results are shown in Table 7(b); the total committed effective dose was 0.06 mSv; this is an increase on the value of 0.04 mSv

**Table 7(a). Individual radiation exposures due to consumption of Irish Sea fish and shellfish, 1994**

Exposed population	Consumption rate used in assessment (see text), kg year <sup>-1</sup>	Nuclide	Exposure, mSv <sup>#</sup>		
			ICRP-26*	ICRP-60 <sup>=</sup>	
Consumers in local fishing community	Fish (plaice and cod):	26	<sup>14</sup> C	0.002	0.003
	Crustaceans (crabs and lobsters):	12	<sup>90</sup> Sr	0.003	0.002
	Molluscs (winkles and other molluscs):	9.7	<sup>99</sup> Tc	0.004	0.007
			<sup>106</sup> Ru	0.003	0.003
			<sup>110m</sup> Ag	0.002	0.002
			<sup>137</sup> Cs	0.007	0.007
			<sup>237</sup> Np	0.002	0.001
			<sup>238</sup> Pu	0.006	0.003
			<sup>239+240</sup> Pu	0.031	0.016
			<sup>241</sup> Pu	0.009	0.004
			<sup>241</sup> Am	0.076	0.032
			Total		0.14
	Consumers associated with commercial fisheries: Whitehaven	Fish (plaice and cod):	57	<sup>14</sup> C	0.002
Crustaceans ( <i>Nephrops</i> ):		21	<sup>99</sup> Tc	0.001	0.002
Molluscs (whelks):		11	<sup>137</sup> Cs	0.010	0.011
			<sup>239+240</sup> Pu	0.005	0.003
			<sup>241</sup> Pu	0.002	0.001
			<sup>241</sup> Am	0.019	0.008
Total		0.04	0.03		
Consumers in Dumfries and Galloway	Fish (plaice, cod and salmon):	38	<sup>137</sup> Cs	0.004	0.005
	Crustaceans (crabs and <i>Nephrops</i> ):	13	<sup>238</sup> Pu	0.002	0.001
	Molluscs (winkles and cockles):	6.6	<sup>239+240</sup> Pu	0.011	0.006
			<sup>241</sup> Pu	0.003	0.001
			<sup>241</sup> Am	0.027	0.012
			Total <sup>x</sup>		0.08
Consumers in Morecambe Bay area	Fish (flounders and plaice):	54	<sup>14</sup> C	0.002	0.002
	Crustaceans (shrimps):	21	<sup>90</sup> Sr	0.002	0.002
	Molluscs (cockles and mussels):	22	<sup>137</sup> Cs	0.022	0.023
			<sup>238</sup> Pu	0.004	0.002
			<sup>239+240</sup> Pu	0.022	0.012
			<sup>241</sup> Pu	0.006	0.003
			<sup>241</sup> Am	0.053	0.023
Total <sup>+</sup>		0.13	0.08		
Consumers associated with commercial fisheries: Fleetwood	Fish (plaice and cod):	82	<sup>14</sup> C	0.002	0.002
	Crustaceans (shrimps):	17	<sup>90</sup> Sr	0.002	0.002
	Molluscs (cockles and whelks):	23	<sup>137</sup> Cs	0.013	0.015
			<sup>238</sup> Pu	0.003	0.002
			<sup>239+240</sup> Pu	0.016	0.008
			<sup>241</sup> Pu	0.001	0.001
			<sup>241</sup> Am	0.041	0.017
Total		0.08	0.05		
Typical member of the fish-eating public consuming fish landed at Whitehaven/Fleetwood	Fish (plaice and cod):	15	<sup>137</sup> Cs	0.002	0.002
	Total		0.002	0.002	

\* Committed effective dose equivalent using methodology of ICRP-26

= Committed effective dose calculated using methodology of ICRP-60

# Due to artificial radionuclides: see text for exposures due to natural radionuclides

x Including exposure due to 1000 h year<sup>-1</sup> occupancy over intertidal sediments

+ Including exposure due to 900 h year<sup>-1</sup> occupancy over intertidal sediments

in 1993 (Camplin, 1994) because of increased discharges of some beta-emitting radionuclides. However the dose remains much less than the dose constraint of 0.3 mSv. External exposure due to liquid discharges during 1994 is considered in sub-section 4.1.2.

Data for natural radionuclides in fish and shellfish are discussed in section 11; however, the effects on the Sellafield critical group of controlled discharges of natural radionuclides from another west Cumbrian source, Albright and Wilson Ltd, Whitehaven, are considered here for completeness. The exposure of the local group of seafood consumers due to the enhancement of concentrations of natural radionuclides in the

Sellafield area in 1994 was 0.63 mSv using a gut uptake factor for polonium of 0.8 (see section 3.3) (on the basis of ICRP-60: 0.34 mSv). Most of this was due to the polonium-210 and lead-210 content of shellfish. These exposures may be compared with an average dose rate of approximately 2.2 mSv year<sup>-1</sup> to members of the UK public from all natural sources of radiation (NRPB, 1993(a)) and are less than the limit of 1 mSv.

Consumption rates in the wider fishing communities of south-west Scotland, Cumbria and northern Lancashire have been kept under review. Consumption rates of groups associated with fisheries in Whitehaven, Dumfries and Galloway, Fleetwood and the Morecambe Bay

**Table 7(b). Exposure of fish and shellfish consumers near Sellafield due to discharges in 1994 for comparison with the dose constraint**

Nuclide	Committed effective dose*, mSv year <sup>-1</sup>
<sup>14</sup> C	0.007
<sup>90</sup> Sr	0.013
<sup>99</sup> Tc	0.028
<sup>106</sup> Ru	0.004
<sup>137</sup> Cs	0.003
<sup>238+239+240</sup> Pu	0.003
Total#	0.06

\* On the basis of a gut transfer factor for Pu and Am of 0.0002 and 0.0005 in winkles and other species respectively (see text). Using ICRP-60 methodology

# Includes the small effect of other nuclides

area are given in Table 7(a), together with the species whose radioactivity concentrations, following the information from habits surveys, formed the basis of the assessments. Because high-rate consumers in all areas may eat both fish and shellfish, the critical groups have been defined by the maximising procedure of summing exposures due to the component consumption rates. In addition, a contribution due to external exposure has been added where appropriate. The committed effective dose equivalents (ICRP-26) from artificial radionuclides received by the different groups in 1994 are given in Table 7(a). The results for Whitehaven were less than those for Dumfries and Galloway, Morecambe Bay or Fleetwood, mainly because of lower radioactivity concentrations in the species of molluscs consumed. The results for Whitehaven, Morecambe Bay and Fleetwood were similar in 1994 to those in 1993 (0.04, 0.14 and 0.11 mSv respectively) (Camplin, 1994). Exposures of the Dumfries and Galloway group reduced to 0.08 mSv (1993: 0.18 mSv) because of a reduction in the consumption rate of molluscs, particularly cockles. All doses were well within the dose limit for members of the public of 1 mSv.

The committed effective dose equivalent from artificial radionuclides, appropriate to a consumption rate of 15 kg year<sup>-1</sup> of fish from landings at Whitehaven and Fleetwood, is also given in Table 7(a). This consumption rate represents an average for typical fish-eating members of the public. The committed effective dose equivalent in 1994 was 0.002 mSv, similar to that for 1993 (Camplin, 1994).

#### 4.1.1.4 Collective dose

Collective doses, received during 1994 from consumption of fish and shellfish, have been estimated for the UK and other European countries. In general, the method used has been to combine data on actual fish and shellfish landings from relevant sea areas with average radioactivity concentrations in fish and shellfish

caught in these areas (Pollard *et al.*, in press; this report; Camplin, 1994). This method differs from that based on modelling of water movements and a (usually) fixed catch rate for different sea areas; the modelling method generally derives the collective dose to be received over a number of years as a result of discharges during the year under review, and the results are not readily comparable with those based on the present method. Sea areas considered in this assessment include the Irish Sea, Scottish waters, the North Sea, the English Channel, Baltic Sea, Norwegian Sea, Spitzbergen/Bear Island area and the Barents Sea. Corrections have been made for the fraction of fish or shellfish consumed. The contribution of weapons-test fallout to the radioactivity concentrations has been subtracted. Consideration has been given to the pathway due to fish offal and industrial fisheries, the product of both of which is fish meal which is fed to pigs, poultry, ruminants and farm-reared fish. Consumption of food products from these animals gives rise to a small contribution to the collective dose, and this has been included. The results are presented in Table 8. The results for 1994 are preliminary, being based on landings statistics provided by the International Council for the Exploration of the Sea (ICES); where data are not yet available, the previous year's data have been used. The doses have been calculated using both ICRP-26 and ICRP-60 methodology. ICRP-60 doses are slightly less than those of ICRP-26, due to reductions in dosimetric factors for transuranics. Further discussion in this section refers to the ICRP-26 data. Previous results for 1993 (Camplin, 1994) have been revised to take account of updated landings. The preliminary result of 5 man-Sv for the UK in 1993, given in the previous report has decreased to 4 man-Sv; the result for other European countries has remained the same at 25 man-Sv.

**Table 8. Collective doses from fish and shell fish, 1993 and 1994<sup>a</sup>**

Population	Collective dose, man-Sv			
	ICRP-26*		ICRP-60 <sup>+</sup>	
	1993	1994 <sup>a</sup>	1993	1994 <sup>a</sup>
UK	4	5	4	4
Other European countries	25	22	24	21

\* Committed effective dose equivalent using methodology of ICRP-26

<sup>+</sup> Committed effective dose calculated using methodology of ICRP-60

<sup>a</sup> Preliminary data

Liquid radioactive waste discharges from Sellafield up to the end of 1994 are the main source of collective dose reported in Table 8; by comparison, the effect of liquid discharges from other establishments is very small. The small contribution due to fallout from the

Chernobyl reactor accident to the Irish Sea, Scottish waters and the North Sea has been included. Most of the collective dose is due to radiocaesium in edible fish; however, approximately one quarter of the total dose is due to plutonium and americium radionuclides in shellfish. Strontium-90 also makes a small contribution to the collective dose, about 5% of the total.

The preliminary results for 1994 of 5 man-Sv for the UK and 22 man-Sv for other European countries are similar to those reported for 1993. It has not been possible to derive a direct estimate of the small Chernobyl contribution in coastal seas around the UK for 1994 because most of the concentrations of caesium-134 fall below detection limits. However, on the basis of concentrations of radioactivity due to the effects of the Chernobyl accident in fish from the Baltic Sea (Ikäheimonen *et al.*, in press; Aarkrog *et al.*, in press; Aarkrog *et al.*, 1995; Camplin, 1994; this report), it is estimated that the collective dose to other European countries from consumption of Baltic Sea fish was 60 man-Sv in 1993 and 1994.

The collective dose for the UK, given in Table 8, may be compared on a *per caput* basis with the annual dose equivalent, averaged over the population, of 2.2 mSv due to natural background radiation (see sub-section 3.3). In 1994, the preliminary UK collective dose through the fish and shellfish pathway as a result of liquid radioactive waste disposal operations amounted to less than 0.01% of this level.

#### 4.1.2 External exposure

A further important pathway leading to radiation exposure as a result of Sellafield discharges derives from uptake of gamma-emitting radionuclides by intertidal sediments in areas frequented by the public. In general, it is the fine-grained muds and silts prevalent in estuaries and harbours, rather than the coarser-grained sands to be found on open beaches, which adsorb the radioactivity more readily. Gamma dose rates currently observed in intertidal areas are mainly due to radiocaesium and natural radionuclides.

A range of coastal locations are regularly monitored, both in the Sellafield vicinity and further afield, using portable gamma-radiation dosimeters. Locations are chosen on account of both dose rates themselves and levels of occupancy by members of the public. Table 9 lists the locations monitored together with the dose rates in air at 1 m above ground level. Monitoring in Scotland is carried out on behalf of the Scottish Office. Dose rates on Irish Sea shorelines, near other nuclear establishments which reflect Sellafield discharges, are given later in this report (see sub-sections 4.2, 4.4, 6.5, 6.11). Variations in sediment type from place to place account for the quite marked fluctuations in dose rate, superimposed on a general decrease with increasing

distance from Sellafield. Dose rates over intertidal areas throughout the Irish Sea in 1994 showed small variations as compared with data for the same locations in 1993 (Camplin, 1994). Data for the River Calder are included for the first time in this report. It is likely that the main cause of observed dose rates being higher than those expected due to natural sources in this area is direct radiation from Calder Hall. However, there may also be a contribution due to radionuclides in small patches of sediments in the river. The occupancy by members of the public, for example anglers, of this section of the river is low. It is unlikely that more than a few tens of hours per year is spent near the sediment patches and, on this basis, the resulting exposures were much less than those of intertidal areas discussed subsequently in this sub-section.

Radioactivity concentrations in surface sediments are also regularly monitored, both because of relevance to dose rates and in order to keep under review distributions of adsorbed radioactivity. Concentrations of beta/gamma radioactivity and transuranics, in most cases at the same locations as the dose rate measurements, are given in Table 10. Variations similar in cause to those of the dose rates are observed, and comparison with results for 1993 (Camplin, 1994) shows small general reductions of gamma radioactivity. The observation that similar reductions have not consistently been seen for gamma dose rates is likely to be due to the influence of sub-surface sediments on dose rate. Data for small patches of sediment in the River Calder are included in Table 10. Cobalt-60 is present in these samples and this may be due to fallout from authorised discharges to air from Calder Hall.

To identify those members of the public subject to the highest external exposures, occupancies of different locations need to be considered. The amounts of time spent by members of the public on intertidal areas of coastline bordering the north-eastern Irish Sea are kept under review; activities leading to significant external exposures are sparse and surveys cover a wide area including Cumbria, and the north Solway coast. In western Cumbria, combining dose rates and occupancy times, the maximum exposure in 1994 was 0.11 mSv for anglers who dig bait near to Sellafield and who fish in the Cumbrian Coastal Area. Their exposure includes an assessment of the contribution to effective dose from beta emitting radionuclides in sediments and due to consumption of locally caught fish. Occupancy of fishing vessels in Whitehaven harbour reduced in 1994 so that the exposure of fishermen reduced from 0.13 in 1993 (Camplin, 1994) to 0.10 in 1994. Both estimates include a small contribution due to consumption of seafood. In the wider area, including Cumbria, Lancashire and the north Solway coast, on the basis of dose rates and occupancy times, it is considered that houseboat dwellers in the Ribble estuary are representative of those who receive the highest external exposures from the effects of discharges from Sellafield (see sub-section 4.2).

**Table 9. Gamma radiation dose rates over areas of the Cumbrian coast and further afield, 1994**

Location	Ground type	No. of sampling observations#	Mean gamma dose rate in air at 1 m, $\mu\text{Gy h}^{-1}$
<b>Cumbria</b>			
Rockliffe Marsh	Salt marsh	4	0.084
Burgh Marsh	"	4	0.10
Port Carlisle	Mud and sand	2	0.10
"	Mud, sand & stones	2	0.093
Greenend	Salt marsh	4	0.085
"	Mud and sand	2	0.070
"	Sand	2	0.076
Cardurnock Marsh	Salt marsh	4	0.11
Newton Arlosh	"	4	0.13
Silloth - silt pond	Grass	2	0.074
" - boat area	Mud and sand	2	0.094
Allonby	Sand	2	0.081
Maryport - Christchurch	Mud	4	0.12
Siddick	Sand	4	0.077
Workington Harbour	Mud	4	0.14
Harrington Harbour	"	4	0.15
Whitehaven - outer harbour	Mud and sand	12	0.12
"	Coal and sand	12	0.13
Whitehaven - inner harbour	Mud and sand	3	0.23
"	Mud	1	0.29
"	Mud, sand & stones	8	0.18
" - yacht basin	Mud	12	0.26
St Bees	Sand	4	0.069
Nethertown	Winkle bed	4	0.10
Sellafield	Sand	4	0.076
R. Calder (Pos. A)	Concrete	1	0.094
" " (Pos. B)	Grass	1	0.23
" " (Pos. C)	Concrete	1	0.36
" " "	Mud, sand & stones	2	0.46
" " "	Sand and gravel	1	0.43
" " "	Soil	2	0.32
" " (Pos. D)	"	1	0.12
" " (Pos. E)	Concrete	1	0.10
" " "	Mud and sand	1	0.089
" " "	Sand and concrete	1	0.078
Seascale	Sand	4	0.072
Drigg pipeline	"	8	0.066
Drigg Barn Scar	Mussel bed	4	0.082
Saltcoats	Salt marsh	4	0.22
Muncaster Bridge	"	4	0.25
Ravenglass - Carleton Marsh	"	4	0.26
Ravenglass - salmon garth	Mud and sand	4	0.15
"	Sand and stones	3	0.091
"	Mussel bed	4	0.091
"	Sand	1	0.077
" - boat area	Mud and sand	12	0.10
"	Sand	4	0.068
" - ford	Mud and sand	4	0.11
" - River Mite	Salt marsh	4	0.23
" - Ravensilla	Mud and sand	12	0.13
"	Salt marsh	12	0.25
" - Eskmeals Nature Reserve	"	4	0.27
Newbiggin	Mud and sand	4	0.23
"	Salt marsh	4	0.30
" - west of bridge	Mud, sand & stones	4	0.12
"	Salt marsh	4	0.29
Tarn Bay	Sand	2	0.066
Silecroft	"	2	0.060
Haverigg	Mud and sand	6	0.086
"	Sand	2	0.069
Low Shaw	Salt marsh	4	0.14
Askham	"	4	0.17
Tummer Hill Marsh	"	4	0.17
Walney Channel	Mud and sand	4	0.10
" - Vickers shore	"	4	0.083
" - west shore	Sand	4	0.059
Roa Island	Mud and sand	4	0.080
Greenodd	Salt marsh	2	0.084
Sand Gate Marsh	"	4	0.11
Flookburgh	Mud and sand	4	0.078
High Foulshaw	Salt marsh	4	0.092
Arnside	Mud and sand	4	0.074
"	Salt marsh	3	0.11

**Table 9. continued**

Location	Ground type	No. of sampling observations#	Mean gamma dose rate in air at 1 m, $\mu\text{Gy h}^{-1}$
<b>Lancashire, Merseyside and North Wales</b>			
Jenny Brown's Point	Salt marsh	1	0.073
Sunderland Point	Mud and sand	4	0.094
Sunderland	Mud, sand & stones	4	0.083
Colloway Marsh	Salt marsh	4	0.17
Lancaster	"	4	0.12
Aldcliffe Marsh	"	4	0.15
Conder Green	Mud and sand	2	0.11
"	Mud	2	0.12
"	Salt marsh	4	0.14
Cockerham Marsh	"	4	0.12
Heads - River Wyre	"	2	0.14
Height o' th' hill - River Wyre	"	4	0.16
Hambleton	Mud	2	0.12
"	Mud and sand	2	0.12
"	Salt marsh	4	0.14
Fleetwood	Sand	4	0.068
" Docks	Salt marsh	4	0.16
Skipool Creek	Mud	2	0.12
"	Mud and sand	2	0.12
Blackpool	Sand	4	0.054
Crossen Marsh	Mud	3	0.11
Crossen Marsh	Mud and sand	1	0.12
"	Salt marsh	4	0.11
Ainsdale	Sand	4	0.052
New Brighton	Mussel bed	4	0.071
West Kirby	Mud and sand	1	0.059
"	Sand	1	0.054
Rock Ferry	Mud	4	0.10
"	Mud and sand	3	0.11
Little Neston Marsh	"	2	0.074
"	Salt marsh	2	0.085
Flint	Mud	3	0.094
"	Mud and sand	1	0.088
"	Salt marsh	4	0.12
Prestatyn	Sand	2	0.054
Rhyl	Mud	2	0.073
Llandudno	Shingle	2	0.080
Caerhun	Salt marsh	2	0.099
Llanfairfechan	"	2	0.083
<b>South-west Scotland</b>			
Garlieston	Mud	1	0.085
"	Mud and sand	3	0.089
Innerwell	"	4	0.084
Bladnoch	Mud	2	0.099
"	Mud and sand	2	0.10
Creetown	Salt marsh	4	0.13
Carluith	Mud and sand	4	0.084
Skyreburn Bay (Water of Fleet)	Salt marsh	4	0.090
Palnackie Harbour	Mud	2	0.095
"	Mud and sand	2	0.11
Gardenburn	Salt marsh	4	0.13
Kippford - Slipway	Mud and sand	2	0.091
" "	Mud	2	0.088
" - Merse	Salt marsh	4	0.16
Cumstoun	"	4	0.12
Carsethorn	Mud and sand	4	0.099
Glencaple Harbour	"	4	0.083

# See sub-section 3.2 for definition

Their boat occupancy in 1994 was similar to that in 1993. Making an allowance for natural background using a dose rate of  $0.07 \mu\text{Gy h}^{-1}$  (see sub-section 3.3) their external exposure in 1994 was  $0.14 \text{ mSv}$ , which is less than the value for 1993 of  $0.26 \text{ mSv}$  calculated on the same basis. The reduction was due to a decrease in gamma dose rates on the boat. The exposure was within the dose limit of  $1 \text{ mSv}$  for members of the

public. Additional exposure of these people, due to consumption of fish and shellfish and handling of fishing gear, was negligible. Most of the external exposure of the houseboat dwellers was due to the radioactivity already in the environment as a result of past discharges from Sellafield. Exposures of these houseboat dwellers due to Springfields discharges are considered in sub-section 4.2.

In addition, the exposure of the critical group from external radiation due to liquid discharges during 1994 was calculated for comparison with the dose constraint. The predictive model used is based on environmental monitoring data for Whitehaven harbour taking account of discharge rates and both beta and gamma exposure over intertidal sediments whilst digging bait for 600 h year<sup>-1</sup>. The total effective dose to the bait diggers was 0.008 mSv, much less than the dose constraint of 0.3 mSv.

It is to be noted that inhalation of resuspended beach sediments and inadvertent ingestion of the same material give rise to only minor radiation exposures to the public compared with the external radiation pathway considered in this sub-section (Wilkins *et al.*, 1994). In areas of salt marsh and sea-washed pastures such as the Ravenglass estuary exposures from pathways other than those due to external radiation need consideration, and this is currently being given from the point of view of regular monitoring needs. Meanwhile, doses including external radiation in such areas were cautiously assessed for 1989 to be well within the dose limit of 1 mSv (Wilkins *et al.*, 1994). This would also have been the case in 1994 because relevant concentrations of activity and dose rates in such areas have reduced since 1989.

#### **4.1.3 Fishing gear**

During immersion in sea water, fishing gear may entrain particles of sediment on which radioactivity is adsorbed. Fishermen handling this gear may be exposed to external radiation, mainly to skin from beta particles. Fishing gear is regularly monitored using portable beta dosimeters. Results for 1994 are presented in Table 11. Measured dose rates were generally less than those for 1993 (Camplin, 1994). Habits surveys keep under review the amounts of time spent by fishermen handling their gear; for those most exposed, a time handling nets and pots of 2500 h year<sup>-1</sup> was appropriate for 1994. The exposure from handling of fishing gear in 1994, including a component due to natural radiation, was 0.34 mSv, which is less than 1% of the dose limit appropriate for exposures to skin of members of the public, based on non-stochastic (deterministic) effects (sub-section 3.3). Handling of fishing gear therefore continues to be a minor radiation exposure pathway.

#### **4.1.4 Porphyra/laverbread pathway**

No harvesting of *Porphyra* in west Cumbria, for consumption after being made into laverbread, was reported in 1994; this pathway has therefore remained essentially dormant. However, monitoring has continued in view of its potential importance and the value of *Porphyra* as an indicator material. Samples of *Porphyra* are regularly collected from selected locations along UK shorelines of the Irish Sea. Results of analyses for 1994 are presented in Table 12. Samples of laverbread from the major manufacturers are regularly

collected from markets in South Wales and analysed. Results for 1994 are presented in Table 13. The exposure of critical laverbread consumers was less than 0.005 mSv, confirming the virtual abeyance of this exposure pathway.

#### **4.1.5 Contact dose-rate monitoring of intertidal areas**

Contact beta and gamma dose rates in intertidal areas are regularly monitored using purpose built large area detectors to locate and remove any material with unusual levels of contamination. No items were detected during 1994. A routine programme of measurements of beta dose rates on contact with shoreline sediments was begun in 1994 in order to establish the contribution to effective dose made by exposures of people, such as bait diggers, who handle sediments regularly, and to estimate their skin exposures for comparison with the non-stochastic dose limit of 50 mSv. The results of the measurements made using portable beta dosimeters are presented in Table 14.

The skin exposure of anglers who dig bait, based on a time handling sediment of 600 h year<sup>-1</sup>, was 0.60 mSv in 1994 which is 1% of the appropriate dose limit. The contribution this source of exposure makes to effective dose is included in the assessment in sub-section 4.1.2.

#### **4.1.6 Radioactivity distributions in sea water**

The distribution of radioactivity in sea water around the British Isles is one factor which determines the variation in exposures at coastal sites as well as collective doses. Understanding the factors which affect the distribution improves the predictive capability. Therefore a programme of research into the distribution of key radionuclides is maintained using research vessels and other means of sampling. Detailed historical data on radiocaesium in sea water have been published in a series of reports to aid model development (Camplin and Steele, 1991; Baxter *et al.*, 1992; Baxter and Camplin 1993(a-c)) and have been used to derive dispersion factors for nuclear sites (Baxter and Camplin, 1994). The research vessel programme on radionuclide distribution currently comprises cruises in the Irish Sea, Scottish waters and the North Sea every two years. The results of the 1993 cruises have been summarised by Camplin (1994) and further cruises are planned for 1995. Data from shoreline sampling in the Irish Sea and Scottish waters in 1994 are given in Table 15.

Concentrations of caesium-137 typical of the north-eastern Irish Sea and northern Scottish Waters were 0.1-1.0 Bq l<sup>-1</sup> and 0.01-0.03 Bq l<sup>-1</sup> respectively. These data show similar levels to those observed from the more detailed sampling in 1993, the general distribution being

**Table 10. Radioactivity in sediment from the Cumbrian coast and further afield, 1994**

Location	Material	No. of sampling observations#	Mean radioactivity concentration (dry), Bq kg <sup>-1</sup>										
			<sup>54</sup> Mn	<sup>60</sup> Co	<sup>95</sup> Zr	<sup>95</sup> Nb	<sup>103</sup> Ru	<sup>106</sup> Ru	<sup>110m</sup> Ag	<sup>125</sup> Sb	<sup>134</sup> Cs	<sup>137</sup> Cs	<sup>144</sup> Ce
<b>Cumbria</b>													
Newton Arlosh	Turf	4	ND	2.8	ND	ND	ND	6.8	ND	1.6	3.0	960	ND
Maryport - Christchurch	Mud	4	"	8.1	33	41	"	330	4.4	20	2.9	850	28
Harrington Harbour	"	4	"	9.0	60	69	"	400	5.4	24	3.1	890	42
Whitehaven - yacht basin	"	4	"	5.4	13	20	"	220	ND	13	2.6	1100	25
St Bees	Sand	4	"	1.5	ND	ND	"	1.8	"	1.3	0.14	72	ND
Braystones	"	1	"	1.7	"	"	"	5.3	"	1.2	0.35	180	"
Sellafield	"	4	"	2.0	"	"	"	2.8	"	0.56	ND	150	"
River Calder (Pos. A)	"	1	"	1.1	"	"	"	ND	"	ND	2.2	190	"
" (Pos. B)	Mud & sand	1	5.1	82	"	"	"	22	"	5.9	21	1300	26
" (Pos. C)	Mud	1	16	5300	"	"	"	ND	"	14	24	2500	9.3
" (Pos. D)	Mud & sand	1	2.7	860	"	"	"	"	"	5.9	6.6	680	ND
" (Pos. E)	"	1	ND	3.1	"	"	"	"	"	ND	1.7	78	"
Seascale	Sand	4	"	1.5	"	"	"	2.3	"	0.98	ND	81	"
Drigg pipeline	"	4	"	1.9	0.59	0.71	"	7.2	"	1.4	"	73	"
River Mite estuary	Mud	2	"	7.5	28	44	0.82	330	3.7	16	1.7	620	36
"	Mud & sand	2	0.44	8.4	26	41	ND	270	4.0	17	2.6	510	21
Ravenglass - Ravensilla	"	4	ND	6.3	29	43	0.66	260	3.2	15	1.3	360	30
Newbiggin	Mud	3	"	7.4	37	53	1.6	310	3.1	16	0.98	510	33
"	Mud & sand	1	"	22	6.4	11	ND	200	ND	15	2.0	510	18
Low Shaw	Turf	4	"	3.8	ND	ND	"	20	"	2.7	4.0	720	ND
Walney Channel	Mud & sand	4	"	1.8	2.6	2.4	"	29	0.36	4.2	0.38	180	0.84
Flookburgh	"	4	"	ND	ND	ND	"	ND	ND	0.33	ND	110	ND
Sand Gate marsh	Turf	4	"	0.50	"	"	"	4.5	"	0.89	0.55	230	"
<b>Lancashire, Merseyside and north Wales</b>													
Sunderland Point	Mud & sand	3	"	1.3	"	"	"	7.3	"	1.1	1.1	300	"
"	Mud	1	"	1.7	"	"	"	19	"	2.5	1.6	450	"
Conder Green	Turf	4	"	1.4	"	"	"	13	"	3.7	0.58	480	"
Hambleton	"	4	"	4.7	"	"	"	ND	"	ND	5.5	1700	"
Skippool Creek	Mud	4	"	2.8	"	"	"	26	"	2.9	1.4	650	"
Fleetwood	Sand	4	"	ND	"	"	"	ND	"	0.24	ND	30	"
Blackpool	"	4	"	"	"	"	"	"	"	ND	"	10	"
New Brighton	"	2	"	"	"	"	"	"	"	"	"	11	"
Rock Ferry	Mud	4	"	0.95	"	"	"	"	"	2.4	0.33	300	"
Rhyl	"	2	"	0.31	"	"	"	"	"	0.65	ND	90	"
Caerhun	Turf	2	"	ND	"	"	"	"	"	ND	2.0	270	"
Cemlyn Bay	Mud	2	"	1.5	"	"	"	"	"	"	1.4	220	"
Llanfairfechan	Turf	2	"	ND	"	"	"	"	"	"	4.5	370	"
<b>South-west Scotland</b>													
Garlieston	Mud	1	"	"	"	"	"	40	"	"	3.8	320	"
"	Mud & sand	3	"	1.6	"	"	"	30	"	4.5	0.67	230	"
Innerwell	"	1	"	ND	"	"	"	ND	"	ND	ND	78	"
Bladnoch	"	1	"	2.1	"	"	"	15	"	"	1.2	400	"
"	Mud	3	"	2.0	"	"	"	46	"	2.8	1.6	450	"
Carlsruith	"	1	"	4.3	"	"	"	49	"	5.1	2.4	580	"
"	Mud & sand	3	"	2.9	1.5	1.7	"	47	"	4.4	0.66	330	"
Kippford Merse	Salt marsh	4	"	4.5	3.0	5.6	"	83	"	7.7	2.8	680	5.1
" Slipway	Mud	3	"	3.1	5.8	8.2	"	84	"	6.1	1.4	410	9.2
"	Mud & sand	1	"	2.0	ND	ND	"	24	"	3.0	0.89	290	ND
Palnackie Harbour	Mud	3	"	3.4	2.3	2.8	"	100	"	1.5	1.1	470	2.4
"	Mud & sand	1	"	2.2	ND	ND	"	23	"	ND	ND	340	ND
Carsethorn	Mud	2	"	2.4	4.1	6.5	"	49	"	4.1	0.91	440	4.1
<b>Isle of Man</b>													
Douglas	"	1	"	ND	ND	ND	"	ND	"	ND	ND	14	ND
<b>Northern Ireland</b>													
Lough Foyle	"	2	"	"	"	"	"	"	"	"	"	5.4	"
Portrush	Sand	2	"	"	"	"	"	"	"	"	"	1.5	"
Ballymacormick	Mud	2	"	"	"	"	"	"	"	"	"	36	"
Strangford Lough - Nickey's Pt	"	2	"	"	"	"	"	"	"	"	"	53	"
Dundrum Bay	"	2	"	"	"	"	"	"	"	"	"	10	"
Carlingford Lough	"	2	"	"	"	"	"	"	"	"	0.65	ND	"
Oldmill Bay	"	2	"	"	"	"	"	"	"	"	ND	"	"

Table 10. continued

Location	Material	No. of sampling observations#	Mean radioactivity concentration (dry), Bq kg <sup>-1</sup>								Total beta
			<sup>154</sup> Eu	<sup>155</sup> Eu	<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Pu	<sup>241</sup> Am	<sup>242</sup> Cm	<sup>243</sup> Cm+ <sup>244</sup> Cm	
<b>Cumbria</b>											
Newton Arlosh	Turf	4	4.5	2.4	NA	NA	NA	260	NA	NA	NA
Maryport - Christchurch	Mud	4	17	11	110	530	“	840	ND	2.0	“
Harrington Harbour	“	4	18	9.4	NA	NA	“	920	NA	NA	“
Whitehaven - yacht basin	“	4	17	4.7	100	480	“	760	ND	1.8	3400
St Bees	Sand	4	2.3	0.69	NA	NA	“	110	NA	NA	NA
Braystones	“	1	3.7	2.5	“	“	“	250	“	“	“
Sellafield	“	4	3.6	1.9	“	“	“	210	“	“	“
River Calder (Pos. A)	“	1	ND	ND	“	“	“	73	“	“	“
“ (Pos. B)	Mud & sand	1	7.5	6.1	“	“	“	58	“	“	“
“ (Pos. C)	Mud	1	11	9.6	“	“	“	140	“	“	“
“ (Pos. D)	Mud & sand	1	ND	3.1	“	“	“	41	“	“	“
“ (Pos. E)	“	1	“	ND	“	“	“	10	“	“	“
Seascale	Sand	4	3.2	0.81	“	“	“	140	“	“	“
Drigg pipeline	“	4	4.2	1.5	“	“	“	250	“	“	“
River Mite estuary	Mud	2	21	8.6	130	630	8800	910	2.3	1.7	“
“ “	Mud & sand	2	17	7.8	NA	NA	NA	810	NA	NA	“
Ravenglass - Ravensilla	“	4	13	5.5	“	“	“	750	“	“	“
Newbiggin	Mud	3	18	7.0	140	630	9100	940	ND	1.6	1700
“	Mud & sand	1	17	7.1	NA	NA	NA	750	NA	NA	2100
Low Shaw	Turf	4	9.7	4.8	“	“	“	490	“	“	NA
Walney Channel	Mud & sand	4	3.7	2.7	“	“	“	200	“	“	“
Flookburgh	“	4	ND	1.1	“	“	“	37	“	“	“
Sand Gate marsh	Turf	4	0.73	0.88	“	“	“	74	“	“	“
<b>Lancashire, Merseyside and north Wales</b>											
Sunderland Point	Mud & sand	3	1.7	2.7	“	“	“	110	“	“	“
“	Mud	1	2.5	3.4	“	“	“	140	“	“	“
Conder Green	Turf	4	2.7	2.5	“	“	“	170	“	“	“
Hambleton	“	4	8.3	1.3	“	“	“	430	“	“	“
Skippool Creek	Mud	4	5.7	2.9	“	“	“	260	“	“	“
Fleetwood	Sand	4	ND	0.13	“	“	“	15	“	“	“
Blackpool	“	4	“	ND	“	“	“	4.1	“	“	“
New Brighton	“	2	“	“	“	“	“	3.0	“	“	“
Rock Ferry	Mud	4	0.37	0.60	“	“	“	85	“	“	“
Rhyl	“	2	ND	ND	“	“	“	150	“	“	“
Caerhun	Turf	2	“	“	“	“	“	53	“	“	“
Cemlyn Bay	Mud	2	“	1.6	5.9	30	“	46	0.10	0.11	“
Llanfairfechan	Turf	2	“	ND	NA	NA	“	55	NA	NA	“
<b>South-west Scotland</b>											
Garlieston	Mud	1	“	5.0	26	130	“	210	ND	0.42	“
“	Mud & sand	3	3.2	2.9	NA	NA	“	250	NA	NA	“
Innerwell	“	1	ND	1.5	“	“	“	45	“	“	“
Bladnoch	Mud	1	4.2	3.1	“	“	“	330	“	“	“
“	Mud	3	4.8	4.7	“	“	“	270	“	“	“
Carluith	“	1	7.1	5.5	33	180	“	270	ND	0.71	“
“	Mud & sand	3	5.7	2.7	NA	NA	“	230	NA	NA	“
Kippford Merse	Salt marsh	4	7.6	4.3	63	320	“	510	ND	0.80	“
“ Slipway	Mud	3	5.3	2.1	36	180	“	290	0.65	0.60	“
“	Mud & sand	2	4.8	2.6	NA	NA	“	210	NA	NA	“
Palnackie Harbour	Mud	3	7.4	1.2	39	190	“	310	0.68	0.58	“
“	Mud & sand	1	4.4	4.2	NA	NA	“	220	NA	NA	“
Carsethorn	Mud	2	2.6	3.1	“	“	“	180	“	“	“
<b>Isle of Man</b>											
Douglas	“	1	ND	1.1	“	“	“	1.2	“	“	“
<b>Northern Ireland</b>											
Lough Foyle	“	2	“	0.98	0.050	0.28	“	0.40	ND	ND	“
Portrush	Sand	2	“	ND	NA	NA	“	ND	NA	NA	“
Ballymacormick	Mud	2	“	0.52	1.5	8.0	“	10	0.020	0.021	“
Strangford Lough	“	2	“	ND	1.4	7.6	“	7.2	ND	0.013	“
-Nickey's Pt	“	2	“	“	“	“	“	“	“	“	“
Dundrum Bay	“	2	“	1.2	NA	NA	“	ND	NA	NA	“
Carlingford Lough	“	2	“	1.6	2.2	13	“	6.9	ND	0.0068	“
Oldmill Bay	“	2	“	ND	2.2	12	“	16	ND	0.025	“

NA = not analysed

ND = not detected

# See sub-section 3.2 for definition

**Table 11. Beta radiation dose rates on contact with fishing gear on vessels operating off Sellafield, 1994**

Vessel	Type of gear	No. of sampling observations#	Mean beta dose rate in tissue, $\mu\text{Sv h}^{-1}$
A	Nets	3	0.17
	Ropes	3	0.11
B	Nets	6	0.13
	Ropes	6	0.23
D	Gill nets	4	0.072
	Pots	2	0.11
E	Gill nets	3	0.14
	Nets	4	0.25
R	Nets	4	0.039
S	Pots	1	0.14
	Gill nets	1	0.28
	Nets	1	ND
T	Gill nets	2	0.083
	Pots	3	0.25
U	Nets	4	0.096
	Ropes	4	0.096

# See sub-section 3.2 for definition  
ND = not detected

**Table 14. Beta radiation dose rates over intertidal areas of the Cumbrian coast, 1994**

Location	Ground type	No. of sampling observations#	$\mu\text{Sv h}^{-1}$
Nethertown promenade	Stones	1	0.39
Pipeline	"	1	0.32
River Ehen	Saltmarsh	1	0.25
Seaburn Sewer	Concrete	1	0.23
	Mud, sand and stones	1	0.35
Seascale	Stones	1	0.45
Low Moor	Sand and stones	1	0.45
	"	1	0.43
Drigg	Sand	1	0.09
Carleton Marsh	Saltmarsh	1	1.2
Ravenglass - Raven Villa	Mud, sand and stones	1	0.38

# See sub-section 3.2 for definition

**Table 12. Radioactivity in Porphyra from UK shorelines of the Irish Sea, 1994**

Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet), Bq kg <sup>-1</sup>									
		<sup>14</sup> C	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>95</sup> Zr	<sup>95</sup> Nb	<sup>99</sup> Tc	<sup>103</sup> Ru	<sup>106</sup> Ru	<sup>110m</sup> Ag	<sup>125</sup> Sb
Braystones south	4	NA	0.42	NA	0.11	0.11	NA	0.11	30	1.0	0.69
Seascale	52*	"	0.19	"	0.07	0.12	"	ND	28	0.87	1.2
St Bees	4	48	0.31	0.84	0.26	0.15	4.8	0.21	39	1.0	1.2
Knock Bay	4	NA	ND	NA	ND	ND	NA	ND	0.53	ND	ND

Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet), Bq kg <sup>-1</sup>										
		<sup>137</sup> Cs	<sup>144</sup> Ce	<sup>154</sup> Eu	<sup>155</sup> Eu	<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Pu	<sup>241</sup> Am	<sup>242</sup> Cm	<sup>243</sup> Cm+ <sup>244</sup> Cm	Total beta
Braystones south	4	3.2	ND	ND	ND	0.61	3.0	39	4.7	0.0065	0.0077	NA
Seascale	52*	2.5	"	"	"	NA	NA	NA	5.3	NA	NA	"
St Bees	4	6.6	0.07	0.13	0.08	0.85	4.0	52	6.8	0.0093	0.017	180
Knock Bay	4	0.63	ND	ND	ND	NA	NA	NA	0.35	NA	NA	NA

ND = not detected

NA = not analysed

# See sub-section 3.2 for definition

\* These samples were counted wet to provide a rapid result

<sup>1</sup> Landing point or sampling area

**Table 13. Radioactivity in laverbread from South Wales, 1994**

Manufacturer	No. of sampling observations#	Mean radioactivity concentration (wet), Bq kg <sup>-1</sup>		
		<sup>137</sup> Cs	<sup>155</sup> Eu	Total beta
A	5	0.04	ND	NA
C	4	0.04	"	"
D	4	ND	"	65
E	1	0.24	0.26	NA

ND = not detected

# See sub-section 3.2 for definition

**Table 15. Radioactivity in sea water from the Irish Sea and Scottish waters, 1994**

Location	No. of sampling observations	Mean radioactivity concentration, Bq l <sup>-1</sup>			
		<sup>3</sup> H	<sup>99</sup> Tc	<sup>134</sup> Cs	<sup>137</sup> Cs
Seascale	4	NA	NA	0.0086	0.33
St Bees	52	12	0.19	0.0050	0.24
Maryport	1	“	“	0.0069	0.55
Silloth	1	“	“	0.0054	0.69
Silecroft	1	“	“	0.0034	0.27
Walney - west shore	4	7.4	“	0.0042	0.32
Isle of Withorn	1	NA	“	0.0038	0.11
Half Moon Bay	1	“	“	0.0015	0.39
Rossal (Fleetwood)	1	“	“	ND	0.26
Ainsdale	1	“	“	“	0.24
New Brighton	1	“	“	0.0025	0.22
Ross Bay	1	“	“	0.0036	0.16
North of Lame	11	“	0.0081	0.0021	0.051
Seafield	4	“	NA	0.0038	0.43
Southernness	4	“	“	0.0043	0.41
Knock Bay	4	0.67	“	0.0016	0.077
Prestatyn	1	NA	“	0.0052	0.068
Llandudno	1	“	“	0.0035	0.054
Cemaes Bay	1	“	“	0.0029	0.037
Holyhead	5	ND	“	0.0049	0.029
Cape Wrath	3	“	“	0.0010	0.026
Pentland Firth	4	NA	“	0.0002	0.021
Fair Isle	2	“	“	ND	0.015
Aberdeen	3	“	“	“	0.019

one of falling concentrations as the distance from Sellafield increases. This distribution is governed by recent discharges from the Sellafield site and the effects of activity previously discharged which had become associated with seabed sediments but is now being remobilised into the water column. However the concentrations now observed are only a small percentage of those prevailing in the late 1970s, typically 30 Bq l<sup>-1</sup> (Baxter *et al.*, 1992), when discharges were higher.

#### 4.1.7 Other surveys

In addition to the monitoring described above, which is related to the more (or potentially more) significant radiation exposure pathways as a consequence of Sellafield discharges, a number of further investigations are undertaken. Some of these are of a research nature; however, they also enable pathways of lower current importance to be kept under review.

Seaweeds are useful indicator materials; they may concentrate certain radionuclides, so they greatly facilitate measurement and assist in the tracing of these radionuclides in the environment. Table 16 presents the results of measurements in 1994 on marine plants from shorelines of the Irish Sea and further afield. Although small quantities of samphire and *Rhodomenia* may be eaten, concentrations of radioactivity were of negligible radiological significance. *Fucus* seaweeds are useful indicators, particularly of fission product radionuclides other than ruthenium-106; samples of *Fucus vesiculosus* were collected both in the Sellafield vicinity and further afield, and the results are presented here.

These clearly showed the effects of increases in discharges of technetium-99 from Sellafield in 1994 as discussed in sub-section 4.1. Such seaweeds are occasionally used as fertilisers and soil conditioners. However, the exposures from consumption of crops grown on land to which seaweed has been applied would have been very low. Monitoring of concentrations of radionuclides in seaweeds in Scotland is carried out on behalf of the Scottish Office. Analyses of similar samples collected in Northern Ireland are carried out on behalf of the DOE(NI).

## 4.2 Springfields, Lancashire

This establishment is mainly concerned with the manufacture of fuel elements for nuclear reactors and the production of uranium hexafluoride. Radioactive waste arisings consist mainly of thorium and uranium and their decay products; liquid discharges are made by pipeline to the Ribble estuary. Discharges of alpha and beta radionuclides increased in 1994 (0.158 and 114 TBq respectively) as compared with 1993 (0.0773 and 62.5 TBq respectively) because more uranium ore concentrate was processed, but they remained well within authorised limits. Public radiation exposure in this vicinity, as a result of site discharges, is relatively low; there is, however, a greater contribution due to Sellafield discharges. The most important pathway is external exposure, due to adsorption of radioactivity on the muddy areas of river banks and in salt marshes. The amounts of time for which members of the public are subject to such exposure are kept under review. The critical group consists of people who live on a houseboat moored in a muddy creek of the Ribble estuary, and is the same group which is affected by discharges from Sellafield (sub-section 4.1.2). No significant change in their occupancy of the boat was noted in 1994. Other activities which have significant occupancies are wildfowling which takes place in intertidal areas and marshes bordering the estuary and angling which is popular in the Preston area (Hunt, 1992). Gamma and beta dose rates are regularly monitored in relevant areas including muddy creeks where houseboats are moored, and some of these measurements are supported by analyses of sediments. In 1994, locally-obtained fish and shellfish continued to be sampled though consumption of seafood from the estuary is considered to be low. A recent study (Rollo *et al.*, 1994) has shown that exposures due to airborne radionuclides which may have come from discharges to the estuary are negligible.

Results for 1994 are shown in Tables 17(a) and (b). Radionuclides detected which were partly or wholly due to Springfields discharges were isotopes of thorium, uranium and their decay products. Natural sources also contributed to these activities. Other radionuclides present were mainly from Sellafield. Any exposures due to Springfields-derived radionuclides in fish and shellfish would have been a small fraction of the total, most of which is due to Sellafield discharges.

**Table 16. Radioactivity in aquatic plants from the Cumbrian coast and further afield, 1994**

Location	Material	No. of sampling observations#	Mean radioactivity concentration (wet), Bq kg <sup>-1</sup>											
			<sup>14</sup> C	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>95</sup> Zr	<sup>95</sup> Nb	<sup>99</sup> Tc	<sup>103</sup> Ru	<sup>106</sup> Ru	<sup>110m</sup> Ag	<sup>125</sup> Sb	<sup>129</sup> I	<sup>131</sup> I
<b>England</b>														
Sellafield	<i>Fucus vesiculosus</i>	4	NA	1.7	19	1.1	0.67	16000	ND	7.7	15	1.6	NA	ND
St Bees	"	4	42	0.87	7.5	0.73	0.50	4100	0.02	3.8	6.4	1.4	1.7	"
"	<i>Rhodomenia spp.</i>	2	NA	0.32	NA	3.5	1.3	NA	0.49	54	5.7	1.5	NA	"
River Calder (Pos. A)	<i>Fontinalis</i>	1	"	0.29	"	ND	ND	"	ND	ND	ND	ND	"	"
River Calder (Pos. B)	"	1	"	0.65	"	"	"	"	"	"	"	"	"	"
River Calder (Pos. C)	"	1	"	6.8	"	"	"	"	"	"	"	1.0	"	"
River Calder (Pos. D)	"	1	"	3.0	"	"	"	"	"	"	"	1.2	"	"
River Calder (Pos. E)	"	1	"	6.1	"	"	"	"	"	"	"	ND	"	"
Rabbit Cat How,														
Ravenglass	Samphire	1	"	ND	"	"	"	0.18	"	"	"	"	"	"
Cockerham Marsh	Samphire	1	"	"	"	"	"	NA	"	"	"	"	"	"
Lavernock Point	<i>Fucus vesiculosus</i>	2	"	"	"	"	"	"	"	"	"	"	"	1.1
<b>Wales</b>														
Portmadog	"	1	"	"	"	"	"	"	"	"	"	"	"	ND
Fishguard	<i>Fucus serratus</i>	1	"	"	"	"	"	23	"	"	"	"	"	"
<b>Scotland</b>														
Port William	<i>Fucus vesiculosus</i>	4	"	0.06	"	"	"	350	"	"	"	0.18	"	"
Garlieston	"	4	"	0.25	"	"	"	NA	"	0.50	0.15	0.47	"	"
Auchencairn	"	4	"	0.26	"	"	"	"	"	ND	0.18	0.42	"	"
Cape Wrath	"	1	"	ND	"	"	"	22	"	"	ND	ND	"	"
Wick	"	1	"	"	"	"	"	13	"	"	"	"	"	"
<b>Northern Ireland</b>														
Ardglass	"	4	"	"	"	"	"	150	"	"	"	0.08	"	"
Portrush	"	2	"	"	"	"	"	NA	"	"	"	ND	"	"
"	<i>Fucus serratus</i>	2	"	"	"	"	"	"	"	"	"	"	"	"
Strangford Lough	<i>Rhodomenia spp.</i>	4	"	"	"	"	"	10	"	"	"	"	"	"
<b>Isles of Scilly</b>														
	<i>Fucus vesiculosus</i>	1	"	"	"	"	"	2.0	"	"	"	"	"	"

Location	Material	No. of sampling observations#	Mean radioactivity concentration (wet), Bq kg <sup>-1</sup>												
			<sup>134</sup> Cs	<sup>137</sup> Cs	<sup>144</sup> Ce	<sup>154</sup> Eu	<sup>155</sup> Eu	<sup>238</sup> Pu	<sup>239</sup> Pu+	<sup>240</sup> Pu	<sup>241</sup> Am	<sup>242</sup> Cm	<sup>243</sup> Cm+	<sup>244</sup> Cm	Total beta
<b>England</b>															
Sellafield	<i>Fucus vesiculosus</i>	4	0.08	14	0.31	ND	0.09	3.1	14	6.6	0.0087	0.0097	11000		
St Bees	"	4	0.07	9.7	ND	"	0.14	1.4	6.5	3.6	ND	0.0055	NA		
"	<i>Rhodomenia spp.</i>	2	0.31	26	0.73	"	ND	1.3	6.0	14	0.022	0.022	"		
River Calder (Pos. A)	<i>Fontinalis</i>	1	ND	10	ND	"	1.6	NA	NA	ND	NA	NA	"		
River Calder (Pos. B)	"	1	0.37	16	"	"	1.0	"	"	"	"	"	"		
River Calder (Pos. C)	"	1	0.49	24	"	"	2.4	"	"	"	"	"	"		
River Calder (Pos. D)	"	1	0.60	19	"	"	2.1	"	"	0.57	"	"	"		
River Calder (Pos. E)	"	1	ND	27	"	"	2.0	"	"	ND	"	"	"		
Rabbit Cat How,															
Ravenglass	Samphire	1	"	1.6	"	"	ND	"	"	2.0	"	"	"		
Cockerham Marsh	Samphire	1	"	1.4	"	"	"	"	"	0.38	"	"	29		
Lavernock Point	<i>Fucus vesiculosus</i>	2	"	0.47	"	"	0.15	"	"	"	"	"	250		
<b>Wales</b>															
Portmadog	"	1	"	0.65	"	"	ND	"	"	"	"	"	NA		
Fishguard	<i>Fucus serratus</i>	1	"	0.36	"	"	"	"	"	"	"	"	300		
<b>Scotland</b>															
Port William	<i>Fucus vesiculosus</i>	4	"	4.1	"	"	0.04	"	"	0.75	"	"	NA		
Garlieston	"	4	0.03	7.1	"	"	0.05	"	"	2.5	"	"	"		
Auchencairn	"	4	0.06	12	"	"	0.08	"	"	2.4	"	"	"		
Cape Wrath	"	1	ND	0.68	"	"	ND	"	"	ND	"	"	250		
Wick	"	1	"	0.49	"	"	0.14	"	"	"	"	"	270		
<b>Northern Ireland</b>															
Ardglass	"	4	"	1.7	"	"	ND	"	"	"	"	"	320		
Portrush	"	2	"	0.29	"	"	"	"	"	"	"	"	NA		
"	<i>Fucus serratus</i>	2	"	0.67	"	"	"	"	"	0.17	"	"	330		
Strangford Lough	<i>Rhodomenia spp.</i>	4	"	3.5	"	"	"	0.065	0.34	0.44	ND	0.00081	790		
<b>Isles of Scilly</b>															
	<i>Fucus vesiculosus</i>	1	"	ND	"	"	"	NA	NA	ND	NA	NA	140		

ND = not detected

NA = not analysed

# See sub-section 3.2 for definition

**Table 17(a). Radioactivity in environmental materials near Springfields, 1994**

Material	Location	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>											
			<sup>60</sup> Co	<sup>99</sup> Tc	<sup>106</sup> Ru	<sup>125</sup> Sb	<sup>134</sup> Cs	<sup>137</sup> Cs	<sup>154</sup> Eu	<sup>155</sup> Eu	<sup>228</sup> Th	<sup>230</sup> Th	<sup>232</sup> Th	<sup>234</sup> Th
Flounder	Ribble Estuary	1	ND	NA	ND	ND	ND	28	ND	ND	NA	NA	NA	ND
Salmon	"	1	"	"	"	"	"	0.48	"	"	"	"	"	"
Sea trout	"	1	"	"	"	"	"	13	"	"	"	"	"	"
Shrimps	"	1	"	0.52	"	"	"	5.9	"	"	"	"	"	14
Turf	Hesketh Bank	4	2.0	NA	7.1	1.4	0.59	660	5.0	2.2	"	"	"	600
Mud	Beaconsall	4	0.80	"	7.3	1.2	0.50	470	1.6	ND	35	107	31	19000
"	Pipeline	3	ND	"	ND	ND	ND	320	ND	"	27	70	25	7300
Mud & sand	"	5	0.68	"	6.5	3.3	"	270	0.8	"	22	290	21	340000
"	Deepdale Brook	4	ND	"	ND	1.2	"	16	ND	3.8	26	350	22	740
Mud	Savick Brook	4	2.3	"	12	5.0	1.0	640	4.2	ND	NA	NA	NA	120000
"	Penwortham	2	ND	"	7.0	ND	ND	370	ND	"	32	110	30	7800
Mud & sand	"	2	1.8	"	14	3.2	"	550	2.4	"	50	240	40	96000

Material	Location	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>												
			<sup>233</sup> Pa	<sup>234</sup> U	<sup>235</sup> U+	<sup>236</sup> U	<sup>238</sup> U	<sup>237</sup> Np	<sup>238</sup> Pu	<sup>239</sup> Pu+	<sup>240</sup> Pu	<sup>241</sup> Pu	<sup>241</sup> Am	<sup>242</sup> Cm	<sup>243</sup> Cm+Total beta
Flounder	Ribble Estuary	1	ND	NA	NA	NA	NA	NA	NA	NA	NA	ND	NA	NA	NA
Salmon	"	1	"	"	"	"	"	"	"	"	"	"	"	"	"
Sea trout	"	1	"	"	"	"	"	"	"	"	"	"	"	"	"
Shrimps	"	1	"	"	"	"	"	"	"	"	"	"	"	"	"
Turf	Hesketh Bank	4	"	"	"	"	"	"	"	"	230	"	"	"	
Mud	Beaconsall	4	"	29	1.3	29	"	"	"	"	190	"	"	"	
"	Pipeline	3	"	32	1.5	29	"	19	110	"	170	ND	0.53	3200	
Mud & sand	"	5	"	53	2.4	47	"	NA	NA	"	120	NA	NA	12000	
"	Deepdale Brook	4	8.8	770	36	720	3.4	"	"	"	ND	"	"	NA	
Mud	Savick Brook	4	ND	NA	NA	NA	NA	28	150	1800	220	0.36	0.37	"	
"	Penwortham	2	"	34	1.4	32	0.33	NA	NA	NA	150	NA	NA	"	
Mud & sand	"	2	"	47	2.3	39	0.70	"	"	"	230	"	"	"	

NA = not analysed

ND = not detected

#See sub-section 3.2 for definition

\*Except for sediment where dry concentrations apply

Gamma dose rates over intertidal areas decreased at most locations in 1994 though there were increases at a few locations. The results of beta dose rate measurements suggest there may have been small decreases in the outer part of the estuary and small increases in the inner part, but the data are very variable. In 1994 the exposure of the critical group of houseboat dwellers including the Sellafield component was 0.14 mSv, a decrease from the value for 1993 (0.26 mSv). The decrease coincides with reducing concentrations of Sellafield gamma emitting radionuclides in parts of the estuary. The exposure was within the dose limit of 1 mSv for members of the public. Most of this exposure was due to the radioactivity already in the environment as a result of past discharges from Sellafield. To help the process of interpreting the ICRP-60 recommendations, the dose contribution due to discharges in 1994 from Springfields has been calculated from appropriate models (HMIP and MAFF, 1991). The contribution is estimated to be 0.02 mSv, an increase from 0.01 mSv in 1993 reflecting the increased discharges from the site.

This dose, in addition to those considered below, is less than the source constraint of 0.3 mSv. It is also a small fraction of the dose received in 1994 due to the combined effects of past and current discharges.

The whole-body exposure of wildfowlers was assessed as being 0.02 mSv in 1994 on the basis of ICRP-26 and 0.03 mSv using ICRP-60. In both cases the effects of beta-emitting nuclides have been considered in addition to gamma emitters. The reason for a slightly higher dose using ICRP-60 is that skin dose contributes to effective dose in the new ICRP recommendations. A significant proportion of the dose is due to Springfields discharges and the total is well within the 1 mSv limit for members of the public and the 0.3 mSv dose constraint. The exposure of anglers was similar to that of wildfowlers.

The critical group for skin irradiation was anglers with skin exposures, including a component due to natural radiation, of 1.8 mSv in 1994. This is 4% of the relevant dose limit for members of the public.

**Table 17(b). Monitoring of radiation dose rates near Springfields, 1994**

Location	Material or ground type	No. of sampling observations#	$\mu\text{Gy h}^{-1}$
<b>Gamma dose rates at 1 m over intertidal areas</b>			
Lytham - Boatyard	Mud	4	0.11
“ - Windmill Marsh	Salt marsh	1	0.12
Warton Marsh	Mud	4	0.14
“	“ †	4	0.15
“	Salt marsh	4	0.14
The Naze	“	1	0.13
Banks marsh	Mud	4	0.16
“	“ †	4	0.16
“	Salt marsh	4	0.19
Hesketh Bank	Mud	4	0.12
“	“ †	4	0.14
“	Salt marsh	4	0.13
Freckleton	Mud	4	0.12
River Douglas	Grass	1	0.18
Becconsall	Mud	4	0.11
“ (boat 2)	Cabin*	4	0.090
“	Mud	2	0.12
“	Mud and sand	2	0.12
Hutton Marsh	Mud	4	0.17
“	Salt marsh	4	0.17
Pipeline	Mud and sand	4	0.11
Pipeline (south bank)	“	4	0.11
“	Salt marsh	4	0.17
Savick Brook - tidal limit	Mud	2	0.23
“	Mud and sand	1	0.10
“ - A583 bridge	Mud	1	0.44
“	Mud and sand	3	0.14
“	Salt marsh	1	0.11
“ - confluence with Ribble	“	“	“
“	Mud	1	0.36
“	Mud and sand	3	0.11
Penwortham	Mud and sand	2	0.086
“	Mud	2	0.14
Lower Penwortham	“	3	0.13
“	Grass	4	0.082
Penwortham Railway Bridge	Mud	2	0.14
“	Mud, sand and stones	1	0.087
“	Grass	4	0.084
River Darwen	Sand and stones	1	0.067
“	Mud, sand and stones	3	0.083
“	Grass	3	0.081
<b>Beta dose rates</b>			
Lytham - Windmill Marsh	Salt marsh	1	0.64
“ - Boatyard	Mud	4	2.5
Warton Marsh	“	4	2.3
“	Salt marsh	4	1.1
The Naze	“	1	0.62
Banks Marsh	Mud	4	2.0
“	Salt marsh	4	1.4
Hesketh Bank	Mud	4	2.4
“	Salt marsh	4	1.4
Freckleton	Mud	4	7.0
River Douglas	Grass	1	0.72
Deepdale Brook	Mud and sand	4	0.62
Becconsall	Mud	4	3.6
Hutton Marsh	“	4	1.4
“	Salt marsh	4	1.8
Pipeline	Mud and sand	4	2.7
Pipeline (south bank)	“	4	2.1
“	Salt marsh	4	1.4
Savick Brook - tidal limit	Mud	2	39
“	Mud and sand	2	1.3
“ - A583 bridge	Mud	1	38
“	Mud and sand	3	12
“	Salt marsh	1	1.3
“ - confluence with Ribble	“	“	“
“	Mud	1	5.9
“	Mud and sand	3	21
Penwortham	Mud	2	15
“	Mud and sand	2	2.0
Lower Penwortham	Mud	3	9.0
“	Mud and sand	1	0.31
“	Grass	4	4.4
Penwortham Railway Bridge	“	4	4.5
“	Mud	2	14
“	Mud, sand and stones	1	0.60
River Darwen	Sand and stones	1	0.33
“	Mud, sand and stones	3	8.5
“	Grass	3	7.6
Ribble estuary	Gill net	2	0.45
“	Shrimp net	3	0.31

# See sub-section 3.2 for definition

\* In the cabin of a houseboat

† 15 cm above substrate

### 4.3 Capenhurst, Cheshire

The main functions undertaken on the Capenhurst site are enrichment of uranium and dismantling of redundant plant. The enrichment facility is operated by URENCO Capenhurst Ltd. Radioactive waste arisings, mainly of uranium and its daughter products, and technetium-99 and neptunium-237 from recycled fuel, are minor; BNFL has authorisations to dispose of small amounts of radioactivity in liquid wastes to the Rivacre Brook and to the North Wirral sewage outfall at Meols. No discharges from Capenhurst took place via Meols in 1994 (see Table 1). An environmental monitoring programme is carried out related to the pathways which could be of radiological significance due to both disposal routes. Aquatic plants are also sampled as indicator materials.

Results for 1994 are presented in Table 18. Concentrations of radionuclides in materials from the Rivacre Brook were similar to those for 1993. The hypothetical critical group for discharges from the site is considered to be people who may inadvertently ingest sediment from the Brook. Taking pessimistic assumptions about their ingestion rates, the exposure of the group was very low, at less than 0.005 mSv in 1994. The concentrations of artificial radioactivity in marine samples are consistent with values expected at this distance from Sellafield.

### 4.4 Chapelcross, Annandale and Eskdale

At this establishment, BNFL operates a magnox-type nuclear power station. Liquid waste is discharged to the Solway Firth under authorisation from the Scottish Office. Discharges in 1994 were similar to those in 1993. Habits surveys have established that three groups of people could receive radiation exposures of potential importance. The first of these groups comprises fishermen who consume local seafood and are exposed to external radiation whilst tending stake nets. The second group are fishermen who receive skin exposures whilst handling nets and the third are wildfowling who are exposed whilst on salt marshes. DFR monitoring, which is carried out on behalf of the Scottish Office, reflects these pathways. Samples of sea water and *Fucus vesiculosus*, as useful indicators, are also analysed. The results of monitoring in 1994 are presented in Tables 19(a) and (b).

Concentrations of artificial radionuclides in the Chapelcross vicinity are mostly due to Sellafield discharges, and the general levels of nuclides given in Table 19(a) are consistent with values expected at this distance from Sellafield. Concentrations of radiocaesium in 1994 were generally similar to those in 1993. The total beta activity in *Fucus vesiculosus* increased due to increases in discharges, particularly of technetium-99, from Sellafield. The exposure of the

**Table 18. Radioactivity in environmental materials near Capenhurst, 1994**

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>							
			<sup>60</sup> Co	<sup>99</sup> Tc	<sup>125</sup> Sb	<sup>137</sup> Cs	<sup>155</sup> Eu	<sup>234</sup> Th	<sup>234</sup> U	<sup>235</sup> U+ <sup>236</sup> U
Shrimps	Hoylake	2	ND	0.25	ND	3.5	ND	ND	NA	NA
Cockles	Dee estuary	4	0.07	3.1	0.07	2.3	“	2.6	“	“
<i>Cladophoraceae sp.</i>	Rivacre Brook	1	ND	270	ND	0.34	“	39	17	1.2
<i>Elodia canadensis</i>	“	1	“	110	“	0.78	0.27	150	25	1.8
Mud	“	2	“	1100	“	16	ND	320	250	17

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>							
			<sup>238</sup> U	<sup>233</sup> Pa	<sup>237</sup> Np	<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Am	<sup>243</sup> Cm+ <sup>244</sup> Cm	Total beta
Shrimps	Hoylake	2	NA	ND	NA	NA	NA	ND	NA	NA
Cockles	Dee estuary	4	“	0.21	“	0.099	0.54	1.5	0.0027	“
<i>Cladophoraceae sp.</i>	Rivacre Brook	1	10	4.6	2.4	NA	NA	ND	NA	390
<i>Elodia canadensis</i>	“	1	19	8.8	8.4	“	“	“	“	380
Mud	“	2	160	59	35	“	“	“	“	NA

NA = not analysed

ND = not detected

#See sub-section 3.2 for definition

<sup>1</sup> Landing point or sampling area

**Table 19(a). Radioactivity in environmental materials near Chapelcross, 1994**

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>											
			<sup>3</sup> H	<sup>14</sup> C	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>95</sup> Zr	<sup>95</sup> Nb	<sup>99</sup> Tc	<sup>106</sup> Ru	<sup>110m</sup> Ag	<sup>125</sup> Sb	<sup>134</sup> Cs	<sup>137</sup> Cs
Flounder	Solway Firth	4	NA	54	ND	0.028	ND	ND	0.67	ND	ND	ND	0.10	43
Sea trout	“	2	“	NA	“	NA	“	“	NA	“	“	“	ND	7.9
Salmon	“	1	“	“	“	“	“	“	“	“	“	“	“	0.48
Shrimps	“	4	“	“	“	0.082	“	“	2.6	“	0.37	“	0.02	13
<i>Fucus vesiculosus</i>	Pipeline	4	“	“	0.23	NA	“	“	NA	0.62	ND	0.30	0.13	26
Mud and sand	“	3	“	“	1.6	“	1.6	1.9	“	26	“	2.1	1.4	310
Sea water	“	4	0.67	“	NA	“	NA	NA	“	NA	NA	NA	0.0038	0.43

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>							
			<sup>154</sup> Eu	<sup>155</sup> Eu	<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Am	<sup>242</sup> Cm	<sup>243</sup> Cm+ <sup>244</sup> Cm	Total beta
Flounder	Solway Firth	4	ND	ND	0.0012	0.0064	0.011	ND	ND	NA
Sea trout	“	2	“	“	0.00059	0.0027	0.0034	“	0.000011	“
Salmon	“	1	“	“	NA	NA	ND	NA	NA	“
Shrimps	“	4	“	“	0.0037	0.020	0.036	ND	ND	“
<i>Fucus vesiculosus</i>	Pipeline	4	“	0.08	0.49	2.9	3.1	“	0.013	910
Mud and sand	“	3	1.5	1.5	13	66	102	0.16	0.14	NA
Sea water	“	4	NA	NA	NA	NA	NA	NA	NA	“

ND = not detected; NA = not analysed

\* Except for sediment where dry concentrations apply and for sea water where units are Bq l<sup>-1</sup>

# See sub-section 3.2 for definition

<sup>1</sup> Landing point or sampling area

critical group of fishermen who consume seafood and are exposed to external radiation over intertidal areas was 0.03 mSv in 1994 (on the basis of ICRP-60: 0.03 mSv), which is 3% of the dose limit of 1 mSv for members of the public. The exposure of the skin of local fishermen, including a component due to natural radiation, decreased in 1994 to 0.05 mSv (0.11 mSv:

1993) corresponding to less than 1% of the dose limit appropriate for exposures to skin of members of the public. Wildfowlers received a dose of 0.02 mSv. The magnitude of the Chapelcross discharges indicates that the local contribution to dose was a tiny fraction of these exposures, most of it being due to Sellafield discharges.

**Table 19(b). Monitoring of radiation dose rates near Chapelcross, 1994**

Location	Material or ground type	No. of sampling observations#	$\mu\text{Sv h}^{-1}$
<b>Beta dose rates on nets</b>			
Seafield	Stake nets	2	0.18
<b>Gamma dose rates at 1 m over intertidal areas</b>			
Seafield	Mud and sand	4	0.088
"	Salt marsh	4	0.092
Battle Hill	Mud and sand	4	0.082
Browhouses	"	4	0.098
Dornoch Brow	"	2	0.089
"	Salt marsh	4	0.096
Powfoot	"	1	0.075
"	Mud and sand	3	0.078
"	Mud, sand and stones	1	0.085
Priestside Bank	Salt marsh	3	0.084
"	* "	3	0.089

# See sub-section 3.2 for definition

\* 15 cm above substrate

## 5. UNITED KINGDOM ATOMIC ENERGY AUTHORITY (UKAEA)

Regular monitoring of the environmental impact of liquid radioactive discharges from three UKAEA sites, namely Harwell, Winfrith and Dounreay, has continued.

### 5.1 Harwell, Oxfordshire

At this establishment the UKAEA operates research facilities. Liquid radioactive wastes are created as a result of decommissioning and decontamination operations and nuclear-related research and development. Liquid waste arisings are small and discharges are made under authorisation to the River Thames at Sutton Courtenay and to the Lydebank Brook to the north of the site. During 1994, the small programme of monitoring of fish and other aquatic materials from the Thames catchment has continued in surveillance of fisheries-related exposure pathways; monitoring of the drinking water pathway is carried out by HMIP (HMIP, 1994). Sampling was also carried out in 1994 upstream of Sutton Courtenay at Newbridge to indicate background levels remote from nuclear establishments. Analyses were carried out of available fish species, with *Nuphar lutea* (yellow water lily) and sediments as indicator materials. In addition, gamma dose rates were measured on the river bank near the outfall.

Habits surveys have identified anglers as the critical

group affected by direct discharges into the river. Their occupancy of the river bank has been assessed to estimate their external exposures. Consumption of freshwater fish was also considered but none was found. Nevertheless, it is considered prudent to include a component in the assessment of the anglers' exposure and a hypothetical consumption of fish at a rate of 1 kg year<sup>-1</sup> was assumed.

The results of the measurements of radioactivity concentrations and dose rates are shown in Tables 20(a) and (b). Concentrations of some nuclides, notably cobalt-60 and caesium-137, were enhanced close to the outfall, but the levels were very small in terms of any radiological effect. External exposures were calculated using a natural background dose rate of 0.06  $\mu\text{Gy h}^{-1}$ . The radiation dose to anglers in 1994 from fish consumption and external occupancy of the river bank would have been 0.009 mSv, or less than 1% of the dose limit of 1 mSv.

### 5.2 Winfrith, Dorset

The principal source of liquid radioactive wastes at this establishment in 1994 was decommissioning and decontamination of the Steam Generating Heavy Water Reactor (SGHWR) which ceased power production in September 1990. Discharges of radionuclides in 1994 were similar to those in 1993. The wastes are disposed of under authorisation to deep water in Weymouth Bay. Concentration of radionuclides by shellfish, followed by local consumption, constitutes the critical exposure pathway; this is reflected in the monitoring programme. External gamma radiation dose rates are monitored locally at Kimmeridge and in Poole Harbour where the intertidal sediment has the potential to adsorb radioactivity. Data are presented in Tables 21(a) and (b).

The impact of Winfrith discharges, as in previous years, was mainly observed in the concentrations of activation product radionuclides. The concentrations of these radionuclides declined in 1994 as compared with previous years; this was due to the lower level of discharges from the site since the closure of the SGHWR. The radiation dose to the critical group of fish and shellfish consumers remained low in 1994 at less than 0.005 mSv, or less than 0.5% of the dose limit of 1 mSv. External gamma radiation dose rates, measured using portable instruments, continued to be indistinguishable from levels typical of the natural background.

### 5.3 Dounreay, Caithness

Liquid radioactive waste discharges from this establishment are made to the Pentland Firth under authorisation by the Scottish Office. Discharges include a minor contribution from the adjoining reactor site (Vulcan Naval Reactor Test Establishment) which is operated by

**Table 20(a). Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Harwell, 1994**

Material	Location	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>						
			<sup>51</sup> Cr	<sup>57</sup> Co	<sup>60</sup> Co	<sup>134</sup> Cs	<sup>137</sup> Cs	<sup>154</sup> Eu	<sup>155</sup> Eu
Pike	Outfall (Sutton Courtenay)	1	ND	ND	ND	0.05	2.8	ND	ND
"	Newbridge	1	"	"	"	ND	ND	"	"
"	Staines	1	"	"	"	"	0.39	"	"
<i>Nuphar lutea</i>	Outfall (Sutton Courtenay)	1	2.3	"	1.6	"	0.27	"	"
"	Newbridge	1	ND	"	ND	"	0.02	"	"
"	Staines	1	"	0.09	"	"	0.06	"	"
Mud and sand	Staines	1	"	0.72	1.1	"	16	"	1.3
"	Outfall (Sutton Courtenay)	1	"	ND	17	"	1000	"	ND
Mud	Newbridge	1	"	"	ND	"	11	"	2.4
"	Outfall (Sutton Courtenay)	3	6.3	"	23	0.38	580	1.8	1.8
"	Lydebank/Ginge Brook Confluence	1	ND	"	1.3	ND	19	ND	ND

Material	Location	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>					
			<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Am	<sup>242</sup> Cm	<sup>243+</sup> <sup>244</sup> Cm	Total beta
Pike	Outfall (Sutton Courtenay)	1	0.000011	0.000051	0.000070	ND	ND	NA
"	Newbridge	1	0.0000062	0.000037	0.000080	"	"	"
"	Staines	1	NA	NA	ND	NA	NA	"
<i>Nuphar lutea</i>	Outfall (Sutton Courtenay)	1	"	"	"	"	"	"
"	Newbridge	1	"	"	"	"	"	"
"	Staines	1	"	"	"	"	"	"
Mud and sand	Staines	1	"	"	"	"	"	400
"	Outfall (Sutton Courtenay)	1	"	"	4.3	"	"	1400
Mud	Newbridge	1	"	"	ND	"	"	NA
"	Outfall (Sutton Courtenay)	3	"	"	4.9	"	"	"
"	Lydebank/Ginge Brook Confluence	1	0.13	0.92	0.47	0.0020	0.0026	"

NA = not analysed

ND = not detected

\* Except for sediment where dry concentrations apply

# See sub-section 3.2 for definition

**Table 20(b). Monitoring of gamma dose rates near Harwell, 1994**

Location	Ground type	No. of sampling observations#	μGy h <sup>-1</sup>
<b>Gamma dose rates at 1 m over river bank</b>			
Outfall (Sutton Courtenay)	Mud	19	0.084
"	Soil	12	0.067
Lydebank/Ginge Brook confluence	Mud	4	0.054
"	Grass	1	0.059
Newbridge	"	3	0.057
Staines	Soil	4	0.056

# See sub-section 3.2 for definition

**Table 21(a). Radioactivity in environmental materials near Winfrith, 1994**

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>									
			<sup>3</sup> H	<sup>60</sup> Co	<sup>65</sup> Zn	<sup>137</sup> Cs	<sup>155</sup> Eu	<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Am	<sup>243</sup> Cm+ <sup>244</sup> Cm	Total beta
Plaice	Weymouth Bay	2	NA	ND	ND	0.17	ND	NA	NA	ND	NA	NA
Cod	"	2	"	"	"	0.30	"	"	"	"	"	"
Crabs	Chapmans Pool	1	"	1.4	"	ND	"	"	"	"	"	"
"	Lulworth Banks	1	"	2.4	"	"	"	"	"	"	"	"
Pacific oysters	Poole	1	"	0.20	0.56	"	"	"	"	"	"	"
Cockles	"	1	"	2.8	ND	0.05	"	"	"	"	"	"
Whelks	Weymouth Bay	1	"	1.1	0.26	ND	"	"	"	"	"	"
"	Poole	1	"	1.4	0.30	"	"	0.00058	0.0029	0.0028	0.00010	"
Clams	"	1	"	3.4	ND	"	"	NA	NA	ND	NA	"
<i>Fucus serratus</i>	Kimmeridge	2	"	2.8	"	0.13	"	"	"	"	"	190
"	Bognor Rock	2	"	2.2	"	0.04	"	"	"	"	"	NA
Mud and sand	Kimmeridge	2	"	0.54	"	0.56	"	"	"	"	"	"
"	Parkstone Bay	1	"	2.6	"	0.74	"	"	"	"	"	"
Mud	"	1	"	5.4	"	2.6	2.1	0.13	0.66	0.49	0.0084	"
"	Hardway	2	"	12	"	4.4	2.3	NA	NA	ND	NA	"
Sea water	Kimmeridge	2	ND	NA	NA	NA	NA	"	"	NA	"	"

NA = not analysed

ND = not detected

\* Except for sediment where dry concentrations apply and for sea water where units are Bq l<sup>-1</sup>

# See sub-section 3.2 for definition

<sup>1</sup> Landing point or sampling area

**Table 21(b). Monitoring of radiation dose rates near Winfrith, 1994**

Location	Ground type	No. of sampling observations#	µGy h <sup>-1</sup>
<b>Gamma dose rates at 1 m over intertidal areas</b>			
Kimmeridge	Mud and sand	2	0.059
Parkstone Bay	Mud	2	0.053
Hardway	"	2	0.061

ND = not detected

# See sub-section 3.2 for definition

the Ministry of Defence (Procurement Executive). Discharges from Dounreay in 1994 were generally similar to those in 1993 reflecting the campaigns of reprocessing of reactor fuel. DFR surveys near Dounreay are carried out on behalf of the Scottish Office. Monitoring in 1994 continued to include sampling of fish and shellfish from the area of the Dounreay outfall and other materials further afield, associated beta and gamma dose rate measurements and a survey in Sandside Bay for particulate contamination. The results are presented in Tables 22(a) and (b). No particulate contamination was found in Sandside Bay.

Habits surveys have confirmed the existence of four potentially critical exposure pathways, three of which involve external irradiation. The first of these is due to radioactivity adsorbed mainly on fine particulate matter becoming entrained on fishing gear which is regularly

handled. This results in skin dose, mainly from beta particles, to the hands and forearms of fishermen. The most exposed group is represented by a small number of people who operate a salmon fishery from Sandside Bay, close to Dounreay. The skin exposure of these fishermen has been assessed including a component due to natural radiation. The dose in 1994 was 0.16 mSv, or less than 0.5% of the dose limit of 50 mSv for skin exposures (see sub-section 3.3).

The second potentially critical pathway arises also from the uptake of radioactivity by particulate material which accumulates in rocky areas of the foreshore and presents a potential source of exposure, mainly to gamma radiation, of those who visit these areas. In 1994, monitoring of sludge at Oigin's Geo showed increased concentrations of radionuclides compared with 1993. However, there is known to be significant variability in

**Table 22(a). Radioactivity in environmental materials near Dounreay, 1994**

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>											
			<sup>3</sup> H	<sup>14</sup> C	<sup>54</sup> Mn	<sup>58</sup> Co	<sup>60</sup> Co	<sup>99</sup> Tc	<sup>106</sup> Ru	<sup>110m</sup> Ag	<sup>125</sup> Sb	<sup>134</sup> Cs	<sup>137</sup> Cs	<sup>144</sup> Ce
Cod	Pipeline	4	NA	21	ND	ND	ND	NA	ND	ND	ND	ND	0.68	ND
Crabs	"	4	"	NA	"	"	0.01	"	"	0.28	"	"	0.37	"
Lobsters	"	4	"	"	"	"	ND	"	"	2.8	"	"	0.59	"
Winkles	Brims Ness	4	"	"	"	"	0.58	"	0.86	23	"	"	0.51	0.17
"	Sandside Bay	4	"	"	"	"	0.70	"	0.68	25	"	"	0.55	0.83
Sludge	Oigins Geo	5	"	"	15	8.2	67	"	3500	310	410	11	350	330
Sand	Sandside Bay	3	"	"	ND	ND	0.07	"	ND	ND	ND	0.14	5.8	ND
Sand and shells	"	1	"	"	"	"	0.39	"	"	"	"	"	0.27	5.9
<i>Fucus vesiculosus</i>	"	4	"	"	0.22	"	1.0	170	0.58	2.8	0.03	0.15	2.6	0.31
"	Brims Ness	4	"	"	0.16	"	1.0	NA	0.62	3.1	0.04	0.08	1.1	0.24
Sea water	Pipeline	4	0.40	"	NA	NA	NA	"	NA	NA	NA	0.0043	0.16	NA

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>									Total beta
			<sup>154</sup> Eu	<sup>155</sup> Eu	<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Pu	<sup>241</sup> Am	<sup>242</sup> Cm	<sup>243</sup> Cm+ <sup>244</sup> Cm		
Cod	Pipeline	4	ND	ND	0.000046	0.00023	NA	0.00029	ND	ND	NA	
Crabs	"	4	"	"	0.0030	0.012	"	0.011	0.00039	0.0002	"	
Lobsters	"	4	"	"	0.0026	0.0087	"	0.014	ND	0.00024	"	
Winkles	Brims Ness	4	"	"	0.17	0.51	"	0.33	0.013	0.0080	"	
"	Sandside Bay	4	"	0.08	0.18	0.53	6.6	0.35	0.0077	0.0076	"	
Sludge	Oigins Geo	5	54	70	360	970	NA	200	15	4.9	"	
Sand	Sandside Bay	3	0.93	1.2	2.1	7.7	"	7.3	0.14	0.10	"	
Sand and shells	"	1	2.0	1.5	NA	NA	"	11	NA	NA	"	
<i>Fucus vesiculosus</i>	"	4	ND	0.02	"	"	"	0.03	"	"	370	
"	Brims Ness	4	"	ND	"	"	"	ND	"	"	NA	
Sea water	Pipeline	4	NA	NA	"	"	"	NA	"	"	"	

NA = not analysed

ND = not detected

\* Except for sediment where dry concentrations apply and for sea water where units are Bq l<sup>-1</sup>

# See sub-section 3.2 for definition

<sup>1</sup> Landing point or sampling area

**Table 22(b). Monitoring of dose rates near Dounreay, 1994**

Location	Material or ground type	No. of sampling observations#	µGy h <sup>-1</sup>
<b>Gamma dose rates at 1 m over intertidal areas</b>			
Oigins Geo	Intertidal sediment	5	0.15
Sandside Bay	Sand	1	0.057
"	Winkle bed	4	0.15
Castletown Harbour	Sand	1	0.078
<b>Beta dose rates on fishing gear</b>			
Sandside Bay	Gill nets	1	0.26
Pipeline offshore	Pots	1	0.18

# See sub-section 3.2 for definition

these concentrations. The more important measurements of gamma dose rates above areas of the foreshore remained unchanged. Public radiation exposure via this pathway remained low, at 0.008 mSv or 0.8% of the dose limit of 1 mSv.

The third potentially critical pathway involves internal exposure of consumers of locally-collected fish and shellfish; fish, crabs, lobsters and winkles from the outfall area are sampled to enable this pathway to be kept under review. Additionally, sea water and seaweed were sampled as indicator materials. Concentrations of radionuclides in 1994 were similar to those for 1993. Exposures from consumption of fish and shellfish continued to be low: for high-rate consumers the radiation dose was less than 0.005 mSv or 0.5% of the dose limit of 1 mSv.

The fourth potential critical pathway is due to consumption of molluscs and external exposure during collection. Gamma dose rates were measured over collecting areas and winkles were analysed for their radioactivity content. Gamma dose rates over the main collecting areas increased in 1994 but the radiation dose due to a combination of consumption of molluscs and external exposure during collection was still low at 0.03 mSv or 3% of the dose limit of 1 mSv. This pathway was the critical one at Dounreay in 1994.

## 6. NUCLEAR POWER STATIONS OPERATED BY THE ELECTRICITY COMPANIES

All but two of these sites are in England or Wales and were operated by Nuclear Electric plc. The power stations at Hunterston and Torness were operated by Scottish Nuclear Ltd.

### 6.1 Berkeley, Gloucestershire and Oldbury, Avon

Berkeley Power Station ceased electricity generation in March 1989, but radioactive wastes still need to be disposed of as part of decommissioning operations. Such operations, particularly within the storage pond area, have resulted in a decrease in discharges from the

Berkeley site. In addition there is a component of the discharge from the adjoining Berkeley Technology Centre. Due to decommissioning of the cooling water system at the Power Station, a new discharge pipeline was installed and came into operation in May 1994. The design of the pipeline ensures good dilution in the Severn Estuary in the new regime of low volumes of waste water to be discharged. Liquid radioactive wastes from both Berkeley and Oldbury are discharged to the same stretch of the Estuary. The stations are therefore considered together for the purpose of DFR environmental monitoring. Habits surveys have confirmed that the two critical pathways for public radiation exposure are internal irradiation following consumption of locally-caught fish and shellfish, and external exposure from occupancy of muddy intertidal areas. Therefore samples of fish and shellfish are analysed and gamma dose rates over sediment are monitored. In addition, measurements of external exposure are supported by analyses of intertidal mud, and *Fucus vesiculosus* is collected as an indicator material.

**Table 23(a). Radioactivity in environmental materials near Berkeley and Oldbury nuclear power stations, 1994**

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>						
			<sup>14</sup> C	<sup>54</sup> Mn	<sup>60</sup> Co	<sup>131</sup> I	<sup>134</sup> Cs	<sup>137</sup> Cs	<sup>155</sup> Eu
Dover sole	Lydney	2	NA	ND	ND	ND	ND	0.43	ND
Flounder	"	1	260	"	"	"	"	0.65	"
"	Littleton Warth	2	180	"	"	"	"	0.47	"
Elvers	River Severn	1	NA	"	"	"	"	0.09	"
Shrimps	Lydney	2	150	"	"	"	"	0.29	"
<i>Fucus vesiculosus</i>	Pipeline (old) <sup>2</sup>	2	NA	0.03	0.20	0.35	0.04	1.0	0.04
"	" (new) <sup>2</sup>	2	"	ND	0.19	0.38	ND	1.1	0.06
Mud	" (old) <sup>2</sup>	2	"	"	ND	ND	0.44	20	2.2
"	" (new) <sup>2</sup>	2	"	"	0.50	"	0.78	33	2.2
"	Lydney	2	"	"	ND	"	0.54	32	ND
"	Littleton Warth	2	"	"	0.35	"	0.99	40	2.0
"	1 km south of Oldbury	2	"	"	0.44	"	0.57	37	2.3

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>					Total beta
			<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Am	<sup>243</sup> Cm+ <sup>244</sup> Cm		
Dover sole	Lydney	2	NA	NA	ND	NA	NA	
Flounder	"	1	"	"	"	"	120	
"	Littleton Warth	2	"	"	"	"	NA	
Elvers	River Severn	1	"	"	"	"	"	
Shrimps	Lydney	2	0.00036	0.0021	0.0026	0.000029	"	
<i>Fucus vesiculosus</i>	Pipeline (old) <sup>2</sup>	2	NA	NA	ND	NA	170	
"	" (new) <sup>2</sup>	2	"	"	"	"	180	
Mud	" (old) <sup>2</sup>	2	"	"	0.12	"	NA	
"	" (new) <sup>2</sup>	2	"	"	ND	"	"	
"	Lydney	2	"	"	"	"	"	
"	Littleton Warth	2	"	"	0.82	"	"	
"	1 km south of Oldbury	2	"	"	ND	"	"	

NA = not analysed

ND = not detected

\* Except for sediment where dry concentrations apply

# See sub-section 3.2 for definition

<sup>1</sup> Landing point or sampling area

<sup>2</sup> Berkeley

**Table 23(b). Monitoring of gamma dose rates near Berkeley and Oldbury nuclear power stations, 1994**

Location	Ground type	No. of sampling observations#	$\mu\text{Gy h}^{-1}$
<b>Gamma dose rates at 1 m over intertidal areas</b>			
1 km south of Oldbury	Mud	2	0.072
2 km south west of Berkeley	"	2	0.067
Guscar Rocks	"	2	0.078
Lydney Locks	"	2	0.072
Berkeley pipeline (old)	"	2	0.072
Berkeley pipeline (new)	"	2	0.079
Sharpness	"	2	0.069
Littleton Warth	"	2	0.070

# See sub-section 3.2 for definition

Data for 1994 are presented in Tables 23(a) and (b). Most of the artificial radioactivity detected in fish and shellfish was due to carbon-14 and radiocaesium. Concentrations of these radionuclides represent the combined effect of discharges from the stations, other nuclear establishments discharging into the Bristol Channel, fallout, and possibly include a small Sellafield-derived component. Most of the artificial carbon-14 is due to discharges from Cardiff (see sub-section 8.2). Apportionment of radiocaesium is difficult at the low levels detected. The concentrations of

transuranics in shrimps were typical of levels to be expected at sites remote from Sellafield. Very small concentrations of other artificial radionuclides, in addition to radiocaesium, were detected in mud and seaweed but, taken together, were of low radiological significance. Directly-measured gamma dose rates were difficult to distinguish from the natural background. The total exposure of the critical group of fish and shellfish consumers including external radiation was low, at less than 0.005 mSv or 0.5% of the dose limit of 1 mSv.

## 6.2 Bradwell, Essex

Radioactive liquid effluent from this power station is discharged to the estuary of the River Blackwater. The two critical pathways are external exposure of people who live in houseboats moored in muddy areas of the estuary and consumption of locally-caught fish and shellfish. DFR environmental monitoring, therefore, reflects both these pathways. Gamma dose rate measurements are supported by analyses of intertidal sediment, and *Fucus vesiculosus* is analysed as an indicator material.

Measurements for 1994 are summarised in Tables 24(a) and (b). Low concentrations of artificial radioactivity were detected due to the combined effects of discharges

**Table 24(a). Radioactivity in environmental materials near Bradwell nuclear power station, 1994**

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>						
			<sup>60</sup> Co	<sup>65</sup> Zn	<sup>99</sup> Tc	<sup>125</sup> Sb	<sup>134</sup> Cs	<sup>137</sup> Cs	<sup>155</sup> Eu
Sole	Bradwell	2	ND	ND	NA	ND	0.08	0.60	ND
Bass	Pipeline	1	"	"	"	"	0.40	2.9	"
Mullet	"	1	"	"	"	"	0.14	2.3	"
Native oysters	Tollesbury N. Channel	2	"	0.84	"	"	0.09	0.48	"
Pacific oysters	Goldhanger Creek	1	"	1.0	"	"	0.13	0.43	"
Winkles	Pipeline	2	0.85	0.26	"	"	0.05	0.86	"
<i>Fucus vesiculosus</i>	Waterside	1	0.59	ND	2.7	"	0.56	2.1	"
<i>Ascophyllum nodosum</i>	"	1	0.54	"	2.4	0.24	0.39	1.8	0.17
Mud	Pipeline	2	8.2	"	NA	ND	4.3	27	1.4
"	West Mersea	2	1.2	"	"	"	1.8	13	2.0
"	Maldon	2	3.3	"	"	"	9.4	80	2.2

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>					
			<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Am	<sup>242</sup> Cm	<sup>243</sup> Cm+ <sup>244</sup> Cm	Total beta
Sole	Bradwell	2	NA	NA	ND	NA	NA	NA
Bass	Pipeline	1	"	"	"	"	"	"
Mullet	"	1	"	"	"	"	"	"
Native oysters	Tollesbury N. Channel	2	0.00062	0.0027	0.0056	0.000051	0.00028	"
Pacific oysters	Goldhanger Creek	1	NA	NA	ND	NA	NA	"
Winkles	Pipeline	2	"	"	"	"	"	"
<i>Fucus vesiculosus</i>	Waterside	1	"	"	"	"	"	210
<i>Ascophyllum nodosum</i>	"	1	"	"	"	"	"	200
Mud	Pipeline	2	"	"	0.72	"	"	NA
"	West Mersea	2	"	"	ND	"	"	"
"	Maldon	2	"	"	"	"	"	"

NA = not analysed

ND = not detected

\* Except for sediment where dry concentrations apply

# See sub-section 3.2 for definition

<sup>1</sup> Landing point or sampling area

**Table 24(b). Monitoring of gamma dose rates near Bradwell, 1994**

Location	Ground type	No. of sampling observations#	$\mu\text{Gy h}^{-1}$
<b>Gamma dose rates at 1 m over intertidal areas</b>			
Pipeline	Mud	2	0.42
"	Sand and shells	3	0.33
1.5 km east of pipeline	Mud and sand	1	0.070
"	Mud and shells	1	0.062
Waterside	Mud	2	0.064
West Mersea	"	2	0.063
Maldon	"	2	0.059

# See sub-section 3.2 for definition

from the station, Sellafield discharges, and fallout. Apportionment of the effects of these sources is difficult because of the low levels detected; concentrations were similar to those for 1993 (Camplin, 1994). Gamma dose rates, as directly measured, were difficult to distinguish from the natural background with the exception of the measurements at one location close to the station which were affected by direct radiation. A calculation based on concentrations of radionuclides in sediments has been used to estimate the external

exposure of the houseboat dwellers who were the critical group in 1994. Their exposure, including the effects of consumption pathways, was small, amounting to 0.01 mSv or 1% of the dose limit of 1 mSv.

### 6.3 Dungeness, Kent

There are two, essentially separate, 'A' and 'B' nuclear power stations on this site; the 'A' station is powered by magnox-type reactors and the 'B' station by advanced gas-cooled reactors (AGRs). Discharges are made via separate, but adjacent, outfalls and for the purposes of DFR environmental monitoring are considered together. The authorisations were revised in 1994 to set lower limits on discharges for both stations. There are two critical radiation exposure pathways as a result of liquid radioactive waste discharges: internal irradiation due to consumption of locally-caught fish and shellfish, and external exposure from occupancy of the foreshore. The monitoring programme therefore includes analyses of fish and shellfish and gamma dose rate surveys of the intertidal areas. Samples of sediment are also collected and analysed. Sea water and *Fucus serratus* are analysed as indicator materials. The results for 1994 are given in Tables 25(a) and (b).

**Table 25(a). Radioactivity in environmental materials near Dungeness nuclear power stations, 1994**

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>											
			<sup>3</sup> H	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>134</sup> Cs	<sup>137</sup> Cs	<sup>155</sup> Eu	<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Am	<sup>242</sup> Cm	<sup>243</sup> Cm+ <sup>244</sup> Cm	Total beta
Plaice	Pipeline	2	NA	ND	NA	ND	0.24	ND	NA	NA	ND	NA	NA	NA
Cod	"	2	"	"	"	"	0.41	"	"	"	"	"	"	"
Bass	"	1	"	"	"	"	0.36	"	"	"	"	"	"	"
Shrimps	"	2	"	0.19	"	0.03	0.27	"	"	"	"	"	"	"
Whelks	"	2	"	0.24	0.0049	ND	0.22	"	0.00062	0.0027	0.0027	ND	0.00025	"
<i>Fucus vesiculosus</i>	Copt Point	2	"	1.1	NA	"	0.18	"	NA	NA	ND	NA	NA	170
Mud	Dungeness	3	"	6.2	"	0.51	3.5	1.0	"	"	0.57	"	"	NA
Mud and sand	Rye Harbour	2	"	5.6	"	ND	2.3	1.5	0.099	0.43	0.35	ND	0.029	"
Sand	Camber Sands	2	"	0.55	"	"	0.27	ND	NA	NA	ND	NA	NA	"
"	Pilot Inn	1	"	0.97	"	"	0.60	0.58	"	"	"	"	"	"
Gravel	"	1	"	ND	"	"	ND	ND	"	"	"	"	"	"
Sea water	Pipeline	2	ND	NA	"	NA	NA	NA	"	"	NA	"	"	"

NA = not analysed

ND - not detected

\* Except for sediment where dry concentrations apply and for sea water where units are Bq l<sup>-1</sup>

# See sub-section 3.2 for definition

<sup>1</sup> Location point or sampling area

**Table 25(b). Monitoring of gamma dose rates near Dungeness nuclear power stations, 1994**

Location	Ground type	No. of sampling observations#	$\mu\text{Gy h}^{-1}$
<b>Gamma dose rates at 1 m over intertidal areas</b>			
Camber Sands	Sand	2	0.050
Old Lifeboat Station	Shingle	2	0.041
Pilot Inn	Sand	1	0.050
"	Shingle	2	0.042
Rye Harbour	Mud and sand	2	0.062

# See sub-section 3.2 for definition

Concentrations of radiocaesium are attributable to discharges from the stations and to weapons-test fallout with a small contribution due to discharges from Sellafield. Apportionment is difficult at these low levels. Trace levels of cobalt-60 in some materials are likely to be due mainly to discharges from other sites rather than to Dungeness. The small concentrations of transuranics in whelks and mud were typical of levels expected at other sites remote from Sellafield. The critical group in 1994 continued to comprise local bait diggers who also eat fish and shellfish. Gamma dose rates over intertidal sediments, measured using portable instruments, were difficult to distinguish from the natural background, thus the external exposure of the

critical group has been based on a calculation using concentrations of radionuclides in sediment. The radiation exposure of the critical group was low, at less than 0.005 mSv or 0.5% of the dose limit of 1 mSv.

## 6.4 Hartlepool, Cleveland

This station is powered by twin AGRs. Discharges of liquid radioactive wastes are made under authorisation to the North Sea. The critical pathway for radiation exposure of the public near the station is internal irradiation following consumption of local fish and shellfish. Collectors of small coal, which is washed ashore along this stretch of coast, account for the highest beach occupancies.

Results of the DFR monitoring programme carried out in 1994 are shown in Tables 26(a) and (b). Concentrations of radiocaesium and transuranics were mainly due to discharges from Sellafield and to weapons-test fallout. Low levels of iodine-131, likely to be from

local hospitals, were detected in seaweed at low levels. Gamma dose rates were indistinguishable from natural background with the exception of measurements at Paddy's Hole. In this location, waste slag from a steel works can be found containing enhanced levels of gamma emitting natural radionuclides. The radiation exposure of the critical group of local fish and shellfish consumers was low, at less than 0.005 mSv or 0.5% of the dose limit of 1 mSv.

## 6.5 Heysham, Lancashire

This establishment comprises two, essentially separate, nuclear power stations both powered by AGRs. Discharges of liquid radioactive waste from both stations are made under authorisation to Morecambe Bay via adjacent outfalls, and for the purposes of DFR environmental monitoring are considered together. A recent habits survey has confirmed that the two critical radiation exposure pathways are due to internal irradiation following consumption of locally-caught shellfish

**Table 26(a). Radioactivity in environmental materials near Hartlepool nuclear power station, 1994**

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>											
			<sup>3</sup> H	<sup>14</sup> C	<sup>99</sup> Tc	<sup>131</sup> I	<sup>137</sup> Cs	<sup>155</sup> Eu	<sup>238</sup> Pu	<sup>239</sup> Pu+	<sup>240</sup> Pu	<sup>241</sup> Am	<sup>243</sup> Cm+	<sup>244</sup> Cm
Plaice	Pipeline	2	NA	47	NA	ND	0.29	ND	NA	NA	ND	NA	NA	NA
Cod	"	2	"	NA	"	"	0.83	"	"	"	"	"	"	"
Crabs	"	2	"	"	"	"	0.18	"	0.00038	0.0019	0.0018	0.000013	"	
Winkles	Pilot Station	2	"	"	"	"	0.33	"	0.0041	0.023	0.015	0.000042	"	
<i>Fucus vesiculosus</i>	"	2	"	"	9.0	3.2	0.43	"	NA	NA	ND	NA	270	
Mud	Greatham Creek	2	"	"	NA	ND	12	2.3	"	"	"	"	NA	
"	Paddy's Hole	2	"	"	"	"	22	3.1	"	"	"	"	"	
Coal & sand	Little Scar	2	"	"	"	"	1.3	0.60	"	"	"	"	"	
Sea water	Pipeline	3	0.58	"	"	NA	NA	NA	"	"	NA	"	"	

NA = not analysed

ND = not detected

\* Except for sediment where dry concentrations apply and for sea water where units are Bq l<sup>-1</sup>

# See sub-section 3.2 for definition

<sup>1</sup> Landing point or sampling area

**Table 26(b). Monitoring of gamma dose rates near Hartlepool nuclear power station, 1994**

Location	Ground type	No. of sampling observations#	µGy h <sup>-1</sup>
<b>Gamma dose rates at 1 m over intertidal areas</b>			
Greatham Creek	Mud	1	0.074
"	Mud and sand	1	0.078
Little Scar	Coal and sand	2	0.055
North Gare	Sand	2	0.054
Paddy's Hole	Mud	2	0.097
"	Stones	1	0.18

# See sub-section 3.2 for definition

and external exposure from occupancy of intertidal areas. The monitoring programme includes analyses of fish and shellfish and measurements of gamma dose rates over intertidal areas. Samples of sediment are also analysed, and sea water and *Fucus vesiculosus* are monitored as indicator materials. Samphire is also collected and analysed because of its use as a foodstuff.

The results for 1994 are given in Tables 27(a) and (b). They include data for Morecambe Bay for completeness though parts of the programme are solely in place in order to monitor the effects of Sellafield. Concentrations of carbon-14 and technetium-99 increased in 1994 due to discharges from Sellafield. Otherwise similar levels to those for 1993 (Camplin, 1994) were observed.

**Table 27(a). Radioactivity in environmental materials near Heysham nuclear power stations, 1994**

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>												
			<sup>3</sup> H	<sup>14</sup> C	<sup>54</sup> Mn	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>95</sup> Zr	<sup>95</sup> Nb	<sup>99</sup> Tc	<sup>106</sup> Ru	<sup>110m</sup> Ag	<sup>125</sup> Sb	<sup>134</sup> Cs	<sup>137</sup> Cs
Flounder	Flookburgh	4	NA	58	ND	ND	NA	ND	ND	NA	ND	ND	ND	0.120	36
Plaice	Morecambe	4	“	NA	“	“	“	“	“	“	“	“	“	ND	12
Bass	“	2	“	“	“	“	“	“	“	“	0.51	“	“	0.16	26
Whitebait	Sunderland Point	1	“	“	“	“	0.16	“	“	“	ND	“	“	ND	11
Cockles	Middleton Sands	4	“	“	“	0.58	NA	“	“	“	1.2	0.06	0.30	“	6.1
Winkles	Red Nab Point	4	“	“	0.05	0.48	“	“	“	“	2.9	3.0	0.70	“	9.6
Shrimps	Flookburgh	4	“	84	ND	ND	0.10	“	“	1.7	ND	0.06	ND	“	12
Mussels	Morecambe	4	“	47	“	0.22	NA	“	“	54	1.7	ND	0.40	“	4.1
<i>Fucus vesiculosus</i>	Half Moon Bay	4	“	NA	“	0.21	“	“	“	2500	0.08	0.04	0.66	0.03	12
Samphire	Cockerham Marsh	1	“	“	“	ND	“	“	“	NA	ND	ND	ND	ND	1.4
Mud and sand	Flookburgh	4	“	“	“	“	“	“	“	“	“	“	0.33	“	110
“	Half Moon Bay	4	“	“	“	0.90	“	“	“	“	5.6	“	1.3	0.20	170
“	Sunderland Point	3	“	“	“	1.3	“	“	“	“	7.3	“	1.1	1.1	300
“	Morecambe	4	“	“	“	1.2	“	0.50	0.45	“	13	“	1.9	0.10	230
	Central Pier														
Turf	Conder Green	4	“	“	“	1.4	“	ND	ND	“	13	“	3.7	0.58	480
“	Sand Gate Marsh	4	“	“	“	0.50	“	“	“	“	4.5	“	0.89	0.55	230
Mud	Sunderland Point	1	“	“	“	1.7	“	“	“	“	19	“	2.5	1.6	450
Sea water	Pipeline	2	18	“	NA	NA	“	NA	NA	“	NA	NA	NA	NA	NA
“	Half Moon Bay	1	NA	“	“	“	“	“	“	“	“	“	“	0.0015	0.39

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>									
			<sup>154</sup> Eu	<sup>155</sup> Eu	<sup>238</sup> Pu	<sup>239</sup> Pu+		<sup>241</sup> Pu	<sup>241</sup> Am	<sup>242</sup> Cm	<sup>243</sup> Cm+	Total beta
Flounder	Flookburgh	4	ND	ND	0.00054	0.0029	NA	0.0046	ND	0.0000082	NA	NA
Plaice	Morecambe	4	“	“	NA	NA	“	ND	NA	NA	“	“
Bass	“	2	“	“	“	“	“	“	“	“	“	“
Whitebait	Sunderland Point	1	“	“	0.041	0.21	2.8	0.32	ND	0.00044	“	“
Cockles	Middleton Sands	4	0.12	“	0.48	2.4	NA	6.5	“	0.011	“	“
Winkles	Red Nab Point	4	ND	“	0.44	2.3	“	3.9	0.012	0.0067	“	“
Shrimps	Flookburgh	4	“	“	0.0056	0.028	0.29	0.043	ND	0.00009	“	“
Mussels	Morecambe	4	“	“	0.35	1.8	NA	3.1	0.0063	0.0030	“	“
<i>Fucus vesiculosus</i>	Half Moon Bay	4	“	“	NA	NA	“	1.0	NA	NA	1800	“
Samphire	Cockerham Marsh	1	“	“	“	“	“	0.38	“	“	29	“
Mud and sand	Flookburgh	4	“	1.1	“	“	“	37	“	“	NA	“
“	Half Moon Bay	4	1.3	1.8	10	54	“	84	ND	0.2	“	“
“	Sunderland Point	3	1.7	2.7	NA	NA	“	110	NA	NA	“	“
“	Morecambe	4	1.8	1.9	“	“	“	92	“	“	“	“
	Central Pier											
Turf	Conder Green	4	2.7	2.5	“	“	“	170	“	“	“	“
“	Sand Gate Marsh	4	0.73	0.88	“	“	“	74	“	“	“	“
Mud	Sunderland Point	1	2.5	3.4	“	“	“	140	“	“	“	“
Sea water	Pipeline	2	NA	NA	“	“	“	NA	“	“	“	“
“	Half Moon Bay	1	“	“	“	“	“	“	“	“	“	“

NA = not analysed

ND = not detected

\*Except for sediment where dry concentrations apply and for sea water where units are Bq l<sup>-1</sup>

#See sub-section 3.2 for definition

<sup>1</sup> Landing point or sampling area

With the exception of tritium in seawater, the effect of discharges from Heysham was not detectable above the Sellafield derived background. Discharges of tritium from the power stations are typical for AGRs in the UK and, in activity terms, are relatively high compared with those for other radionuclides. However, the radiotoxicity of tritium is very low and their radiological significance is very small indeed. The

radiation exposure in 1994 to the critical group of fishermen including a component due to external radiation was 0.13 mSv (on the basis of ICRP-60: 0.08 mSv) which is well within the dose limit of 1 mSv. Most of this exposure was due to the effects of discharges from Sellafield. Concentrations of radioactivity in samphire were of negligible radiological significance.

**Table 27(b). Monitoring of gamma dose rates near Heysham nuclear power stations, 1994**

Location	Ground type	No. of sampling observations#	$\mu\text{Gy h}^{-1}$
<b>Gamma dose rates at 1 m over intertidal areas</b>			
Greenodd	Salt marsh	2	0.084
Sand Gate marsh	"	4	0.11
Flookburgh	Mud and sand	4	0.078
High Foulshaw	Salt marsh	4	0.092
Arnside	Mud and sand	4	0.074
Jenny Brown's Point	Salt marsh	1	0.073
Morecambe Central Pier	Mussel bed	4	0.075
"	Mud and sand	4	0.081
Half Moon Bay	"	4	0.083
Pipeline	"	2	0.072
"	Sand	2	0.075
Red Nab Point	Mud and sand	4	0.088
Sunderland Point	"	4	0.094
Sunderland	Mud, sand and stones	4	0.083
Colloway Marsh	Salt marsh	4	0.17
Lancaster	"	4	0.12
Aldcliffe Marsh	"	4	0.15
Conder Green	Mud	2	0.12
"	Mud and sand	2	0.11
"	Salt marsh	4	0.14
Cockerham Marsh	Salt marsh	4	0.12

# See sub-section 3.2 for definition

## 6.6 Hinkley Point, Somerset

At this establishment there are two essentially separate 'A' and 'B' nuclear power stations; the 'A' station is powered by magnox-type reactors and the 'B' station by AGRs. Liquid radioactive waste discharges are made via the same outfall and for the purposes of DFR environmental monitoring they are considered together. Those members of the public subject to the greatest (but still small) radiation exposures as a result of these discharges are those who eat large amounts of locally-caught fish and shrimps and spend time on muddy intertidal areas. The monitoring programme includes analyses of locally-caught fish and shellfish, and external exposure is monitored by means of gamma dose rate measurements, supported by analyses of sediment. In addition, sea water and *Fucus* seaweed are monitored as indicator materials.

The results for 1994, presented in Tables 28(a) and (b), indicate concentrations of radionuclides representing the combined effect of releases from the stations, from other establishments which discharge to the Bristol Channel, from Sellafield, and from fallout. Apportionment is generally difficult at the low levels detected. However, the tritium detected in sea water was due to discharges from the 'B' station and the carbon-14 in

**Table 28(a). Radioactivity in environmental materials near Hinkley Point nuclear power stations, 1994**

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>							
			<sup>3</sup> H	<sup>14</sup> C	<sup>35</sup> S	<sup>54</sup> Mn	<sup>60</sup> Co	<sup>134</sup> Cs	<sup>137</sup> Cs	<sup>155</sup> Eu
Flounder	Stolford	2	NA	130	ND	ND	ND	0.09	0.94	ND
Shrimps	"	2	"	96	"	"	"	0.19	0.70	"
<i>Fucus vesiculosus</i>	Pipeline	2	"	NA	NA	0.33	0.20	0.70	2.8	"
Mud & sand	"	2	"	"	"	0.48	ND	2.0	13	"
"	River Parrett	1	"	"	"	ND	"	4.0	44	"
Mud	1.6 km east of pipeline	2	"	"	"	0.51	0.86	4.9	40	1.9
"	River Parrett	1	"	"	"	ND	ND	2.5	45	ND
Sea water	Pipeline	2	110	"	"	NA	NA	NA	NA	NA

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>					
			<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Am	<sup>242</sup> Cm	<sup>243</sup> Cm+ <sup>244</sup> Cm	Total beta
Flounder	Stolford	2	NA	NA	ND	NA	NA	NA
Shrimps	"	2	0.00035	0.0015	0.0023	0.00029	0.000028	"
<i>Fucus vesiculosus</i>	Pipeline	2	NA	NA	ND	NA	NA	220
Mud & sand	"	2	"	"	"	"	"	NA
"	River Parrett	1	"	"	"	"	"	"
Mud	1.6 km east of pipeline	2	"	"	"	"	"	"
"	River Parrett	1	"	"	"	"	"	"
Sea water	Pipeline	2	"	"	NA	"	"	"

NA = not analysed

ND = not detected

\* Except for sediment where dry concentrations apply and for sea water where units are Bq l<sup>-1</sup>

# See sub-section 3.2 for definition

<sup>1</sup> Landing point or sampling area

**Table 28(b). Monitoring of gamma dose rates near Hinkley Point nuclear power stations, 1994**

Location	Ground type	No. of sampling observations#	µGy h <sup>-1</sup>
0.8 km east of pipeline	Mud	2	0.067
0.8 km west of pipeline	Mud	1	0.13
"	Mud and sand	1	0.15
1.6 km east of pipeline	Mud	2	0.068
Pipeline	Mud and sand	2	0.088
River Parrett	Mud	2	0.070

# See sub-section 3.2 for definition

seafood was likely to have been due to discharges from Amersham International, Cardiff. The concentrations in shrimps of transuranic nuclides were of negligible radiological significance. Gamma radiation dose rates over intertidal sediment, measured using portable instruments, were indistinguishable from the natural background with the exception of the measurements close to the station which were affected by direct radiation. From marine pathways the critical group of

fish and shellfish consumers received an exposure of 0.007 mSv or 0.7% of the dose limit of 1 mSv. This estimate includes a component due to external radiation from artificial radioactivity in sediments but excludes the effects of direct radiation from the site.

## 6.7 Hunterston, Cunninghame

This establishment comprises 'A' and 'B' stations; the 'A' station was designed for magnox-type reactors and the 'B' station for AGRs. The 'A' station ceased power production at the end of March 1990. Liquid radioactive waste discharges are made to the Firth of Clyde under authorisation of the Scottish Office. There are two pathways which contribute to the radiation exposure of the critical group: fish and shellfish consumption leading to internal irradiation, and occupancy of intertidal areas leading to external exposure. DFR regularly monitor, on behalf of the Scottish Office, samples of fish and shellfish and carry out gamma dose rate measurements on the foreshore. Samples of sand are analysed in support of the gamma dose rate measurements and sea water and *Fucus* seaweed are analysed as indicator materials. The results of monitoring in 1994 are shown in Tables 29(a) and (b).

**Table 29(a). Radioactivity in environmental materials near Hunterston nuclear power stations, 1994**

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>									
			<sup>3</sup> H	<sup>51</sup> Cr	<sup>54</sup> Mn	<sup>58</sup> Co	<sup>60</sup> Co	<sup>65</sup> Zn	<sup>99</sup> Tc	<sup>110m</sup> Ag	<sup>134</sup> Cs	<sup>137</sup> Cs
Cod	Millport	2	NA	ND	ND	ND	ND	ND	NA	ND	ND	4.7
Saithe	"	1	"	"	"	"	"	"	"	"	0.08	9.5
Crabs	"	2	"	"	"	"	"	"	"	0.13	ND	1.0
<i>Nephrops</i>	"	2	"	"	"	"	"	"	"	ND	"	4.2
Velvet swimming crabs	Largs	1	"	"	0.42	"	2.5	"	"	"	"	0.92
Lobsters	"	1	"	"	ND	"	ND	"	"	"	"	0.88
Oysters	Fairlie	1	"	"	0.10	"	0.24	0.19	"	0.32	"	0.73
Winkles	Pipeline	2	"	2.4	1.9	0.12	3.5	0.10	"	2.5	0.06	1.6
<i>Fucus spiralis</i>	"	2	"	ND	4.7	0.17	5.0	0.20	52	0.50	0.32	6.6
Sand	"	2	"	"	2.4	ND	0.92	ND	NA	ND	ND	10
Sea water	"	16	3.7	NA	NA	NA	NA	NA	"	NA	0.0042	0.089

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>							Total beta
			<sup>155</sup> Eu	<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Am	<sup>242</sup> Cm	<sup>243</sup> Cm+ <sup>244</sup> Cm		
Cod	Millport	2	ND	NA	NA	ND	NA	NA	NA	NA
Saithe	"	1	"	"	"	"	"	"	"	"
Crabs	"	2	"	0.0038	0.021	0.029	ND	0.000091	"	"
<i>Nephrops</i>	"	2	"	NA	NA	ND	NA	NA	"	"
Velvet swimming crabs	Largs	1	"	"	"	"	"	"	"	"
Lobsters	"	1	"	"	"	"	"	"	"	"
Oysters	Fairlie	1	"	"	"	"	"	"	"	"
Winkles	Pipeline	2	"	0.040	0.17	0.060	0.0012	0.0021	"	"
<i>Fucus spiralis</i>	"	2	0.24	NA	NA	ND	NA	NA	270	"
Sand	"	2	ND	"	"	0.41	"	"	NA	"
Sea water	"	16	NA	"	"	NA	"	"	"	"

NA = not analysed

ND = not detected

\* Except for sand where dry concentrations apply and for sea water where units are Bq l<sup>-1</sup>

# See sub-section 3.2 for definition

<sup>1</sup> Landing point or sampling area

**Table 29(b). Monitoring of gamma dose rates near Hunterston nuclear power stations, 1994**

Location	Ground type	No. of sampling observations#	$\mu\text{Gy h}^{-1}$
<b>Gamma dose rates at 1 m over intertidal areas</b>			
0.5 km north of pipeline	Sand	2	0.055
0.5 km south of pipeline	Sand & stones	2	0.072

# See sub-section 3.2 for definition

The concentrations of artificial radioactivity in this area are predominantly due to Sellafield discharges, the general values being consistent with those to be expected at this distance from Sellafield. Small concentrations of activation products such as manganese-54 were probably due to discharges from the site; however these were of negligible radiological significance. In 1994, the exposure, including external radiation, of members of the critical group of fish and shellfish consumers near Hunterston was low, at 0.02 mSv or 2% of the dose limit of 1 mSv (on the basis of ICRP-60 : 0.01 mSv).

**Table 30(a). Radioactivity in environmental materials near Sizewell nuclear power station, 1994**

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>								
			<sup>3</sup> H	<sup>60</sup> Co	<sup>137</sup> Cs	<sup>155</sup> Eu	<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Am	<sup>243</sup> Cm+ <sup>244</sup> Cm	Total beta
Cod	Sizewell	1	NA	ND	0.46	ND	NA	NA	ND	NA	NA
Shrimps	"	1	"	"	0.48	"	0.00020	0.00096	0.0012	0.000014	"
Crabs	"	2	"	0.13	0.17	"	0.00026	0.0013	0.0022	0.000063	"
Pacific oysters	Blyth estuary	1	"	ND	0.07	"	NA	NA	ND	NA	"
Whelks	Dunwich	1	"	0.29	0.09	"	"	"	"	"	"
Mud	Southwold	2	"	2.8	15	1.9	"	"	"	"	770
Sand	Rifle Range	2	"	0.52	0.39	0.32	"	"	"	"	NA
"	Aldeburgh	2	"	ND	0.35	ND	"	"	"	"	"
Sea water	"	2	ND	NA	NA	NA	"	"	NA	"	"

NA = not analysed

ND = not detected

\* Except for sediment where dry concentrations apply and for sea water where units are Bq l<sup>-1</sup>

# See sub-section 3.2 for definition

<sup>1</sup> Landing point or sampling area

**Table 30(b). Monitoring of gamma dose rates near Sizewell nuclear power station, 1994**

Location	Ground type	No. of sampling observations#	$\mu\text{Gy h}^{-1}$
<b>Gamma dose rates at 1 m over intertidal areas</b>			
Pipeline	Sand	1	0.081
"	Sand and shingle	1	0.12
Dunwich	Sand	1	0.043
"	Shingle	1	0.044
Rifle range	Sand	2	0.044
Sizewell Hall	"	1	0.045
"	Sand and shingle	1	0.043
Aldeburgh	"	2	0.045
Southwold Harbour	Mud	5	0.064

# See sub-section 3.2 for definition

## 6.8 Sizewell, Suffolk

At this establishment there is an 'A' station powered by magnox-type reactors; a 'B' station, to be powered by a PWR, was under construction in 1994. Radioactive liquid effluent from the 'A' station is discharged under authorisation to the North Sea. The authorisation was revised in 1994 to set lower limits for discharges. A habits survey has established that consumption of fish and shellfish and occupancy of intertidal areas are the two critical radiation exposure pathways. The results of monitoring in the area in 1994 are shown in Tables 30(a) and (b).

The radioactivity concentrations represent the combined effect of discharges from the 'A' station and from Sellafield, as well as of fallout. Apportionment is difficult at the low levels detected. Trace levels of cobalt-60 in some shellfish and mud are likely to have been due to discharges from the station, but their radiological significance was negligible. The total radiation exposure of local fish and shellfish consumers

was low, at less than 0.005 mSv or 0.5% of the dose limit of 1 mSv. Measured gamma dose rates were indistinguishable from the natural background with the exception of the measurements close to the station which were affected by direct radiation. The above exposure of the critical group includes a small contribution for their external exposure based on a calculation using radionuclide concentrations in sediment.

## 6.9 Torness, East Lothian

This station, which is powered by two AGRs, came into operation at the end of 1987. Discharges of radioactive wastes to the North Sea are authorised by the Scottish Office. A recent habits survey, on behalf of the Scottish Office, has shown that potentially critical pathways for radiation exposure of the public are internal irradiation

from consumption of local fish and shellfish and external exposure from occupancy of intertidal areas whilst collecting shellfish. These pathways form the basis of the regular monitoring programme. Samples of fish and shellfish are collected and analysed, and samples of sea water and *Fucus vesiculosus* are monitored as indicator materials. Measurements are also made of gamma dose rates over intertidal areas, supported by analyses of sediment, and beta dose rates on fishing gear.

Results of this monitoring in 1994 are shown in Tables 31(a) and (b). Concentrations of artificial radionuclides were mainly due to the distant effects of Sellafield discharges and to fallout, though trace levels of activation products were likely to have been due to discharges from the station. In 1994, the group of fish and shellfish

**Table 31(a). Radioactivity in environmental materials near Torness nuclear power station, 1994**

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>							
			<sup>3</sup> H	<sup>54</sup> Mn	<sup>60</sup> Co	<sup>99</sup> Tc	<sup>110m</sup> Ag	<sup>134</sup> Cs	<sup>137</sup> Cs	<sup>155</sup> Eu
Cod	Pipeline	2	NA	ND	ND	NA	ND	ND	0.92	ND
Crabs	Cove	2	“	“	“	“	“	“	0.14	“
Lobsters	“	1	“	“	“	“	“	“	ND	“
<i>Nephrops</i>	Dunbar	4	“	“	“	“	“	“	0.51	“
Winkles	Pipeline	2	“	“	0.19	“	2.5	“	0.35	“
<i>Fucus vesiculosus</i>	“	1	“	0.45	0.89	6.5	0.12	“	0.29	“
<i>Fucus serratus</i>	“	1	“	0.84	0.31	7.8	0.15	“	0.46	“
Mud	Eyemouth Harbour	1	“	ND	ND	NA	ND	1.1	50	1.4
Mud and sand	Dunbar Inner Harbour	2	“	“	“	“	“	ND	20	0.82
“	Barns Ness	1	“	“	“	“	“	“	8.7	1.7
Sand	Thornton Loch Beach	2	“	“	0.14	“	“	“	2.5	ND
Sea water	Pipeline	12	3.2	NA	NA	“	NA	“	0.0018	NA

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>						Total beta
			<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Am	<sup>242</sup> Cm	<sup>243</sup> Cm+ <sup>244</sup> Cm		
Cod	Pipeline	2	NA	NA	ND	NA	NA	NA	
Crabs	Cove	2	“	“	0.093	“	“	“	
Lobsters	“	1	“	“	ND	“	“	“	
<i>Nephrops</i>	Dunbar	4	0.00074	0.0041	0.0054	0.000025	0.000033	“	
Winkles	Pipeline	2	NA	NA	ND	NA	NA	“	
<i>Fucus vesiculosus</i>	“	1	“	“	0.28	“	“	300	
<i>Fucus serratus</i>	“	1	“	“	ND	“	“	180	
Mud	Eyemouth Harbour	1	“	“	“	“	“	NA	
Mud and sand	Dunbar Inner Harbour	2	“	“	0.77	“	“	“	
“	Barns Ness	1	“	“	ND	“	“	“	
Sand	Thornton Loch Beach	2	“	“	“	“	“	“	
Sea water	Pipeline	12	“	“	NA	“	“	“	

NA = not analysed

ND = not detected

\* Except for sediment where dry concentrations apply and for sea water where units are Bq l<sup>-1</sup>

# See sub-section 3.2 for definition

<sup>1</sup> Landing point or sampling area

**Table 31(b). Monitoring of radiation dose rates near Torness, 1994**

Location	Material or ground type	No. of sampling observations#	$\mu\text{Sv h}^{-1}$
<b>Beta dose rates on nets</b>			
Cove	Pots	2	ND
Dunbar Harbour	Nets	2	ND
<b>Gamma dose rates at 1 m over intertidal areas</b>			
Barns Ness	Mud, sand & stones	1	0.063
"	Sand and stones	1	0.061
Skateraw Harbour	Sand	2	0.055
Thornton Loch Beach	"	2	0.054
Eyemouth Harbour	"	1	0.074
Dunbar Inner Harbour	Mud and sand	2	0.071
St Abbs	"	2	0.077

# See sub-section 3.2 for definition  
ND = not detected

consumers received the same exposure as a separate group of shellfish collectors: this exposure was low, at less than 0.005 mSv, or 0.5% of the dose limit of 1 mSv. There was no detectable beta radiation from fishermen's nets or pots.

## 6.10 Trawsfynydd, Gwynedd

This station is being decommissioned. Low level discharges have continued during 1994 mainly from the fuel storage ponds. Discharges are made to the freshwater Lake Trawsfynydd under authorisation of the Welsh Office and HMIP. The critical group is exposed through consumption of fish caught in the lake and external exposure over the lake shoreline; the important radionuclides are those of caesium and, to a lesser extent, strontium-90. Species of fish regularly consumed are brown trout, rainbow trout and a small amount of perch. Perch and most brown trout are

**Table 32(a). Radioactivity in environmental materials near Trawsfynydd nuclear power station, 1994**

Material	Location	No. of sampling observations <sup>+</sup>	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>									
			<sup>3</sup> H	<sup>14</sup> C	<sup>35</sup> S	<sup>54</sup> Mn	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>106</sup> Ru	<sup>125</sup> Sb	<sup>134</sup> Cs	<sup>137</sup> Cs
Brown trout	Lake	7	NA	36	ND	ND	ND	16	ND	ND	19	220
Rainbow trout	"	7	"	NA	"	"	"	0.94	"	"	0.51	4.0
Rainbow trout	Hatchery	1	"	"	NA	"	"	NA	"	"	0.49	3.9
Perch	Lake	4	"	"	ND	"	"	6.5	"	"	36	430
Rudd	"	2	"	"	NA	"	"	NA	"	"	20	220
Eel	"	1	"	"	"	"	"	"	"	"	9.9	110
<i>Fontinalis</i>	Afon Prysor	2	"	"	"	"	"	"	"	0.21	0.43	9.2
"	Gwylan Stream	2	"	"	"	0.93	26	"	47	43	3.9	66
Mud	Pipeline (bankside)	2	"	"	"	2.1	110	"	450	110	180	2500
"	Hot lagoon	2	"	"	"	ND	96	"	370	820	300	5900
"	Barrier Wall	2	"	"	"	"	140	"	650	960	400	7100
Mud, sand and stones	Gwylan Stream	2	"	"	"	"	12	"	18	80	68	2000
Peat	Below Maent. HEP Stn.	1	"	"	"	"	650	"	900	900	180	3000
Water	Bailey bridge	4	0.40	"	"	NA	NA	"	NA	NA	0.013	0.065
"	Cold lagoon	4	NA	"	"	"	"	"	"	"	0.010	0.055
"	Afon Prysor	3	"	"	"	"	"	"	"	"	0.0037	0.0064

Material	Location	No. of sampling observations <sup>+</sup>	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>										
			<sup>144</sup> Ce	<sup>154</sup> Eu	<sup>155</sup> Eu	<sup>238</sup> Pu	<sup>239</sup> Pu+	<sup>241</sup> Pu	<sup>241</sup> Am	<sup>242</sup> Cm	<sup>243</sup> Cm+	Total beta	
Brown trout	Lake	7	ND	ND	ND	0.00017	0.00039	NA	0.00062	0.000022	0.000044	NA	
Rainbow trout	"	7	"	"	"	0.000057	0.00012	"	0.00029	ND	0.000026	"	
Rainbow trout	Hatchery	1	"	"	"	NA	NA	"	ND	NA	NA	"	
Perch	Lake	4	"	"	"	0.00019	0.00056	"	0.0011	0.000048	0.000069	"	
Rudd	"	2	"	"	"	NA	NA	"	ND	NA	NA	"	
Eel	"	1	"	"	"	0.000026	0.00012	"	0.00020	ND	ND	"	
<i>Fontinalis</i>	Afon Prysor	2	"	"	1.0	NA	NA	"	ND	NA	NA	"	
"	Gwylan Stream	2	30	7.2	7.8	"	"	"	9.9	"	"	"	
Mud	Pipeline (bankside)	2	260	50	32	"	"	"	86	"	"	"	
"	Hot lagoon	2	110	38	29	33	81	2300	120	2.1	5.5	8300	
"	Barrier wall	2	170	59	40	NA	NA	NA	150	NA	NA	NA	
Mud, sand and stones	Gwylan Stream	2	ND	ND	ND	"	"	"	2.4	"	"	"	
Peat	Below Maent. HEP Stn.	1	190	79	54	"	"	"	130	"	"	"	
Water	Bailey bridge	4	NA	NA	NA	"	"	"	NA	"	"	"	
"	Cold lagoon	4	"	"	"	"	"	"	"	"	"	"	
"	Afon Prysor	3	"	"	"	"	"	"	"	"	"	"	

NA = not analysed

ND = not detected

\* Except for mud and peat where dry concentrations apply and for water where units are Bq l<sup>-1</sup>

+ See sub-section 3.2 for definition

**Table 32(b). Monitoring of gamma dose rates near Trawsfynydd nuclear power station, 1994**

Location	Ground type	No. of sampling observations#	µGy h <sup>-1</sup>
<b>Gamma dose rates at 1 m over areas near lake shoreline</b>			
Bailey Bridge	Peat	2	0.079
South end of lake	"	2	0.068
Cae Adda boat mooring	"	2	0.066

# See sub-section 3.2 for definition

indigenous to the lake but rainbow trout are introduced from a hatchery. Because of the limited period which they spend in the lake, introduced fish generally exhibit lower radiocaesium concentrations than those of indigenous fish.

The monitoring programme reflects the exposure pathways. Samples of brown trout, rainbow trout, perch and other fish are regularly analysed. Gamma dose rates over lake shoreline areas are also regularly monitored, and these measurements are supported by analyses of shoreline sediments. Mud from the lake bed is also analysed; these materials contribute radioactivity to the fishes' diet. Additional information is gained from analyses of the moss *Fontinalis* which is a sensitive indicator for a number of radionuclides, and from analyses of lake water. The data from analyses of water which flows into the lake have been included for comparison purposes. The results of DFR monitoring are shown in Tables 32(a) and (b).

The concentrations of radiocaesium in lake water and fish decreased in 1994 as a result of decreasing discharges. In 1994, as in previous years, transuranic nuclides from station discharges and fallout were also observed in fish; these concentrations continued to be of negligible radiological significance.

A recent habits survey has established that consumption of brown trout reduced in 1994. This, taken with the reduction in concentrations noted above, indicates that exposure of the critical group of fish consumers reduced in 1994 to 0.03 mSv (1993: 0.08 mSv) and is within the dose limits of 1 mSv. The exposure of the critical group given above includes a contribution due to lakeside external exposure based on measurements of gamma dose rates. A natural background dose rate of 0.06 mGy h<sup>-1</sup>.

## 6.11 Wylfa, Gwynedd

Liquid radioactive wastes from this station are discharged to the Irish Sea under authorisation of the Welsh Office and HMIP. The two critical pathways are due to consumption of local fish and shellfish and to occupancy of intertidal areas. Monitoring is carried out in respect of these pathways. Samples of sediment are analysed in support of the gamma dose rate measurements, and the indicators sea water and the seaweed *Fucus vesiculosus* are also sampled. The results of monitoring in 1994 are presented in Tables 33(a) and (b).

Concentrations of artificial radionuclides were mainly due to the distant effects of Sellafield discharges though trace levels of activation products were likely to have been due to discharges from the station. Data for 1994 indicate that the radiation exposure of the critical group of high-rate fish and shellfish consumers was low, at 0.01 mSv, or 1% of the dose limit of 1 mSv (on the basis of ICRP-60: 0.009 mSv). The magnitude of discharges from the station suggest that the local contribution would have been a small fraction of this exposure. Gamma dose rates, measured using portable instruments, continued to be difficult to distinguish from the natural background, but a small contribution due to external exposure of the critical group has been included in the above total.

**Table 33(a). Radioactivity in environmental materials near Wylfa nuclear power station, 1994**

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>														Total beta	
			<sup>3</sup> H	<sup>14</sup> C	<sup>60</sup> Co	<sup>99</sup> Tc	<sup>110m</sup> Ag	<sup>134</sup> Cs	<sup>137</sup> Cs	<sup>155</sup> Eu	<sup>238</sup> Pu	<sup>239</sup> Pu+	<sup>240</sup> Pu	<sup>241</sup> Pu	<sup>241</sup> Am	<sup>242</sup> Cm		<sup>243</sup> Cm+
Plaice	Pipeline	2	NA	41	ND	NA	ND	ND	2.8	ND	NA	NA	NA	ND	NA	NA	NA	NA
Crabs	"	2	"	NA	"	1.3	0.47	"	1.0	"	0.0061	0.032	"	0.15	ND	0.00025	"	"
Winkles	Cemaes Bay	2	"	"	0.12	NA	ND	"	1.4	"	0.05	0.27	3.1	0.40	"	0.00055	"	"
<i>Fucus vesiculosus</i>	Cemlyn Bay	2	"	"	ND	"	"	"	2.0	"	NA	NA	NA	0.30	NA	NA	240	"
Mud	"	2	"	"	1.5	"	"	1.4	220	1.6	5.9	30	"	46	0.10	0.11	NA	"
Sea water	"	4	ND	"	NA	"	NA	NA	NA	NA	NA	NA	"	NA	NA	NA	NA	"

NA = not analysed

ND = not detected

\* Except for sediment where dry concentrations apply

# See sub-section 3.2 for definition

<sup>1</sup> Landing point or sampling area

**Table 33(b). Monitoring of gamma dose rates near Wylfa nuclear power station, 1994**

Location	Ground type	No. of sampling observations#	$\mu\text{Gy h}^{-1}$
<b>Gamma dose rates at 1 m over intertidal areas</b>			
Cemaes Bay	Sand	7	0.057
"	Mud	1	0.057
Cemlyn Bay	"	4	0.083

# See sub-section 3.2 for definition

## 7. DEFENCE ESTABLISHMENTS

Regular monitoring of the effects of liquid radioactive waste discharges to sea from naval establishments has continued, and the results are reported in this section. Liquid radioactive wastes are also discharged from the

Atomic Weapons Establishment, Aldermaston, to the Thames catchment. For this site, the drinking water pathway is monitored by HMIP (HMIP, 1994). In 1994, however, a small programme of monitoring of fish and other aquatic materials has continued in surveillance of discharges to the Thames catchment from Aldermaston and other nuclear establishments. The relevant results are reported in this section.

### 7.1 Atomic Weapons Establishment, Aldermaston, Berkshire

Liquid radioactive waste discharges are small (Table 1) and are made under authorisation to the River Thames at Pangbourne and to the sewage works at Silchester. DFR monitoring continued including sampling in a local pond and in Foudry Brook which is downstream of the Silchester disposal route. Monitoring upstream of nuclear sites on the Thames at Newbridge was carried out to indicate background levels remote from nuclear establishments. Analyses were carried out on

**Table 34(a). Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Aldermaston, 1994**

Material	Location	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>							
			<sup>57</sup> Co	<sup>60</sup> Co	<sup>137</sup> Cs	<sup>155</sup> Eu	<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Am	Total beta
Pike	Newbridge	1	ND	ND	ND	ND	0.0000062	0.000037	0.000080	NA
	Outfall (Pangbourne)	1	"	"	0.60	"	ND	0.000055	0.000097	"
	Staines	1	"	"	0.39	"	NA	NA	ND	"
Crayfish	Decoy Pond	1	NA	NA	NA	NA	0.00013	0.00064	0.0013	"
<i>Nuphar lutea</i>	Outfall (Pangbourne)	1	ND	0.08	0.09	ND	NA	NA	ND	"
	Staines	1	0.09	ND	0.06	"	"	"	"	"
	Newbridge	1	ND	"	0.02	"	"	"	"	"
Clay	Outfall (Pangbourne)	1	"	0.27	2.3	1.9	"	"	"	470
Mud & sand	Staines	1	0.72	1.1	16	1.3	"	"	"	400
Mud	Foudry Brook	1	ND	ND	3.3	1.5	"	"	"	"
	Newbridge	1	"	"	11	2.4	"	"	"	"

NA = not analysed

ND = not detected

\* Except for sediment where dry concentrations apply

# See sub-section 3.2 for definition

**Table 34(b). Monitoring of gamma dose rates near Aldermaston, 1994**

Location	Ground type	No. of sampling observations#	$\mu\text{Gy h}^{-1}$
<b>Gamma dose rates at 1 m over river bank</b>			
Pangbourne	Grass	1	0.056
Newbridge	"	3	0.057
Staines	Soil	4	0.056

# see sub-section 3.2 for definition

pike and crayfish with *Nuphar lutea* (yellow water lily) and sediments as indicator materials. In addition, gamma dose rates were measured on the river bank near the main outfall on the River Thames.

Habits surveys have established that the critical group affected by discharges into the river comprises anglers whose occupancy of the river bank has been assessed to estimate their external exposures. No consumption of freshwater fish has been established, however the assessment has conservatively included consumption of fish at a low rate of 1 kg year<sup>-1</sup>.

**Table 35(a). Radioactivity in environmental materials near naval establishments, 1994**

Establishment	Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>									
				<sup>3</sup> H	<sup>60</sup> Co	<sup>65</sup> Zn	<sup>95</sup> Zr	<sup>95</sup> Nb	<sup>106</sup> Ru	<sup>110m</sup> Ag	<sup>125</sup> Sb	<sup>131</sup> I	<sup>134</sup> Cs
Barrow	Mud	Walney Channel (outfall)	2	NA	1.7	ND	ND	ND	21	ND	4.1	ND	0.52
"	Mud and sand	" (Vickerstown Church)	4	"	1.8	"	2.6	2.4	29	0.36	4.2	"	0.38
Chatham	Mud	Commodores Hard	1	"	4.3	"	ND	ND	ND	ND	ND	"	0.59
"	"	Hoo Marina	1	"	1.6	"	"	"	"	"	"	"	ND
Devonport	Dogfish	Plymouth Sound	1	"	ND	"	"	"	"	"	"	"	"
"	Crabs	"	2	"	"	0.13	"	"	"	"	"	"	"
"	Mussels	Wearde Quay	1	"	0.15	ND	"	"	"	"	"	"	"
"	<i>Fucus vesiculosus</i>	Kinterbury	2	"	0.05	"	"	"	"	"	"	"	"
"	Mud	Torpoint Ferry East	2	"	0.44	"	"	"	"	"	"	"	"
"	"	Kinterbury	2	"	0.51	"	"	"	"	"	"	"	"
"	"	Torpoint South	2	"	ND	"	"	"	"	"	"	"	"
Faslane	Mud and sand	Carnban boatyard	2	"	5.2	"	"	"	"	"	1.9	"	0.65
"	Sea water	"	1	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA
Rosyth	Crabs	East of dockyard	2	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND
"	<i>Fucus vesiculosus</i>	"	2	"	"	"	"	"	"	"	"	0.99	"
"	Mud	Blackness Castle	1	"	"	"	"	"	"	"	"	ND	"
"	"	East of dockyard	2	"	0.34	"	"	"	"	"	"	"	0.66
"	"	Port Edgar	2	"	ND	"	"	"	"	"	"	"	ND
"	Mud and sand	West of dockyard	2	"	"	"	"	"	"	"	"	"	"
"	"	Blackness Castle	1	"	"	"	"	"	"	"	"	"	"
"	Sand	Burntisland Bay	2	"	"	"	"	"	"	"	"	"	"
Holy Loch	Mud and sand	Mid-Loch	1	"	0.38	"	"	"	"	"	"	"	"

Establishment	Material	Location <sup>1</sup>	No of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>						
				<sup>137</sup> Cs	<sup>144</sup> Ce	<sup>154</sup> Eu	<sup>155</sup> Eu	<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Am
Barrow	Mud	Walney Channel (outfall)	2	200	ND	4.6	1.1	NA	NA	210
"	Mud and sand	" (Vickerstown Church)	4	180	0.84	3.7	2.7	"	"	200
Chatham	Mud	Commodores Hard	1	15	ND	ND	2.5	"	"	ND
"	"	Hoo Marina	1	19	"	"	2.1	"	"	"
Devonport	Dogfish	Plymouth Sound	1	0.39	"	"	ND	"	"	"
"	Crabs	"	2	ND	"	"	"	"	"	"
"	Mussels	Wearde Quay	1	0.09	"	"	"	"	"	"
"	<i>Fucus vesiculosus</i>	Kinterbury	2	0.27	"	"	"	"	"	"
"	Mud	Torpoint Ferry East	2	6.6	"	"	1.9	"	"	0.66
"	"	Kinterbury	2	4.5	"	"	2.0	0.018	0.49	0.16
"	"	Torpoint South	2	3.2	"	"	0.95	NA	NA	ND
Faslane	Mud and sand	Carnban boatyard	2	39	"	"	1.0	"	"	"
"	Sea water	"	1	NA	NA	NA	NA	"	"	NA
Rosyth	Crabs	East of dockyard	2	0.12	ND	ND	ND	"	"	ND
"	<i>Fucus vesiculosus</i>	"	2	0.57	"	"	"	"	"	"
"	Mud	Blackness Castle	1	22	"	"	"	"	"	"
"	"	East of dockyard	2	24	"	"	2.0	"	"	"
"	"	Port Edgar	2	30	"	"	0.84	"	"	0.56
"	Mud and sand	West of dockyard	2	6.6	"	"	1.0	"	"	ND
"	"	Blackness Castle	1	11	"	"	0.90	"	"	"
"	Sand	Burntisland Bay	2	0.90	"	"	ND	"	"	"
Holy Loch	Mud and sand	Mid-Loch	1	12	"	"	"	"	"	"

NA = not analysed

ND = not detected

\* Except for sediment where dry concentrations apply and for sea water where units are Bq l<sup>-1</sup>

# See sub-section 3.2 for definition

<sup>1</sup> Landing point or sampling area

The results of measurements of radioactivity concentrations are shown in Tables 34(a) and (b). The concentrations of artificial radioactivity detected were very low. The gamma dose rate on the river bank at Pangbourne was indistinguishable from natural background. External exposures were calculated using a model based on concentrations of radionuclides in sediment. The overall radiological significance was very low: the radiation dose to anglers from occupancy of the river bank near the outfall and consumption of fish would have been much less than 0.005 mSv or 0.5% of the dose limit of 1 mSv. The significance of crayfish consumption was similar to that for anglers who may be affected by discharges made direct to the River Thames.

## 7.2 Naval establishments

Liquid wastes containing small quantities of radioactivity are discharged from the establishments at Barrow, Devonport, Faslane and Rosyth under authorisation/agreement with the relevant enforcement authorities (Table 1). DFR carry out monitoring programmes near all of these establishments and, in the case of Faslane and Rosyth, on behalf of the Scottish Office. Monitoring is also carried out in the Holy Loch and near Chatham in surveillance of the effects of past discharges.

Public radiation exposures due to the effects of any discharges from these establishments are primarily due to external radiation from sediments, the nuclide of main importance being cobalt-60. Regular assessments of doses to critical groups take account of the effects of discharges from other nuclear establishments (e.g. Sellafield) as well as exposure pathways additional to external radiation, such as any consumption of fish and shellfish. Measurements of gamma dose rates are regularly carried out near all establishments; these are supported by analyses of sediments. Marine foodstuffs, sea water and seaweed are also analysed where appropriate.

Results of monitoring in 1994 are presented in Tables 35(a) and (b). The small concentrations of cobalt-60 mainly reflect discharges from the establishments; levels of other radionuclides are mainly due to discharges from Sellafield and to weapons-test fallout. Gamma dose rates over intertidal sediments, directly measured using portable instruments, were generally difficult to distinguish from the natural background, such that public radiation exposure has been estimated where necessary by calculation based on concentrations of radionuclides in sediments. In 1994, the exposure of critical groups, including the effects of other sources and taking account of consumption of marine foods and occupancy times, continued to remain low near these naval establishments, at less than 0.03 mSv year<sup>-1</sup>. This represents less than 3% of the dose limit of 1 mSv.

**Table 35(b). Monitoring of gamma dose rates near naval establishments, 1994**

Establishment	Location	Ground type	No. of sampling observations#	µGy h <sup>-1</sup>
<b>Gamma dose rates at 1 m over intertidal areas</b>				
Barrow	Walney Channel (1 km south of outfall)	Mud and sand	4	0.083
"	" (Vickerstown church)	"	4	0.099
Chatham	Commodores Hard	Mud	1	0.057
"	Hoo Marina	"	1	0.060
"	Medway Yacht Club	"	1	0.057
Devonport	Kinterbury	"	1	0.070
"	"	Mud and sand	1	0.075
"	Brunel Bridge East	Mud	1	0.071
"	"	Mud, sand and stones	1	0.082
"	Torpoint Ferry East	Mud	2	0.073
"	Stonehouse	"	2	0.065
"	Torpoint South	"	2	0.078
Faslane	Gareloch Head	Mud, sand and stones	2	0.059
"	Gulley Bridge Pier	Sand and stones	1	0.066
"	"	Stones	1	0.069
"	Rhu Narrows	"	1	0.061
"	"	Sand and stones	1	0.053
"	Rosneath	Mussel bed	1	0.059
"	"	Sand and shingle	1	0.068
"	Carnban boatyard	Mud, sand and stones	2	0.076
Rosyth	Blackness Castle	Mud and sand	1	0.065
"	"	Mud	1	0.065
"	Burntisland Bay	Sand	2	0.054
"	East of Dockyard	Sand and shells	1	0.058
"	"	Sand and stones	1	0.066
"	Port Edgar	Mud	2	0.066
"	West of Dockyard	Mud, sand and stones	1	0.081
"	"	Mud and sand	1	0.077
Holy Loch	North Sandbank	"	1	0.061
"	Kilmun Pier	Sand and stones	1	0.065
"	Mid-Loch	Mussel bed	1	0.050

# See sub-section 3.2 for definition

## 8. AMERSHAM INTERNATIONAL PLC

This company manufactures radioactive materials for use in medicine, research and industry. The company's principal establishment is located in Amersham, Buckinghamshire, from which radioactive discharges are made into the catchment of the River Thames. Environmental monitoring in respect of these discharges is carried out by the HMIP (HMIP, 1994). However, in 1994, DFR continued its small programme of fisheries-related monitoring in connection with discharges of liquid radioactive wastes to the Thames and its catchment. Results relevant to the Amersham Laboratory are presented in this section. The monitoring programme in surveillance of discharges from the Cardiff Laboratory has continued, and the results of this programme are also presented.

### 8.1 Amersham Laboratory, Buckinghamshire

Discharges of liquid radioactive wastes are made under authorisation to the Maple Lodge sewage works;

releases enter the Grand Union Canal and the River Colne. In 1994, the programme of monitoring of fish and other aquatic materials has continued in surveillance of the effects of these discharges, including monitoring at Newbridge on the Thames which is remote from nuclear establishments. Analyses were carried out of pike with *Nuphar lutea* (yellow water lily) and sediments as indicator materials.

Habits surveys have identified anglers as the critical group affected by discharges into the canal/river system. Their occupancy of the river bank has been assessed to estimate their external exposures. Consumption of freshwater fish was also considered but none was found. Nevertheless, it is considered prudent to include a component in the assessment of the anglers' exposure and a hypothetical consumption of fish at a rate of 1 kg year<sup>-1</sup> was assumed.

The results of the measurements of radioactivity concentrations are presented in Tables 36(a) and (b). The concentrations of radioactivity detected were very low. Concentrations of some radionuclides were slightly enhanced close to the outfall, but the overall effect was of very low radiological significance. The gamma dose rate on the river bank of Union Canal was

**Table 36(a). Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Amersham, 1994**

Material	Location	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>									
			<sup>14</sup> C	<sup>54</sup> Mn	<sup>57</sup> Co	<sup>58</sup> Co	<sup>60</sup> Co	<sup>65</sup> Zn	<sup>131</sup> I	<sup>134</sup> Cs	<sup>137</sup> Cs	
Pike	Newbridge	1	NA	ND	ND	ND						
	Outfall (Grand Union Canal)	1	61	"	0.11	"	"	"	"	"	0.08	0.36
	Staines	1	NA	"	ND	"	"	"	"	"	ND	0.39
<i>Nuphar lutea</i>	Outfall (Grand Union Canal)	1	"	0.10	0.86	0.45	"	0.48	0.95	"	"	ND
	Staines	1	"	ND	0.09	ND	"	ND	ND	"	"	0.06
	Newbridge	1	"	"	ND	"	"	"	"	"	"	0.02
Mud	Outfall (Grand Union Canal)	1	"	"	5.7	1.6	"	2.3	"	"	"	8.7
	Newbridge	1	"	"	ND	ND	"	ND	"	"	"	11
Mud and sand	Staines	1	"	"	0.72	"	1.1	"	"	"	"	16

Material	Location	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>				
			<sup>155</sup> Eu	<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Am	Total beta
Pike	Newbridge	1	ND	0.000062	0.000037	0.000080	NA
	Outfall (Grand Union Canal)	1	"	NA	NA	ND	"
	Staines	1	"	"	"	"	"
<i>Nuphar lutea</i>	Outfall (Grand Union Canal)	1	"	"	"	"	"
	Staines	1	"	"	"	"	"
	Newbridge	1	"	"	"	"	"
Mud	Outfall (Grand Union Canal)	1	1.8	"	"	"	310
	Newbridge	1	2.4	"	"	"	NA
Mud and sand	Staines	1	1.3	"	"	"	400

NA = not analysed

ND = not detected

\* Except sediment where dry concentrations apply

# See sub-section 3.2 for definition

**Table 36(b). Monitoring of gamma dose rates near Amersham, 1994**

Location	Ground type	No. of sampling observations#	$\mu\text{Sv h}^{-1}$
<b>Gamma dose rates at 1 m over river bank</b>			
Grand Union Canal	Soil	1	0.047
Newbridge	Grass	3	0.057
Staines	Soil	4	0.056

# See sub-section 3.2 for definition

indistinguishable from natural background. External exposures were calculated using a model based on concentrations of radionuclides in sediment. If any fish were eaten, the radiation dose, including that due to occupancy of river or canal banks near the outfall for times typical of enthusiastic anglers, would have been much less than 0.005 mSv or 0.5% of the dose limit of 1 mSv.

## 8.2 Cardiff Laboratory, South Glamorgan

A second laboratory, situated near Cardiff, produces labelled compounds used in research and diagnostic kits used in medicine for the *in vitro* testing of clinical samples. An authorisation issued by HMIP and the Welsh Office regulates disposals of liquid radioactive wastes from this establishment to a sewer discharging into the Severn estuary.

The DFR monitoring programme, carried out on behalf of the Welsh Office, reflects the two critical pathways due to consumption of marine foods and to external exposure over muddy intertidal areas. Measurements of external exposure are supported by analyses of intertidal sediment. Sea water and *Fucus* seaweed are collected as indicator materials. The radiological consequences of discharges from this establishment are small and mainly due to carbon-14. Additional artificial radionuclides detected are due to fallout, other establishments which discharge small amounts of radioactive wastes to the Severn estuary and the Bristol Channel, and possibly to discharges from Sellafield.

**Table 37(a). Radioactivity in environmental materials near Cardiff, 1994**

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>							
			<sup>3</sup> H	<sup>14</sup> C	<sup>35</sup> S	<sup>131</sup> I	<sup>134</sup> Cs	<sup>137</sup> Cs	<sup>155</sup> Eu	Total beta <sup>x</sup>
Flounder	East of new pipeline	1	NA	670	NA	ND	ND	0.42	ND	NA
Winkles	Orchard Ledges	1	"	330	"	"	"	0.50	"	"
Mussels	"	1	"	530	"	NA	NA	NA	NA	"
<i>Fucus vesiculosus</i>	"	2	"	25	"	2.0	ND	0.50	ND	"
<i>Fucus spiralis</i>	East of new pipeline	2	"	17	35	1.2	"	0.40	"	160
Mud	"	2	"	12	NA	ND	0.85	23	0.15	NA
"	West of new pipeline	2	"	17	"	"	0.86	21	1.6	"
Sea water	Orchard Ledges	2	17	NA	"	NA	NA	NA	NA	"

NA = not analysed

ND = not detected

\* Except sediment where dry concentrations apply and for sea water where units are Bq l<sup>-1</sup>

# See sub-section 3.2 for definition

<sup>x</sup> Includes contribution from carbon-14 at low counting efficiency due to the low energy of beta particles emitted by this radionuclide

<sup>1</sup> Landing point or sampling area

**Table 37(b). Monitoring of gamma dose rates near Cardiff, 1994**

Location	Ground type	No. of sampling observations#	$\mu\text{Gy h}^{-1}$
<b>Gamma dose rates at 1 m over intertidal areas</b>			
East of pipeline	Mud	2	0.071
West of pipeline	"	2	0.065

# See sub-section 3.2 for definition

The results of monitoring in 1994 are presented in Tables 37(a) and (b). Of the separate radionuclides listed, only tritium, carbon-14 and sulphur-35 were discharged by this establishment in 1994; the presence of the other radionuclides was therefore due to the combined background effects noted above. The exposure of the critical group of fish and shellfish consumers including external irradiation was 0.01 mSv or 1% of the dose limit of 1 mSv. The external irradiation of the critical group was calculated on the basis of concentrations of radionuclides in sediment. Gamma dose rates over sediment, as measured using portable instruments, were indistinguishable from those expected from the natural background.

## 9. CHANNEL ISLANDS MONITORING

Marine environmental samples provided by the Channel Islands States have continued to be analysed, mainly in surveillance of the effects of radioactive liquid discharges from the French reprocessing plant at Cap de la Hague. Fish and shellfish are monitored in relation to the internal irradiation pathway; sediment is analysed with relevance to external exposures. Sea water and seaweeds are sampled as indicator materials and, in the latter case, because of their use as fertilisers.

The results for 1994 are given in Table 38. Concentrations of activity in fish and shellfish were low and generally similar to those in previous years. Apportionment to different sources, including fallout, is difficult in view of the low levels detected. A theoretical assessment based on a pessimistic choice of consumption rates and occupancy gives an estimated exposure of 0.01 mSv in 1994 or 1% of the dose limit for members of the public. The concentrations of artificial radionuclides in the marine environment of the Channel Islands therefore continued to be of negligible radiological significance.

**Table 38. Radioactivity in environmental materials from the Channel Islands, 1994**

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>											
			<sup>3</sup> H	<sup>14</sup> C	<sup>54</sup> Mn	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>99</sup> Tc	<sup>106</sup> Ru	<sup>110m</sup> Ag	<sup>125</sup> Sb	<sup>129</sup> I	<sup>134</sup> Cs	<sup>137</sup> Cs
Rays	Guernsey	1	NA	NA	ND	ND	NA	NA	ND	ND	ND	NA	ND	1.1
Crabs	Guernsey	1	"	"	"	0.55	"	"	"	0.21	"	"	"	ND
"	Jersey	1	"	"	"	0.58	"	"	"	0.21	"	"	"	"
"	Alderney	2	"	39	"	0.38	"	ND	"	0.05	"	"	"	"
Lobsters	Guernsey	1	"	NA	"	0.27	"	NA	"	ND	"	"	"	"
"	Jersey	1	"	"	"	ND	"	"	"	"	"	"	"	0.16
"	Alderney	1	"	"	"	"	"	"	"	"	"	"	"	ND
Winkles	Alderney Quenard Point	1	"	"	"	0.90	0.083	"	"	"	"	"	"	"
Oysters	Jersey	1	"	"	"	0.30	NA	"	"	0.33	"	"	"	0.05
Limpets	Guernsey	1	"	"	"	0.41	"	"	"	ND	"	"	"	0.08
"	Jersey La Rozel	1	"	"	"	0.40	"	"	"	0.14	"	"	"	ND
"	Alderney Quenard Point	1	"	"	"	0.54	"	"	"	ND	"	"	"	"
Ormers	Guernsey	1	"	"	"	ND	"	"	"	"	"	"	"	"
<i>Porphyra</i>	Guernsey Fermain Bay	4	"	"	"	0.02	"	"	"	"	"	"	"	"
"	Alderney Quenard Point	3	"	"	"	0.05	"	"	0.63	"	"	"	"	0.02
"	Jersey Greve de Lecq	3	"	"	"	0.30	"	"	ND	"	"	"	"	0.11
<i>Fucus vesiculosus</i>	Alderney Quenard Point	4	"	"	"	1.4	"	"	"	"	"	1.0	"	0.11
<i>Fucus serratus</i>	Guernsey Fermain Bay	4	"	"	"	0.80	0.083	"	"	"	"	NA	"	0.08
"	Jersey La Rozel	3	"	"	"	1.2	0.13	"	"	"	"	"	"	0.14
"	Alderney Quenard Point	2	"	"	"	1.8	0.11	"	"	"	"	0.56	"	0.11
<i>Laminaria digitata</i>	Jersey Verclut	3	"	"	"	0.06	NA	"	"	"	"	NA	"	0.10
Mud	Jersey St Helier	1	"	"	0.67	29	"	"	4.8	"	0.80	"	"	5.4
Mud & sand	Guernsey Bordeaux Harbour	1	"	"	ND	0.67	"	"	ND	"	ND	"	"	2.0
Sand	Alderney Lt. Crabbe Harbour	1	"	"	"	0.74	"	"	"	"	0.58	"	"	2.1
Sea water	Alderney	5	0.62	NA	NA	NA	"	"	NA	NA	NA	"	ND	0.0057
"	Guernsey	4	ND	"	"	"	"	"	"	"	"	"	"	0.0048
"	Jersey	1	NA	"	"	"	"	"	"	"	"	"	"	0.0031

Table 38. continued

Material	Location <sup>1</sup>	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg <sup>-1</sup>							
			<sup>154</sup> Eu	<sup>155</sup> Eu	<sup>238</sup> Pu	<sup>239</sup> Pu+ <sup>240</sup> Pu	<sup>241</sup> Am	<sup>242</sup> Cm	<sup>243</sup> Cm+ <sup>244</sup> Cm	Total beta
Rays	Guernsey	1	ND	ND	0.00013	0.00054	0.0013	ND	ND	120
Crabs	Guernsey	1	“	“	0.00049	0.0011	0.0029	“	0.00085	57
“	Jersey	1	“	“	0.00061	0.0011	0.0052	0.000031	0.0017	91
“	Alderney	2	“	“	0.00070	0.0017	0.0044	ND	0.0011	56
Lobsters	Guernsey	1	“	“	0.00063	0.0015	0.013	0.00024	0.0031	34
“	Jersey	1	“	“	0.00043	0.00098	0.0034	0.000050	0.00062	92
“	Alderney	1	“	“	0.00040	0.00078	0.0043	ND	0.0011	53
Winkles	Alderney Quenard Point	1	“	“	0.018	0.066	0.055	0.00011	0.0082	69
Oysters	Jersey	1	“	“	0.0055	0.011	0.014	0.000068	0.0033	70
Limpets	Guernsey	1	“	“	NA	NA	ND	NA	NA	53
“	Jersey La Rozel	1	“	“	0.0069	0.014	0.023	0.00015	0.0049	75
“	Alderney Quenard Point	1	“	“	0.0082	0.013	0.038	0.00022	0.012	110
Ormers	Guernsey	1	“	“	NA	NA	ND	NA	NA	78
<i>Porphyra</i>	Guernsey Fermain Bay	4	“	“	0.0026	0.0070	0.0091	0.000067	0.0019	130
“	Alderney Quenard Point	3	“	“	NA	NA	ND	NA	NA	99
“	Jersey Greve de Lecq	3	“	0.03	“	“	“	“	“	270
<i>Fucus vesiculosus</i>	Alderney Quenard Point	4	“	ND	“	“	“	“	“	180
<i>Fucus serratus</i>	Guernsey Fermain Bay	4	“	“	0.013	0.031	0.012	0.00015	0.0033	180
“	Jersey La Rozel	3	“	“	0.022	0.041	0.021	0.00017	0.0054	270
“	Alderney Quenard Point	2	“	“	0.015	0.032	0.014	0.00020	0.0042	290
<i>Laminaria digitata</i>	Jersey Verclut	3	“	“	NA	NA	ND	NA	NA	330
Mud	Jersey St Helier	1	1.7	1.5	1.1	2.3	3.9	0.021	0.79	620
Mud & sand	Guernsey Bordeaux Harbour	1	ND	0.80	0.098	0.32	0.27	ND	0.048	480
Sand	Alderney Lt. Crabbe Harbour	1	“	ND	NA	NA	ND	NA	NA	370
Sea water	Alderney	2	NA	NA	“	“	NA	“	“	NA
“	Guernsey	4	“	“	“	“	“	“	“	“
“	Jersey	1	“	“	“	“	“	“	“	“

<sup>1</sup> Sampling area or landing point

NA = not analysed

ND = not detected

\* Except for sediment where dry concentrations apply and for sea water where units are Bq l<sup>-1</sup>

# See sub-section 3.2 for definition

## 10. MONITORING OF THE FRESHWATER ENVIRONMENT FOR RADIOACTIVITY FROM THE CHERNOBYL REACTOR ACCIDENT

The small-scale programme of surveillance of the effects of fallout from this accident has continued in 1994. Parts of the freshwater environment continued to show the effect of fallout from Chernobyl. The results of monitoring for 1994 are presented in this section. Sampling locations were mostly in areas of relatively high deposition of fallout from Chernobyl, namely Cumbria, North Wales and parts of Scotland. Samples from areas of low deposition in England were also obtained for completeness and comparison.

Table 39 presents concentrations of caesium-134 and -137 in fish and water. Artificial radionuclides, other than those of radiocaesium were, in 1994, no longer detectable from the Chernobyl accident.

**Table 39. Caesium radioactivity in the freshwater environment, 1994**

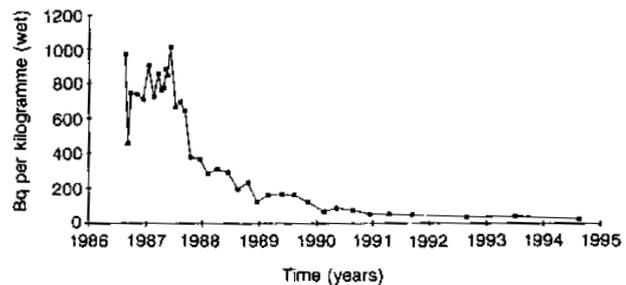
Location	Material	No. of samples	Mean radioactivity concentration* (wet), Bq kg <sup>-1</sup>	
			<sup>134</sup> Cs	<sup>137</sup> Cs
<b>England</b>				
Branthwaite	Rainbow trout	1	ND	0.32
Narborough	"	1	"	0.10
Ennerdale Water	Brown trout	1	0.92	26
"	Water	1	ND	0.0028
Devoke Water	Perch	1	18	550
"	Brown trout	1	1.5	42
"	Water	1	ND	0.020
<b>Wales</b>				
Llyn Hiraethlyn	Perch	1	10	280
"	Water	1	ND	0.019
<b>Scotland</b>				
Loch Dee	Brown trout	1	11	350
"	Water	3	0.0020	0.027

ND = not detected

\* Except for water where units are Bq l<sup>-1</sup>

Concentrations of radiocaesium in freshwater fish varied widely between locations, reflecting the areas of deposition of radioactivity from Chernobyl and the small sampling programme. Perch had the highest concentrations of any of the freshwater species but, as they are not eaten in large quantities, their radiological

significance is low. Where there are data for the same species and locations to compare with results for 1993 (Camplin, 1994) there are likely to be statistical fluctuations but concentrations of radiocaesium were generally similar in 1994 to those in 1993. Figure 2 shows a plot of mean total radiocaesium concentrations in brown trout from Ennerdale Water against time. In recent years, the rate of decline has reduced and it is likely that levels have now become more stable.



**Figure 2. Radiocaesium in brown trout - Ennerdale Water**

Radiation exposures have been estimated using a procedure based on cautious assumptions, as previously (Camplin, 1994). A consumption rate of brown trout of 37 kg year<sup>-1</sup>, sustained for one year, was taken to be an upper estimate for adults subject to the highest exposures. Actual exposures are likely to be lower, not only because this consumption rate is cautious (Leonard *et al.*, 1990) but also because, in practice, hatchery-reared or farmed fish of much lower radiocaesium concentrations may contribute to the diet. In 1994, estimated exposures were less than 0.2 mSv on the basis of both ICRP-26 and ICRP-60 in all areas of the UK.

The ICRP (ICRP, 1993) provides guidance in the context of emergencies, which includes suggested levels of averted dose above which particular countermeasures would almost certainly be justified. It recommends that intervention should be taken by restricting a single foodstuff if the averted effective dose is in excess of 10 mSv in a year. Given that the dose estimates here are cautious, it is clear that the residual contamination of freshwater fish from fallout from Chernobyl is only of minor radiological importance.

## 11. NATURAL RADIONUCLIDES

In view of the radiological importance of natural radionuclides to fish and shellfish consumers (Pentreath *et al.*, 1989; Rollo *et al.*, 1992; Camplin *et al.*, in press), a small programme of monitoring these radionuclides in the UK marine environment has continued. Previous surveys (Rollo *et al.*, 1992) have established that an

**Table 40. Natural radioactivity in fish and shellfish from the Irish Sea, 1994**

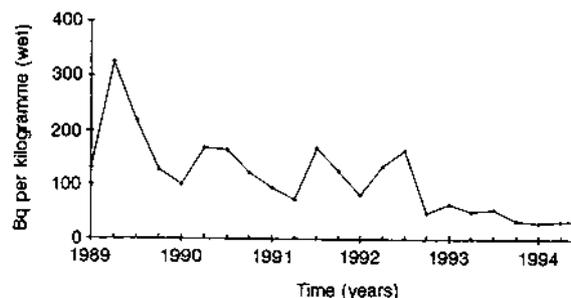
Material	Location	No. of sampling observations#	Mean radioactivity concentration (wet), Bq kg <sup>-1</sup>								
			<sup>210</sup> Po	<sup>210</sup> Pb	<sup>226</sup> Ra	<sup>228</sup> Th	<sup>230</sup> Th	<sup>232</sup> Th	<sup>234</sup> U	<sup>235</sup> U	<sup>238</sup> U
Winkles	Saltom Bay	4	24	3.1	NA	NA	NA	NA	NA	NA	NA
"	Parton	4	32	4.4	0.59	0.57	1.6	0.41	1.6	0.064	1.5
"	North Harrington	4	27	NA	NA	NA	NA	NA	NA	NA	NA
"	Fleswick Bay	4	18	"	"	"	"	"	"	"	"
"	Nethertown	3	14	2.5	"	"	"	"	"	"	"
"	Drigg	4	NA	NA	"	0.51	0.62	0.41	"	"	"
"	Tarn Bay	4	12	"	"	NA	NA	NA	"	"	"
Mussels	Parton	2	75	"	"	"	"	"	"	"	"
"	Nethertown	4	41	4.2	"	"	"	"	"	"	"
Limpet	St Bees	4	18	1.9	"	"	"	"	"	"	"
Crabs	Parton	5	21	1.4	"	0.14	0.058	0.023	0.099	0.0040	0.093
"	St Bees	4	18	0.43	"	NA	NA	NA	NA	NA	NA
"	Sellafield coastal area	4	10	NA	"	"	"	"	"	"	"
Lobsters	Parton	5	11	0.12	"	0.025	0.013	0.0038	0.019	0.0007	0.016
"	St Bees	5	12	0.32	"	NA	NA	NA	NA	NA	NA
Cod	Parton	5	0.63	0.026	"	0.014	0.0014	0.0006	0.0036	0.000031	0.0035

NA = not analysed

#See sub-section 3.2 for definition

important source was the Albright and Wilson chemical plant at Whitehaven in Cumbria which has manufactured phosphoric acid from imported phosphate ore. Phosphogypsum, a waste product of this process, has been discharged as a liquid slurry by pipeline to Saltom Bay. The radioactive waste discharges are authorised by HMIP and contain low levels of natural radioactivity consisting mainly of thorium, uranium and their daughter products. Discharge rates during 1994 were much less than those made previously due to changes in waste treatment techniques and the cessation of use of phosphate ore.

The results of DFR monitoring for natural radioactivity near the site in 1994 are shown in Table 40. 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 natural radionuclides are enhanced near Whitehaven but quickly reduce to background levels further away. Concentrations of polonium-210 and lead-210 were generally lower than in 1993 due to reductions in discharges and radioactive decay of activity already in the environment. Further reductions in concentrations are expected in 1995. Figure 3 shows how concentrations of polonium-210 in winkles have decreased substantially since 1989. It also demonstrates the seasonal variations in concentrations which have been previously observed (Rollo *et al.*, 1992). The critical radiation exposure pathway is internal irradiation, due to the ingestion of natural radioactivity in local fish and shellfish. In this assessment, the contribution due to background levels of natural radionuclides has been subtracted. The critical group consists of people who consume seafood collected from Saltom Bay and



**Figure 3. Polonium-210 in Parton winkles**

Parton. Consumption rates were reviewed in 1994 and small changes to fish and shellfish data were made. The results of the assessment of exposures using the current generic ICRP advice for a gut transfer factor of 0.5 for polonium are shown in Table 41 with the contributions of individual radionuclides. This advice is applied in the absence of specific information. On the basis of ICRP-26 the committed effective dose equivalent to the critical group in 1994 was 0.41 mSv. ICRP-60 dose coefficients for the natural radionuclides considered are lower than those for ICRP-26 because of changes in tissue weighting factors. Therefore the committed effective dose on the basis of ICRP-60, at 0.22 mSv in 1994, is less than that for ICRP-26.

As discussed in section 3.3, a research study at this laboratory involving the consumption of crab meat containing natural levels of polonium-210 provides evidence for a gut transfer factor of 0.8 for polonium. Estimates of exposures due to polonium intakes due to consumption of seafood have therefore also been calculated using the conservative assumption that the value of 0.8 applies to the total intake of polonium. These data, shown in Table 41, indicate that the critical

**Table 41. Individual radiation exposures from natural radionuclides due to consumption of fish and shellfish from the Whitehaven area, 1994**

Exposed population	Nuclide	Effective dose equivalent, mSv ICRP-26		Effective dose, mSv ICRP-60	
		Po gut uptake 0.5	Po gut uptake 0.8	Po gut uptake 0.5	Po gut uptake 0.8
Consumers in Saltom Bay and Parton	<sup>210</sup> Pb	0.04	0.04	0.01	0.01
	<sup>210</sup> Po	0.37	0.60	0.21	0.33
	U, Th, Ra nuclides	0.005	0.005	0.003	0.003
	Total	0.41	0.64	0.22	0.34

group dose on the basis of ICRP-26 has reduced from 0.93 mSv in 1993 (Camplin, 1994) to 0.64 mSv in 1994 (on the basis of ICRP-60 : 0.48 in 1993, 0.34 mSv in 1994). The estimated exposures in 1994 are therefore less than the dose limit for members of the public of 1 mSv.

The fish and shellfish consumed by the critical group also contains artificial radionuclides due to Sellafield discharges. The additional exposure due to artificial radionuclides has been calculated using data from subsection 4.1. In 1994 these exposures added a further 0.04 mSv on the basis of ICRP-26 (ICRP-60 : 0.03 mSv) to the doses above.

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## APPENDIX 1. Areas of work related to the monitoring programme and staff responsibilities

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Area of work	Staff
1. Inspection of nuclear sites	W C Camplin S W Conney W Hendrickson G J Hunt F Skelding B D Smith N Wood
2. Management of the monitoring programme and fieldwork	P Caldwell D J Coles C J Gough T M Jeffs J D Parr D J Swift J R Tipple
3. Assessment of radiation exposure	A J Baxter W C Camplin T C Doddington L Duckett T E Eaton S F N Rollo G R Round L M Thurston C A Smedley
4. Analysis of samples	D J Allington M R Allison T A Bailey P Blowers R A Bonfield S Cogan P Davidson H S Emerson L A Goldspink R Hillier M J Howes R D Ibbett K A Langston M B Lovett I McMeekan G Santillo P A Smedley G A Sutton A Taylor A K Young
5. Provision of laboratory and field equipment	D J Andrews M D Baldwin I A Huggins G E Moore R J Read M Sherlock

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## APPENDIX 2. Dosimetric data

Radionuclide <sup>†</sup>	Half-life (years)	Mean $\gamma$ energy (MeV per disintegration)	Dose* per unit intake by ingestion using the following methodology (Sv Bq <sup>-1</sup> )	
			ICRP-26	ICRP-60
Hydrogen-3	1.24 10 <sup>1</sup>	0.0	1.60 10 <sup>-11</sup>	1.80 10 <sup>-11</sup>
Carbon-14	5.73 10 <sup>3</sup>	0.0	5.60 10 <sup>-10</sup>	5.80 10 <sup>-10</sup>
Sulphur-35	2.39 10 <sup>-1</sup>	0.0	6.95 10 <sup>-10</sup>	7.80 10 <sup>-10</sup>
Manganese-54	8.56 10 <sup>-1</sup>	8.364 10 <sup>-1</sup>	7.24 10 <sup>-10</sup>	7.30 10 <sup>-10</sup>
Iron-55	2.7	1.691 10 <sup>-3</sup>	4.46 10 <sup>-10</sup>	3.40 10 <sup>-10</sup>
Cobalt-57	7.42 10 <sup>-1</sup>	1.25 10 <sup>-1</sup>	3.10 10 <sup>-10</sup>	2.10 10 <sup>-10</sup>
Cobalt-58	1.94 10 <sup>-1</sup>	9.976 10 <sup>-1</sup>	9.40 10 <sup>-10</sup>	7.50 10 <sup>-10</sup>
Cobalt-60	5.27	2.500	7.04 10 <sup>-9</sup>	3.40 10 <sup>-9</sup>
Zinc-65	6.67 10 <sup>-1</sup>	5.845 10 <sup>-1</sup>	3.90 10 <sup>-9</sup>	3.90 10 <sup>-9</sup>
Strontium-90 <sup>†</sup>	2.91 10 <sup>1</sup>	3.163 10 <sup>-3</sup>	3.77 10 <sup>-8</sup>	3.22 10 <sup>-8</sup>
Zirconium-95 <sup>†</sup>	1.75 10 <sup>-1</sup>	1.505	1.72 10 <sup>-9</sup>	1.55 10 <sup>-9</sup>
Niobium-95	9.62 10 <sup>-2</sup>	7.660 10 <sup>-1</sup>	6.80 10 <sup>-10</sup>	5.90 10 <sup>-10</sup>
Technetium-99	2.13 10 <sup>5</sup>	0.0	3.46 10 <sup>-10</sup>	6.40 10 <sup>-10</sup>
Ruthenium-103 <sup>†</sup>	1.07 10 <sup>-1</sup>	4.685 10 <sup>-1</sup>	8.10 10 <sup>-10</sup>	7.30 10 <sup>-10</sup>
Ruthenium-106 <sup>†</sup>	1.01	2.049 10 <sup>-1</sup>	7.50 10 <sup>-9</sup>	7.00 10 <sup>-9</sup>
Silver-110 m <sup>†</sup>	6.84 10 <sup>-1</sup>	2.740	2.89 10 <sup>-9</sup>	2.80 10 <sup>-9</sup>
Antimony-125	2.77	4.312 10 <sup>-1</sup>	7.02 10 <sup>-10</sup>	9.80 10 <sup>-10</sup>
Iodine-129	1.57 10 <sup>7</sup>	2.463 10 <sup>-2</sup>	6.40 10 <sup>-8</sup>	1.10 10 <sup>-7</sup>
Caesium-134	2.06	1.550	1.90 10 <sup>-8</sup>	1.90 10 <sup>-8</sup>
Caesium-137 <sup>†</sup>	3.00 10 <sup>1</sup>	5.651 10 <sup>-1</sup>	1.30 10 <sup>-8</sup>	1.40 10 <sup>-8</sup>
Barium-140 <sup>†</sup>	3.49 10 <sup>-2</sup>	2.502	4.41 10 <sup>-9</sup>	5.40 10 <sup>-9</sup>
Cerium-144 <sup>†</sup>	7.78 10 <sup>-1</sup>	5.282 10 <sup>-2</sup>	5.80 10 <sup>-9</sup>	5.20 10 <sup>-9</sup>
Promethium-147	2.62	4.374 10 <sup>-6</sup>	2.55 10 <sup>-10</sup>	4.40 10 <sup>-10</sup>
Europium-154	8.80	1.237	2.47 10 <sup>-9</sup>	3.10 10 <sup>-9</sup>
Europium-155	4.96	6.062 10 <sup>-2</sup>	3.68 10 <sup>-10</sup>	5.30 10 <sup>-10</sup>
Lead-210 <sup>†</sup>	2.23 10 <sup>1</sup>	4.810 10 <sup>-3</sup>	2.03 10 <sup>-6</sup>	7.02 10 <sup>-7</sup>
Bismuth-210	1.37 10 <sup>-2</sup>	0.0	1.56 10 <sup>-9</sup>	2.10 10 <sup>-9</sup>
Polonium-210 (c)	3.79 10 <sup>-1</sup>	0.0	2.18 10 <sup>-6</sup>	1.20 10 <sup>-6</sup>
Polonium-210 (d)			3.48 10 <sup>-6</sup>	1.92 10 <sup>-6</sup>
Radium-226 <sup>†</sup>	1.60 10 <sup>3</sup>	1.765	2.96 10 <sup>-7</sup>	2.80 10 <sup>-7</sup>
Thorium-228 <sup>†</sup>	1.91	1.567	3.42 10 <sup>-7</sup>	2.32 10 <sup>-7</sup>
Thorium-230	7.7 10 <sup>4</sup>	1.553 10 <sup>-3</sup>	3.45 10 <sup>-7</sup>	1.80 10 <sup>-7</sup>
Thorium-232	1.41 10 <sup>10</sup>	1.332 10 <sup>-3</sup>	1.83 10 <sup>-6</sup>	9.20 10 <sup>-7</sup>
Uranium-234	2.44 10 <sup>5</sup>	1.733 10 <sup>-3</sup>	7.03 10 <sup>-8</sup>	3.90 10 <sup>-8</sup>
Uranium-238 <sup>†</sup>	4.47 10 <sup>9</sup>	2.235 10 <sup>-2</sup>	6.67 10 <sup>-8</sup>	4.17 10 <sup>-8</sup>
Neptunium-237 <sup>†</sup>	2.14 10 <sup>6</sup>	2.382 10 <sup>-1</sup>	5.40 10 <sup>-7</sup>	1.10 10 <sup>-7</sup>
Plutonium-238 (a)	8.77 10 <sup>1</sup>	1.812 10 <sup>-3</sup>	4.30 10 <sup>-7</sup>	2.30 10 <sup>-7</sup>
Plutonium-238 (b)			1.70 10 <sup>-7</sup>	9.20 10 <sup>-8</sup>
Plutonium-240 (a)	6.54 10 <sup>3</sup>	1.731 10 <sup>-3</sup>	4.80 10 <sup>-7</sup>	2.50 10 <sup>-7</sup>
Plutonium-240 (b)			1.90 10 <sup>-7</sup>	1.00 10 <sup>-7</sup>
Plutonium-241 (a)	1.44 10 <sup>1</sup>	2.546 10 <sup>-6</sup>	9.30 10 <sup>-9</sup>	4.80 10 <sup>-9</sup>
Plutonium-241 (b)			3.70 10 <sup>-9</sup>	1.92 10 <sup>-9</sup>
Americium-241 (a)	4.32 10 <sup>2</sup>	3.253 10 <sup>-2</sup>	4.90 10 <sup>-7</sup>	2.10 10 <sup>-7</sup>
Americium-241 (b)			2.00 10 <sup>-7</sup>	8.40 10 <sup>-8</sup>
Curium-242	4.46 10 <sup>-1</sup>	1.832 10 <sup>-3</sup>	1.80 10 <sup>-8</sup>	1.60 10 <sup>-8</sup>
Curium-243	2.85 10 <sup>1</sup>	1.347 10 <sup>-1</sup>	3.40 10 <sup>-7</sup>	2.00 10 <sup>-7</sup>
Curium-244	1.81 10 <sup>1</sup>	1.700 10 <sup>-3</sup>	2.70 10 <sup>-7</sup>	1.70 10 <sup>-7</sup>

<sup>†</sup> Energy and dose per unit intake data include the effects of radiations of short-lived daughter products

\* ICRP-26 and ICRP-60 data are for committed effective dose equivalents and committed effective doses respectively. References are given in the main text. All data are for adults

(a) Gut transfer factor  $5 \times 10^{-4}$  for consumption of all foodstuffs except Irish Sea winkles

(b) Gut transfer factor  $2 \times 10^{-4}$  for consumption of Irish Sea winkles

(c) Gut transfer factor 0.5. ICRP-26 value determined by scaling that for gut transfer factor of 0.1

(d) Gut transfer factor 0.8. Values determined by scaling those for gut transfer factor of 0.1

## APPENDIX 3. Radioactivity in surface and coastal waters of the British Isles, 1989 to 1994

This appendix consists of tables of the major discharges, concentrations of activity in environmental materials and radiation dose rates in the aquatic environment of the United Kingdom over the six year period 1989 to 1994. All of the data have been taken from this report, Hunt (1990) and Camplin (1992, 1993(a) and (b) and 1994). The data have been selected on the basis of attempting to provide an overview of the changes in the aquatic environment over this period. The source references contain the complete record of observations made each year.

Changes in concentrations and dose rates from year to year may be due to a number of factors including discharges, environmental processes such as hydrographic dispersion and the weather, and sample characteristics such as sediment grain size. Changes in sampling methodology, field instrument use and laboratory analytical methods are less likely to give rise to changes in the reported levels in the environment because these aspects have generally remained consistent throughout the six year period. Where appropriate, discussion referring to the trends in time shown by the data is given in the main text of this report. Table 3.1 shows the contents of this Appendix.

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**Table 3.1. Table numbers and contents**

Number	Contents
3.2	Sellafield discharges
3.3	Sellafield fish
3.4	Sellafield crustaceans
3.5	Sellafield molluscs
3.6	Sellafield seaweed
3.7	Sellafield sediments
3.8	Sellafield gamma doses
3.9	Sellafield beta doses
3.10	Drigg
3.11	Springfields
3.12	Capenhurst
3.13	Chapelcross
3.14	Harwell
3.15	Winfrith
3.16	Dounreay
3.17	Berkeley and Oldbury
3.18	Bradwell
3.19	Dungeness
3.20	Hartlepool
3.21	Heysham
3.22	Hinkley Point
3.23	Hunterston
3.24	Sizewell
3.25	Torness
3.26	Trawsfynydd
3.27	Wylfa
3.28	Aldermaston
3.29	Barrow
3.30	Devonport
3.31	Faslane
3.32	Rosyth
3.33	Amersham
3.34	Cardiff
3.35	Channel Islands
3.36	Chernobyl (Ennerdale)
3.37	Whitehaven

**Table 3.2. Discharges of liquid waste from Sellafield**

Radionuclide	Discharge (TBq)					
	1989	1990	1991	1992	1993	1994
Tritium	2144.02	1698.62	1800	1200	2310	1680
Carbon-14	2.03	1.97	2.44	0.804	2.03	8.16
Cobalt-60	0.17	0.17	0.087	0.071	0.087	0.113
Strontium-90	9.17	4.22	4.09	4.14	17.1	28.9
Zirconium-95+Niobium-95	11.11	6.82	12.4	10.2	9.61	3.24
Technetium-99	6.07	3.82	3.86	3.18	6.06	72.0
Ruthenium-106	24.96	16.54	18.7	12.6	17.1	6.75
Iodine-129	0.17	0.11	0.159	0.068	0.161	0.157
Caesium-134	1.73	1.15	0.765	0.834	1.19	0.611
Caesium-137	28.60	23.46	15.6	15.2	21.9	13.8
Cerium-144	3.78	2.01	1.73	1.73	2.51	0.836
Plutonium alpha	1.21	1.14	1.08	0.935	1.33	0.663
Plutonium-241	30.24	31.61	29.5	25.3	37.5	14.4
Americium-241	1.06	0.75	0.744	0.542	0.873	0.381

**Table 3.3. Monitoring of radioactivity in fish due to Sellafield discharges<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Concentration of activity, Bq kg <sup>-1</sup> wet					
			1989	1990	1991	1992	1993	1994
Cod	Sellafield Offshore area	Carbon-14	86	95	74	75	41	98
		Cobalt-60	ND	ND	0.14	ND	ND	ND
		Strontium-90	0.087	0.12	0.072	0.096	0.044	0.16
		Technetium-99	0.27	0.39	0.22	0.28	0.13	1.9
		Caesium-134	0.9	0.5	0.67	ND	0.17	ND
		Caesium-137	41	27	30	19	18	10
		Promethium-147	0.020	0.013	0.10	0.092	NA	NA
		Neptunium-237	0.0003	NA	NA	0.00026	NA	NA
		Plutonium-238	0.0017	NA	0.0020	0.0024	0.0023	0.0027
		Plutonium-239+240	0.0074	NA	0.0092	0.011	0.010	0.013
		Americium-241	0.016	ND	0.017	0.027	0.017	0.021
		Curium-243+244	0.00004	NA	0.000040	0.000060	0.000026	0.000029
Cod	Mid-North Sea	Carbon-14	NA	NA	15	21	26	29
		Cobalt-60	ND	ND	0.05	ND	ND	ND
		Strontium-90	NA	NA	NA	0.0045	0.0030	0.0028
		Caesium-134	0.08	0.04	0.01	ND	ND	ND
		Caesium-137	2.4	1.9	2.1	1.0	0.86	0.75
Cod	Iceland area	Carbon-14	NA	19	16	13	23	29
		Caesium-137	0.3	0.3	0.22	0.28	0.22	0.15

NA = not analysed

ND = not detected

<sup>†</sup> Data may include contributions from sources other than Sellafield

**Table 3.4. Monitoring of radioactivity in crustaceans due to Sellafield discharges<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Concentration of activity, Bq kg <sup>-1</sup> wet					
			1989	1990	1991	1992	1993	1994
Crabs	Sellafield coastal area	Carbon-14	120	100	100	110	76	90
		Cobalt-60	6.7	3.4	0.06	1.5	0.61	0.57
		Strontium-90	1.5	1.2	0.97	0.52	1.1	1.3
		Zirconium-95	ND	ND	0.16	ND	0.06	ND
		Technetium-99	8.4	5.8	3.5	1.8	3.4	21
		Ruthenium-103	ND	ND	ND	ND	0.08	ND
		Ruthenium-106	37	11	10	6.9	4.9	3.3
		Silver-110m	8.3	4.4	6.0	27	15	12
		Antimony-125	ND	0.7	0.29	ND	0.10	0.13
		Caesium-134	ND	ND	ND	ND	0.08	ND
		Caesium-137	7.6	10	8.5	6.2	5.4	4.3
		Cerium-144	ND	ND	ND	ND	0.11	0.11
		Promethium-147	4.1	2.7	2.2	1.0	1.0	0.63
		Neptunium-237	0.11	0.060	0.044	0.021	0.041	0.033
		Plutonium-238	0.39	0.25	0.16	0.11	0.012	0.092
		Plutonium-239+240	1.6	1.0	0.70	0.48	0.49	0.42
		Plutonium-241	34	29	14	7.1	8.9	8.1
		Americium-241	3.5	3.6	2.9	2.1	1.9	1.9
		Curium-242	ND	0.0045	0.0057	0.0017	0.0010	0.0036
		Curium-243+244	0.0097	0.011	0.011	0.0059	0.0053	0.0045
Lobsters	Sellafield coastal area	Carbon-14	NA	160	110	150	130	120
		Cobalt-60	2.7	2.0	0.84	0.62	0.48	0.31
		Zinc-65	ND	ND	ND	ND	0.13	ND
		Strontium-90	NA	0.65	0.25	0.29	0.42	0.53
		Technetium-99	NA	630	220	170	390	2400
		Ruthenium-106	6.6	8.9	3.2	1.3	1.3	0.81
		Silver-110m	10	6.7	8.3	28	23	19
		Antimony-125	ND	0.2	0.08	0.03	0.12	0.05
		Caesium-134	ND	0.2	0.28	0.06	0.10	0.03
		Caesium-137	14	14	11	9.6	9.4	6.9
		Cerium-144	ND	0.6	ND	ND	0.07	0.10
		Promethium-147	NA	4.8	4.8	1.6	2.1	1.5
		Europium-154	ND	0.08	ND	ND	ND	ND
		Europium-155	ND	0.06	ND	ND	ND	ND
		Neptunium-237	NA	0.12	0.14	0.069	0.12	0.11
		Plutonium-238	0.14	0.16	0.13	0.088	0.093	0.072
		Plutonium-239+240	0.64	0.67	0.57	0.40	0.42	0.34
		Plutonium-241	NA	21	11	7.5	7.6	4.6
		Americium-241	5.4	7.4	8.7	4.7	5.1	5.6
		Curium-242	ND	ND	0.010	0.011	0.0022	0.010
Curium-243+244	0.023	0.029	0.028	0.013	0.012	0.020		
Nephrops	Whitehaven	Carbon-14	NA	NA	NA	41	39	53
		Cobalt-60	0.03	1.3	ND	0.36	ND	ND
		Strontium-90	NA	NA	NA	0.094	0.15	0.11
		Technetium-99	NA	NA	NA	26	36	170
		Silver-110m	ND	ND	ND	0.66	0.60	0.74
		Caesium-134	0.2	0.09	0.14	ND	ND	ND
		Caesium-137	15	12	12	11	10	11
		Plutonium-238	0.050	0.052	0.018	0.057	0.050	0.049
		Plutonium-239+240	0.24	0.26	0.096	0.35	0.25	0.24
		Americium-241	0.86	0.67	0.43	1.9	0.74	1.3
		Curium-243+244	0.0019	0.0020	0.0012	0.0020	0.0018	0.0035
		Nephrops	Northern North Sea	Technetium-99	1.1	NA	NA	NA
Silver-110m	0.4			ND	ND	ND	ND	ND
Caesium-137	0.7			0.7	0.53	0.41	0.28	0.39
Plutonium-238	0.00070			0.00080	0.00078	0.00083	0.00054	0.00018
Plutonium-239+240	0.0036			0.0038	0.0045	0.0043	0.0036	0.0014
Americium-241	0.0046			0.0060	0.0038	0.0049	0.0044	0.0026
Curium-242	ND			0.00015	0.000020	ND	0.000050	0.000016
Curium-243+244	ND	0.00010	0.000020	0.000041	0.000045	0.000021		

NA = not analysed

ND = not detected

<sup>†</sup> Data may include contributions from sources other than Sellafield

**Table 3.5. Monitoring of radioactivity in molluscs due to Sellafield discharges<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Concentration of activity, Bq kg <sup>-1</sup> wet					
			1989	1990	1991	1992	1993	1994
Winkles	Nethertown	Carbon-14	79	65	71	62	59	110
		Cobalt-60	7.6	5.6	4.2	3.4	3.0	2.7
		Strontium-90	12	13	12	12	16	7.1
		Zirconium-95	17 *	2.7	20	5.0	8.5	2.5
		Niobium-95		3.2	16	3.8	9.0	2.2
		Technetium-99	36	72	21	22	57	140
		Ruthenium-103	0.9	0.2	0.86	0.27	0.30	0.12
		Ruthenium-106	170	87	130	55	94	47
		Silver-110m	12	8.0	32	62	56	51
		Antimony-125	4.8	5.5	5.1	2.9	4.0	3.0
		Caesium-134	0.6	0.4	0.24	0.10	0.05	0.01
		Caesium-137	34	31	29	25	24	18
		Cerium-144	7.8	4.0	6.3	1.9	6.1	1.6
		Promethium-147	29	14	11	6.4	8.7	3.4
		Europium-154	1.4	1.3	1.3	0.93	0.57	0.24
		Europium-155	0.9	0.7	0.52	0.23	0.37	0.07
		Neptunium-237	0.58	0.32	0.62	0.19	0.67	0.28
		Plutonium-238	6.6	5.6	5.8	4.9	5.2	3.5
		Plutonium-239+240	28	25	25	22	23	16
		Plutonium-241	540	430	450	350	370	240
Americium-241	45	41	42	38	40	29		
Curium-242	0.13	0.11	0.12	0.046	0.078	0.0086		
Curium-243+244	0.15	0.10	0.14	0.10	0.11	0.064		
Cockles	Morecambe Bay	Carbon-14	NA	NA	NA	29	47	NA
		Cobalt-60	1.6	1.6	1.1	0.89	0.60	0.58
		Strontium-90	1.0	1.0	0.81	0.72	0.84	NA
		Technetium-99	NA	NA	NA	4.4	6.7	NA
		Ruthenium-106	4.4	4.4	4.1	1.6	1.7	1.2
		Silver-110m	ND	ND	0.04	0.52	0.12	0.06
		Antimony-125	0.4	0.4	0.54	0.30	0.43	0.30
		Caesium-134	0.2	0.2	0.60	ND	ND	ND
		Caesium-137	15	15	10	8.5	9.0	6.1
		Europium-154	ND	ND	0.14	0.15	0.08	0.12
		Europium-155	ND	ND	0.08	0.11	0.04	ND
		Plutonium-238	0.65	0.77	0.62	0.59	0.56	0.48
		Plutonium-239+240	3.2	3.4	3.0	3.0	2.9	2.4
		Plutonium-241	52	54	39	40	38	NA
		Americium-241	7.6	8.5	7.1	7.9	7.7	6.5
		Curium-242	0.019	ND	ND	ND	ND	ND
		Curium-243+244	0.022	0.024	0.019	0.015	0.023	0.011
Mussels	Mid North Sea	Cobalt-60	0.03	ND	0.11	0.53	ND	ND
		Antimony-125	ND	ND	0.08	ND	ND	ND
		Caesium-137	0.2	0.08	0.29	0.13	0.31	0.10
		Plutonium-238	0.00033	0.00025	0.00024	0.00015	0.00037	0.00015
		Plutonium-239+240	0.0048	0.044	0.0027	0.0018	0.0038	0.0025
		Americium-241	0.0021	0.0021	0.0021	0.0013	0.0027	0.0016
		Curium-243+244	0.00004	ND	0.000010	0.000012	0.0000062	ND

\* Including niobium-95

ND = not detected

NA = not analysed

<sup>†</sup> Data may include contributions from sources other than Sellafield

**Table 3.6. Monitoring of radioactivity in seaweed due to Sellafield discharges<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Concentration of activity, Bq kg <sup>-1</sup> wet					
			1989	1990	1991	1992	1993	1994
Porphyra	St Bees	Carbon-14	NA	18	25	31	26	48
		Cobalt-60	0.8	0.6	0.52	0.15	0.27	0.31
		Strontium-90	0.97	0.42	0.88	0.21	0.85	0.84
		Zirconium-95	5.7 *	1.2	2.9	0.61	1.1	0.26
		Niobium-95		0.8	2.8	ND	1.5	0.15
		Techneium-99	2.3	0.94	1.8	0.92	0.99	4.8
		Ruthenium-103	1.2	0.4	0.66	0.14	0.18	0.21
		Ruthenium-106	130	93	76	33	43	39
		Silver-110m	0.1	0.2	1.6	2.0	0.81	1.0
		Antimony-125	4.5	4.2	3.6	1.5	1.9	1.2
		Caesium-134	0.05	ND	ND	ND	0.02	ND
		Caesium-137	9.3	4.4	5.1	5.1	6.0	6.6
		Cerium-144	2.2	0.7	0.93	ND	0.70	0.07
		Europium-154	ND	ND	0.20	ND	ND	0.13
		Europium-155	0.1	0.2	ND	ND	ND	0.08
		Plutonium-238	2.2	0.90	NA	0.63	1.1	0.85
		Plutonium-239+240	9.8	4.2	NA	3.0	5.2	4.0
		Plutonium-241	180	70	81	44	87	52
		Americium-241	17	7.6	12	5.4	8.8	6.8
		Curium-242	0.074	0.015	NA	ND	0.012	0.0093
Curium-243+244	0.033	0.020	NA	0.012	0.014	0.017		
Laverbread	South Wales 'A'	Cobalt-60	0.2	ND	ND	ND	ND	ND
		Silver-110m	ND	ND	ND	0.04	ND	ND
		Caesium-137	0.7	0.4	0.64	0.37	0.15	0.04
		Americium-241	ND	ND	0.19	0.09	0.10	ND
<i>F. vesiculosus</i>	Sellafield	Cobalt-60	8.1	3.4	2.3	1.4	1.4	1.7
		Strontium-90	4.6	2.3	2.9	2.9	1.7	19
		Zirconium-95	9.2 *	2.1	5.4	5.0	3.0	1.1
		Niobium-95		ND	3.0	1.5	1.7	0.67
		Techneium-99	1800	1500	1100	800	1100	16000
		Ruthenium-103	0.07	ND	0.09	ND	ND	ND
		Ruthenium-106	35	21	22	10	9.7	7.7
		Silver-110m	4.1	2.7	14	26	10	15
		Antimony-125	4.0	5.3	3.7	1.7	1.5	1.6
		Caesium-134	0.9	0.6	0.38	0.28	0.19	0.08
		Caesium-137	34	26	22	17	14	14
		Cerium-144	1.6	ND	0.85	ND	0.50	0.31
		Promethium-147	8.3	2.9	3.2	1.5	NA	NA
		Europium-154	0.3	ND	ND	ND	ND	ND
		Europium-155	0.4	ND	ND	ND	ND	0.09
		Plutonium-238	4.8	3.9	NA	2.4	2.4	3.1
		Plutonium-239+240	20	17	NA	11	10	14
		Americium-241	9.7	7.0	7.1	4.7	5.7	6.6
		Curium-242	0.044	0.021	NA	0.0092	0.0067	0.0087
		Curium-243+244	0.031	0.017	NA	0.011	0.012	0.0097

NA = not analysed

ND = not detected

\* Including niobium-95

<sup>†</sup> Data may include contributions from sources other than Sellafield

**Table 3.7. Monitoring of radioactivity in sediments due to Sellafield discharges<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Concentration of activity, Bq kg <sup>-1</sup> dry					
			1989	1990	1991	1992	1993	1994
Sand	Sellafield	Cobalt-60	4.5	3.7	3.2	2.4	2.0	2.0
		Zirconium-95	1.8*	1.7	1.7	ND	ND	ND
		Ruthenium-106	18	11	8.5	4.2	3.2	2.8
		Antimony-125	ND	0.8	0.68	0.87	0.48	0.56
		Caesium-134	1.8	1.4	0.52	0.55	0.53	ND
		Caesium-137	270	230	210	170	160	150
		Cerium-144	2.8	1.7	0.58	ND	ND	ND
		Europium-154	6.9	6.9	5.8	3.1	3.4	3.6
		Europium-155	4.0	3.2	2.2	2.0	1.7	1.9
Americium-241	230	250	220	220	170	210		
Mud	Whitehaven yacht basin	Cobalt-60	18	19	10	9.8	7.9	5.4
		Zirconium-95	91*	50	120	38	120	13
		Niobium-95		62	130	36	150	20
		Ruthenium-103	2.1	ND	ND	ND	ND	ND
		Ruthenium-106	430	380	450	320	540	220
		Silver-110m	ND	ND	2.7	8.0	4.0	ND
		Antimony-125	21	22	23	18	20	13
		Caesium-134	1.8	12	7.1	5.4	5.9	2.6
		Caesium-137	1900	1500	1400	1300	1300	1100
		Cerium-144	47	58	50	36	110	25
		Europium-154	34	31	29	27	24	17
		Europium-155	22	20	14	14	13	4.7
		Plutonium-238	180	150	160	160	180	100
		Plutonium-239+240	810	740	730	730	810	480
		Americium-241	1100	1100	1100	1100	1200	760
		Curium-242	ND	2.9	3.2	1.5	ND	ND
Curium-243+244	2.6	2.8	3.1	2.3	2.4	1.8		
Turf <sup>1</sup>	Kippford Merse	Cobalt-60	18	19	9.4	9.1	6.6	4.5
		Zirconium-95	4.1*	4.4	6.9	1.4	ND	3.0
		Niobium-95		ND	6.6	2.9	ND	5.6
		Ruthenium-106	180	150	120	86	92	83
		Antimony-125	2.8	2.4	12	5.3	9.7	7.7
		Caesium-134	33	12	11	9.8	3.2	2.8
		Caesium-137	1300	1000	1100	1000	800	680
		Cerium-144	ND	11	10	ND	9.0	5.1
		Europium-154	19	15	16	15	12	7.6
		Europium-155	15	9.7	10	7.9	3.8	4.8
		Plutonium-238	110	85	77	86	68	63
		Plutonium-239+240	500	430	380	420	320	320
		Americium-241	650	620	550	640	470	510
		Curium-242	ND	1.8	1.2	ND	ND	ND
Curium-243+244	2.7	2.4	1.4	1.7	1.3	0.80		

\* Including Niobium-95

ND = not detected

<sup>†</sup> Data may include contributions from sources other than Sellafield

<sup>1</sup> Salt marsh from 1993

**Table 3.8. Monitoring of gamma dose rates due to Sellafield discharges<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Gamma dose rate, $\mu\text{Gy h}^{-1}$					
			1989	1990	1991	1992	1993	1994
Sand	Sellafield	Gamma dose	0.096	0.087	0.083	0.086	0.079	0.076
Mud	Whitehaven yacht basin	Gamma dose	0.33	0.32	0.30	0.29	0.27	0.26
Salt marsh	Newbiggin	Gamma dose	0.43	0.41	0.41	0.36	0.33	0.30
Salt marsh	Kippford merse	Gamma dose	0.21	0.18	0.17	0.17	0.16	0.16

<sup>†</sup> Data may include contributions from sources other than Sellafield

**Table 3.9. Monitoring of beta dose rates due to Sellafield discharges<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Beta dose rate, $\mu\text{Sv h}^{-1}$					
			1989*	1990	1991	1992	1993	1994
Nets	Vessel A	Beta dose	0.28	0.22	0.25	0.17	0.13	0.17
Nets	Vessel B	Beta dose	0.28	0.39	0.24	0.16	0.20	0.13
Pots	Vessel D	Beta dose	0.44	0.39	0.42	0.42	0.36	0.11

\* Data from source reference have been scaled to account for subsequent change in instrument calibration factor

<sup>†</sup> Data may include contributions from sources other than Sellafield

**Table 3.10. Discharges of liquid waste from Drigg, and radioactivity in environmental materials and radiation dose rates near Drigg<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharge, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992	1993	1994
Liquid waste	Sea pipeline	Total alpha			5 10 <sup>-4</sup>	7.82 10 <sup>-4</sup>	6.71 10 <sup>-4</sup>	0.00116
		Total beta <sup>(2)</sup>			0.014	0.0278	0.0206	0.0246
		Tritium			2.2	3.0	2.4	2.24
Winkles	Drigg	Carbon-14	94	59	73	80	74	160
		Manganese-54	0.1	ND	ND	ND	ND	ND
		Colbalt-60	12	8.5	5.3	4.1	3.7	3.3
		Strontium-90	14	7.5	7.5	6.9	NA	NA
		Zirconium-95	62 <sup>(1)</sup>	1.9	5.7	2.0	14	0.51
		Niobium-95		1.6	10	0.34	12	0.76
		Technetium-99	97	150	110	40	48	1200
		Ruthenium-103	3.2	0.4	0.53	ND	0.69	ND
		Ruthenium-106	330	130	130	52	120	43
		Antimony-125	6.5	5.9	4.0	1.9	4.0	3.1
		Caesium-134	0.7	ND	ND	ND	0.06	ND
		Caesium-137	40	23	18	16	15	11
		Cerium-144	19	4.3	3.1	0.56	11	0.38
		Promethium-147	52	16	11	5.6	9.7	3.3
		Europium-154	2.8	0.5	1.2	ND	0.47	0.19
		Europium-155	1.6	0.5	0.52	ND	ND	ND
		Neptunium-237	1.6	0.31	0.40	0.15	0.42	0.17
		Plutonium-238	12	6.3	4.7	3.6	4.0	3.2
Plutonium-239+240	50	27	21	17	18	15		
Plutonium-241	980	470	350	250	280	210		
Americium-241	84	54	40	31	34	30		
Curium-242	0.33	0.11	0.10	0.037	0.063	0.0027		
Curium-243+244	0.22	0.16	0.10	0.073	0.076	0.059		
Sand	Drigg pipeline	Gamma dose	0.080	0.076	0.071	0.066	0.072	0.067
Mussel bed	Drigg Barn Scar	Gamma dose	0.12	0.10	0.094	0.089	0.10	0.082

ND = not detected

<sup>†</sup> Environmental data may include contributions from sources other than Drigg

\* Concentrations in wet material

<sup>1</sup> Including niobium-95

<sup>2</sup> Excluding tritium

**Table 3.11. Discharges of liquid waste from Springfields, and radioactivity in environmental materials and radiation dose rates near Springfields\***

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity, Bq kg <sup>-1</sup> wet † or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991 <sup>(1)</sup>	1992	1993	1994
Liquid waste		Total alpha	0.38	0.20	0.170	0.106	0.0773	0.158
		Total beta	114	92	38.4	121	62.5	114
		Technetium-99			0.0192	0.104	0.0947	0.0159
		Thorium-230			0.0042	0.0306	0.0194	0.0902
		Thorium-232			0.0003	0.0015	0.00078	0.0014
		Neptunium-237			0.0003	0.0002	0.00025	0.00019
		Uranium			0.0184	0.0597	0.049	0.0553
Shrimps	Ribble Estuary	Technetium-99	NA	NA	NA	NA	NA	0.52
		Caesium-134	0.3	ND	ND	ND	ND	ND
		Caesium-137	9.9	6.7	7.6	8.7	7.5	5.9
		Thorium-228	0.0086	0.0084	0.013	0.0069	NA	NA
		Thorium-230	0.039	0.0085	0.018	0.016	NA	NA
		Thorium-232	0.0057	0.0040	0.0047	0.0039	NA	NA
		Thorium-234	ND	ND	ND	ND	ND	14
		Plutonium-238	NA	NA	0.0070	0.0042	NA	NA
		Plutonium-239+240	NA	NA	0.033	0.020	NA	NA
		Americium-241	ND	ND	ND	0.029	ND	ND
		Curium-243+244	NA	NA	0.000080	ND	NA	NA
Mud	Becconsall	Cobalt-60	5.6	5.5	4.4	1.0	0.95	0.80
		Ruthenium-106	45	34	51	14	12	7.3
		Antimony-125	ND	2.3	5.9	1.2	ND	1.2
		Caesium-134	11	6.8	5.4	1.3	0.43	0.50
		Caesium-137	980	870	800	480	380	470
		Cerium-144	ND	ND	ND	ND	3.0	ND
		Europium-154	9.8	6.5	1.3	2.6	0.36	1.6
		Europium-155	9.9	1.9	ND	ND	0.36	ND
		Thorium-228	60	46	46	40	33	35
		Thorium-230	460	290	500	120	86	110
		Thorium-232	75	50	47	36	30	31
		Thorium-234	51000	81000	61000	33000	17000	19000
		Protactinium-233	5.4	ND	ND	ND	ND	ND
		Uranium-234	NA	41	43	35	38	29
		Uranium-235 + 236	NA	1.9	1.7	ND	2.0	1.3
		Uranium-238	NA	40	39	35	36	29
		Americium-241	270	280	270	310	130	190
Mud, or mud and sand	Pipeline	Gamma dose	0.14	0.15	0.10	0.12	0.11	0.11
Mud	Becconsall	Gamma dose	0.15	0.16	0.13	0.12	0.11	0.11
Mud	Penwortham	Gamma dose	0.15	0.16	0.17	0.21	0.16	0.14

NA = not analysed

ND = not detected

\* Environmental data may include contributions from sources other than Springfields

† dry for sediments

<sup>1</sup> Discharge quantities may not be for a whole calendar year. Further details can be found in annual report

**Table 3.12. Discharges of liquid waste from Capenhurst and radioactivity in environmental materials near Capenhurst\***

Material or ground type	Landing point or sampling area	Radionuclide	Discharges, TBq and concentration of activity, Bq kg <sup>-1</sup> wet <sup>†</sup>					
			1989	1990	1991	1992	1993	1994
Liquid waste	Rivacre Brook	Uranium	0.00067	0.0030	0.00293	0.00161	0.00158	0.00106
		Uranium daughters	0.0077	0.010	0.0077	0.0069	0.0068	0.0066
		Non-uranic alpha	0.000032	0.00013	0.000136	0.000068	0.0000994	0.0000461
		Technetium-99	0.00087	0.0066	0.00767	0.00389	0.0049	0.00335
Water weed ( <i>Cladophora rupestris</i> )	Rivacre Brook	Cobalt-60	0.4	0.2	0.04	ND	ND	ND
		Technetium-99	27	450	770	250	300	270
		Antimony-125	NA	NA	0.13	ND	ND	ND
		Caesium-134	ND	ND	0.15	ND	ND	ND
		Caesium-137	0.5	0.6	1.8	1.5	1.3	0.34
		Europium-155	0.4	0.7	0.86	ND	ND	ND
		Thorium-234	NA	430	810	220	170	39
		Protactinium-233	ND	140	5.9	19	16	4.7
		Uranium-234	NA	NA	170	71	62	17
		Uranium-235+236	NA	NA	14	5.2	3.8	1.2
		Uranium-238	NA	NA	130	47	37	10
		Neptunium-237	NA	NA	55	12	10	2.4
Mud <sup>(1)</sup>	Rivacre Brook	Cobalt-60	2.7	0.4	0.51	0.42	0.15	ND
		Technetium-99	360	2500	1900	2000	1200	1100
		Caesium-134	12	3.6	1.4	0.52	0.56	ND
		Caesium-137	52	31	17	17	18	16
		Europium-155	4.7	11	2.7	6.1	0.64	ND
		Thorium-234	5800	1900	640	280	410	320
		Protactinium-233	30	130	68	44	66	48
		Uranium-234	NA	810	500	620	290	250
		Uranium-235+236	NA	47	34	38	20	17
		Uranium-238	NA	530	300	430	180	160
Neptunium-237	2.8	180	90	71	43	53		

ND = not detected

NA = not analysed

\* Environmental data may include contributions from sources other than Capenhurst

<sup>†</sup> dry for sediments

<sup>1</sup> Mud and sand in 1993

**Table 3.13. Discharges of liquid waste from Chapelcross, and radioactivity in environmental materials and radiation dose rates near Chapelcross<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992	1993	1994
Liquid waste		Total alpha	0.38	0.0005	0.0002	0.0002	0.000504	0.00084
		Total beta <sup>(1)</sup>	0.215	0.11	0.11	0.07	0.265	0.307
		Tritium	0.63	0.28	1.87	0.69	0.497	0.485
Flounder		Carbon-14	NA	22	32	30	39	54
		Strontium-90	NA	NA	NA	NA	0.038	0.028
		Technetium-99	NA	NA	NA	NA	NA	0.67
		Caesium-134	1.1	0.6	0.5	0.29	ND	0.10
		Caesium-137	69	65	64	53	45	43
		Plutonium-238	NA	NA	NA	NA	0.0037	0.0012
		Plutonium-239+240	NA	NA	NA	NA	0.019	0.0064
		Americium-241	ND	ND	ND	ND	0.029	0.011
	Curium-243+244	NA	NA	NA	NA	0.000027	ND	
Shrimps		Strontium-90	NA	NA	NA	NA	0.70	0.082
		Technetium-99	NA	NA	NA	NA	NA	2.6
		Silver-110m	NA	NA	0.20	0.96	0.49	0.37
		Caesium-134	0.2	0.2	0.05	ND	0.04	0.02
		Caesium-137	27	21	18	16	15	13
		Plutonium-238	NA	NA	NA	NA	0.0048	0.0037
		Plutonium-239+240	NA	NA	NA	NA	0.026	0.020
		Americium-241	ND	ND	ND	ND	0.044	0.036
		Curium-242	NA	NA	NA	NA	0.00014	ND
	Curium-243+244	NA	NA	NA	NA	0.00013	ND	
Mud <sup>(2)</sup>		Cobalt-60	3.4	2.9	1.8	1.4	1.2	1.6
		Zirconium-95	ND	1.2	1.8	2.0	2.6	1.6
		Niobium-95	ND	1.9	1.6	ND	0.7	1.9
		Ruthenium-106	52	41	23	26	22	26
		Antimony-125	2.1	3.6	0.75	1.2	3.2	2.1
		Caesium-134	6.0	5.4	2.7	1.2	0.75	1.4
		Caesium-137	610	620	440	330	290	310
		Europium-154	4.4	5.4	0.92	1.8	0.65	1.5
		Europium-155	4.2	ND	1.7	1.4	2.0	1.5
		Plutonium-238	21	NA	12	11	12	13
		Plutonium 239+240	97	NA	56	52	67	66
		Americium-241	140	120	82	78	89	100
		Curium-242	0.048	NA	ND	ND	0.12	0.16
		Curium-243+244	0.51	NA	0.14	0.13	0.21	0.14
Mud and sand	Seafield	Gamma dose	0.10	0.097	0.11	0.096	0.089	0.088
Salt marsh	Seafield	Gamma dose	0.11	0.097	0.094	0.090	0.099	0.092
Mud and sand	Battle Hill	Gamma dose	0.11	0.097	0.086	0.090	0.086	0.082

NA = not analysed

ND = not detected

<sup>†</sup> Environmental data may include contributions from sources other than Chapelcross

\* Dry concentrations for sediments; wet for other materials

<sup>1</sup> Excluding tritium

<sup>2</sup> Mud and sand in 1993 and 1994

**Table 3.14. Discharges of liquid waste from Harwell, and radioactivity in environmental materials and gamma dose rates near Harwell<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992 <sup>(2)</sup>	1993	1994
Liquid waste	Sutton Courtenay	Total activity <sup>(1)</sup>	0.24	0.17	0.231	0.14		
		Total alpha				0.000063	0.000104	0.000103
		Total beta <sup>(1)</sup>				0.00161	0.00199	0.00467
		Tritium	1.6	1.0	0.444	0.2157	0.48	0.503
		Cobalt-60				0.000445	0.000514	0.00091
Pike	Outfall	Caesium-137				0.0006	0.000348	0.00055
		Cobalt-60		0.09	ND	ND	ND	ND
		Caesium-134		0.1	0.29	0.08	0.14	0.05
		Caesium-137		5.8	16	3.0	5.9	2.8
		Plutonium-238		0.00003	0.000040	0.000044	0.000073	0.000011
		Plutonium-239+240		0.00012	0.00024	0.00020	0.00027	0.000051
		Americium-241		0.00023	0.00018	0.00032	0.00042	0.000070
Mud, or sand and mud	Sutton Courtenay	Chromium-51		ND	ND	ND	ND	6.3
		Cobalt-60		57	32	26	16	23
		Antimony-125		6.6	ND	ND	ND	ND
		Caesium-134		3.3	1.9	0.95	ND	0.38
		Caesium-137		190	650	570	520	580
		Europium-154		ND	ND	ND	ND	1.8
		Europium-155		ND	ND	2.7	ND	1.8
		Americium-241		ND	ND	6.2	ND	4.9
Soil or mud	Sutton Courtenay	Gamma dose			0.078	0.069	0.081	0.076

NA = not analysed

ND = not detected

<sup>†</sup> Environmental data may include the effects of sources other than Harwell

\* Dry concentrations for sediments; wet for other materials

<sup>1</sup> Excluding tritium

<sup>2</sup> Discharge quantities may not be for a whole calendar year. Further details can be found in annual report

**Table 3.15. Discharges of liquid waste from Winfrith, and radioactivity in environmental materials and radiation dose rates near Winfrith<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992	1993	1994
Liquid waste <sup>(1)</sup>		Total alpha	0.0045	0.004	0.00286	0.00203	0.00169	0.00209
		Tritium	149.1	39.2	13.2	13.8	74.0	57.0
		Cobalt-60	1.422	1.2	0.152	0.007	0.00559	0.00697
		Zinc-65	0.388	0.19	0.0213	0.0006	0.00032	0.00022
		Other radionuclides	6.53	2.6	0.492	0.108	0.0491	0.0556
Plaice	Weymouth Bay	Carbon-14	NA	NA	14	30	NA	NA
		Iron-55	0.6	0.3	NA	NA	NA	NA
		Zinc-65	0.3	ND	ND	ND	ND	ND
		Caesium-137	0.4	0.5	0.43	ND	0.10	0.17
Crabs	Weymouth Bay <sup>(2)</sup>	Manganese-54	0.8	0.07	ND	ND	ND	ND
		Iron-55	29	14	NA	NA	NA	NA
		Cobalt-58	0.7	0.03	ND	ND	ND	ND
		Cobalt-60	21	9.6	7.2	3.3	3.8	2.4
		Zinc-65	100	33	9.2	2.4	0.67	ND
		Technetium-99	3.0	NA	NA	NA	NA	NA
		Silver-110m	0.3	ND	ND	ND	ND	ND
		Caesium-137	0.03	ND	0.02	ND	0.05	ND
		Plutonium-238	0.00040	0.00033	0.00047	NA	NA	NA
		Plutonium-239+240	0.0013	0.0013	0.0015	NA	NA	NA
		Americium-241	0.0021	0.0022	0.0018	ND	ND	ND
		Curium-242	0.00004	0.00002	0.000047	NA	NA	NA
Curium-243+244	0.00021	0.00011	0.00012	NA	NA	NA		
Oysters	Poole	Iron-55	2.5	NA	NA	NA	NA	NA
		Cobalt-60	0.8	0.9	1.1	1.2	0.25	0.20
		Zinc-65	92	60	43	27	0.49	0.56
		Silver-110m	ND	ND	0.14	0.25	ND	ND
Mud	Poole Harbour <sup>(3)</sup>	Manganese-54	2.1	0.4	ND	ND	ND	ND
		Iron-55	92	NA	NA	NA	NA	NA
		Cobalt-60	22	14	14	8.7	9.1	5.4
		Zinc-65	2.3	ND	ND	ND	ND	ND
		Antimony-125	ND	ND	ND	0.54	ND	ND
		Caesium-137	5.6	3.8	5.2	3.0	3.2	2.6
		Europium-155	ND	ND	2.4	1.4	1.6	2.1
		Plutonium-238	0.19	0.097	0.17	0.12	0.16	0.13
		Plutonium-239+240	0.87	0.49	0.75	0.56	0.72	0.66
		Plutonium-241	NA	NA	NA	5.7	NA	NA
		Americium-241	0.66	0.36	0.56	0.40	0.55	0.49
		Curium-242	ND	ND	ND	ND	0.0019	ND
		Curium-243+244	ND	0.0065	0.0098	0.011	0.0091	0.0084
Sand, or sand and mud	Kimmeridge	Gamma dose	0.085	0.085	0.064	0.064	0.067	0.059
Mud	Poole Harbour <sup>(3)</sup>	Gamma dose	0.068	0.050	0.058	0.053	0.051	0.053

ND = not detected

NA = not analysed

<sup>†</sup> Environmental data may include contributions from sources other than Winfrith

<sup>1</sup> Inner pipeline

\* Dry concentrations for sediments; wet for other materials

<sup>2</sup> Lubworth Banks in 1993 and 1994

<sup>3</sup> Parkstone Bay in 1994

**Table 3.16. Discharges of liquid waste from Dounreay, and radioactivity in environmental materials and radiation dose rates near Dounreay<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> and gamma dose rate, µGy h <sup>-1</sup>							
			1989	1990	1991	1992	1993	1994		
Liquid waste		Total alpha <sup>(1)</sup>	0.0268	0.022	0.03	0.0259	0.0994	0.103		
		Total beta <sup>(2)</sup>	6.46	4.3	5.6	6.39	7.95	8.97		
		Tritium	0.51	0.30	0.82	2.89	1.03	3.22		
		Cobalt-60	<0.031	0.023	0.04	0.0250	0.0183	0.010		
		Strontium-90	1.27	1.3	1.1	1.75	1.37	1.60		
		Zirconium-95 +Niobium-95	<0.036	0.01	0.02	0.012	0.0144	0.012		
		Ruthenium-106	<0.733	0.34	0.52	0.499	0.809	0.355		
		Silver-110m	0.00381	0.01	0.04	0.006	0.0073	0.0068		
		Caesium-137	3.1	2.2	3.5	3.08	3.84	4.70		
		Cerium-144	0.0177	0.038	0.04	0.0240	0.0916	0.0264		
		Plutonium-241	0.542	0.72	0.563	0.0442	1.29	0.945		
		Curium-242	<0.00353	0.019	0.003	0.009	0.00121	0.0007		
	Cod		Carbon-14	NA	ND	19	20	26	21	
		Caesium-134	0.2	ND	ND	ND	ND	ND		
		Caesium-137	2.6	1.8	1.4	1.0	0.69	0.68		
		Plutonium-238	0.00008	0.00007	0.00015	0.00029	0.000068	0.000046		
		Plutonium-239+240	0.00035	0.00030	0.00069	0.0014	0.00028	0.00023		
		Americium-241	0.00048	0.00051	0.0012	0.0022	0.00039	0.00029		
		Curium-242	ND	ND	0.000020	0.0000066	ND	ND		
		Curium-243+244	ND	ND	0.000010	0.0000068	ND	ND		
Crabs		Cobalt-60	ND	ND	ND	ND	0.06	0.01		
		Silver-110m	4.9	1.9	2.0	1.0	1.1	0.28		
		Caesium-134	0.2	ND	ND	ND	ND	ND		
		Caesium-137	0.3	0.3	0.30	0.19	0.32	0.37		
		Plutonium-238	0.0020	0.0015	0.0036	0.0017	0.0033	0.0030		
		Plutonium-239+240	0.0079	0.0066	0.012	0.0073	0.011	0.012		
		Americium-241	0.013	0.011	0.015	0.0091	0.015	0.011		
		Curium-242	0.0015	0.0026	0.0057	0.00031	0.0014	0.00039		
		Curium-243+244	0.00044	0.00044	0.00057	0.00011	0.00044	0.0002		
		Manganese-54	ND	0.8	ND	0.15	0.03	ND		
Winkles	Sandside Bay	Cobalt-60	1.5	1.3	1.4	1.5	0.91	0.70		
		Ruthenium-106	24	0.9	2.3	ND	2.4	0.68		
		Silver-110m	85	42	78	58	18	25		
		Antimony-125	ND	ND	ND	ND	0.16	ND		
		Caesium-134	ND	ND	ND	ND	0.05	ND		
		Caesium-137	0.2	0.9	0.22	0.19	0.53	0.55		
		Cerium-144	1.1	1.0	0.88	ND	0.13	0.83		
		Europium-155	ND	ND	ND	ND	0.05	0.08		
		Plutonium-238	0.093	0.060	0.088	0.12	0.16	0.18		
		Plutonium-239+240	0.22	0.20	0.22	0.34	0.43	0.53		
		Plutonium-241	NA	2.6	3.7	3.5	7.4	6.6		
		Americium-241	0.27	0.32	0.47	0.53	0.32	0.35		
		Curium-242	0.037	0.050	0.048	0.027	0.018	0.0077		
		Curium-243+244	0.0088	0.0097	0.013	0.011	0.0067	0.0076		
		Sand	Sandside Bay	Manganese-54	ND	ND	ND	0.06	ND	ND
				Cobalt-60	0.3	0.3	0.08	0.25	0.10	0.07
Caesium-134	0.3			0.1	0.14	0.18	ND	0.14		
Caesium-137	7.9			8.4	7.1	6.6	5.7	5.8		
Cerium-144	4.4			0.5	ND	ND	ND	ND		
Europium-154	2.2			3.4	ND	0.87	1.3	0.93		
Europium-155	3.2			3.6	2.4	2.1	1.6	1.2		
Plutonium-238	4.0			3.1	2.7	2.4	2.7	2.1		
Plutonium-239+240	14			12	11	8.8	9.8	7.7		
Americium-241	15			10	97	8.3	9.8	7.3		
Curium-242	0.36			0.26	0.31	0.13	0.14	0.14		
Curium-243+244	0.23			0.17	0.15	0.16	0.14	0.10		
Intertidal sediment	Oigins Geo			Gamma dose	0.15	0.15	0.16	0.15	0.15	0.15
Sand	Sandside	Gamma dose	0.080	0.054	0.059	0.066	0.060	0.057		

NA = not analysed

ND = not detected

<sup>†</sup> Environmental data may include contributions from sources other than Dounreay

\* Dry concentrations for sediments; wet for other materials

<sup>1</sup> Excluding curium-242

<sup>2</sup> Excluding tritium

**Table 3.17. Discharges of liquid waste from Berkeley and Oldbury, and radioactivity in environmental materials and radiation dose rates near Berkeley and Oldbury<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992 <sup>(4)</sup>	1993	1994
Liquid waste	Berkeley	Total activity	0.23 <sup>(2)</sup>	0.33 <sup>(2)</sup>	0.200 <sup>(2)</sup>	0.0902 <sup>(1)</sup>	0.258 <sup>(1)</sup>	0.0974 <sup>(1)</sup>
		Tritium	3.53	1.35	0.095	0.156	0.265	0.292
		Caesium-137				0.0664	0.120	0.0463
Liquid waste	Oldbury	Total activity	0.41 <sup>(2)</sup>	0.43 <sup>(2)</sup>	0.284 <sup>(2)</sup>	0.397 <sup>(1)</sup>	0.481 <sup>(1)</sup>	0.345 <sup>(1)</sup>
		Tritium	0.72	1.7	0.202	0.215	0.229	0.263
		Caesium-137				0.0246	0.0262	0.045
Flounder <sup>(3)</sup>		Carbon-14	73	110	740	190	120	180
		Caesium-134	ND	ND	ND	0.02	ND	ND
		Caesium-137	ND	0.9	0.85	0.58	0.76	0.47
Shrimps		Carbon-14	NA	NA	120	130	180	150
		Caesium-134	0.06	ND	ND	0.03	ND	ND
		Caesium-137	0.7	0.4	0.31	0.47	0.61	0.29
		Plutonium-238	NA	NA	NA	NA	0.00088	0.00036
		Plutonium-239+240	NA	NA	NA	NA	0.0048	0.0021
		Americium-241	ND	ND	ND	ND	0.0041	0.0026
		Curium-242	NA	NA	NA	NA	0.000034	ND
		Curium-243+244	NA	NA	NA	NA	0.000091	0.000029
Mud	Area of pipelines <sup>(5)</sup>	Manganese-54	0.3	ND	ND	ND	ND	ND
		Cobalt-60	0.4	0.2	ND	0.13	ND	0.50
		Caesium-134	2.1	2.2	2.5	0.79	ND	0.78
		Caesium-137	51	41	44	34	42	33
		Europium-155	1.2	1.1	2.0	1.1	2.9	2.2
		Americium-241	ND	ND	ND	ND	0.88	ND
Mud	Berkeley pipeline <sup>(5)</sup>	Gamma dose		0.075	0.074	0.072	0.073	0.079
Mud	Guscar Rocks	Gamma dose		0.077	0.080	0.077	0.085	0.078
Mud	Lydney Locks	Gamma dose		0.068	0.070	0.073	0.074	0.072

NA = not analysed

ND = not detected

\* Dry concentrations for sediments; wet for other materials

<sup>1</sup> Excluding tritium and caesium-137

<sup>2</sup> Excluding tritium

<sup>†</sup> Environmental data may include the effects of sources other than Berkeley and Oldbury

<sup>3</sup> Dover sole in 1992; sampling was from Littleton Warth in 1994

<sup>4</sup> Discharged quantities may not be for a whole calendar year. Further details can be found in annual report

<sup>5</sup> Berkeley new pipeline in 1994

**Table 3.18 Discharges of liquid waste from Bradwell, and radioactivity in environmental materials and radiation dose rates near Bradwell<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992	1993	1994
Liquid waste		Total activity <sup>1</sup>	0.39	0.32	0.453	1.38		
		Tritium	0.96	1.4	1.37	3.92	3.03	2.17
		Zinc-65	0.0016	0.00097	0.00021	0.0012		
		Caesium-137					0.355	0.316
		Other radionuclides					0.248	0.406
Bass		Caesium-134	ND <sup>(2)</sup>	ND <sup>(2)</sup>	0.38	0.71	0.98	0.40
		Caesium-137	0.9 <sup>(2)</sup>	1.0 <sup>(2)</sup>	2.2	3.0	4.6	2.9
Crabs		Cobalt-60			0.23	0.37		
		Caesium-134			ND	0.24		
		Caesium-137			0.48	0.64		
Native Oysters		Cobalt-60		0.2	0.50	0.19	ND	ND
		Zinc-65		6.6	8.0	1.5	0.88	0.84
		Silver-110m		0.5	ND	ND	ND	ND
		Caesium-134		ND	ND	0.26	0.18	0.09
		Caesium-137		0.3	0.41	1.0	0.81	0.48
		Plutonium-238		0.00045	0.00062	0.00026	0.00083	0.00062
		Plutonium-239+240		0.0020	0.0024	0.0012	0.0037	0.0027
		Americium-241		0.00048	0.0067	0.0041	0.0078	0.0056
		Curium-242		ND	0.000050	ND	0.000018	0.000051
Curium-243+244		0.00031	0.00044	0.00029	0.00031	0.00028		
Pacific Oysters		Cobalt-60	ND	ND	ND	0.08	ND	ND
		Zinc-65	12	1.4	1.3	2.2	1.1	1.0
		Silver-110m	1.4	ND	0.17	0.09	ND	ND
		Caesium-134	ND	ND	ND	0.1	0.25	0.13
		Caesium-137	0.3	ND	0.09	0.41	0.86	0.43
		Plutonium-238	0.00047	NA	NA	NA	NA	NA
		Plutonium-239+240	0.0019	NA	NA	NA	NA	NA
		Americium-241	0.0068	ND	ND	ND	ND	NA
		Curium-243+244	0.00029	NA	NA	NA	NA	NA
Fucus vesiculosus		Cobalt-60	1.0	1.1	0.78	0.74	0.51	0.59
		Zinc-65	0.2	ND	ND	0.18	ND	ND
		Technetium-99	NA	NA	3.7	4.1	1.90	2.7
		Antimony-125	0.2	ND	ND	0.07	ND	ND
		Caesium-134	ND	0.08	0.38	1.9	0.63	0.56
		Caesium-137	1.5	1.4	2.1	6.9	2.7	2.1
		Europium-155	ND	0.1	ND	0.11	ND	ND
Mud	Maldon <sup>(3)</sup>	Manganese-54	0.2	0.1	ND	ND	ND	ND
		Cobalt-60	5.3	7.5	4.5	3.0	2.7	3.3
		Ruthenium-103	ND	0.2	ND	ND	ND	ND
		Ruthenium-106	5.3	1.2	ND	ND	ND	ND
		Antimony-125	1.4	0.5	ND	ND	ND	ND
		Caesium-134	1.1	0.6	2.3	8.9	12	9.4
		Caesium-137	21	25	29	46	84	80
		Europium-155	1.6	0.8	1.5	1.7	1.2	2.2
Mud	Pipeline	Gamma dose		0.12	0.25	0.076	0.10	0.42
Mud	West Mersea	Gamma dose		0.071	0.062	0.067	0.064	0.063
Mud	Maldon	Gamma dose			0.059	0.059	0.056	0.059

NA = not analysed

ND = not detected

\* Dry concentrations for sediment; wet for other materials

<sup>1</sup> Excluding Tritium

<sup>2</sup> Mixed fish

<sup>3</sup> Several locations near the site prior to 1993

<sup>†</sup> Environmental data may include contributions from sources other than Bradwell

**Table 3.19. Discharges of liquid waste from Dungeness, and radioactivity in environmental materials and radiation dose rates near Dungeness<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992	1993	1994 <sup>(5)</sup>
Liquid waste	'A' Station	Total activity <sup>(1)</sup>	0.23	0.39	0.374	0.507	1.03	0.401
		Tritium	0.20	0.71	0.492	0.451	4.43	0.1706
		Caesium-137						0.185
		Other radionuclides						0.143
	'B' Station	Total activity <sup>(1)(2)</sup>	0.0025	0.0091	0.0103	0.008	0.019	0.0359
		Tritium	16	7.20	76.1	93.3	269	408
		Sulphur-35	0.25	0.05	0.379	0.550	0.652	0.901
		Cobalt-60						0.0024
		Other radionuclides						0.0225
Cod		Caesium-137	0.7	1.0	0.92	0.60	0.47	0.41
Shrimps		Cobalt-60	ND	0.5	0.37	0.19	0.21	0.19
		Zinc-65	ND	0.2	0.11	ND	ND	ND
		Ruthenium-106	ND	0.9	ND	ND	ND	ND
		Caesium-134	ND	ND	ND	ND	0.08	0.03
		Caesium-137	ND	0.3	0.16	0.10	0.47	0.27
Mud, or mud and sand	Rye Harbour	Manganese-54	1.2	0.6	ND	ND	ND	ND
		Cobalt-60	16	22	8.3	9.7	6.7	5.9
		Ruthenium-106	9.4	4.3	ND	ND	ND	ND
		Antimony-125	2.4	ND	ND	0.63	ND	ND
		Caesium-137	4.5	4.2	3.0	3.0	2.7	2.3
		Europium-155	ND	1.0	2.0	ND	1.7	1.5
		Plutonium-238	0.23	0.14	0.10	0.16	0.14	0.099
		Plutonium-239+240	0.83	0.64	0.49	0.59	0.61	0.43
		Americium-241	0.60	0.42	0.34	0.48	0.49	0.35
		Curium-242	ND	ND	ND	ND	0.0026	ND
		Curium-243+244	0.048	0.038	0.029	0.052	0.043	0.029
Sand	Old lifeboat station	Gamma dose		0.050	0.047	0.053	0.042 <sup>(4)</sup>	0.041 <sup>(4)</sup>
Sand	Pilot Inn	Gamma dose		0.045	0.053	0.064	0.054	0.050
Mud, or mud and sand	Rye Harbour	Gamma dose	0.078	0.063	0.066	0.060	0.059 <sup>(3)</sup>	0.062 <sup>(3)</sup>

NA = not analysed

ND = not detected

<sup>1</sup> Excluding tritium

<sup>2</sup> Excluding sulphur-35

<sup>†</sup> Environmental data may include contributions from sources other than Dungeness

\* Dry concentrations for sediments; wet for other materials

<sup>3</sup> Mud and sand

<sup>4</sup> Shingle

<sup>5</sup> Discharges may not be for a whole calendar year. Further details can be found in annual report

**Table 3.20. Discharges of liquid waste from Hartlepool, and radioactivity in environmental materials and radiation dose rates near Hartlepool<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992	1993	1994
Liquid waste		Tritium	112	166	142	277	350	289
		Sulphur-35	0.43	0.92	0.35	0.838	0.732	0.446
		Other radionuclides	0.021	0.020	0.036	0.0486	0.0515	0.0104
Cod		Caesium-134	0.2	ND	ND	ND	ND	ND
		Caesium-137	3.1	1.9	1.4	1.1	0.92	0.83
Crabs		Cobalt-60	ND	ND	ND	0.04	ND	ND
		Silver-110m	0.3	ND	ND	ND	ND	ND
		Caesium-137	0.4	0.2	0.37	0.24	0.21	0.18
		Plutonium-238	0.00040	0.00029	0.00065	0.00083	0.00044	0.00038
		Plutonium-239+240	0.0017	0.0016	0.0033	0.0045	0.0024	0.0019
		Americium-241	0.0013	0.0012	0.0027	0.0060	0.0017	0.0018
		Curium-242	ND	ND	ND	0.000016	ND	ND
		Curium-243+244	ND	0.00001	ND	0.000024	0.000014	0.000013
Winkles		Cobalt-60	ND	0.1	ND	ND	ND	ND
		Iodine-131	ND	ND	ND	ND	0.18	ND
		Caesium-134	0.05	ND	ND	ND	ND	ND
		Caesium-137	1.0	0.7	0.55	0.50	0.27	0.33
		Plutonium-238	0.010	0.0046	0.0058	0.0049	0.0041	0.0041
		Plutonium-239+240	0.050	0.024	0.031	0.026	0.021	0.023
		Americium-241	0.020	0.010	0.015	0.013	0.015	0.015
		Curium-242	0.00009	ND	ND	0.000071	ND	ND
		Curium-243+244	0.00007	ND	0.000050	0.000035	0.000040	0.000042
Mud		Caesium-134	1.8	0.5	ND	ND	ND <sup>(1)</sup>	ND
		Caesium-137	44	35	23	18	20 <sup>(1)</sup>	22
		Europium-155	1.9	0.7	2.6	2.3	1.5 <sup>(1)</sup>	3.1
Coal and sand	Little Scar	Gamma dose		0.053	0.054	0.059	0.055	0.055
Mud	Paddy's Hole	Gamma dose		0.082	0.092	0.093	0.097	0.097
Sand	North Gare	Gamma dose		0.051	0.056	0.055	0.055	0.054

NA = not analysed

ND = not detected

\* Dry concentrations for sediments; wet for other materials

<sup>†</sup> Environmental data may include contributions from sources other than Hartlepool

<sup>1</sup> Paddy's Hole

**Table 3.21. Discharges of liquid waste from Heysham, and radioactivity in environmental materials and gamma dose rates near Heysham<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992	1993	1994
Liquid waste	Station 1	Tritium	195	157	309	272	394	376
		Sulphur-35	0.48	0.40	0.69	0.56	0.59	0.557
		Other radionuclides	0.058	0.058	0.026	0.0315	0.024	0.00866
Liquid waste	Station 2	Tritium	106	45.2	107	252	460	356
		Sulphur-35	0.086	0.073	0.002	0.0499	0.0922	0.0836
		Cobalt-60	0.000007	0.000007	0.00143	0.00135	0.00151	0.000777
		Other radionuclides	0.0058	0.011	0.007	0.0223	0.0220	0.0428
Flounder		Carbon-14	NA	46	36	32	37	58
		Caesium-134	0.7	0.4	0.56	0.18	0.26	0.12
		Caesium-137	59	54	39	40	46	36
		Plutonium-238	NA	NA	NA	0.00042	0.00043	0.00054
		Plutonium-239+240	NA	NA	NA	0.0021	0.0022	0.0029
		Americium-241	ND	ND	ND	0.0041	0.0042	0.0046
		Curium-242	NA	NA	NA	ND	0.000013	ND
		Curium-243+244	NA	NA	NA	0.0000083	0.000010	0.0000082
Mussels		Carbon-14	NA	NA	NA	35	34	47
		Cobalt-60	0.7	0.3	0.46	0.35	0.29	0.22
		Technetium-99	NA	NA	NA	NA	NA	54
		Ruthenium-106	2.4	2.1	5.2	2.1	5.9	1.7
		Silver-110m	ND	ND	ND	0.22	0.04	ND
		Antimony-125	ND	0.2	0.62	0.41	0.12	0.40
		Caesium-134	0.2	0.1	ND	ND	ND	ND
		Caesium-137	6.8	4.5	4.7	3.7	2.4	4.1
		Plutonium-238	0.37	0.23	0.17	0.16	0.35	0.35
		Plutonium-239+240	1.8	1.1	0.84	0.82	1.7	1.8
		Americium-241	3.3	1.8	1.4	1.4	2.9	3.1
		Curium-242	ND	ND	ND	0.0040	ND	0.0063
		Curium-243+244	0.0067	0.0054	0.0039	0.0023	0.0058	0.0030
Mud, or sand and mud	Morecambe Central Pier	Cobalt-60			3.6	1.9	1.6	1.2
		Zirconium-95			ND	5.6	ND	0.50
		Niobium-95			ND	2.7	ND	0.45
		Ruthenium-106			55	22	24	13
		Antimony-125			7.6	1.8	1.8	1.9
		Caesium-134			2.8	1.0	0.57	0.10
		Caesium-137			660	300	250	230
		Europium-154			6.6	2.1	0.68	1.8
		Europium-155			3.6	2.4	2.8	1.9
Americium-241			280	120	89	92		
Sediment	Half Moon Bay	Gamma dose		0.088	0.10	0.095	0.10	0.083
Mussel bed	Morecambe Central Pier	Gamma dose		0.079	0.079	0.078	0.074	0.075
Sediment	Sunderland Point	Gamma dose		0.11	0.092	0.091	0.089	0.094

NA = not analysed

ND = not detected

\* Dry concentrations for sediments; wet for other materials

<sup>†</sup> Environmental data may include the effects of sources other than Heysham

**Table 3.22. Discharges of liquid waste from Hinkley Point, and radioactivity in environmental materials and gamma dose rates near Hinkley Point<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990 <sup>(4)</sup>	1991	1992	1993	1994
Liquid waste	'A'	Total activity <sup>(3)</sup>	0.90	0.39				
		Total activity <sup>(1)</sup>		0.053	0.286	0.164	0.261	0.237
		Tritium	1.1	0.91	0.781	0.706	0.779	0.712
		Sulphur-35	0.16	0.23				
		Caesium-137		0.084	0.443	0.446	0.425	0.486
Liquid waste	'B'	Total activity <sup>(3)</sup>	0.031	0.030				
		Total activity <sup>(2)</sup>		0.0075	0.022	0.013	0.014	0.0201
		Tritium	266	295	277	317	390	336
		Sulphur-35	0.99	1.59	1.51	1.27	1.74	1.36
		Cobalt-60		0.00026	0.004	0.00295	0.00122	0.00126
Flounder		Carbon-14	86	54	150	100	140	130
		Sulphur-35	NA	NA	17	NA	NA	ND
		Caesium-134	0.1	0.2	0.10	0.14	0.05	0.09
		Caesium-137	1.5	1.8	1.2	1.2	0.75	0.94
Shrimps		Carbon-14	NA	80	93	100	120	96
		Sulphur-35	NA	NA	16	NA	NA	ND
		Strontium-90	0.13	0.18	NA	NA	NA	NA
		Caesium-134	0.1	0.07	0.04	0.17	0.13	0.19
		Caesium-137	0.7	0.7	0.54	0.83	0.71	0.70
		Europium-155	ND	ND	ND	ND	0.06	ND
		Plutonium-238	0.00018	0.00016	0.00022	0.00039	0.00016	0.00035
		Plutonium-239+240	0.00088	0.00068	0.0010	0.0016	0.00069	0.0015
		Americium-241	0.00074	0.00071	0.0012	0.0022	0.00070	0.0023
		Curium-242	ND	ND	ND	ND	ND	0.00029
Curium-243+244	ND	0.00003	0.000020	0.000024	0.000028	0.000028		
Mud	1.6 km east of pipe <sup>(5)</sup>	Manganese-54		0.2	ND	ND	ND	0.51
		Cobalt-60		0.6	0.91	0.77	1.6	0.86
		Caesium-134		2.2	2.3	5.4	2.7	4.9
		Caesium-137		44	39	55	37	40
		Europium-155		1.6	1.3	1.6	2.3	1.9
Mud, or sand and mud	0.8 km west of pipe	Gamma dose		0.12	0.070	0.087	0.16	0.14
Mud, or sand and mud	Pipeline outlet	Gamma dose		0.080	0.15	0.085	0.099	0.088
Mud, or sand and mud	0.8 km east of pipe	Gamma dose		0.066	0.062	0.12	0.081	0.067

NA = not analysed

ND = not detected

<sup>†</sup> Environmental data may include the effects of sources other than Hinkley Point

\* Dry concentrations for sediments; wet for other materials

<sup>1</sup> Excluding tritium and caesium-137

<sup>2</sup> Excluding tritium, sulphur-35 and cobalt-60

<sup>3</sup> Excluding tritium and sulphur-35

<sup>4</sup> Discharge quantities may not be for a whole calendar year. Further details can be found in annual report

<sup>5</sup> Various locations prior to 1993

**Table 3.23. Discharges of liquid waste from Hunterston, and radioactivity in environmental materials and gamma dose rates near Hunterston<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992	1993	1994
Liquid waste	'A'	Total activity <sup>(1)</sup>	0.62	0.32	0.28	0.21	0.291	0.209
		Tritium	0.76	0.52	0.25	0.17	0.358	0.195
Liquid waste	'B'	Total activity <sup>(2)</sup>	0.039	0.05	0.04	0.02	0.0335	0.0315
		Tritium	333	353	257	245	362	423
		Sulphur-35	1.2	2.5	1.48	1.7	2.14	1.54
Cod		Carbon-14	NA	NA	21	26	NA	NA
		Caesium-134	0.4	0.09	ND	0.05	ND	ND
		Caesium-137	7.7	5.2	6.1	4.3	4.7	4.7
Lobsters		Cobalt-60	ND	1.3	ND	0.36	ND	ND
		Caesium-137	2.3	2.1	1.6	1.6	1.3	0.88
Winkles		Chromium-51	ND	ND	ND	ND	9.3	2.4
		Manganese-54	4.7	9.0	ND	4.0	3.1	1.9
		Iron-59	ND	ND	ND	ND	0.15	ND
		Cobalt-58	0.6	0.2	0.16	0.20	0.28	0.12
		Cobalt-60	7.5	8.5	8.3	8.6	4.8	3.5
		Zinc-65	3.2	0.4	0.14	0.15	0.22	0.10
		Silver-110m	4.4	2.2	2.3	1.3	1.0	2.5
		Caesium-134	0.2	ND	ND	ND	0.11	0.06
		Caesium-137	2.4	2.7	2.0	1.6	2.4	1.6
		Europium-155	ND	ND	ND	ND	0.07	ND
		Plutonium-238	0.033	0.052	0.058	0.059	0.056	0.040
		Plutonium-239+240	0.13	0.19	0.24	0.27	0.23	0.17
		Americium-241	0.056	0.087	0.10	0.12	0.11	0.060
Curium-242	0.0021	0.0025	0.0015	0.00089	0.0014	0.0012		
Curium-243+244	0.0034	0.0051	0.0045	0.0021	0.0036	0.0021		
Sand		Manganese-54	2.8	4.9	ND	3.1	1.6	2.4
		Cobalt-60	1.9	1.8	2.6	1.8	1.1	0.92
		Caesium-134	1.4	0.3	0.44	ND	0.19	ND
		Caesium-137	37	17	22	16	25	10
		Europium-155	ND	0.7	ND	0.20	0.39	ND
		Americium-241	ND	ND	0.31	ND	0.38	0.41
Sand	0.5 km north of pipeline	Gamma dose		0.062	0.051	0.057	0.060	0.055
Sand and stones	0.5 km south of pipeline	Gamma dose		0.079	0.069	0.070	0.073	0.072

NA = not analysed

ND = not detected

<sup>†</sup> Environmental data may include the effects of sources other than Hunterston

\* Dry concentrations for sediments; wet for other materials

<sup>1</sup> Excluding tritium

<sup>2</sup> Excluding tritium and sulphur-35

**Table 3.24. Discharges of liquid waste from Sizewell, and radioactivity in environmental materials and gamma dose rates near Sizewell†**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992	1993	1994 <sup>(2)</sup>
Liquid waste		Total activity <sup>(1)</sup>	0.36	0.43	0.47	0.383	0.275	0.106
		Tritium	2.1	5.0	5.6	5.08	2.79	3.57
		Caesium-137						0.057
		Other radionuclides						0.129
Cod		Carbon-14	NA		22	19	NA	NA
		Caesium-134	ND		ND	0.17	ND	ND
		Caesium-137	2.5		1.1	2.3	0.69	0.46
Shrimps		Caesium-134	0.2	0.3	0.54	0.27		ND
		Caesium-137	1.4	1.6	1.2	0.83		0.48
		Plutonium-238	0.00003	0.00017	0.0010	0.00021		0.00020
		Plutonium-239+240	0.00023	0.00085	0.0045	0.00075		0.00096
		Americium-241	0.00013	0.0016	0.0078	0.0010		0.0012
		Curium-243+244	ND	ND	0.000050	ND		0.000014
Pacific oysters	Blyth estuary	Zinc-65	0.8	0.5	ND	ND	ND	ND
		Silver-110m	1.7	ND	ND	ND	ND	ND
		Caesium-137	0.2	0.5	0.56	0.13	0.11	0.07
Whelks	Dunwich	Cobalt-60	ND		0.92	0.40	ND	0.29
		Silver-110m	1.3		ND	ND	ND	ND
		Caesium-137	ND		ND	0.31	ND	0.09
Mud	Southwold	Cobalt-60	3.3	6.2	2.8	2.0	1.3	2.8
		Ruthenium-106	6.8	ND	ND	ND	ND	ND
		Caesium-134	1.5	0.6	ND	ND	ND	ND
		Caesium-137	28	24	22	18	13	15
		Europium-155	1.5	1.1	0.86	1.5	1.1	1.9
Sand	Pipeline	Gamma dose		0.046	0.047	0.088	0.048	0.081
Sand, or sand and stones	Aldeburgh	Gamma dose		0.041	0.044	0.046	0.045	0.045
Mud	Southwold Harbour	Gamma dose		0.059	0.062	0.068	0.060	0.064

NA = not analysed

ND = not detected

† Environmental data may include the effects of sources other than Sizewell

\* Dry concentrations for sediments; wet for other materials

<sup>1</sup> Excluding tritium

<sup>2</sup> Discharges may not be for a whole calendar year. Further details can be found in annual report

**Table 3.25. Discharges of liquid waste from Torness, and radioactivity in environmental materials and gamma dose rates near Torness<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992	1993	1994
Liquid waste		Total alpha	0.000015	0.000008	0.000009	0.000014	0.0000119	8.14 10 <sup>-6</sup>
		Beta activity <sup>(1)</sup>	0.0156	0.0018	0.0054	0.011	0.00844	0.00117
		Tritium	92.3	82	132	250	235	220
		Sulphur-35	0.168	0.081	0.044	0.048	0.0210	0.0189
		Cobalt-60	0.000043	0.000029	0.0014	0.0035	0.00140	0.000255
Cod		Carbon-14	NA	ND	23	28	NA	NA
		Caesium-137	1.6	2.2	1.8	1.6	0.98	0.92
Crabs		Cobalt-60	ND	ND	ND	0.09	ND	ND
		Silver-110m	1.5	0.4	ND	ND	0.07	ND
		Caesium-137	0.5	0.4	0.21	0.32	0.17	0.14
		Americium-241	ND	ND	ND	ND	ND	0.093
Winkles		Cobalt-60	ND	ND	0.82	0.72	0.44	0.19
		Silver-110m	1.9	0.7	0.20	1.2	4.3	2.5
		Caesium-137	0.5	0.5	0.29	0.52	0.43	0.35
Mud, or sand and mud	Barns Ness	Caesium-134	ND	0.6	ND	ND	ND	ND
		Caesium-137	ND	7.0	21	10	9.6	8.7
		Europium-155	ND	ND	ND	1.6	ND	1.7
Mud, sand and stones	Barns Ness	Gamma dose			0.060	0.065	0.063	0.063
Sand	Skateraw Harbour	Gamma dose		0.060	0.053	0.058	0.060	0.055
Sand	Thornton Loch Beach	Gamma dose		0.058	0.047	0.054	0.055	0.054

NA = not analysed

ND = not detected

<sup>†</sup> Environmental data may include the effects of sources other than Torness

\* Dry concentrations for sediments; wet for other materials

<sup>1</sup> Excluding tritium, sulphur-35 and cobalt-60

**Table 3.26. Discharges of liquid waste from Trawsfynydd, and radioactivity in environmental materials and gamma dose rates near Trawsfynydd<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991 <sup>(3)</sup>	1992	1993	1994
Liquid waste		Total activity <sup>(2)</sup>			0.0250	0.167	0.0267	0.0123
		Total activity <sup>(1)</sup>	0.28	0.33	0.271			
		Tritium	0.49	2.5	0.3567	0.222	0.075	0.121
		Strontium-90			0.00232	0.0536	0.00603	0.00220
		Caesium-137	0.036	0.041	0.03376	0.0227	0.00848	0.0094
Brown trout		Carbon-14	NA	38	51	38	54	36
		Sulphur-35	34	110	64	23	20	ND
		Cobalt-60	0.1	0.05	0.03	0.03	ND	ND
		Strontium-90	9.2	8.4	9.0	12	25	16
		Caesium-134	45	73	100	56	43	19
		Caesium-137	230	340	420	310	310	220
		Plutonium-238	0.00021	0.00033	0.00036	0.00022	0.00024	0.00017
		Plutonium-239+240	0.00082	0.0013	0.0013	0.00065	0.0010	0.00039
		Americium-241	0.0013	0.0020	0.0019	0.0010	0.0013	0.00062
		Curium-242	0.00008	0.00023	0.00020	0.000086	0.000021	0.000022
		Curium-243+244	0.00002	0.00003	0.000035	0.000033	0.000028	0.000044
Perch		Carbon-14	NA	49	43	NA	NA	NA
		Sulphur-35	100	280	75	28	18	ND
		Cobalt-60	0.4	ND	ND	ND	0.06	ND
		Strontium-90	5.1	5.0	5.4	8.4	10	6.5
		Caesium-134	110	160	180	150	110	36
		Caesium-137	600	740	870	880	880	430
		Plutonium-238	0.00017	0.00014	0.00011	0.00055	0.00016	0.00019
		Plutonium-239+240	0.00061	0.00044	0.00045	0.0022	0.00058	0.00056
		Americium-241	0.0012	0.00064	0.00074	0.0041	0.0010	0.0011
		Curium-242	0.00012	0.00014	0.00017	0.00017	ND	0.000048
		Curium-243+244	0.00003	0.00002	0.000040	0.000059	0.000049	0.000069
Mud	Hot lagoon	Manganese-54	ND	ND	4.7	ND	ND	ND
		Cobalt-60	120	170	150	120	80	96
		Zirconium-95	ND	45	11	ND	ND	ND
		Niobium-95	ND	180	51	ND	ND	ND
		Ruthenium-106	57	890	1200	1000	690	370
		Antimony-125	480	1300	1900	2200	1300	820
		Caesium-134	190	660	690	600	400	300
		Caesium-137	6900	6700	7100	6500	5900	5900
		Cerium-144	33	620	690	450	260	110
		Europium-154	50	54	50	58	47	38
		Europium-155	34	36	35	37	29	29
		Plutonium-238	34	NA	35	36	35	33
		Plutonium-239+240	140	NA	100	97	89	81
		Plutonium-241	NA	ND	ND	2700	2400	2300
		Americium-241	210	140	150	140	120	120
		Curium-242	2.2	NA	23	10	5.0	2.1
Curium-243+244	5.2	NA	7.4	7.2	7.9	5.5		
Peat	Hot lagoon	Cobalt-60	96	40	54	74		
		Ruthenium-106	25	ND	130	380		
		Antimony-125	250	90	470	840		
		Caesium-134	70	34	61	140		
		Caesium-137	2100	450	730	1000		
		Cerium-144	20	14	86	190		
		Europium-154	25	ND	22	21		
		Europium-155	14	ND	ND	9.9		
		Plutonium-238	17	2.7	6.2	11		
		Plutonium-239+240	69	11	23	34		
		Americium-241	97	17	35	49		
		Curium-242	1.2	0.53	2.8	4.4		
		Curium-243+244	1.9	0.42	1.1	2.3		
Water	Bailey Bridge	Tritium	NA	NA	NA	NA	NA	0.40
		Strontium-90	0.22	0.16	NA	NA	NA	NA
		Caesium-134	0.055	0.10	0.050	0.025	0.015	0.013
		Caesium-137	0.19	0.27	0.16	0.11	0.076	0.065
Peat	Bailey Bridge	Gamma dose		0.098	0.085	0.083	0.077	0.079
Peat	South end of lake	Gamma dose		0.088	0.084	0.10	0.070	0.068
Mud or peat	Cae Adda boat mooring	Gamma dose		0.069	0.064	0.065	0.063	0.066

NA = not analysed

ND = not detected

<sup>†</sup> Environmental data may include the effects of sources other than Trawsfynydd

\* Dry concentrations for sediments; wet for other materials

<sup>1</sup> Excluding tritium

<sup>2</sup> Excluding tritium, strontium-90 and caesium-137

<sup>3</sup> Discharge quantities may not be for a whole calendar year. Further details can be found in annual report

**Table 3.27. Discharges of liquid waste from Wylfa, and radioactivity in environmental materials and radiation dose rates near Wylfa<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992	1993	1994
Liquid waste		Total activity <sup>(1)</sup>	0.063	0.072	0.0877	0.0443	0.068	0.0539
		Tritium	3.0	5.4	5.68	2.75	5.92	6.98
Plaice		Carbon-14	NA	NA	27	34	39	4.1
		Cobalt-60	ND	0.3	ND	ND	ND	ND
		Caesium-134	0.1	ND	ND	ND	ND	ND
		Caesium-137	2.8	2.5	3.0	2.3	4.7	2.8
Crabs		Cobalt-60	0.2	ND	0.17	ND	ND	ND
		Technetium-99	NA	NA	NA	2.2	0.41	1.3
		Silver-110m	1.0	0.07	ND	0.16	0.34	0.47
		Caesium-137	1.6	1.7	1.6	1.6	1.3	1.0
		Europium-155	ND	ND	ND	0.10	ND	ND
		Plutonium-238	NA	NA	NA	0.0043	0.0076	0.0061
		Plutonium-239+240	NA	NA	NA	0.021	0.038	0.032
		Americium-241	ND	ND	ND	0.092	0.12	0.15
		Curium-242	NA	NA	NA	0.00010	ND	ND
		Curium-243+244	NA	NA	NA	0.00027	0.00039	0.00025
Winkles		Cobalt-60	0.4	0.4	0.20	ND	0.09	0.12
		Ruthenium-106	ND	0.7	ND	ND	ND	ND
		Silver-110m	0.8	0.2	ND	0.37	0.08	ND
		Antimony-125	ND	ND	ND	0.30	0.07	ND
		Caesium-137	2.5	3.7	1.5	1.4	1.4	1.4
		Plutonium-238	0.075	0.20	0.048	0.026	0.036	0.05
		Plutonium-239+240	0.36	0.98	0.24	0.14	0.19	0.27
		Plutonium-241	NA	NA	NA	0.82	3.8	3.1
		Americium-241	0.43	1.3	0.31	0.18	0.27	0.40
		Curium-242	ND	ND	0.0016	ND	ND	ND
Curium-243+244	0.0017	0.0030	0.00099	0.00031	ND	0.00055		
Mud		Cobalt-60		2.4	1.7	0.35	1.1	1.5
		Caesium-134		4.2	2.5	1.6	1.9	1.4
		Caesium-137		320	250	250	270	220
		Europium-155		ND	0.73	1.9	1.4	1.6
		Plutonium-238		9.6	7.1	6.4	7.6	5.9
		Plutonium-239+240		48	39	34	39	30
		Americium-241		71	54	49	55	46
		Curium-242		ND	0.16	ND	0.060	0.10
Curium-243+244		0.16	0.12	0.12	0.12	0.11		
Sand	Cemaes Bay	Gamma dose		0.056	0.057	0.058	0.059	0.057
Mud	Cemlyn Bay	Gamma dose		0.084	0.083	0.083	0.084	0.083
Rock	Amlwch Harbour	Gamma dose		0.091	0.091	0.090		

NA = not analysed

ND = not detected

<sup>†</sup> Environmental data may include the effects of sources other than Wylfa

\* Dry concentrations for sediments; wet for other materials

<sup>1</sup> Excluding tritium

**Table 3.28. Discharges of liquid waste from Aldermaston, and radioactivity in environmental materials and radiation dose rates near Aldermaston<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, μGy h <sup>-1</sup>					
			1989	1990	1991	1992 <sup>(2)</sup>	1993	1994
Liquid waste	Pangbourne	Alpha activity				0.0000222	0.0000535	9.07 10 <sup>-6</sup>
		Total activity <sup>(1)</sup>	0.049	0.045	0.047	0.0288		
		Tritium	0.022	0.60	0.017	0.0274	0.0313	0.0284
		Plutonium-241				0.0000888	0.0000214	0.0000363
		Other radionuclides				0.0000108	0.00002	9.55 10 <sup>-6</sup>
Pike	Pangbourne	Caesium-137		0.7	0.91	0.79	0.97	0.60
		Plutonium-238		0.00003	0.000035	0.00024	0.000090	ND
		Plutonium-239+240		0.00015	0.00016	0.00011	0.00038	0.000055
		Americium-241		0.00012	0.00018	0.00024	0.00048	0.000097
Sediment, mud or clay	Pangbourne	Cobalt-60	1.3	2.4	1.2	ND	ND	0.27
		Caesium-137	7.2	29	15	1.7	0.50	2.3
		Europium-155	ND	ND	ND	1.6	1.7	1.9
Grass	Pangbourne	Gamma dose			0.052	0.061	0.062	0.056

NA = not analysed

ND = not detected

<sup>†</sup> Environmental data may include the effects of sources other than Aldermaston

\* Dry concentrations for sediments; wet for other materials

<sup>1</sup> Excluding tritium

<sup>2</sup> Discharge quantities may not be for a whole calendar year. Further details can be found in annual report

**Table 3.29. Discharges of liquid waste from Barrow, and radioactivity in environmental materials and radiation dose rates near Barrow<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992	1993	1994
Liquid waste		Tritium					1.82 10 <sup>-3</sup>	9.54 10 <sup>-4</sup>
		Manganese-54					3.32 10 <sup>-9</sup>	1.39 10 <sup>-8</sup>
		Cobalt-58					1.55 10 <sup>-9</sup>	1.17 10 <sup>-8</sup>
		Cobalt-60					1.47 10 <sup>-8</sup>	3.11 10 <sup>-8</sup>
		Tin-113					1.47 10 <sup>-9</sup>	1.46 10 <sup>-8</sup>
		Antimony-124					1.81 10 <sup>-9</sup>	8.31 10 <sup>-9</sup>
		Other radionuclides					5.88 10 <sup>-8</sup>	6.38 10 <sup>-8</sup>
Mud and sand	Walney Channel <sup>(1)</sup>	Cobalt-60					2.1	1.8
		Zirconium-95					7.7	2.6
		Niobium-95					5.8	2.4
		Ruthenium-106					55	29
		Silver-110m						0.36
		Antimony-125					4.0	4.2
		Caesium-134					0.43	0.38
		Caesium-137					190	180
		Cerium-144					7.0	0.84
		Europium-154					4.8	3.7
		Europium-155					3.4	2.7
		Americium-241					220	200
Mud and sand	1 km south of outfall	Gamma dose					0.088	0.083

NA = not analysed

ND = not detected

<sup>†</sup> Environmental data may include the effects of sources other than Barrow

\* Dry concentrations for sediments; wet for other materials

<sup>1</sup> Vickerstown Church

**Table 3.30. Discharges of liquid waste from Devonport, and radioactivity in environmental materials and radiation dose rates near Devonport<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992	1993	1994
Liquid waste <sup>(2)</sup>		Total activity <sup>(1)</sup>	0.000115	0.000009	0.000151	0.000341	0.000365	0.000184
		Tritium	0.064	0.049	0.0432	0.0519	0.0684	0.0669
		Cobalt-60	0.0039	0.0014	0.00116	0.00212	0.00135	0.000184
Mussels	Wearde Quay	Cobalt-60	0.1	0.2	0.21	0.25	0.15	0.15
		Caesium-137	ND	0.3	0.50	0.09	0.06	ND
Mud	Kinterbury <sup>(3)</sup>	Cobalt-60	1.3	ND	0.55	1.3	1.1	0.51
		Caesium-137	5.7	3.3	5.2	5.1	5.7	4.5
		Europium-155	ND	0.6	1.4	2.3	1.8	2.0
		Plutonium-238	NA	NA	0.024	0.026	0.029	0.018
		Plutonium-239+240	NA	NA	0.50	0.53	0.55	0.49
		Americium-241	ND	ND	0.16	0.18	0.18	0.16
		Curium-243+244	NA	NA	ND	0.0016	ND	ND
Mud	Kinterbury	Gamma dose				0.073	0.070	0.071
Mud	Brunel Bridge	Gamma dose				0.072	0.078	0.071

NA = not analysed

ND = not detected

<sup>†</sup> Environmental data may include the effects of sources other than Devonport

\* Dry concentrations for sediments; wet for other materials

<sup>1</sup> Excluding tritium and cobalt-60

<sup>2</sup> By Devonport Management Ltd via pipeline

<sup>3</sup> Various locations prior to 1994

**Table 3.31. Discharges of liquid waste from Faslane, and radioactivity in environmental materials and radiation dose rates near Faslane<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992	1993 <sup>(2)</sup>	1994
Liquid waste		Total activity <sup>(1)</sup>	0.000032	0.000084	0.00011	0.000037	0.0000552	
		Alpha activity					7.27 10 <sup>-6</sup>	0.00001292
		Beta activity <sup>(3)</sup>					5.90 10 <sup>-5</sup>	0.000115
		Tritium					0.0219	0.113
		Cobalt-60					4.50 10 <sup>-5</sup>	0.000064
Mud, or mud and sand	Carnban boatyard <sup>(4)</sup>	Cobalt-60	16	14	45	13	ND	5.2
		Silver-110m	ND	ND	1.5	ND	ND	1.9
		Antimony-125	2.7	2.8	4.9	2.9	ND	ND
		Caesium-134	4.2	1.8	1.8	ND	ND	0.65
		Caesium-137	100	76	77	60	8.5	39
		Cerium-144	ND	ND	2.2	ND	ND	ND
		Europium-155	ND	ND	1.5	0.71	ND	1.0
		Americium-241	ND	ND	0.49	0.33	1.7	ND
Mud and sand, or mud, sand and stones	Gareloch Head	Gamma dose				0.054	0.053	0.059
						0.089	0.10	0.076

ND = not detected

NA = not analysed

<sup>†</sup> Environmental data may include the effects of sources other than Faslane

\* Dry concentrations for sediments; wet for other materials

<sup>1</sup> Excluding tritium

<sup>2</sup> Discharge quantities may not be for a whole calendar year. Further details can be found in annual report

<sup>3</sup> Excluding tritium and cobalt-60

<sup>4</sup> From 1994

**Table 3.32. Discharges of liquid waste from Rosyth, and radioactivity in environmental materials and radiation dose rates near Rosyth<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992	1993	1994
Liquid waste		Total alpha	0.75 10 <sup>-6</sup>	6 10 <sup>-7</sup>	6 10 <sup>-7</sup>	9.2 10 <sup>-7</sup>	8.04 10 <sup>-7</sup>	4.7 10 <sup>-7</sup>
		Beta activity <sup>(1)</sup>	0.000248	0.0002	0.0002	0.00038	0.000337	0.00029
		Tritium	0.0060	0.00056	0.0015	0.0065	0.00429	0.00806
		Cobalt-60	0.000788	0.0005	0.0005	0.0009	0.000841	0.00067
Crabs		Silver-110m	0.2	ND	ND	ND	ND	ND
		Caesium-137	0.5	0.5	0.25	0.29	0.20	0.12
		Europium-155	ND	ND	0.11	ND	ND	ND
Mud	Blackness Castle <sup>(2)</sup>	Cobalt-60	0.6	0.2	ND	0.27	ND	ND
		Antimony-125	ND	ND	ND	ND	0.13	ND
		Caesium-134	2.1	1.3	1.3	0.39	0.27	ND
		Caesium-137	35	28	33	52	36	22
		Europium-155	1.0	0.8	0.80	2.2	1.4	ND
		Americium-241	ND	ND	ND	ND	0.25	ND
Mud, or mud and sand	Blackness Castle	Gamma dose				0.067	0.070	0.065
Sand	Burntisland Bay	Gamma dose				0.057	0.058	0.054

NA = not analysed

ND = not detected

\* Dry concentrations for sediments; wet for other materials

<sup>1</sup> Excluding tritium and cobalt-60

<sup>2</sup> Various locations prior to 1994

<sup>†</sup> Environmental data may include the effects of sources other than Rosyth

**Table 3.33. Discharges of liquid waste from Amersham, and radioactivity in environmental materials and radiation dose rates near Amersham<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992 <sup>(1)</sup>	1993	1994
Liquid waste		Total activity <sup>(2)</sup>	0.79	1.07	0.9	0.245		
		Total alpha				0.000064	0.0000712	0.0000725
		Beta > 0.4 MeV				0.00804	0.00887	0.0103
		Tritium	0.055	0.032	0.013	0.03741	0.0263	0.0115
		Iodine-125				0.038	0.0408	0.0444
		Caesium-137				0.000027	0.0000726	0.0000435
		Other radionuclides				0.156	0.112	0.112
Pike	Grand Union Canal	Carbon-14		130	96	76	98	61
		Sulphur-35		9.1	31	NA	NA	NA
		Cobalt-57		ND	0.02	0.17	0.07	0.11
		Caesium-134		ND	ND	ND	ND	0.08
		Caesium-137		0.7	0.56	0.90	0.81	0.36
Mud	Grand Union Canal	Cobalt-57	ND	ND	25	14	38	5.7
		Cobalt-58	9.7	5.2	4.5	2.5	7.1	1.6
		Cobalt-60	ND	2.1	0.79	1.2	ND	ND
		Zinc-65	11	5.0	3.6	2.5	14	2.3
		Caesium-134	2.6	ND	0.61	ND	ND	ND
		Caesium-137	20	8.4	12	14	14	8.7
		Europium-155	ND	3.2	0.67	ND	ND	1.8
Grass or soil	Grand Union Canal	Gamma dose			0.044		0.051	0.047

NA = not analysed

ND = not detected

<sup>†</sup> Environmental data may include the effects of sources other than Amersham

\* Dry concentrations for sediments; wet for other materials

<sup>1</sup> Discharge quantities may not be for a whole calendar year. Further details can be found in annual report

<sup>2</sup> Excluding tritium

**Table 3.34. Discharges of liquid waste from Cardiff, and radioactivity in environmental materials and radiation dose rates near Cardiff<sup>†</sup>**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg <sup>-1</sup> or gamma dose rate, µGy h <sup>-1</sup>					
			1989	1990	1991	1992	1993	1994
Liquid waste		Beta/gamma activity <sup>(1)</sup>	0.021	0.022	0.018	0.019	0.0158	0.0173
		Tritium	601	609	555	440	397	535
		Carbon-14	1.53	1.57	1.33	1.4	1.3	1.06
Flounder		Carbon-14	940	790	810	680	1000	670
		Sulphur-35	ND	30	12	NA	NA	NA
		Caesium-137	0.8	0.6	0.47	0.56	0.53	0.42
Mud	West of new pipeline <sup>(2)</sup>	Carbon-14	12	14	13	14	18	17
		Cobalt-60	ND	ND	ND	0.18	ND	ND
		Caesium-134	2.2	1.5	1.4	0.52	0.35	0.86
		Caesium-137	35	31	41	32	29	21
		Europium-155	1.7	1.0	ND	1.1	0.43	1.6
Mud	East of pipeline	Gamma dose			0.071	0.076	0.078	0.071
Mud, or mud and sand	West of pipeline	Gamma dose			0.061	0.063	0.064	0.065

NA = not analysed

ND = not detected

<sup>1</sup> Excluding tritium, carbon-14 and radioisotopes of calcium and strontium

<sup>2</sup> Various locations prior to 1994

\* Dry concentrations for sediments; wet for other materials

<sup>†</sup> Environmental data may include the effects of sources other than Cardiff

**Table 3.35. Radioactivity in environmental materials in the Channel Islands**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Concentration of activity*, Bq kg <sup>-1</sup>					
			1989	1990	1991	1992	1993	1994
Ray	Guernsey	Carbon-14	19	NA	NA	NA	NA	NA
		Caesium-137	0.7	1.3	0.78	2	0.75	1.1
		Plutonium-238	0.00017	0.00039	0.00014	0.00013	0.000061	0.00013
		Plutonium-239+240	0.00024	0.0015	0.00050	0.00049	0.00025	0.00054
		Americium-241	0.00036	0.0017	0.00093	0.00077	0.00033	0.0013
		Curium-243+244	ND	ND	0.000020	0.000019	ND	ND
Crabs	Guernsey	Cobalt-60	0.4	1.4	3.0	0.98	1.0	0.55
		Zinc-65	ND	0.9	ND	ND	ND	ND
		Ruthenium-106	ND	1.8	ND	ND	ND	ND
		Silver-110m	0.5	0.6	0.57	0.22	0.19	0.21
		Caesium-137	ND	0.2	0.14	ND	0.09	ND
		Plutonium-238	0.0016	0.0012	0.0011	0.0017	0.0010	0.00049
		Plutonium-239+240	0.0033	0.0019	0.0016	0.0027	0.0020	0.0011
		Americium-241	0.0047	0.0048	0.0060	0.0082	0.0056	0.0029
		Curium-242	0.00007	ND	0.000050	0.000072	0.000027	ND
		Curium-243+244	0.0017	0.0020	0.0021	0.0029	0.0018	0.00085
Oysters	Jersey	Cobalt-60	1.1	1.0	0.62	0.67	0.46	0.30
		Zinc-65	1.6	0.8	ND	0.14	ND	ND
		Ruthenium-106	4.9	5.9	2.0	ND	ND	ND
		Silver-110m	2.5	3.4	2.1	0.99	0.34	0.33
		Caesium-137	ND	0.2	0.11	0.07	0.05	0.05
		Plutonium-238	0.0093	0.011	0.012	0.0074	0.0063	0.0055
		Plutonium-239+240	0.014	0.018	0.019	0.013	0.012	0.011
		Americium-241	0.014	0.017	0.021	0.014	0.011	0.014
		Curium-242	0.00023	0.00017	0.00016	0.00011	0.000085	0.000068
Curium-243+244	0.0049	0.0050	0.0046	0.0038	0.0029	0.0033		
Sand, or mud and sand	Guernsey Bordeaux Harbour	Cobalt-60	1.6	1.6	1.4	1.3	0.96	0.67
		Ruthenium-106	4.7	3.3	ND	ND	ND	ND
		Antimony-125	1.1	1.2	ND	ND	0.44	ND
		Caesium-137	2.4	2.6	2.3	2.6	2.3	2.0
		Europium-155	ND	0.6	ND	ND	0.80	0.80
		Plutonium-238	0.10	0.12	0.096	0.16	0.11	0.098
		Plutonium-239+240	0.37	0.37	0.36	0.42	0.37	0.32
		Americium-241	0.30	0.34	0.31	0.51	0.34	0.27
		Curium-242	ND	ND	0.0027	0.0024	0.0015	ND
		Curium-243+244	0.050	0.075	0.065	0.12	0.056	0.048

NA = not analysed

ND = not detected

\* Dry concentrations for sediments; wet for other materials

**Table 3.36. Radioactivity in brown trout from Ennerdale Water**

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Concentration of activity, Bq kg <sup>-1</sup> wet					
			1989	1990	1991	1992	1993	1994
Brown trout	Ennerdale Water	Caesium-134	24	5.5	1.6	ND	ND	0.92
		Caesium-137	130	66	49	36	41	26

*ND = not detected*

**Table 3.37. Radioactivity in fish and shellfish near Whitehaven\***

Material or ground type	Landing point or sampling area	Radionuclide or dose measurement	Concentration of activity, Bq kg <sup>-1</sup> wet					
			1989	1990	1991	1992	1993	1994
Cod	Parton	Lead-210		0.045	0.038	0.050	0.025	0.026
		Polonium-210		4.5	1.6	2.5	0.80	0.63
		Thorium-228		0.0081	0.017	NA	0.024	0.014
		Thorium-230		0.0053	0.0032	NA	0.013	0.0014
		Thorium-232		0.00080	0.00044	NA	0.0051	0.0006
		Uranium-234		0.012	0.0053	NA	0.0049	0.0036
		Uranium-235		0.00050	0.00030	NA	0.00026	0.000031
		Uranium-238		0.011	0.0050	NA	0.0044	0.0035
Crabs	Parton	Lead-210		0.63	0.69	3.0	6.4	1.4
		Polonium-210		130	44	56	32	21
		Radium-226		NA	0.26	0.11	NA	NA
		Thorium-228		0.075	0.13	0.078	0.10	0.14
		Thorium-230		0.10	0.068	0.096	0.053	0.058
		Thorium-232		0.013	0.011	0.012	0.019	0.023
		Uranium-234		0.20	0.10	0.11	0.15	0.099
		Uranium-235		0.0067	0.0052	0.0033	0.0064	0.0040
		Uranium-238		0.18	0.096	0.10	0.14	0.093
Winkles	Parton	Lead-210	NA	14	28	19	6.8	4.4
		Polonium-210	210	140	120	110	50	32
		Radium-226	NA	NA	2.9	0.19	0.2	0.59
		Thorium-228	NA	0.83	0.92	0.66	1.5	0.57
		Thorium-230	NA	9.8	28	14	4.7	1.6
		Thorium-232	NA	0.56	0.72	0.51	1.1	0.41
		Uranium-234	NA	6.0	15	5.6	4.5	1.6
		Uranium-235	NA	0.21	0.57	0.22	0.22	0.064
		Uranium-238	NA	5.8	15	5.5	4.4	1.5

\* This table is limited to natural radionuclides in relation to discharges from Whitehaven Works

NA = not analysed

ND = not detected

## APPENDIX 4. Estimates of concentrations of radionuclides due to natural sources\*

Radionuclide	Concentration of radioactivity Bq kg <sup>-1</sup> (wet)						
	Fish	Crustaceans	Crabs	Lobsters	Molluscs	Winkles	Mussels
Carbon-14	20	20			20		
Lead-210	0.025		0.30	0.08		0.69	1.1
Polonium-210	0.28		8.5	4.6		7.1	25.6
Radium-226	0	0.03			0.08		
Thorium-228	0.0054		0.04	0.0096	0.089		
Thorium-230	0.00081		0.008	0.0026	0.038		
Thorium-232	0.00097		0.01	0.0014	0.063		
Uranium-234	0.0045		0.0547	0.0403	0.714		
Uranium-238	0.0039		0.0458	0.0351	0.621		

\* Based on sampling and analysis carried out by MAFF. These values are subtracted from measured values when assessing exposures due to man-made sources



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