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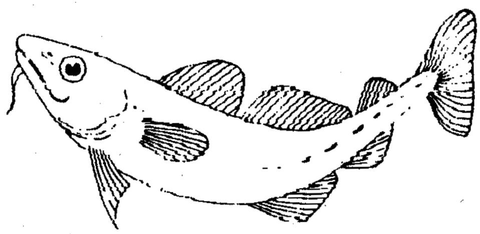
Number 42



Radioactivity in Surface and Coastal Waters of the British Isles, 1993

MAFF
Directorate of Fisheries Research
Lowestoft, 1994

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD
DIRECTORATE OF FISHERIES RESEARCH

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LOWESTOFT
1994

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CONTENTS   Page

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 1993 were well 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 1993 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 dose rates and concentrations were generally similar to those in 1992. The results 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 1993 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 established methodology of ICRP-26 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 given. Both methods incorporate accepted values for gut transfer factors of transuranics, i.e. 0.0002 for winkles in the Irish Sea, 0.0005 in other cases. Exposures were all within the dose limit of 1 mSv year^{-1} for members of the public or the skin dose limit of 50 mSv year^{-1} as appropriate.

5. Exposures of high-rate fish and shellfish consumers due to artificial radionuclides near Sellafield decreased slightly in 1993, as compared with 1992, due to decreases in consumption of molluscs. Exposures of people associated with fisheries at Whitehaven, Dumfries and Galloway, Morecambe Bay and Fleetwood were similar in 1993 to exposures in 1992. The reduction in consumption rates of molluscs near Sellafield resulted in high-rate consumers of fish and shellfish in south Scotland receiving higher exposures than those near to Sellafield. The calculated exposures of the groups depends on the values used for gut transfer factors. A generic factor of 0.0005 was used for consumption of molluscs in south Scotland. A lower factor of 0.0002 was used for consumption of winkles from near Sellafield based on direct experimental evidence. Use of these factors has been endorsed by NRPB. Further experimental studies are being undertaken but in the meantime the critical group of seafood consumers in south Scotland is cautiously estimated using the generic factor to have received 0.18 mSv in 1993.

6. External radiation dose rates have declined substantially since the 1970s, approaching more closely the level of the natural radiation background. More precise estimates of natural background gamma dose rates were needed to distinguish the effects of man-made radioactivity. Values of natural background dose rates were therefore reviewed in 1993 and, as a result, it was necessary to adopt lower values than were used in previous assessments. There have been some consequential increases in the external exposures in this report compared with the previous one. However, the critical group for external exposures continued to be a small group of houseboat dwellers in the Ribble estuary. Their dose in 1993 was 0.26 mSv which is little different from the recalculated value for 1992, 0.25 mSv, using the same assumption for natural background.

7. Exposures of the critical group of fish and shellfish consumers due to enhanced concentrations of natural radionuclides from Whitehaven Works (Albright and Wilson Ltd) have reduced substantially. On the basis of ICRP-26 methodology, the dose in 1993 was 0.32 mSv compared with 0.64 mSv in 1992 (ICRP-60: 0.19 mSv and 0.33 mSv respectively). Discharges of radionuclides from Whitehaven were reduced in 1993 due to

changes in waste treatment techniques and the cessation of use of phosphate ore. As a consequence, further reductions in concentrations of radionuclides in shellfish are expected in 1994.

8. The collective dose to the UK population from fish and shellfish consumption in 1993 was 5 man-Sv, the same as the value for 1992. Excluding the effects of Chernobyl on Baltic Sea fish, the collective dose to all other European countries was 25 man-Sv, similar to the value for 1992. The most significant radioactive waste discharges giving rise to collective dose were those of radiocaesium from Sellafield. The effects of the Chernobyl accident on Baltic Sea fish added a further 70 man-Sv to the collective dose to other European countries. The effects of Chernobyl on the UK population from fish consumption would have been small.

Summary Table: Estimates of public radiation exposure from discharges of liquid radioactive waste in the UK, 1993

Establishment	Radiation exposure pathway	Critical group	Exposure, mSv ICRP-26[=]	Exposure, mSv ICRP-60[+]
British Nuclear Fuels plc				
Sellafield and Drigg[x]	Fish and shellfish consumption	Local fishing community	0.15	0.10
	Fish and shellfish consumption	Fishermen (Scottish coast)	0.18	0.11
	External	Houseboat dwellers (River Ribble)	0.26	0.26
	External[d]	Fishermen (Whitehaven)	0.13	0.13
	Handling of fishing gear	Local fishing community	0.61[#]	0.61[#]
	Porphyra/laverbread consumption	Consumers in South Wales	<0.005	<0.005
Springfields	External	Houseboat dwellers (River Ribble)	0.26[a]	0.26[a]
	"	Wildfowlers	0.03[b]	0.04[b]
	" (skin)	"	2.2[#]	2.2[#]
Capenhurst	Inadvertent ingestion of sediment	Local community	<0.005	<0.005
Chapelcross	Fish and shellfish consumption) External)	Local fishermen	0.04[a]	0.04[a]
	"	Wildfowlers	0.02[a]	0.02[a]
	Handling of fishing gear	Local fishermen	0.11[#a]	0.11[#a]
United Kingdom Atomic Energy Authority				
Harwell	Fish consumption) External)	Anglers	0.01	0.01
Winfrith	Fish and shellfish consumption	Local fishing community	<0.005	<0.005
Dounreay	Handling of fishing gear	Local fishermen	0.13[#b]	0.13[#b]
	External	Local community	0.008[b]	0.008[b]
	Fish and shellfish consumption	Local fishing community	<0.005[b]	<0.005[b]
	Mollusc consumption) External)	Mollusc collectors	0.02[b]	0.02[b]
Nuclear Power Stations Operated by the Electricity Companies				
Berkeley and Oldbury	Fish and shellfish consumption) External)	Local fishing community	0.006[b]	0.006[b]
Bradwell	Fish and shellfish consumption) External)	Houseboat dwellers	0.01[b]	0.01[b]
Dungeness	External) Fish and shellfish consumption)	Bait diggers	0.005	0.005
Hartlepool	Fish and shellfish consumption	Local fishing community	<0.005[a]	<0.005[a]
Heysham	Fish and shellfish consumption	Local fishermen	0.14[a]	0.09[a]
Hinkley Point	Fish and shellfish consumption) External)	Local fishing community	0.008[b]	0.008[b]
Hunterston	Fish and shellfish consumption) External)	Local fishing community	0.01[a]	0.01[a]
Sizewell	Fish and shellfish consumption) External)	Local fishing community	<0.005[b]	<0.005[b]
Torness	Fish and shellfish consumption) External)	Local fishing community	<0.005[a]	<0.005[a]
	Handling of fishing gear	Local fishing community	0.24[#]	0.24[#]
Trawsfynydd	Fish consumption) External)	Local fishing community	0.08	0.08
Wylfa	Fish and shellfish consumption) External)	Local fishing community	0.01[a]	0.01[a]
Defence Establishments				
Aldermaston	Fish consumption) External)	Anglers	<0.005	<0.005
Barrow	External	Local community	0.03[a]	0.03[a]
Chatham	External	Houseboat dwellers	0.007[b]	0.007[b]
Devonport	Fish and shellfish consumption) External)	Local community	<0.005	<0.005
Faslane	External	Boatyard workers	0.02[b]	0.02[b]
Rosyth	External	Dredgermen	0.01[a]	0.01[a]
Holy Loch	External	Local community	<0.005[a]	<0.005[a]
Amersham International plc				
Amersham	Fish consumption) External)	Anglers	<0.005	<0.005
Cardiff	Fish and shellfish consumption) External)	Local fishing community	0.02	0.02
Albright and Wilson Ltd				
Whitehaven[c]	Fish and shellfish consumption	Local fishing community	0.32	0.19

[=] *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 year^{-1}. (see sub-section 3.3)*

[#] *Exposure to skin including a component due to natural sources of beta radiation, to be compared with the dose limit of 50 mSv year^{-1} (see sub-section 3.3)*

[a] *Mainly due to discharges from Sellafield*

[b] *Partly due to discharges from Sellafield*

[+] *Unless otherwise stated, represents committed effective dose calculated using methodology of ICRP-60 to be compared with the dose limit of 1mSv year^{-1} (see sub-section 3.3)*

[x] *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 1993 was 0.23 mSv (on the basis of ICRP-60: 0.14 mSv)*

[c] *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 0.1 for polonium which is currently recommended by NRPB (see Section 11). The exposure due to artificial radionuclides in 1993 was 0.04 mSv (on the basis of ICRP-60:0.03 mSv)*

[d] *Includes a small contribution due to consumption*

1. INTRODUCTION

This report presents the results of the environmental monitoring programme carried out during 1993 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, 1993) 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 1993 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, 1994), the latest available data being for the year 1992. Details of the 1993 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 1993. 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, 1986). The percentages of the authorised (or agreed) limits taken up in 1993 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 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 total beta radioactivity and of specific gamma-emitting nuclides. Pure beta emitters and alpha emitters (including transuranics) are also measured in appropriate cases.

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

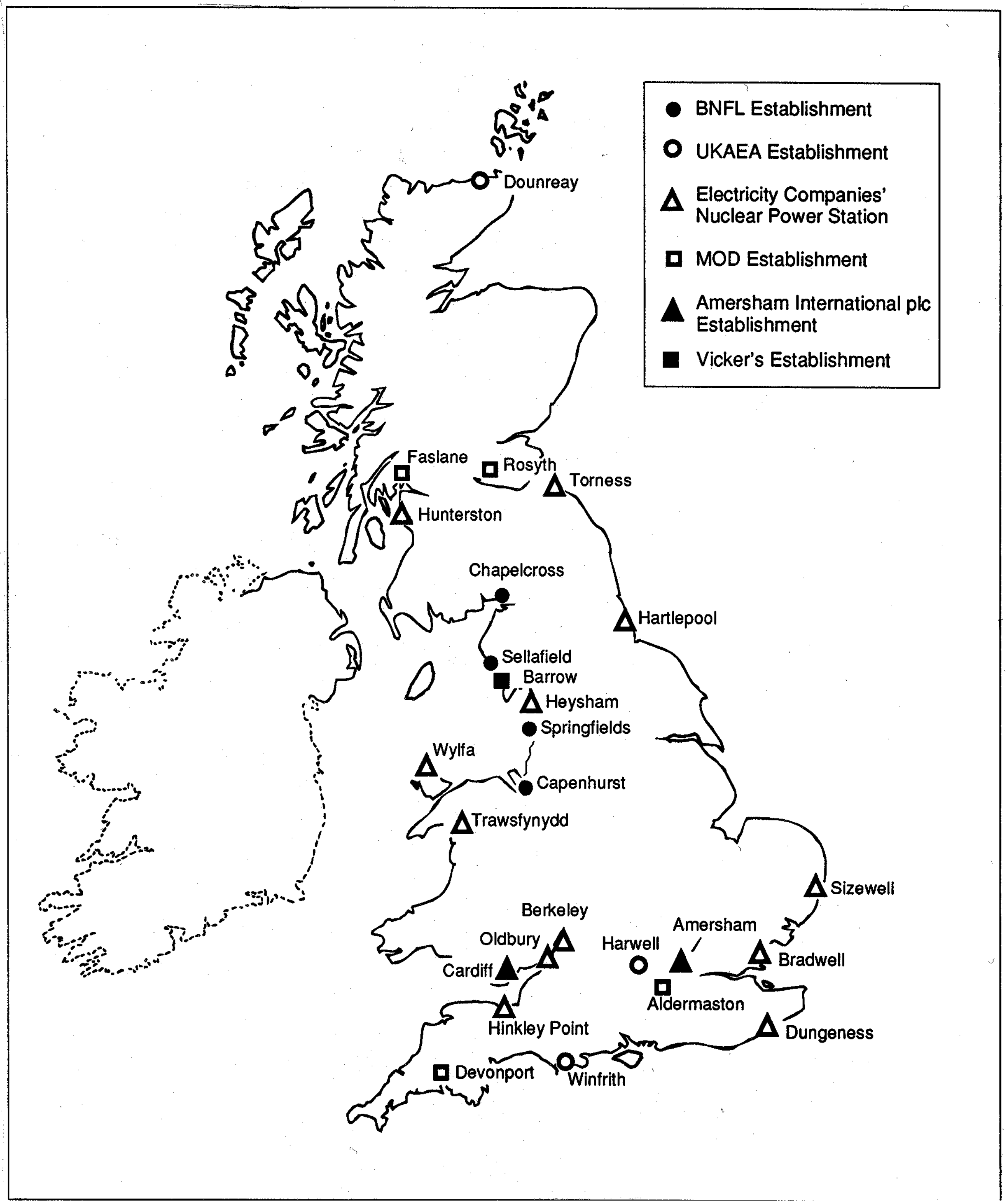

Figure 1. UK nuclear establishments giving rise to principal discharges of liquid radioactive waste

Table 1. Principal discharges of liquid radioactive waste from UK nuclear establishments, 1993

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1993	
			TBq [12]	% of limit[13]
British Nuclear Fuels plc				
Sellafield Sea pipelines	Total alpha	10	2.59	26
	Total beta[19]	500	97.0	9
	Tritium	3500	2310	66
	Carbon-14	4	2.03	51
	Cobalt-60	8	0.087	1.1
	Strontium-90	35	17.1	49
	Zirconium-95+Niobium-95	180	9.61	5.3
	Technetium-99	10	6.06	61
	Ruthenium-106	170	17.1	10
	Iodine-129	0.4	0.161	40
	Caesium-134	10	1.19	13
	Caesium-137	110	21.9	20
	Cerium-144	22	2.51	11
	Plutonium alpha	7	1.33	19
	Plutonium-241	170	37.5	22
	Americium-241	3	0.873	29
Seaburn sewer	Total activity	0.148	0.000517	<1
Drigg Sea pipeline	Total alpha	0.1	0.000671	<1
	Total beta[1]	0.3	0.0206	6.9
	Tritium	120	2.4	2.0
Stream[17]	Total alpha	$9\ 10^{4}$	167	<1
	Total beta[1]	$1.2\ 10^{6}$	2730	<1
	Tritium	$6\ 10^{8}$	$2.3\ 10^{5}$	<1
Springfields	Total alpha	4	0.0773	1.9
	Total beta	240	62.5	26
	Technetium-99	0.6	0.0947	16
	Thorium-230	2	0.0194	<1
	Thorium-232	0.2	0.00078	<1
	Neptunium-237	0.04	0.00025	<1
	Uranium	0.15	0.049	33
Capenhurst Rivacre Brook	Uranium	0.02	0.00158	7.9
	Uranium daughters	0.02	0.0068	34
	Non-uranic alpha	0.003	0.0000994	3.3
	Technetium-99	0.1	0.0049	4.9
Meols outfall	Technetium-99	0.148	Nil	Nil
	Others	0.00148	“	“
Chapelcross	Total alpha	0.1	0.000504	<1
	Total beta[1]	25	0.265	1.1
	Tritium	5.5	0.497	9.0
United Kingdom Atomic Energy Authority				
Harwell (pipeline)	Total alpha	0.001	0.000104	10
	Total beta[1]	0.02	0.00199	10
	Tritium	4	0.48	12
	Cobalt-60	0.007	0.000514	7.4
	Caesium-137	0.007	0.000348	5
Harwell (Lydebank Brook)	Total alpha	0.0005	0.0000967	19
	Total beta [1]	0.002	0.000577	29
	Tritium	0.1	0.0797	80
Winfrith (inner pipeline)	Total alpha	0.3	0.00169	<1
	Tritium	650	74.0	11
	Cobalt-60	10	0.00559	<1
	Zinc-65	6	0.00032	<1
	Other radionuclides	80	0.0491	<1
Winfrith (outer pipeline)	Total alpha	0.004	0.000134	3.4
	Tritium	1	0.0203	2.0
	Other radionuclides	0.01	0.00021	2.1
Dounreay	Total alpha[4]	0.75	0.0994	13
	Total beta[1]	110	7.95	7.2
	Tritium	130	1.03	<1
	Cobalt-60	1	0.0183	1.8
	Strontium-90	12	1.37	11
	Zirconium-95+Niobium-95	6	0.0144	<1
	Ruthenium-106	12	0.809	6.7
	Silver-110m	0.4	0.0073	1.8
	Caesium-137	50	3.84	7.7
	Cerium-144	12	0.0916	<1
	Plutonium-241	15	1.29	8.6
	Curium-242	1	0.00121	<1

Table 1. continued

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1993 TBq[12]	% of limit[13]
Nuclear Electric plc				
Berkeley	Total activity[1,7]	0.4	0.258	65
	Tritium	8	0.265	3.3
	Caesium-137	0.2	0.120	60
Bradwell	Tritium	30	3.03	10
	Caesium-137	0.75	0.355	47
	Other radionuclides	1	0.248	25
Dungeness				
'A' Station	Total activity[1]	7.4	1.03	14
	Tritium	74	4.43	5.9
'B' Station	Total activity[1,5]	4	0.019	<1
	Tritium	650	269	41
	Sulphur-35	25	0.652	2.6
Hartlepool	Tritium	1850	350	19
	Sulphur-35	8	0.732	9.2
	Other radionuclides	4	0.0515	1.3
Heysham				
Station 1	Tritium	1850	394	21
	Sulphur-35	7.5	0.59	7.9
	Other radionuclides	4	0.024	<1
Station 2	Tritium	1200	460	38
	Sulphur-35	7	0.0922	1.3
	Cobalt-60	0.036	0.00151	4.2
	Other radionuclides	0.45	0.0220	4.9
Hinkley Point				
'A' Station	Total activity[1,7]	1	0.261	26
	Tritium	25	0.779	3.1
	Caesium-137	1.5	0.425	28
'B' Station	Total activity[1,5,8]	0.25	0.014	5.7
	Tritium	650	390	60
	Sulphur-35	2	1.74	87
	Cobalt-60	0.035	0.00122	3.5
Oldbury	Total activity[1,7]	1.3	0.481	37
	Tritium	25	0.229	<1
	Caesium-137	0.7	0.0262	3.7
Sizewell	Total activity[1]	7.4	0.275	3.7
	Tritium	111	2.79	2.5
Trawsfynydd	Total activity[1,7,16]	0.72	0.0267	3.7
	Tritium	12	0.075	<1
	Strontium-90	0.08	0.00603	7.5
	Caesium-137	0.05	0.00848	17
Wylfa[19]	Total activity[1]	0.15	0.068	45
	Tritium	40	5.92	15
Scottish Nuclear Ltd				
Hunterston				
'A' Station[2]	Total activity[1]	2	0.291	5
	Tritium	5	0.358	7.2
'B' Station	Total activity[1,5]	3.7	0.0335	<1
	Tritium	1480	362	24
	Sulphur-35	26	2.14	8.2
Torness	Total alpha	0.0045	0.0000119	<1
	Beta activity[1,5,8]	0.45	0.00844	1.9
	Tritium	1200	235	20
	Sulphur-35	10	0.0210	<1
	Cobalt-60	0.05	0.00140	2.8

Table 1. continued

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1993	
			TBq [12]	% of limit[13]
Ministry of Defence (Procurement Executive)				
Aldermaston (pipeline) [6]	Alpha activity	0.00015	0.0000535	36
	Tritium	0.05	0.0313	63
	Plutonium-241	0.0006	0.000214	36
	Other radionuclides	0.00015	0.00002	13
Aldermaston (Silchester)[6]	Alpha activity	0.0001	0.000023	23
	Beta activity	0.0003	0.0000574	19
Ministry of Defence (Navy Department)				
Barrow [3]	Tritium	0.02	1.82 10^{-3}	9.1
	Manganese-54	2.5 10^{-7}	3.32 10^{-9}	1.3
	Cobalt-58	7 10^{-7}	1.55 10^{-9}	<1
	Cobalt-60	7 10^{-8}	1.47 10^{-8}	21
	Tin-113	2.5 10^{-7}	1.47 10^{-9}	<1
	Antimony-124	2 10^{-6}	1.81 10^{-9}	<1
	Other radionuclides	3.5 10^{-6}	5.88 10^{-8}	1.7
Devonport [9,15]	Total beta		Nil	
	Tritium		"	
	Cobalt-60		"	
Devonport [14,15] (sewer)	Total activity		0.000766	
	Cobalt-60		0.000659	
Devonport [14] (pipeline)	Total activity [1,8]	0.002	0.000365	18
	Tritium	0.12	0.0684	57
	Cobalt-60	0.016	0.00135	8.4
Faslane[18]	Total activity [1]	0.037	0.0000552	<1
	Alpha activity	0.0005	7.27 10^{-6}	2.9
	Beta activity[1,8]	0.0002	5.90 10^{-5}	59
	Tritium	1	0.0219	4.4
	Cobalt-60	0.0005	4.50 10^{-5}	18
Rosyth[10]	Total alpha	1 10^{-6}	8.04 10^{-7}	80
	Beta activity[1,8]	0.01	0.000337	3.4
	Tritium	0.01	0.00429	43
	Cobalt-60	0.055	0.000841	1.5
Amersham International plc				
Amersham	Total alpha	0.0003	0.0000712	24
	Beta >0.4 MeV	0.1	0.00887	9
	Tritium	0.2	0.0263	13
	Iodine-125	0.2	0.0408	20
	Caesium-137	0.005	0.0000726	1.5
	Other radionuclides	0.3	0.112	37
Cardiff	Beta/gamma activity[11]	0.096	0.0158	17
	Tritium	1400	397	28
	Carbon-14	2	1.3	65

[1] *Excluding tritium*
[2] *The limits shown took effect on 1/2/93*
[3] *Discharges from Barrow are included with those from MoD (Navy Department) sites because they are related to submarine activities. Discharges are made by Vickers Shipbuilding and Engineering Ltd*
[4] *Excluding curium-242*
[5] *Excluding sulphur-35*
[6] *Discharges were made by the Ministry of Defence until 31 March 1993, and by Hunting-BRAE Ltd thereafter*
[7] *Excluding caesium-137*
[8] *Excluding cobalt-60*
[9] *Discharges are made by the Ministry of Defence*
[10] *Discharges are made by Babcock Thorn Ltd*
[11] *Excluding tritium, carbon-14 and radioisotopes of calcium and strontium*
[12] *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*
[13] *Data quoted to 2 significant figures except when values are less than 1%*
[14] *Discharges are made by Devonport Management Ltd*
[15] *The authorisation is a limit on concentration of total activity of 4 10^{-6} TBq m^{-3}. At no time did the concentration exceed the limit. The quantity discharged is expressed in TBq in 1993*
[16] *Excluding strontium-90*
[17] *Values are expressed in terms of concentrations of activity in Bq m^{-3}*
[18] *Authorisation was revised with effect from 1 July 1993. The first block of data relates to the period 1 January 1993 to 30 June 1993; the second block of data relates to the period 1 July 1993 to 31 December 1993. '% limit' refers to equivalent limit for 6 months*
[19] *Excluding tritium, carbon-14 and plutonium-241*

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 main advantage of total beta measurements is that they can be carried out quickly to give an early warning of any change in radioactivity concentrations which might require further investigation; they also provide reassurance that no beta-emitting radionuclides of significance have been neglected.

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 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. 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, 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.

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.

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

Radionuclide	Approximate limit of detection*, Bq kg^{-1}
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

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. 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.

** 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*

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 at least one year; standard practice is to combine annual rates of consumption or occupancy of the more highly exposed members of the public (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 unsustained) 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 shellfish, 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 – by up 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 fish and shellfish, the concentrations apply to the edible parts, because the purpose is assessment of internal exposure of the consumer. For sediments, whose water content is more variable, dry concentrations are given.

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. Further discussion of natural radioactivity is given in section 11 of this report.

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^{-1}	Comments
Fish	40 to 100	Mostly ^{40}K
Shellfish	40 to 100	"
Seaweed	200 to 600	"
Sand	200 to 400	^{40}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^{-1}		

**Except sediments for which dry concentrations apply*

Tables of results in the main text of this report refer to 1993. However, tables of selected results spanning the five-year period 1989-93 are included in Appendix 3 for ease of reference when analysing the change of levels 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, 1986). The 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 mainly based on the recommendations of the ICRP as set out in ICRP Publication 26 (ICRP, 1977). 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, as are the Basic Safety Standards for Radiation Protection promulgated by the International Atomic Energy Agency (IAEA, 1982). In this report, results have also been interpreted on the basis of the recommendations of ICRP Publication 26, taking account of explanatory statements by the ICRP (ICRP, 1987) and advice from the NRPB (NRPB, 1987).

The ICRP has published a comprehensive revision of its recommendations, in ICRP Publication 60 (ICRP, 1991), as a result of which the Euratom Directive and IAEA basic safety standards are under review. The ICRP-60 recommendations are being considered by the UK Government together with recent advice from the NRPB (NRPB, 1993(a) and (b)). To assist in this process of consideration, and in keeping with the practice of providing up-to-date information, the relevant implications of ICRP-60 are addressed in this report.

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 are compared with the average natural background level of approximately 2.2 mSv (NRPB, 1993(c)).

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 $year^{-1}$. 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 $year^{-1}$. 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.

In this report, the effective doses to the critical groups calculated from the monitoring data are compared with the principal dose limit of 1 mSv $year^{-1}$. 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 $year^{-1}$; 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(a)) that the dose constraint for a single new source should not exceed 0.3 mSv $year^{-1}$ 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 $year^{-1}$. 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 use of constraints is appropriate for predictive assessments, 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 $year^{-1}$ 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 1993. In a definitive assessment of dose for comparison with the constraint, it is necessary to consider all sources of exposure at a site.

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).

Where there is a choice, the most recent information is adopted. ICRP-60's dose calculations are based on data taken from Phipps *et al*. (1991). For reference, data on dose per unit intake are provided in Appendix 2 of this report.

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 the Irish Sea, a gut transfer factor of 0.0002 is used for plutonium and americium. For other foods and for winkles from outside the Irish Sea, the factor of 0.0005 is used for these radioelements. The current NRPB advice for polonium is that a gut transfer factor of 0.1 for adults is appropriate and it is noted that more information is needed on the absorption of this element. 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). This and other data are being considered by NRPB in formulating their advice on human dosimetry. Until further advice is given, the exposures for control purposes due to polonium intakes have been calculated using the extant advice of a factor of 0.1. However, the effect of the conservative assumption that the value of 0.8 applies 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^{-1} has been taken as producing an effective dose equivalent rate of 0.87 mSv h^{-1} (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^{-2}. In this case, dose rate factors in Sv $year^{-1}$ per Bq cm^{-2} are used which are calculated for a depth in tissue of 7 mg cm^{-2} (Kocher and Eckerman, 1987). The 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. Prior to this report, the gamma dose rate background in the aquatic environment was taken to be 0.087 μGy h^{-1} for most situations and 0.06 μGy h^{-1} for measurements over sandy substrates. For this report background levels have been reviewed based on the extensive data set collected for locations close to and, in some cases, remote from, nuclear sites. As a result, in the assessments for this year's report, the estimates of natural background have reduced to 0.05 μGy h^{-1} for sandy substrates, 0.07 μGy h^{-1} for mud and salt marsh and 0.06 μGy h^{-1} for other substrates. 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 continued to be 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.

In order to interpret monitoring results in terms of committed effective dose equivalents to critical groups, the remaining data required are, as appropriate, rates of food consumption and/or occupancy of areas relevant to external exposure. 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. In this report, critical group habits data relevant to a given establishment are combined with the results of environmental monitoring and appropriate dosimetric data as above to estimate the committed effective dose equivalent to the critical group, which may then be compared with the appropriate dose limitation criteria.

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 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 is carried out.

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 the irradiated Magnox and oxide fuel from the UK nuclear power programme, and some fuel from abroad. Reprocessing of oxide fuels made no contribution to discharges in 1993 as the Thermal Oxide Reprocessing Plant (THORP) commenced operation in March 1994. Most of the radioactive waste separated from the fuel is presently stored on site; relatively small quantities of radioactivity 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 a requirement on BNFL to use 'best practicable means' to minimise 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). In 1992 BNFL applied for new discharge authorisations for the site, in part to account for the operation of THORP and the Enhanced Actinide Removal Plant (EARP). The new authorisations took effect in January 1994 and will be considered in next year's report.

Discharges from the Sellafield pipelines during 1993 are summarised in Table 1. The site ion-exchange effluent plant (SIXEP) and the salt evaporator operated during 1993 and reprocessing of Magnox fuel took place for most of the year. Site discharges generally increased because of the sustained period of reprocessing and an increase in decommissioning operations. Total alpha and beta discharges were 2.59 and 97.0 TBq respectively (1992: 1.55 and 57 TBq respectively). However, all discharges were well within the limits set by the Authorising Departments and typical of the low levels experienced in the late 1980s and early 1990s.

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 1993 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 1993 above those due to Sellafield. Monitoring of the Drigg Stream is carried out by HMIP (HMIP, 1994).

Regular monitoring of Sellafield continued during 1993. Important radiation exposure pathways were still from consumption of fish and shellfish and from external exposure to gamma 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 1993, as in previous recent years, there was no harvesting of *Porphyra* in the immediate vicinity of Sellafield for manufacture of laverbread, but monitoring continued because the pathway remains potentially important. A research programme also continued. The aims of this programme are 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. Results from the research programme are included where relevant. A general review of radioactivity in the Irish Sea has been compiled by Kershaw *et al.* (1992).

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 total beta activity and caesium-134 and -137 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 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^{-1} for caesium-137 in cod. 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).

Concentrations of radiocaesium in fish from the eastern Irish Sea in 1993 were generally similar to those in 1992. Specific radionuclides, other than caesium-134 and -137, which were detected in fish in 1993, 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. Levels in 1993 were similar to those for 1992. The data confirm that the radiological significance of these radionuclides 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 total beta activity and beta/gamma-emitting nuclides 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 DFR samples, supplies of winkles, mussels and limpets were obtained from consumers who collected them in the Sellafield Coastal Area exploited by this critical group.

Table 4(a). Beta/gamma radioactivity in fish from the Irish Sea vicinity and further afield, 1993

Sampling area/ landing point	Sample	No. of sampling observa-tions[3]	Mean radioactivity concen-tration (wet), Bq kg^{-1}		
			Total beta	^{134}Cs	^{137}Cs
Sellafield coastal area[1]	Cod	5	150	0.37	24
"	Plaice	2	150	0.33	23
"	Grey mullet	1	130	0.22	19
"	Bass	1	140	0.13	17
Sellafield offshore area[1]	Cod	2	160	0.17	18
"	Plaice	3	130	0.04	14
"	Dab	4	150	0.06	18
"	Whiting	1	130	0.19	31
"	Spurdog	1	100	ND	17
"	Flounder	1	130	"	28
Ravenglass[2]	Cod	13	140	0.12	17
"	Plaice	7	120	0.13	15
"	Salmon	1	120	ND	2.2
Whitehaven[2]	Cod	4	130	0.05	15
"	Plaice	4	98	0.03	13
"	Ray	4	94	ND	8.4
Parton[2]	Cod	5	NA	0.19	20
Morecambe Bay[1]	Flounder	4	150	0.26	46
"	Plaice	4	100	0.02	11
"	Bass	2	140	0.22	33
"	Whitebait	1	100	ND	14
Cumbrian rivers[4]	Sea trout	5	130	0.04	16
"	Salmon	1	120	ND	2.2
Fleetwood[2]	Cod	4	130	0.05	12
"	Plaice	4	110	ND	8.9
"	Fish meal[5]	4	260	"	2.1
"	Fish oil[5]	4	NA	"	ND
Isle of Man[2]	Cod	4	120	"	6.5
"	Plaice	4	96	"	4.5
"	Herring	4	120	0.02	6.8
Inner Solway[1]	Flounder	4	160	ND	45
"	Sea trout	2	140	0.16	24
Kircudbright[2]	Plaice	2	84	ND	3.9
North Anglesey[2]	Ray	4	99	0.02	4.5
"	Plaice	2	90	ND	4.7
Ribble Estuary[1]	Flounder	1	130	"	20
"	Salmon	1	180	"	0.46
"	Sea trout	1	140	0.34	43
Northern Ireland[2]	Cod	7	130	0.01	6.9
"	Whiting	8	120	ND	11
"	Herring	4	120	"	3.3
"	Spurdog	5	94	"	6.5
Celtic Sea[1]	Angler fish	1	90	"	0.37
Loch Leven[1]	Salmon	1	99	"	0.72
Minch[1]	Cod	4	130	"	1.2
"	Plaice	4	98	"	0.61
"	Mackerel	1	130	"	0.51
"	Haddock	4	110	"	0.77
"	Herring	3	120	"	0.75
West of Scotland[1]	Mackerel	2	110	"	0.17
Shetland[1]	Fish meal[5]	4	390	"	1.0
"	Fish oil	4	NA	"	ND
Northern North Sea[1]	Cod	6	120	"	0.70
"	Plaice	4	98	"	0.35
"	Herring	7	120	"	0.61
"	Haddock	8	120	"	0.56
"	Whiting	1	NA	"	1.1
"	Mackerel	2	"	"	0.22
"	Saithe	4	"	"	0.74

Table 4(a). continued

Sampling area/ landing point	Sample	No. of sampling observa- tions[3]	Mean radioactivity concen- tration (wet), Bq kg^{-1}		
			Total beta	^{134}Cs	^{137}Cs
Mid-North Sea[1]	Cod	9	120	ND	0.86
"	Plaice	5	91	"	0.34
"	Haddock	3	NA	"	0.41
"	Herring	7	120	"	0.64
"	Mackerel	2	NA	"	0.46
"	Whiting	2	"	"	1.1
Southern North Sea[1]	Cod	2	120	"	0.86
"	Plaice	2	77	"	0.69
"	Herring	2	120	"	0.74
"	Whiting	1	NA	"	1.1
"	Mackerel	1	"	"	0.32
English Channel[1]	Cod	3	120	0.02	0.62
"	Plaice	3	84	ND	0.12
"	Mackerel	1	120	"	0.98
Skagerrak[1]	Herring	2	100	"	3.1
"	Cod	2	110	"	1.2
Norwegian Sea[1]	Cod	1	120	"	0.50
"	Saithe	1	130	"	0.58
Iceland area[1]	Cod	2	100	"	0.22
Icelandic processed[2]	Cod	2	130	"	0.24
Barents Sea[1]	Cod	1	NA	"	0.50
Baltic Sea[1]	Cod	3	120	0.69	12
"	Herring	3	110	0.62	11
Sea of Okhotsk[1]	Pollack	4	NA	ND	0.26

NA = not analysed; ND = not detected; [1]Sampling area; [2]Landing point; [3]See sub-section 3.2 for definition; [4]Samples collected from a number of rivers by National Rivers Authority; [5]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, 1993

Sampling area/ landing point	Sample	No. of sampling observa- tions[3]	Mean radioactivity concentration (wet), Bq kg^{-1}				
			^{14}C	^{60}Co	^{90}Sr	^{99}Tc	^{147}Pm
Sellafield offshore area[1]	Cod	2	41	ND	0.044	0.13	NA
"	Plaice	3	76	"	0.087	1.1	0.0089
Whitehaven[2]	Cod	4	40	"	0.022	NA	NA
"	Plaice	4	NA	"	0.023	"	"
Morecambe Bay[1]	Flounder	4	37	"	NA	"	"
"	Whitebait	1	NA	"	0.084	"	"
Fleetwood[2]	Fish meal[5]	4	"	"	0.16	"	"
"	Cod	4	36	"	NA	"	"
Isle of Man[2]	Plaice	4	31	"	"	"	"
Inner Solway[1]	Flounder	4	39	"	0.038	"	"
North Anglesey[1]	Ray	4	37	"	NA	"	"
"	Plaice	2	39	"	"	"	"
Northern Ireland[2]	Cod	4	33	"	"	"	"
Minch[1]	Mackerel	1	38	"	0.013	"	"
Shetland[1]	Fish meal[5]	4	NA	"	0.0073	"	"
Northern North Sea[1]	Cod	4	"	"	0.0035	"	"
"	Haddock	4	30	"	NA	"	"
Mid-North Sea[1]	Cod	4	26	"	0.0030	"	"
"	Plaice	4	27	"	0.0041	"	"
English Channel[1]	Cod	3	NA	0.04	0.0069	"	"
"	Plaice	3	"	ND	0.0069	"	"
Iceland area[1]	Cod	2	23	"	NA	"	"
Icelandic processed[2]	Cod	2	24	"	"	"	"

ND = not detected; NA = not analysed; [1]Sampling area; [2]Landing point; [3]See sub-section 3.2 for definition; [4]Samples collected from a number of rivers by North West Water; [5]Concentrations refer to weight of sample as supplied

Table 5. Beta/gamma radioactivity in shellfish from the Irish Sea vicinity and further afield, 1993

Sampling point/ landing area	Sample	No. of sampling observa-tions[3]	Mean radioactivity concentration (wet)*, Bq kg^{-1}										
			Total beta	^{14}C	^{60}Co	^{65}Zn	^{90}Sr	^{95}Zr	^{95}Nb	^{99}Tc	^{103}Ru	^{106}Ru	^{110m}Ag
Sellafield coastal area[1]	Crabs	8	100	76	0.61	ND	1.1	0.06	ND	3.4	0.08	4.9	15
“	Lobsters	8	290	130	0.49	0.13	0.42	ND	“	390	ND	1.3	23
“	Winkles[4]	12	280	62	2.4	ND	6.7	2.6	3.1	38	“	63	44
“	“[5]	4	300	NA	3.0	“	NA	5.5	4.8	NA	0.33	82	55
“	Mussels[4]	4	160	“	1.5	“	“	1.0	0.88	“	0.07	29	0.97
“	Limpets[4]	4	340	“	1.3	“	“	5.1	5.0	“	0.13	73	30
Sellafield offshore area[1]	Whelks	1	240	“	3.9	“	“	ND	ND	“	ND	48	75
St Bees[1]	Winkles	4	320	58	3.0	“	8.3	8.5	9.4	31	0.36	80	42
“	Mussels	4	200	NA	1.6	“	NA	5.7	5.7	NA	0.38	75	9.0
“	Limpets	4	360	“	1.3	“	“	6.7	7.0	“	0.21	81	42
Nethertown[1]	Winkles	12	350	59	3.0	“	16	8.5	9.0	57	0.30	94	56
“	Mussels	4	270	73	2.1	“	NA	7.8	7.4	54	0.22	120	6.4
“	“[7]	1	250	NA	1.9	0.33	“	6.8	8.6	NA	0.34	98	8.0
Whitrigg[1]	Shrimps	1	110	“	0.23	ND	“	0.80	0.50	“	ND	7.9	15
Drigg[1]	Winkles	4	410	74	3.7	“	“	14	12	48	0.69	120	65
Ravenglass[1]	Mussels	4	170	NA	1.6	“	“	0.94	0.99	62	ND	34	1.4
“	Cockles	4	160	“	3.2	“	“	1.8	1.7	NA	0.07	27	5.5
Ravenglass[2]	Whelks	2	110	“	1.1	“	“	ND	ND	“	ND	11	19
“	Crabs	4	98	“	0.61	“	0.62	“	“	2.0	“	1.9	12
“	Lobsters	4	230	“	ND	“	0.14	“	“	160	“	ND	15
Tarn Bay[1]	Winkles	4	230	“	2.1	“	NA	4.7	4.4	NA	0.11	55	31
Saltom Bay[1]	“	4	180	“	1.3	“	“	1.5	1.7	“	0.08	29	12
Whitehaven[2]	*Nephrops*	4	130	39	ND	“	0.15	ND	ND	36	ND	ND	0.60
“	Whelks	3	130	64	0.41	“	0.16	“	“	NA	“	2.3	5.0
Parton[1]	Winkles	4	250	NA	1.3	“	NA	3.1	3.6	“	0.10	33	13
“	Crabs	4	NA	“	0.39	“	“	ND	ND	“	ND	2.6	6.2
“	Lobsters	4	“	“	0.03	“	“	“	“	“	“	ND	5.0
Haverigg[2]	Cockles	1	150	“	0.92	“	“	1.3	1.8	“	0.14	22	0.77
Millom[1]	Mussels	2	88	“	0.34	“	“	ND	ND	“	ND	7.6	0.39
Roosebeck[1]	Pacific oysters	4	94	“	0.27	“	“	“	“	“	“	2.4	13
Morecambe Bay[1]	Shrimps	4	78	47	ND	“	0.080	“	“	“	“	ND	0.06
“ (Flookburgh)[2]	Cockles	4	90	47	0.60	“	0.84	“	“	6.7	“	1.7	0.12
“ (Middleton Sands)[1]	“	4	78	NA	0.67	“	NA	“	“	NA	“	2.7	0.09
Fleetwood[2]	Squid	1	84	“	ND	“	“	“	“	“	“	ND	ND
“	Whelks	4	94	48	0.09	“	“	“	“	“	“	0.18	0.54
Isle of Man[2]	Scallops	4	110	NA	ND	“	“	“	“	“	“	ND	0.03
Inner Solway	Shrimps	4	81	“	“	“	0.07	“	“	“	“	“	0.49
Southerness[1]	Winkles	4	140	“	0.50	“	1.4	0.27	“	31	“	6.2	4.9
Kirkcudbright[2]	Scallops	3	80	“	ND	“	NA	ND	“	NA	“	ND	ND
“	Queens	4	81	“	0.05	“	“	“	“	“	“	“	0.43
North Solway coast[1]	Winkles	4	110	“	0.53	“	“	“	“	“	“	6.0	4.4
“	Cockles	4	100	“	0.82	“	“	0.19	0.22	“	“	5.0	0.19
Wirral[1]	Shrimps	2	73	“	ND	“	“	ND	ND	0.62	“	ND	ND
“	Cockles	4	70	“	0.12	“	“	“	“	1.6	“	“	“
Conwy[2]	Mussels	3	36	“	ND	“	“	“	“	NA	“	“	“
Northern Ireland[2]	*Nephrops*	8	97	“	“	“	“	“	“	4.0	“	“	“
“	Winkles	4	73	“	“	“	“	“	“	NA	“	“	0.25
“	Mussels	2	32	“	“	“	“	“	“	4.3	“	“	ND
Minch[1]	*Nephrops*	4	91	“	“	“	“	“	“	NA	“	“	“
Northern North Sea[1]	“	3	93	“	“	“	“	“	“	“	“	“	“
Mid North Sea[1]	Mussels[6]	2	34	“	“	“	“	“	“	“	“	“	“
Southern North Sea[1]	Cockles	2	29	“	0.75	“	“	“	“	“	“	“	“
“	“[8]	2	23	“	0.14	“	“	“	“	“	“	“	“
“	Mussels	4	61	“	ND	“	“	“	“	“	“	“	“

Table 5. continued

Sampling point/ landing area	Sample	No. of sampling observa-tions[3]	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
			^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{147}Pm	^{154}Eu	^{155}Eu
Sellafield coastal area[1]	Crabs	8	0.10	0.08	5.4	0.11	1.0	ND	ND
	Lobsters	8	0.12	0.10	9.4	0.07	2.1	"	"
"	Winkles[4]	12	3.0	ND	17	3.4	5.4	0.32	0.29
"	" [5]	4	4.3	"	16	4.1	NA	0.43	0.21
"	Mussels[4]	4	1.7	0.03	5.0	0.98	"	0.67	0.13
"	Limpets[4]	4	6.8	ND	21	3.7	"	1.0	ND
Sellafield offshore area[1]	Whelks	1	1.7	"	5.4	ND	"	ND	"
St Bees[1]	Winkles	4	3.6	0.14	25	5.8	8.1	0.51	0.27
"	Mussels	4	2.4	ND	8.1	3.4	NA	0.57	0.23
"	Limpets	4	3.6	0.14	25	5.8	"	0.51	0.27
Nethertown[1]	Winkles	12	4.0	0.05	24	6.1	8.7	0.57	0.37
"	Mussels	4	5.1	ND	9.6	4.9	NA	0.44	0.11
"	" [7]	1	7.6	"	10	6.7	"	0.83	0.57
Whitrigg[1]	Shrimps	1	ND	0.18	9.2	0.40	"	ND	ND
Drigg[1]	Winkles	4	4.0	0.06	15	11	9.7	0.47	"
Ravenglass[1]	Mussels	4	2.0	ND	5.1	0.71	NA	0.33	0.10
"	Cockles	4	1.0	0.06	9.7	2.2	"	1.0	0.38
Ravenglass[2]	Whelks	2	ND	ND	3.3	ND	"	ND	ND
"	Crabs	4	"	"	4.4	"	0.59	"	"
"	Lobsters	4	"	"	7.6	"	0.71	"	"
Tarn Bay[1]	Winkles	4	2.0	"	14	4.2	NA	"	"
Saltom Bay[1]	"	4	3.6	0.04	16	2.3	"	0.32	"
Whitehaven[2]	*Nephrops*	4	ND	ND	10	ND	"	ND	"
"	Whelks	3	"	"	3.1	"	"	"	"
Parton[1]	Winkles	4	2.0	0.12	27	2.5	"	0.49	0.17
"	Crabs	4	ND	ND	5.3	ND	"	ND	ND
"	Lobsters	4	"	0.13	8.1	"	"	"	"
Haverigg[2]	Cockles	1	0.71	ND	12	1.2	"	0.66	0.29
Millom[1]	Mussels	2	0.63	"	3.5	ND	"	ND	0.07
Roosebeck[1]	Pacific oysters	4	ND	"	3.9	"	"	"	ND
Morecambe Bay[1]	Shrimps	4	"	0.03	15	"	"	"	"
" (Flookburgh)[2]	Cockles	4	0.43	ND	9.0	"	"	0.08	0.04
" (Middleton Sands)[1]	"	4	0.30	"	8.1	0.09	"	0.05	ND
Fleetwood[2]	Squid	1	ND	"	3.4	ND	"	ND	"
"	Whelks	4	"	"	2.5	"	"	"	"
Isle of Man[2]	Scallops	4	"	"	1.4	"	"	"	"
Inner Solway[1]	Shrimps	4	"	0.04	15	"	"	"	"
Southerness[1]	Winkles	4	0.95	ND	12	"	"	"	"
Kirkcudbright[2]	Scallops	3	ND	"	1.1	"	"	"	"
"	Queens	4	"	0.01	1.6	"	"	"	"
North Solway coast[1]	Winkles	4	0.68	ND	5.6	"	"	"	"
"	Cockles	4	ND	"	9.1	0.27	"	"	0.09
Wirral[1]	Shrimps	2	"	"	5.2	ND	"	"	ND
"	Cockles	4	0.02	0.02	3.6	"	"	"	"
Conwy[2]	Mussels	3	ND	ND	1.1		"	"	"
Northern Ireland[2]	*Nephrops*	8	"	"	2.6	"	"	"	"
"	Winkles	4	"	"	0.99	"	"	"	"
"	Mussels	2	"	"	1.8	"	"	"	"
Minch[1]	*Nephrops*	4	"	"	0.52	"	"	"	"
Northern North Sea[1]	"	3	"	"	0.28	"	"	"	"
Mid North Sea[1]	Mussels[6]	2	"	"	0.31	"	"	"	"
Southern North Sea[1]	Cockles	2	"	"	0.11	"	"	"	"
"	" [8]	2	"	"	0.11	"	"	"	"
"	Mussels	4	"	"	0.31	"	"	"	0.14

NA = not analysed; ND = not detected; [1]Sampling area; [2]Landing point; [3]See sub-section 3.2 for definition; [4]Samples collected by Consumer 116; [5]Samples collected by Consumer 460; [6]Landed in Denmark; [7]Preserved in vinegar; [8]Landed in Holland

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. However, few beta/gamma-emitting radionuclides from Sellafield are detected outside the Irish Sea. 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 those for crustaceans. Concentrations of beta/gamma-emitting radionuclides in shellfish in 1993 were generally similar to or slightly more than those in 1992 in line with the modest increase in discharges noted above.

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 1993 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 significantly, 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 1993, when compared with 1992, concentrations of transuranic nuclides in fish and shellfish were similar.

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 larger population 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, contains 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 landed are lower.

The consumption rates of the local fishing community described above were kept under review in 1993. 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 given 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 1993 for all three classes of foodstuff such that rates of 28 kg $year^{-1}$ fish, 15 kg $year^{-1}$ crustaceans and 7.8 kg $year^{-1}$ 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 1992 of 37, 6.0 and 11 kg $year^{-1}$ for the three classes of foodstuff respectively (Camplin, 1993(a)).

The habits survey data show that above-average consumers in each of the component sub-groups are not generally 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. 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

Table 6. Transuranic radioactivity in fish and shellfish from the Irish Sea vicinity and further afield, 1993

Sampling area/ landing point	Sample	No. of sampling observa- tions[3]	Mean radioactivity concentration (wet), Bq kg^{-1}						
			^{237}Np	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Sellafield coastal area[1]	Cod	2	NA	0.0012	0.0055	NA	0.010	0.000012	0.000035
“	Plaice	1	“	0.0022	0.0098	“	0.019	0.000057	0.000064
“	Crabs	2	0.041	0.012	0.49	8.9	1.9	0.0010	0.0053
“	Lobsters	2	0.12	0.093	0.42	7.6	5.1	0.0022	0.012
“	Winkles[4]	1	0.38	3.4	15	230	27	0.072	0.053
“	“ [5]	1	NA	3.1	13	220	26	0.060	0.054
“	Mussels[4]	1	“	2.3	11	170	21	ND	0.053
“	Limpets[4]	1	“	4.2	18	300	33	“	0.10
Sellafield offshore area[1]	Cod	1	“	0.0023	0.010	NA	0.017	“	0.000026
“	Plaice	1	0.0011	0.0028	0.014	“	0.021	“	0.000054
“	Whelks	1	NA	0.95	4.3	65	15	0.082	0.033
St Bees[1]	Mussels	2	“	3.0	13	220	22	0.045	0.055
“	Winkles	1	0.46	4.5	21	330	36	0.065	0.069
“	Limpets	1	NA	4.2	19	NA	35	0.087	0.16
Nethertown[1]	Winkles	4	0.67	5.2	23	370	40	0.078	0.11
“	Mussels	4	NA	4.1	17	NA	27	0.047	0.060
	“ [12]	1	“	4.2	19	“	32	0.10	0.37
Whitrigg[1]	Shrimps	1	“	NA	NA	“	4.1	NA	NA
Drigg[1]	Winkles	4	0.42	4.0	18	280	34	0.063	0.076
Ravenglass[1]	Mussels	1	NA	2.2	9.7	150	19	ND	0.058
“	Cockles	1	“	2.8	13	96	35	0.020	0.10
Ravenglass[2]	Cod[6]	1	“	0.00084	0.0040	NA	0.0066	ND	0.000023
“	Plaice[6]	1	“	0.0018	0.0078	“	0.015	0.00010	0.000042
“	Crabs[7]	1	“	0.072	0.33	4.8	1.7	ND	0.0035
“	Lobsters[7]	1	“	0.049	0.24	3.5	3.4	“	0.011
“	Whelks[7]	1	“	0.37	1.6	25	2.4	0.0035	0.0065
Tarn Bay[1]	Winkles	1	“	2.9	13	210	23	0.058	0.052
Whitehaven[2]	Cod	1	“	0.00048	0.0023	NA	0.0042	ND	0.000012
“	Plaice	1	“	0.00058	0.0029	“	0.0058	“	0.000019
“	Rays	1	“	0.00039	0.0017	“	0.0030	“	0.0000036
“	*Nephrops*	1	“	0.050	0.25	“	0.74	“	0.0018
“	Whelks	1	“	0.26	1.3	18	2.4	0.0026	0.0036
Saltom Bay[1]	Winkles	4	“	NA	NA	NA	19	NA	NA
Parton[1]	Winkles	1	“	2.9	14	200	22	0.038	0.046
“	Crabs	1	“	NA	NA	NA	1.2	NA	NA
“	Lobsters	1	“	“	“	“	0.81	“	“
Haverigg[2]	Cockles	1	“	2.7	12	“	28	0.044	0.075
Millom[1]	Mussels	1	“	0.62	2.9	“	6.2	0.019	0.010
Roosebeck[1]	Pacific oysters	1	“	0.26	1.3	“	0.68	ND	0.0018
Morecambe Bay	Flounder	1	“	0.00043	0.0022	“	0.0042	0.000013	0.000010
“	Shrimps	1	“	0.0048	0.025	0.40	0.040	ND	0.00013
“ (Flookburgh)[2]	Cockles	1	“	0.56	2.9	38	7.7	“	0.023
“ (Middleton Sands)[1]	“	1	“	0.64	3.3	NA	7.9	“	0.016
Fleetwood[2]	Cod	1	“	0.00037	0.0018	“	0.0033	“	0.0000075
“	Plaice	1	“	0.00037	0.0018	“	0.0032	0.0000096	0.0000072
“	Fishmeal[8]	1	“	0.0047	0.025	“	0.039	ND	ND
“	Whelks	1	“	0.079	0.40	6.0	0.49	“	0.00085
Isle of Man[2]	Cod	1	“	0.00019	0.00096	NA	0.0015	0.0000058	0.0000054
“	Plaice	1	“	0.00032	0.0016	“	0.0023	ND	0.0000054
“	Herring	1	“	0.00038	0.0019	“	0.0029	“	0.0000055
“	Scallops	1	“	0.021	0.099	“	0.035	0.000094	0.00013
Inner Solway[1]	Sea trout	1	“	0.0011	0.0055	“	0.0080	ND	0.000011
“	Flounder	1	“	0.0037	0.019	“	0.029	“	0.000027
“	Shrimp	1	“	0.0048	0.026	“	0.044	0.00014	0.00013
Southerness[1]	Winkles	1	“	0.68	3.4	47	5.6	ND	0.016

Table 6. continued

Sampling area/ landing point	Sample	No. of sampling observa-tions[3]	Mean radioactivity concentration (wet), Bq kg^{-1}						
			^{237}Np	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Kirkcudbright[2]	Plaice	1	“	0.00047	0.0024	NA	0.0043	“	0.0000089
“	Scallops	1	“	0.027	0.14	“	0.051	0.00016	0.000073
“	Queens	1	“	0.026	0.13	“	0.16	0.00017	0.00029
North Solway coast[1]	Winkles	1	“	0.61	3.0	44	5.6	0.0071	0.013
“	Cockles	1	“	1.1	5.1	NA	13	0.016	0.032
Wirral[1]	Cockles	1	“	0.13	0.72	“	1.9	ND	0.0029
Conwy[2]	Mussels	1	“	0.037	0.20	“	0.33	0.00099	0.0013
North Anglesey[2]	Rays	1	“	0.00023	0.00091	“	0.0015	ND	0.0000063
Northern Ireland[2]	Whiting	1	“	0.00088	0.0047	“	0.0081	“	0.000017
“	*Nephrops*	1	“	0.0073	0.039	“	0.11	“	0.00031
“	Winkles	1	“	0.039	0.21	“	0.11	0.00017	0.00028
Minch[1]	Cod	1	“	0.00012	0.00062	“	0.00054	ND	ND
“	Haddock	1	“	0.000060	0.00032	“	0.0010	“	“
“	Mackerel	1	“	0.000025	0.00019	“	0.00039	“	“
“	*Nephrops*	1	“	0.00068	0.0042	“	0.0045	“	0.000018
Shetland[1]	Fishmeal[11]	1	“	0.00060	0.0052	“	0.0015	“	0.0000088
Northern North Sea[1]	*Nephrops*	1	“	0.00054	0.0036		0.0044	0.000050	0.000045
“	Cod	1	“	0.00048	0.00023	“	0.00041	ND	0.0000029
“	Haddock	1	“	0.00011	0.00057	“	0.00081	0.0000085	0.0000053
Mid-North Sea[1]	Mussels[9]	1	“	0.00037	0.0038	“	0.0027	ND	0.0000062
Southern North Sea[1]	Cockles	1	“	0.0025	0.011	“	0.015	0.000047	0.0010
“	“ [10]	1	“	0.0019	0.0058	“	0.0082	0.000030	0.00093
“	Mussels	1	“	0.0042	0.025	“	0.011	ND	0.000034
Icelandic processed[2]	Cod	1	“	0.000049	0.00026	“	0.00043	“	ND

ND = not detected
NA = not analysed
[1]Sampling area; [2]Landing point; [3]See sub-section 3.2 for definition; [4] Samples collected by Consumer 116; [5]Samples collected by Consumer 460; [6]Samples provided by Fisherman A; [7]Samples provided by Fisherman B; [8]Concentrations refer to weight as supplied; [9]Landed in Denmark; [10]Landed in Holland; [11]Concentrations refer to weight of samples as supplied; [12]Preserved in vinegar

upon 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 calculated on the basis of a mix of 80% crabs and 20% 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 80% winkles and 20% 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 1993 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 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 1993 was 0.15 mSv. This represents a small decrease from 0.19 mSv reported on the same basis for 1992 (Camplin, 1993(a)), mainly due to decrease in consumption of molluscs. These committed effective dose equivalents, on the basis of ICRP-26, are within the dose limit for members of the public of 1 mSv $year^{-1}$.

Table 7(a). Individual radiation exposures due to consumption of Irish Sea fish and shellfish, 1993

Exposed population	Consumption rate used in assessment (see text), kg year^{-1}		Nuclide	Exposure, mSv# ICRP-26*	Exposure, mSv# ICRP-60=
Consumers in local fishing community	Fish (plaice and cod):	28	^{90}Sr	0.004	0.003
	Crustaceans (crabs and lobsters):	15	^{106}Ru	0.005	0.007
	Molluscs (winkles and other molluscs):	7.8	^{110m}Ag	0.002	0.002
			^{137}Cs	0.009	0.009
			^{237}Np	0.002	0.001
			^{238}Pu	0.007	0.004
			$^{239+240}$Pu	0.034	0.021
			^{241}Pu	0.010	0.006
			^{241}Am	0.077	0.046
			Total	0.15	0.10
Consumers associated with commercial fisheries: Whitehaven	Fish (plaice and cod):	49	^{137}Cs	0.011	0.011
	Crustaceans (*Nephrops*):	11	$^{239+240}$Pu	0.005	0.003
	Molluscs (whelks):	6	^{241}Pu	0.002	0.001
			^{241}Am	0.011	0.007
			Total	0.03	0.02
Consumers in Dumfries and Galloway	Fish (plaice, cod and salmon):	38	^{137}Cs	0.005	0.005
	Crustaceans (crabs and *Nephrops*):	13	^{238}Pu	0.008	0.005
	Molluscs (cockles):	16	$^{239+240}$Pu	0.041	0.024
			^{241}Pu	0.016	0.009
			^{241}Am	0.108	0.064
			Total	0.18	0.11
Consumers in Morecambe Bay area	Fish (flounders and plaice):	54	^{137}Cs	0.026	0.026
	Crustaceans (shrimps):	21	^{238}Pu	0.005	0.003
	Molluscs (cockles and mussels):	22	$^{239+240}$Pu	0.028	0.016
			^{241}Pu	0.008	0.004
			^{241}Am	0.067	0.040
			Total	0.14	0.09
Consumers associated with commercial fisheries: Fleetwood	Fish (plaice and cod):	82	^{137}Cs	0.016	0.016
	Crustaceans (shrimps):	17	^{238}Pu	0.004	0.003
	Molluscs (cockles and whelks):	23	$^{239+240}$Pu	0.025	0.014
			^{241}Pu	0.005	0.003
			^{241}Am	0.061	0.036
			Total	0.11	0.07
Typical member of the fish-eating public consuming fish landed at Whitehaven/Fleetwood	Fish (plaice and cod):	15	^{137}Cs	0.002	0.002
			Total	0.003	0.003

* *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*

Continuing with ICRP-26 methodology, the exposure of the critical group has also been considered in comparison with the recommendation on lifetime exposure (sub-section 3.3). In 1993, and in recent previous years, realistically-assessed exposures were within the principal dose limit of 1 mSv year^{-1}. For a few years prior to this, exposures were in excess of 1 mSv year^{-1} but within the subsidiary dose limit of 5 mSv year^{-1}. There has been an overall decline in concentrations of radiologically significant nuclides in environmental materials as a result of reduced discharges; consumption rates of shellfish would need to increase substantially for exposures to exceed the principal dose limit. These exposures are now considered likely to remain below the 1 mSv year^{-1} level, and dose rates above this level have not occurred for long enough for lifetime exposures to have exceeded, on average, 1 mSv year^{-1}. This statement takes account of predicted exposures from future discharges (Hunt, 1986).

Table 7(b). Exposure of fish and shellfish consumers near Sellafield due to discharges in 1993 for comparison with the ICRP-60 dose limit

Nuclide	Committed effective dose*, mSv year^{-1}
^{14}C	0.002
^{90}Sr	0.007
^{99}Tc	0.002
^{106}Ru	0.013
^{137}Cs	0.004
^{237}Np	0.002
$^{238+239+240}$Pu	0.005
^{241}Pu	0.003
^{241}Am	0.004
Total#	0.04

* *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)*
\# *Includes the small effect of other nuclides*

The recommendations of ICRP-60 and the advice of the NRPB on them are under consideration by the UK Government, but their effects are considered here to provide up-to-date information and as an aid to further study of the implications of these recommendations. The committed effective dose to the local critical group in 1993 was 0.10 mSv. Differences for individual radionuclides, from the ICRP-26 calculation, reflect the revised tissue weighting factors which give, for example, increased exposures for ruthenium-106 but reductions for the transuranic nuclides. Using ICRP-60 methodology, this committed effective dose should not strictly be compared directly with the dose limit for a practice of 1 mSv year^{-1}, because a significant contribution is due to the effects of radioactivity already in the environment, which can only be subject to intervention. However, as discussed in sub-section 3.3, it would be appropriate to use 1 mSv year^{-1} as a limit against which to compare the combined effects of current and past discharges, calculated using ICRP-60 dose coefficients. If this limit were exceeded, then intervention would need to be considered. In 1993, the committed effective dose to the local critical group of 0.10 mSv 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 1993 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 0.04 mSv. This dose is much less than the maximum constraint recommended by NRPB for a single new source of 0.3 mSv and is also a small fraction of the dose received in 1993 due to the combined effects of past and current discharges.

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 enhanced concentrations of natural radionuclides in the Sellafield area in 1993 was 0.23 mSv using the current recommendation on the choice of gut uptake factor for polonium (see section 3.3) (on the basis of ICRP-60: 0.14 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 of approximately 2.2 mSv year^{-1} to members of the UK public from all natural sources of radiation (NRPB, 1993(c)) 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 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. The committed effective dose equivalents (ICRP-26) from artificial radionuclides received by the different groups 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 consumption rates and radioactivity concentrations in molluscs. The results for Whitehaven, Dumfries and Galloway, Morecambe Bay and Fleetwood were similar in 1993 to those in 1992 (0.03, 0.16, 0.13 and 0.12 mSv respectively) (Camplin, 1993(a)). All doses were well within the dose limit for members of the public of 1 mSv year^{-1}.

The committed effective dose equivalent from artificial radionuclides, appropriate to a consumption rate of 15 kg year^{-1} 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 1993 was 0.003 mSv, similar to that for 1992 (Camplin, 1993(a)).

4.1.1.4 Collective dose

Collective doses, received during 1993 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, 1993(a)). 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 1993 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 1992 (Camplin, 1993(a)) have been revised to take account of updated landings and import/export statistics. The preliminary result of 8 man-Sv for the UK in 1992, given in the previous report (Camplin, 1993(a)), has decreased to 5 man-Sv; the result for other European countries has increased from 22 to 26 man-Sv. These changes are largely due to import/export factors.

Table 8. Collective doses from fish and shellfish, 1992 and 1993[a]

Population	Collective dose, man-Sv			
	ICRP-26*		ICRP-60+	
	1992	1993[a]	1992	1993[a]
UK	5	5	4	4
Other European countries	26	25	23	23

* *Committed effective dose equivalent using methodology of ICRP-26*
\+ *Committed effective dose calculated using methodology of ICRP-60*
[a] *Preliminary data*

Liquid radioactive waste discharges from Sellafield up to the end of 1993 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 1993 of 5 man-Sv for the UK and 25 man-Sv for other European countries are similar to those reported for 1992. It has not been possible to derive a direct estimate of the small Chernobyl contribution in coastal seas around the UK for 1993 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 (Ilus *et al*., in press; Aarkrog *et al*., in press; Camplin, 1993(a); this report), it is estimated that the collective dose to other European countries from consumption of Baltic Sea fish was 70 man-Sv in 1992 and 60 man-Sv in 1993. The 1992 estimates are less than those made previously (Camplin, 1993(a)) because further catch data have become available for use in the assessment. The decrease in collective dose from 1992 to 1993 is due to a reduction in catches of fish from the Baltic Sea.

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 1993, 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.

4.1.1.5 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 from place to place. 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)). The research vessel programme currently comprises cruises in the Irish Sea, Scottish waters and the North Sea every two years. The results of the 1993 cruises are summarised here.

The distribution of caesium-137 observed during the November 1993 cruise to the Irish Sea and Scottish waters is shown in Figures 2 and 3. Comparison with the caesium-137 contours for the November 1991 cruise (Camplin, 1993(b)) suggests that concentrations in the eastern Irish Sea have not changed significantly, although concentrations to the south-west of the Isle of Man and in the Celtic Sea are lower than in November 1991. In contrast, concentrations observed in the North Channel and in the Scottish coastal current are higher than in November 1991. The evidence suggests an increased flow rate of Atlantic water northwards through the Irish Sea in 1993, forcing more water from the Irish Sea through the North Channel.

The total amount of caesium-137 in water of the Irish Sea is shown in Figure 4. Following use of zeolite in the late 1970s and early 1980s and the operation of SIXEP at Sellafield since 1985, which substantially reduced discharges, the inventory of caesium-137 in the water of the Irish Sea continued its decline until 1989, when it levelled off to a relatively stable situation. The most recent data for 1993 suggests there has been a small further reduction in the caesium-137 content of the Irish Sea.

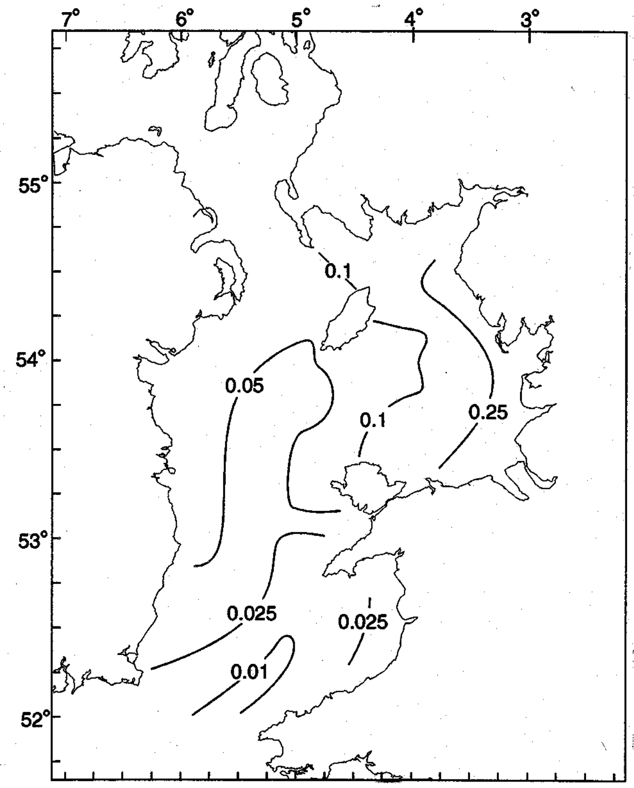

Figure 2. ***Concentrations (Bq kg⁻¹) of caesium-137 in filtered surface water from the Irish Sea, November 1993***

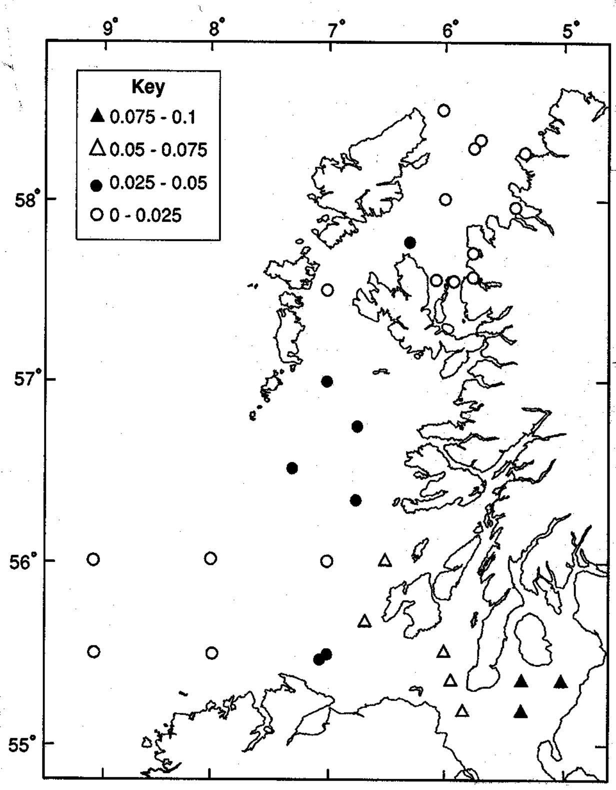

Figure 3. ***Concentrations (Bq kg⁻¹) of caesium-137 in filtered water from the west of Scotland, November 1993***

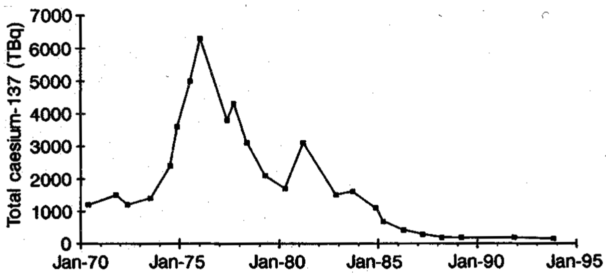

Figure 4. ***Inventory of caesium-137 in the Irish sea***

Caesium-137 data for the North Sea, collected during August and September 1993, are shown in Figure 5. Comparison with the distribution observed in August and September 1991 (Camplin, 1993(b)) shows a small reduction in concentration, in particular in the central North Sea.

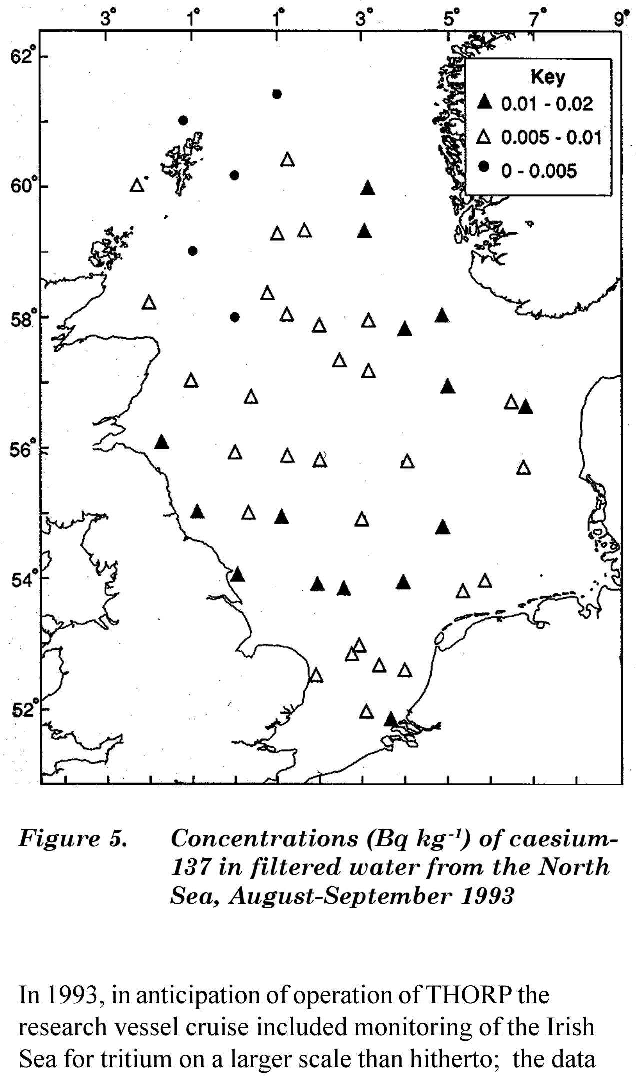

Figure 5. ***Concentrations (Bq kg⁻¹) of caesium-137 in filtered water from the North Sea, August-September 1993***

In 1993, in anticipation of operation of THORP the research vessel cruise included monitoring of the Irish Sea for tritium on a larger scale than hitherto; the data are presented in Figure 6. A similar distribution to that for caesium-137 exists with Sellafield as the main source for this radionuclide, though there is some evidence that discharges of tritium from Heysham nuclear power stations may have been detected in Morecambe Bay. The distribution of tritium in coastal

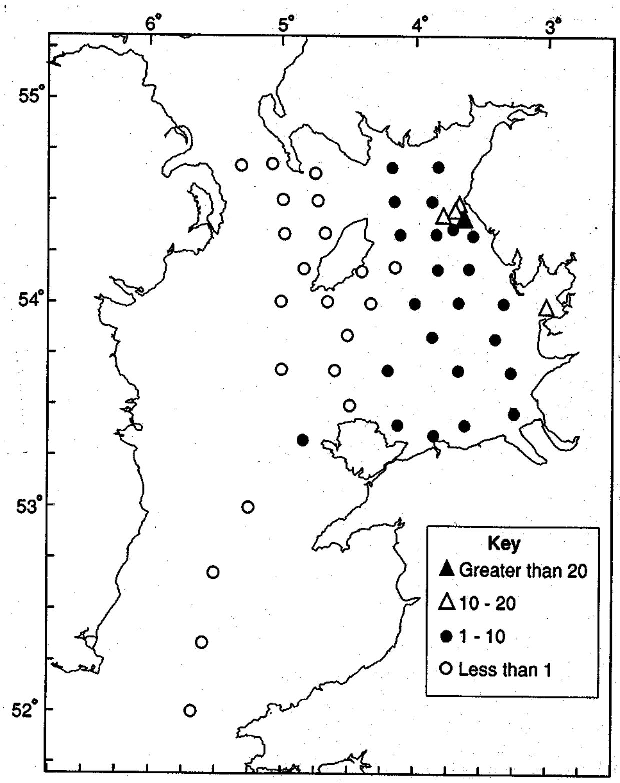

Figure 6. ***Concentrations (Bq kg^{-1}) of tritium in water from the Irish Sea, November 1993***

waters could increase in future years as the THORP plant increases its throughput. Although the concentrations of tritium in sea water are higher than those of caesium-137, they are of much less significance because tritium has very low energy radiations.

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 are mainly due to radiocaesium.

A range of coastal locations are regularly monitored, both in the Sellafield vicinity and further afield, using portable gamma-radiation dosemeters. 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 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 1993 generally showed small reductions as compared with those in 1992 (Camplin, 1993(a)).

Radioactivity concentrations in 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 1992 (Camplin, 1993(a)) shows small general reductions of gamma radioactivity in line with the behaviour of dose rates. Data for small patches of mud 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 1993 was 0.13 mSv for occupancy of fishing vessels in Whitehaven harbour including a small contribution due to consumption of fish and shellfish. 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 persons who live on board a boat 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). Their occupancy of the boat in 1993 was similar to that in 1992. Making an allowance for natural background using the updated factor of 0.07 μGy h^{-1} (see sub-section 3.3) their external exposure in 1993 was 0.26 mSv, which is a small increase on the value for 1992 calculated on the same basis of 0.25 mSv. The exposure was within the dose limit of 1 mSv year^{-1} 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.

Table 9. Gamma radiation dose rates over intertidal areas of the Cumbrian coast and further afield, 1993

Location	Ground type	No. of sampling observations#	Mean gamma dose rate in air at 1 m, μGy h^{-1}
Cumbria			
Rockliffe Marsh	Salt marsh	4	0.080
Burgh Marsh	"	4	0.097
Port Carlisle	Mud and sand	1	0.085
"	Mud, sand & stones	3	0.11
Greenend	Salt marsh	4	0.082
"	Mud and sand	3	0.073
"	Sand	1	0.068
Cardurnock Marsh	Salt marsh	4	0.11
Newton Arlosh	"	4	0.13
Silloth - silt pond	Mud	1	0.21
" "	Grass	1	0.075
" - boat area	Mud and sand	2	0.10
Allonby	Sand	2	0.077
Maryport - Christchurch	Mud	4	0.12
Siddick	Sand	4	0.073
Workington Harbour	Mud	4	0.17
Harrington Harbour	"	3	0.17
"	Mud, sand & stones	1	0 17
Whitehaven - outer harbour	Mud and sand	11	0.12
" "	Coal and sand	11	0.13
Whitehaven - inner harbour	Mud and sand	2	0.18
" "	Mud, sand & stones	9	0.17
" - yacht basin	Mud	11	0.27
St Bees	Sand	4	0.071
Nethertown	Winkle bed	4	0.11
Sellafield	Sand	4	0.079
Seascale	"	4	0.076
Drigg pipeline	"	8	0.072
Drigg Barn Scar	Mussel bed	4	0.10
Saltcoats	Salt marsh	4	0.24
Ravenglass - Carleton Marsh	"	4	0.30
Ravenglass - salmon garth	Mud and sand	4	0.16
" "	Sand and stones	2	0.079
" "	Mussel bed	4	0.10
" "	Sand	2	0.084
" - boat area	Mud and sand	13	0.11
" "	Sand	3	0.067
" - ford	Mud and sand	4	0.11
" - River Mite	Salt marsh	4	0.23
" - Ravenvilla	Mud	1	0.15
" "	Mud and sand	11	0.14
" "	Salt marsh	12	0.26
" - Eskmeals Nature Reserve	"	4	0.25
" - River Esk flooded pasture	"	4	0.25
Newbiggin	Mud and sand	4	0.24
"	Salt marsh	4	0.33
" - west of bridge	Mud, sand & stones	4	0.13
" "	Salt marsh	4	0.30
Tarn Bay	Sand	2	0.073
Silecroft	"	2	0.062
Haverigg - boat area	Mud and sand	2	0.10
" "	Mud	2	0.10
" - river mouth	Mud and sand	2	0.080
" "	Sand	2	0.073
Borwick Rails- Millom	Mud and sand	4	0.093
Low Shaw	Salt marsh	4	0.11
Askham	"	4	0.17
Tummer Hill Marsh	"	4	0.19
Walney Channel	Mud and sand	4	0.11
" - Vickers shore	"	4	0.088
" - west shore	Sand	4	0.059
Roa Island	Mud and sand	4	0.086
Greenodd	Salt marsh	2	0.078
Sand Gate Marsh	"	4	0.12
Flookburgh	Mud and sand	3	0.084
"	Sand	1	0.078
High Foulshaw	Salt marsh	4	0.095
Arnside	Mud and sand	4	0.072

Table 9. continued

Location	Ground type	No. of sampling observations#	Mean gamma dose rate in air at 1 m, $\mu Gy\ h^{-1}$
Lancashire, Merseyside and North Wales			
Jenny Brown's Point	Salt marsh	4	0.079
Sunderland Point	Mud and sand	4	0.089
Sunderland	Mud, sand & stones	4	0.078
Colloway Marsh	Salt marsh	4	0.18
Lancaster	"	4	0.12
Aldcliffe Marsh	"	4	0.16
Conder Green	Mud and sand	3	0.12
"	Mud	1	0.10
"	Salt marsh	4	0.14
Cockerham Marsh	"	4	0.12
Heads - River Wyre	"	2	0.13
Height o' th' hill - River Wyre	"	4	0.17
Hambleton	Mud	3	0.12
"	Mud and sand	1	0.13
"	Salt marsh	4	0.15
Fleetwood Docks	"	4	0.18
Skippool Creek	Mud	3	0.12
"	Mud and sand	1	0.13
Fleetwood	Sand	4	0.065
Blackpool	"	4	0.054
Crossen Marsh	Mud	4	0.11
"	Salt marsh	4	0.12
Ainsdale	Sand	4	0.055
New Brighton	Mussel bed	4	0.074
West Kirby	Mud and sand	1	0.062
"	Sand	1	0.063
Rock Ferry	Mud	4	0.11
Runcorn	"	1	0.091
"	Mud and sand	1	0.10
"	Salt marsh	2	0.11
Little Neston Marsh	Mud and sand	2	0.077
"	Salt marsh	2	0.085
Flint	Mud	3	0.095
"	Mud and sand	1	0.088
"	Salt marsh	4	0.13
Prestatyn	Sand	2	0.057
Rhyl	Mud	2	0.078
Llandudno	Shingle	2	0.085
Caerhun	Salt marsh	2	0.11
Llanfairfechan	"	2	0.090
South-west Scotland			
Garlieston	Mud	2	0.096
"	Mud and sand	2	0.093
Innerwell	"	4	0.087
Bladnoch	Mud	4	0.10
Creetown	Salt marsh	4	0.13
Carsluith	Mud and sand	3	0.086
"	Mud	1	0.087
Skyreburn Bay (Water of Fleet)	Salt marsh	4	0.091
Palnackie Harbour	Mud	2	0.12
"	Mud and sand	2	0.10
Gardenburn	Salt marsh	4	0.13
Kippford - Slipway	Mud and sand	2	0.086
" "	Mud	2	0.089
" - Merse	Salt marsh	4	0.16
Cumstoun	"	4	0.11
Carsethorn	Mud and sand	4	0.11
Glencaple Harbour	"	4	0.088

 # See sub-section 3.2 for definition

The converse situation, of the critical group of fish and shellfish consumers also receiving exposure from external pathways, also needs to be considered. Habits survey data indicate, however, that the external component is too small to make a significant difference to the result for their exposure already given in sub-section 4.1.1; additions of this small order are considered to be adequately taken into account by the maximising process of summing exposures from the consumption of fish, crustaceans and molluscs.

It is to be noted that the levels of radionuclide concentrations in sediments (shown in Table 10) give rise to only very minor radiation exposures to the public following inhalation of resuspended particulates, including those from the surf zone (Pattenden *et al*., 1981).

Table 10. Radioactivity in sediment from the Cumbrian coast and further afield, 1993

Sampling point and sediment type		No. of sampling observa-tions#	Mean radioactivity concentration (dry), Bq kg^{-1}										
			Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{95}Zr	^{95}Nb	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs
Cumbria													
Newton Arlosh	Turf	4	1500	ND	3.6	ND	ND	ND	ND	14	ND	ND	3.8
Maryport - Christchurch	Mud	4	3400	"	10	"	110	140	"	600	2.5	29	5.2
Harrington Harbour	"	4	3300	"	9.2	"	120	160	1.3	660	3.5	32	4.9
Whitehaven - yacht basin	"	4	4200	"	7.9	"	120	150	ND	540	4.0	20	5.9
St Bees	Sand	4	400	"	2.4	"	ND	ND	"	1.1	ND	ND	0.32
Sellafield	"	4	1300	"	2.0	"	"	"	"	3.2	"	0.48	0.53
River Calder (Pos. A)	Mud	1	1100	"	3.8	"	"	"	"	ND	"	ND	1.9
" (Pos. B)	"	1	2300	8.8	130	6.8	"	"	"	41	"	6.4	44
" (Pos. C)	"	1	13000	7.1	860	ND	"	"	"	ND	"	ND	61
" (Pos. D)	"	1	4800	ND	900	"	"	"	"	"	"	"	18
" (Pos. E)	"	1	990	"	7.0	"	"	"	"	"	"	"	9.9
Seascale	Sand	4	560	"	1.8	"	"	"	"	3.3	"	0.27	0.45
Drigg pipeline	"	4	510	"	2.1	"	1.9	0.57	"	11	"	1.2	0.54
River Mite estuary	Mud	3	2100	"	9.5	"	59	76	1.3	400	3.4	22	2.0
"	Mud & sand	1	980	"	4.8	"	24	31	ND	110	ND	8.4	ND
Ravenglass - Ravenvilla	"	4	1700	"	7.6	"	27	39	"	190	1.3	11	1.5
Newbiggin	Mud	1	4000	"	10	"	46	70	"	390	6.9	21	1.2
"	Mud & sand	3	1700	"	8.0	"	38	47	"	220	ND	14	0.57
Millom	"	4	820	"	2.0	"	13	12	"	77	0.93	4.2	0.80
Low Shaw	Turf	4	1400	"	5.9	"	ND	ND	"	27	ND	ND	8.2
Walney Channel	Mud & sand	4	930	"	2.1	"	7.7	5.8	"	55	"	4.0	0.43
Flookburgh	"	4	670	"	0.37	"	ND	ND	"	4.3	"	ND	0.51
Sand Gate marsh	Turf	4	980	"	1.2	"	"	"	"	ND	"	"	1.8
Lancashire, Merseyside and north Wales													
Sunderland Point	Mud & sand	4	880	"	1.1	"	"	"	"	12	"	1.8	1.0
Conder Green	Turf	4	1600	"	2.7	"	"	"	"	13	"	3.1	2.9
Hambleton	"	4	2400	"	5.1	"	"	"	"	ND	"	6.4	6.6
Skippool Creek	Mud	3	1700	"	2.4	"	1.6	3.5	"	37	"	4.8	2.8
"	Mud & sand	1	1600	"	3.4	"	ND	ND	"	46	"	ND	3.4
Fleetwood	Sand	4	410	"	ND	"	"	"	"	ND	"	"	ND
Blackpool	"	4	240	"	"	"	"	"	"	"	"	"	"
New Brighton	"	2	370	"	"	"	"	"	"	"	"	"	"
"	Mud	1	1200	"	1.5	"	"	"	"	19	"	4.2	1.6
Rock Ferry	"	4	1000	"	0.50	"	"	"	"	ND	"	0.94	0.73
Rhyl	"	2	770	"	0.21	"	"	"	"	"	"	ND	1.3
Caerhun	Turf	2	1000	"	ND	"	"	"	"	"	"	"	1.5
Cemlyn Bay	Mud	2	1100	"	1.1	"	"	"	"	"	"	"	1.9
Llanfairfechan	Turf	2	1000	"	ND	"	"	"	"	"	"	"	6.1
South-west Scotland													
Garlieston	Mud	3	1300	"	3.2	"	5.1	7.4	"	90	"	1.6	2.3
"	Mud & sand	1	1100	"	2.5	"	ND	ND	"	26	"	2.6	2.0
Innerwell	"	2	800	"	1.6	"	1.8	"	"	25	"	1.5	0.97
Bladnoch	Mud	4	1700	"	4.3	"	4.8	4.9	"	67	"	3.6	2.9
Carsluith	"	2	1200	"	2.9	"	ND	ND	"	31	"	ND	0.79
"	Mud & sand	2	1100	"	2.6	"	7.5	15	"	63	"	4.0	1.5
Kippford Merse	Salt marsh	4	1800	"	6.6	"	ND	ND	"	92	"	9.7	3.2
" Slipway	Mud	2	1300	"	2.8	"	6.0	8.8	"	62	"	4.0	1.4
" "	Mud & sand	2	940	"	1.8	"	8.3	9.6	"	70	"	ND	ND
Palnackie Harbour	Mud	3	1400	"	3.6	"	4.1	6.0	"	75	"	4.4	1.7
" "	Mud & sand	1	1100	"	3.1	"	7.6	13	"	65	"	ND	2.4
Carsethorn	Mud	1	1500	"	2.7	"	ND	ND	"	17	"	"	2.5
"	Mud & sand	1	900	"	ND	"	"	"	"	48	"	"	ND
Isle of Man													
Douglas	Mud	1	800	"	"	"	"	"	"	ND	"	1.4	1.6
Ramsey	Sand	1	520	"	"	"	"	"	"	"	"	ND	ND
Northern Ireland													
Lough Foyle	Mud	2	430	"	4.1	"	"	"	"	"	"	1.6	0.64
Portrush	Sand	2	200	"	ND	"	"	"	"	"	"	ND	ND
Ballymacormick	Mud	2	440	"	"	"	"	"	"	"	"	"	"
Strangford Lough - Nickey's Pt	"	2	620	"	"	"	"	"	"	"	"	"	"
Dundrum Bay	Sand	1	630	"	"	"	"	"	"	"	"	"	"
" "	Mud	1	650	"	"	"	"	"	"	"	"	"	"
Carlingford Lough	"	2	920	"	"	"	"	"	"	"	"	"	1.1
Oldmill Bay	"	2	720	"	"	"	"	"	"	"	"	0.77	0.47

Table 10. continued

Sampling point and sediment type		No. of sampling observa-tions#	Mean radioactivity concentration (dry), Bq kg^{-1}									
			^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Cumbria												
Newton Arlosh	Turf	4	990	ND	2.0	2.3	NA	NA	NA	240	NA	NA
Maryport - Christchurch	Mud	4	1000	110	22	13	140	650	“	1000	1.7	2.2
Harrington Harbour	“	4	1000	110	27	11	NA	NA	“	990	NA	NA
Whitehaven - yacht basin	“	4	1300	110	24	13	180	810	“	1200	ND	2.4
St Bees	Sand	4	98	ND	3.0	1.6	NA	NA	“	140	NA	NA
Sellafield	“	4	160	“	3.4	1.7	“	“	“	170	“	“
River Calder (Pos. A)	Mud	1	430	“	ND	2.3	“	“	“	18	“	“
“ (Pos. B)	“	1	1400	34	9.1	ND	“	“	“	51	“	“
“ (Pos. C)	“	1	5900	ND	28	16	“	“	“	330	“	“
“ (Pos. D)	“	1	960	“	ND	4.2	“	“	“	59	“	“
“ (Pos. E)	“	1	380	“	“	ND	“	“	“	ND	“	“
Seascale	Sand	4	110	“	3.7	2.1	“	“	“	180	“	“
Drigg pipeline	“	4	85	0.93	4.8	2.3	“	“	“	220	“	“
River Mite estuary	“	3	660	44	24	11	200	890	13000	1400	ND	2.3
“ “ “	Mud & sand	1	320	11	13	9.7	NA	NA	NA	540	NA	NA
Ravenglass - Ravenvilla	“	4	390	34	13	7.0	“	“	“	700	“	“
Newbiggin	Mud	1	550	29	21	7.5	130	630	9100	900	ND	2.0
“	Mud & sand	3	530	39	18	6.8	NA	NA	NA	720	NA	NA
Millom	“	4	200	11	3.5	2.2	“	“	“	220	“	“
Low Shaw	Turf	4	860	ND	13	2.9	“	“	“	510	“	“
Walney Channel	Mud & sand	4	190	7.0	4.8	3.4	“	“	“	220	“	“
Flookburgh	“	4	170	ND	ND	ND	“	“	“	40	“	“
Sand Gate marsh	Turf	4	490	“	1.8	0.73	“	“	“	120	“	“
Lancashire, Merseyside and north Wales												
Sunderland Point	Mud & sand	4	310	ND	0.82	0.63	“	“	“	100	“	“
Conder Green	Turf	4	1100	“	3.2	2.6	“	“	“	290	“	“
Hambleton	“	4	1800	“	7.0	ND	“	“	“	420	“	“
Skippool Creek	Mud	3	730	4.2	7.8	“	“	“	“	280	“	“
“	Mud & sand	1	820	ND	9.6	5.2	“	“	“	320	“	“
Fleetwood	Sand	4	34	“	ND	0.38	“	“	“	14	“	“
Blackpool	“	4	12	“	“	ND	“	“	“	3.8	“	“
New Brighton	“	2	32	“	“	“	“	“	“	9.9	“	“
“	Mud	1	340	“	4.0	2.2	“	“	“	110	“	“
Rock Ferry	“	4	420	“	0.72	2.2	“	“	“	120	“	“
Rhyl	“	2	190	“	ND	ND	“	“	“	48	“	“
Caerhun	Turf	2	290	“	“	“	“	“	“	60	“	“
Cemlyn Bay	Mud	2	270	“	“	1.4	7.6	39	“	55	0.059	0.12
Llanfairfechan	Turf	2	360	“	“	1.3	NA	NA	“	55	NA	NA
South-west Scotland												
Garlieston	Mud	3	340	15	4.9	3.2	32	150	“	240	ND	0.45
“	Mud & sand	1	210	ND	3.5	2.8	NA	NA	“	140	NA	NA
Innerwell	“	2	170	“	0.80	3.2	“	“	“	110	“	“
Bladnoch	Mud	4	590	5.6	6.4	4.6	“	“	“	330	“	“
Carsluith	“	2	260	ND	2.6	3.5	20	100	“	160	ND	0.39
“	Mud & sand	2	250	5.1	5.5	2.3	NA	NA	“	180	NA	NA
Kippford Merse	Salt marsh	4	800	9.0	12	3.8	68	320	“	470	ND	1.3
“ Slipway	Mud	2	350	ND	5.0	ND	27	140	“	230	0.42	0.40
“ “	Mud & sand	2	280	6.1	3.6	1.6	NA	NA	“	180	NA	NA
Palnackie Harbour	Mud	3	440	3.9	7.0	4.0	38	190	“	290	ND	0.52
“ “	Mud & sand	1	300	9.5	ND	ND	NA	NA	“	170	NA	NA
Carsethorn	Mud	1	590	ND	“	“	“	“	“	170	“	“
“	Mud & sand	1	210	“	“	4.1	“	“	“	110	“	“
Isle of Man												
Douglas	Mud	1	68	“	“	ND	“	“	“	3.1	“	“
Ramsey	Sand	1	16	“	“	“	“	“	“	ND	“	“
Northern Ireland												
Lough Foyle	Mud	2	28	“	“	“	0.41	2.3	“	0.78	ND	ND
Portrush	Sand	2	1.9	“	“	“	NA	NA	“	ND	NA	NA
Ballymacormick	Mud	2	42	“	“	“	1.7	9.0	“	11	0.013	0.020
Strangford Lough - Nickey’s Pt	“	2	52	“	“	1.5	1.3	6.6	“	6.0	0.014	0.010
Dundrum Bay	Sand	1	15	“	“	ND	NA	NA	“	1.6	NA	NA
“ “	Mud	1	17	“	“	“	“	“	“	1.9	“	“
Carlingford Lough	“	2	180	“	“	1.6	2.5	14	“	7.5	0.012	0.0084
Oldmill Bay	“	2	82	“	“	1.8	2.5	13	“	17	0.031	0.033

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

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 dosemeters. Results for 1993 are presented in Table 11. Measured dose rates were similar to those for 1992 (Camplin, 1993(a)). Habits surveys keep under review the amounts of time spent by fishermen handling their gear; for those most exposed, an increase in the time handling nets and pots to a value of 2500 h year^{-1} was noted. The maximum exposure from handling of fishing gear in 1993, including a component due to natural radiation, would have been 0.61 mSv, which is 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 the Sellafield vicinity, for consumption after being made into laverbread, was reported in 1993; 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 1993 are presented in Table 12. Samples of laverbread from the major manufacturers are regularly collected from markets in South Wales and analysed. Results for 1993 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.

Table 11. Beta radiation dose rates on contact with fishing gear on vessels operating off Sellafield, 1993

Vessel	Type of gear	No. of sampling observations#	Mean beta dose rate in tissue, µSv h^{-1}
A	Nets	4	0.13
	Ropes	4	0.039
B	Nets	8	0.20
	Ropes	8	0.28
D	Gill nets	3	0.13
	Pots	2	0.36
E	Gill nets	4	0.24
	Nets	2	0.31
R	Nets	4	0.10
S	Pots	1	0.30
T	Gill nets	3	0.32
	Pots	1	0.54
U	Nets	4	0.14
	Ropes	4	0.080

 # See sub-section 3.2 for definition

Table 12. Radioactivity in Porphyra from UK shorelines of the Irish Sea, 1993

Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet), Bq kg^{-1}										
		Total beta	^{14}C	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{99}Tc	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb
Braystones south	4	160	NA	0.28	NA	0.86	0.43	NA	0.20	36	0.87	0.62
Seascale	52*	NA	“	0.12	“	1.5	1.3	“	0.17	52	1.4	1.5
St Bees	4	160	26	0.27	0.85	1.1	1.5	0.99	0.18	43	0.81	1.9
Knock Bay	4	110	NA	ND	NA	ND	ND	NA	ND	0.38	ND	ND

Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet), Bq kg^{-1}									
		^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Pu	^{241}Am	^{242}Cm	$^{243}Cm+^{244}Cm$
Braystones south	4	ND	3.4	0.25	ND	5.8	2.7	43	4.9	0.0091	0.0095
Seascale	52*	“	3.6	0.37	0.04	NA	NA	NA	6.3	NA	NA
St Bees	4	0.02	6.0	0.70	ND	1.1	5.2	87	8.8	0.012	0.014
Knock Bay	4	ND	0.59	ND	“	NA	NA	NA	0.35	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*

Table 13. *Radioactivity in laverbread from South Wales, 1993*

Manufacturer	No. of sampling observa-tions#	Mean radioactivity concentration (wet), Bq kg^{-1}		
		Total beta	^{137}Cs	^{241}Am
A	4	55	0.15	0.10
C	4	32	0.17	ND
D	4	93	0.22	0.06
E	1	83	0.66	ND

ND = not detected

 # See sub-section 3.2 for definition

4.1.5 Contact dose-rate monitoring of intertidal areas

Contact beta and gamma dose rates in intertidal areas are regularly monitored to locate and remove any material with unusual levels of contamination. A summary of items detected during 1993 is presented in Table 14. The rate of detection decreased as compared with 1992 and, in particular, no contaminated hydroids such as were found after damage to the sea pipeline in 1992 were found. Finds were typical of those in recent years prior to 1992. The presence of contaminated items only represents a pathway for exposure of the public in the unlikely event of prolonged contact with them. The standard with which to compare the dose rates is the dose limit of 50 mSv year^{-1} for exposures to skin of members of the public (sub-section 3.3). It would be necessary for direct skin contact to be maintained for several hundred hours or more for this dose to be reached and it is therefore considered unlikely that anyone has received a dose to skin in excess of the limit.

Table 14. *Summary of contact beta and gamma dose rate monitoring of intertidal areas of Cumbria, 1993*

Month	No. of items detected (> 0.01mGy h^{-1} but below 0.1 mGy h^{-1})	Location and dose rates (mGy h^{-1}) of items 0.1 mGy h^{-1} and above
January	-	-
February	2	-
March	2	Ehen spit: 0.17
April	-	-
May	-	-
June	-	-
July	-	10m south of pipeline: 0.12
August	2	-
September	2	-
October	-	-
November	-	-
December	-	-

4.1.6 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 15 presents the results of measurements in 1993 on marine plants from shorelines of the Irish Sea and further afield. Concentrations were similar to those for 1992. Although small quantities of samphire and *Rhodymenia* may be eaten and seaweeds are occasionally used as fertilisers, concentrations of radioactivity are of negligible radiological significance. *Fucus* seaweeds are useful indicators, particularly of fission product radionuclides other than ruthenium-106; samples of *Fucus vesiculosus* are collected both in the Sellafield vicinity and further afield, and the results are presented here. Monitoring in Scotland is carried out on behalf of the Scottish Office. Analyses of 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 beta-emitting radionuclides decreased in 1993 (62.5 TBq) as compared with 1992 (121 TBq) because less uranium ore concentrate was processed. 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 1993. 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.

Table 15. Radioactivity in marine plants from shorelines of the Irish Sea and further afield, 1993

Type of seaweed and sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet), Bq kg^{-1}										
		Total beta	^{14}C	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{99}Tc	^{106}Ru	^{110m}Ag	^{125}Sb	^{129}I
Fucus vesiculosus												
Sellafield	4	1000	NA	1.4	1.7	3.0	1.7	1100	9.7	10	1.5	NA
St Bees	4	990	26	1.2	2.9	3.1	1.8	1300	9.8	11	1.8	1.9
Port William	4	320	NA	0.1	NA	0.12	0.05	150	ND	0.09	0.42	NA
Garlieston	4	380	“	0.4	“	0.24	0.14	NA	0.85	0.20	0.37	“
Auchencairn	4	430	“	0.4	“	0.27	ND	“	ND	0.37	0.67	“
Cape Wrath	1	190	“	ND	“	ND	“	12	“	ND	ND	“
Wick	1	180	“	“	“	“	“	6.9	“	“	“	“
Ardglass	5	210	“	“	“	“	“	49	“	“	0.06	“
Portrush	2	210	“	“	“	“	“	NA	“	“	0.11	“
Portmadog	1	180	“	“	“	“	“	“	“	“	ND	“
Fishguard	1	200	“	“	“	“	“	20	“	“	“	“
Lavernock Point	2	220	“	“	“	“	“	NA	“	“	“	“
Isles of Scilly	1	150	“	“	“	“	“	1.5	“	“	“	“
Fucus serratus												
Portrush	2	190	“	“	“	“	“	NA	“	“	“	“
Alaria esculenta												
Isle of Man	1	1600	“	“	“	“	“	“	“	“	“	“
Rhodymenia spp.												
St Bees	2	630	“	0.3	“	4.6	2.1	“	27	3.9	0.64	“
Strangford Lough	4	830	“	ND	“	ND	ND	1.4	0.26	ND	ND	“
Samphire												
Rabbit Cat How, Ravenglass	1	31	“	“	“	0.95	“	0.92	3.5	“	“	“
Cockerham Marsh	1	46	“	“	“	ND	“	NA	ND	“	“	“

Type of seaweed and sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet), Bq kg^{-1}									
		^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Fucus vesiculosus											
Sellafield	4	0.19	14	0.50	ND	ND	2.4	10	5.7	0.0067	0.012
St Bees	4	0.25	13	0.40	“	“	2.2	9.9	6.1	0.012	0.013
Port William	4	ND	4.9	ND	“	0.04	NA	NA	0.70	NA	NA
Garlieston	4	“	8.5	“	“	0.06	“	“	3.0	“	“
Auchencairn	4	“	14	“	“	ND	“	“	2.8	“	“
Cape Wrath	1	“	0.6	“	“	“	“	“	ND	“	“
Wick	1	“	0.3	“	“	“	“	“	“	“	“
Ardglass	5	“	2.1	“	“	“	“	“	“	“	“
Portrush	2	“	1.0	“	“	“	“	“	0.09	“	“
Portmadog	1	0.08	1.7	“	“	0.17	“	“	ND	“	“
Fishguard	1	ND	0.96	“	“	ND	“	“	“	“	“
Lavernock Point	2	“	0.4	“	“	“	“	“	“	“	“
Isles of Scilly	1	“	0.2	“	“	“	“	“	“	“	“
Fucus serratus											
Portrush	2	“	0.4	“	“	“	“	“	0.11	“	“
Alaria esculenta											
Isle of Man	1	“	8.1	“	“	“	“	“	ND	“	“
Rhodymenia spp.											
St Bees	2	0.49	31	1.3	0.28	0.17	1.4	6.3	12	0.041	0.028
Strangford Lough	4	ND	4.1	ND	ND	0.04	0.09	0.45	0.57	ND	0.0012
Samphire											
Rabbit Cat How, Ravenglass	1	“	3.6	“	0.25	ND	NA	NA	5.4	NA	NA
Cockerham Marsh	1	“	1.9	“	ND	“	“	“	0.50	“	“

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

In 1993, locally-obtained fish and shellfish continued to be sampled though there is little consumption of seafood from the estuary. 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 1993 are shown in Tables 16(a) and (b). Radionuclides detected which were partly or wholly due to Springfields discharges were isotopes of thorium, uranium and neptunium and their decay products. Natural sources also contributed to activities of thorium, uranium and their decay products. 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.

Beta and gamma dose rates over intertidal areas were generally similar to those for 1992. Exposure of the critical group of houseboat dwellers has been assessed on the basis of the revised estimates of natural background dose rates (see sub-section 3.3). In 1993 their exposure including the Sellafield component was 0.26 mSv, a small increase on the value for 1992 (0.25 mSv) calculated on the same basis. The increase is likely to be due to environmental fluctuations and is not significant. The exposure was within the dose limit of 1 mSv year^{-1} 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 1993 from Springfields has been calculated from appropriate models (HMIP and MAFF, 1991). The contribution is estimated to be 0.01 mSv. This dose, in addition to those considered below, is less than the maximum constraint recommended by NRPB for a single new source of 0.3 mSv. It is also a small fraction of the dose received in 1993 due to the combined effects of past and current discharges.

The whole-body exposure of wildfowlers was assessed as being 0.03 mSv in 1993 on the basis of ICRP-26 and 0.04 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

Table 16(a). Radioactivity in environmental materials near Springfields, 1993

Material	Sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}											
			Total beta	^{60}Co	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu	^{228}Th	^{230}Th	^{232}Th
Flounder	Ribble Estuary	1	130	ND	ND	ND	ND	20	ND	ND	ND	NA	NA	NA
Salmon	“	1	180	“	“	“	“	0.46	“	“	“	“	“	“
Sea trout	“	1	130	“	“	“	0.34	43	“	“	“	“	“	“
Shrimps	“	1	100	“	“	“	ND	7.5	“	“	“	“	“	“
Turf	Hesketh Bank	4	1500	2.6	15	2.1	1.5	610	“	4.0	2.4	“	“	“
Mud	Becconsall	4	13000	0.95	12	ND	0.43	380	3.0	0.36	0.36	33	86	30
“	Pipeline	3	18000	0.86	25	1.9	2.1	610	ND	4.8	ND	36	130	32
Mud & sand	“	5	470000	0.38	13	1.7	0.34	240	9.6	1.5	0.95	40	210	17
“	Deepdale Brook	1	3400	ND	ND	ND	ND	34	ND	ND	6.2	49	370	36
Mud	“	3	2800	“	“	1.5	“	17	“	“	5.4	24	280	22
“	Savick Brook	4	230000	2.6	41	7.4	3.0	800	6.1	5.7	ND	NA	NA	NA
“	Penwortham	4	93000	2.6	31	3.7	3.4	700	3.5	4.4	“	46	230	37

Material	Sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}									
			^{234}Th	^{233}Pa	^{234}U	^{235}U+ ^{236}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Flounder	Ribble Estuary	1	ND	ND	NA	NA	NA	NA	NA	NA	ND	NA	NA
Salmon	“	1	“	“	“	“	“	“	“	“	“	“	“
Sea trout	“	1	“	“	“	“	“	“	“	“	“	“	“
Shrimps	“	1	“	“	“	“	“	“	“	“	“	“	“
Turf	Hesketh Bank	4	490	“	“	“	“	“	“	“	210	“	“
Mud	Becconsall	4	17000	“	38	2.0	36	“	“	“	130	“	“
“	Pipeline	3	24000	“	410	18	380	“	26	140	220	ND	0.45
Mud & sand	“	5	230000	“	150	6.1	110	“	NA	NA	100	NA	NA
“	Deepdale Brook	1	1500	“	1700	78	1500	“	“	“	ND	“	“
Mud	“	3	1000	12	1400	66	1300	5.4	“	“	“	“	“
“	Savick Brook	4	330000	ND	NA	NA	NA	NA	41	220	310	0.81	0.40
“	Penwortham	4	140000	“	81	2.7	61	0.99	NA	NA	260	NA	NA

NA = not analysed
ND = not detected
#See sub-section 3.2 for definition
**Except for sediment where dry concentrations apply*

Table 16(b). Monitoring of radiation dose rates near Springfields, 1993

Location	Material	No. of sampling observa-tions#	μGy h⁻¹
Gamma dose rates at 1 m over intertidal areas			
Lytham - Boatyard	Mud	4	0.12
" - Windmill Marsh	Salt marsh	1	0.14
Warton Marsh	Mud	4	0.15
"	Salt marsh	4	0.16
The Naze	"	1	0.15
Hesketh Bank	Mud	4	0.13
"	Salt marsh	4	0.13
Freckleton	Mud	4	0.13
River Douglas	Grass	1	0.20
Becconsall	Mud	3	0.11
"	Mud and sand	1	0.11
" (boat 2)	Cabin*	8	0.10
" "	Mud	3	0.13
" "	Mud and sand	1	0.12
Hutton Marsh	Mud	4	0.16
"	Salt marsh	4	0.14
Pipeline	Mud	3	0.11
"	Mud and sand	2	0.12
Pipeline (south bank)	"	4	0.098
"	Salt marsh	4	0.18
Penwortham	Mud and sand	1	0.10
"	Mud	3	0.16
Lower Penwortham	"	4	0.14
"	Grass	4	0.097
Penwortham Railway Bridge	Mud	3	0.11
"	Mud, sand and stones	1	0.11
"	Grass	4	0.081
River Darwen	Mud and sand	1	0.089
"	Mud	1	0.083
"	Mud,sand and stones	1	0.091
"	Grass	4	0.079
Beta dose rates			μSv h⁻¹
Lytham - Windmill Marsh	Salt marsh	1	1.1
Warton Marsh	Mud	4	4.0
The Naze	Salt marsh	1	0.96
Hesketh Bank	Mud	4	3.1
River Douglas	Grass	1	1.4
Deepdale Brook	Mud	1	0.78
"	Mud and sand	2	0.87
"	Soil	1	1.1
Becconsall	Mud	1	11
" (boat 2)	"	1	ND
Hutton Marsh	"	4	6.6
Pipeline (south bank)	Mud and sand	4	3.7
Savick Brook	Mud	4	53
Penwortham	"	3	34
"	Mud and sand	1	3.1
Lower Penwortham	Mud	4	27
"	Grass	4	2.7
Penwortham Railway Bridge	"	4	1.4
"	Mud	3	11
"	Mud, sand and stones	1	7.0
River Darwen	Mud	2	3.2
"	Mud,sand and stones	1	0.43
"	Mud and sand	1	3.4
"	Grass	4	0.75
Ribble estuary	Gill net	2	1.0
"	Shrimp net	1	0.34
"	Fyke net	1	1.1

#See sub-section 3.2 for definition
**In the cabin of a houseboat*

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 less than that of wildfowlers.

The critical group for skin irradiation was anglers with skin exposures, including a component due to natural radiation, of 2.2 mSv in 1993. This is 4% of the relevant dose limit for members of the public.

4.3 Capenhurst, Cheshire

The main function of the Capenhurst Works is enrichment of uranium. Radioactive waste arisings, mainly of uranium and its daughter products, and technetium-99 and neptunium-237 from recycled fuel, are minor; the Works 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 1993 (see Table 1). An environmental monitoring programme related to the pathways which could be of radiological significance due to both disposal routes has been established. Aquatic plants are also sampled as indicator materials.

Results for 1993 are presented in Table 17. Concentrations of radionuclides in materials from the Rivacre Brook were similar to those for 1992. 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 1993. The concentrations of artificial radioactivity in marine samples are consistent with values expected at this distance from Sellafield. Concentrations of technetium-99 in such samples were low, reflecting the low levels of discharges of this radionuclide from Sellafield.

4.4 Chapelcross, Dumfriesshire

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 of beta activity excluding tritium were 0.265 TBq in 1993 compared with 0.07 Tbq in 1992 and reflected operations to empty the fuel element storage ponds for cleaning and maintenance. 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 wildfowlers who are exposed whilst on salt marshes. DFR monitoring, which is carried out on behalf of the Scottish Office, reflects these pathways. Samples of *Fucus vesiculosus*, as useful indicators, are also analysed. The results of monitoring in 1993 are presented in Tables 18(a) and (b).

Table 17. Radioactivity in environmental materials near Capenhurst, 1993

Material	Sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			Total beta	^{60}Co	^{99}Tc	^{125}Sb	^{134}Cs	^{137}Cs	^{155}Eu	^{234}Th
Cockles	Dee estuary	4	70	0.12	1.6	0.02	0.02	3.6	ND	7.8
Shrimps	Hoylake	2	73	ND	0.62	ND	ND	5.2	"	ND
"	Dee Estuary	1	78	"	NA	"	0.06	7.6	"	"
Cladophoraceae rupestris	Rivacre Brook	2	610	"	300	"	ND	1.3	"	170
Mud and sand	"	2	2200	0.15	1200	"	0.56	18	0.64	410

Material	Sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
			^{234}U	^{235}U+ ^{236}U	^{238}U	^{233}Pa	^{237}Np	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{243}Cm+ ^{244}Cm
Cockles	Dee estuary	4	NA	NA	NA	0.42	NA	0.13	0.72	1.9	0.0029
Shrimps	Hoylake	2	"	"	"	ND	"	NA	NA	ND	NA
"	Dee estuary	1	"	"	"	"	"	"	"	"	"
Cladophoraceae rupestris	Rivacre Brook	2	62	3.8	37	16	10	"	"	"	"
Mud and sand	"	2	290	20	180	66	43	"	"	"	"

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

Table 18(a). Radioactivity in environmental materials near Chapelcross, 1993

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{14}C	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{106}Ru	^{110m}Ag	^{125}Sb
Flounder	4	160	39	ND	0.038	ND	ND	ND	ND	ND
Sea trout	2	140	NA	"	NA	"	"	"	"	"
Shrimps	4	81	"	"	0.07	"	"	"	0.49	"
Fucus vesiculosus	4	350	"	0.28	NA	"	"	"	ND	0.39
Mud and sand	4	830	"	1.2	"	2.6	0.7	22	"	3.2

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		^{134}Cs	^{137}Cs	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Flounder	4	ND	45	ND	ND	0.0037	0.019	0.029	ND	0.000027
Sea trout	2	0.16	24	"	"	0.0011	0.0055	0.0080	"	0.000011
Shrimps	4	0.04	15	"	"	0.0048	0.026	0.044	0.00014	0.00013
Fucus vesiculosus	4	0.11	18	"	0.10	0.61	3.0	3.3	0.0076	0.0080
Mud and sand	4	0.75	290	0.65	2.0	12	67	89	0.12	0.21

ND = not detected; NA = not analysed
** Except for sediment where dry concentrations apply*
 # See sub-section 3.2 for definition

Table 18(b). Monitoring of radiation dose rates near Chapelcross, 1993

Location	Material	No. of sampling observa-tions#	µSv h^{-1}
Beta dose rates on nets			
Seafield	Stake nets	3	0.44
Gamma dose rates at 1 m over intertidal areas			µGy h^{-1}
Seafield	Mud and sand	3	0.089
"	Salt marsh	4	0.099
Battle Hill	Mud and sand	4	0.086
Browhouses	"	4	0.096
Dornoch Brow	"	1	0.090
"	Mud, sand and stones	1	0.090
"	Salt marsh	4	0.098
Powfoot	"	3	0.079
" *	"	4	0.079

 # See sub-section 3.2 for definition
** 15 cm above substrate*

Concentrations of artificial radionuclides in the Chapelcross vicinity are mostly due to Sellafield discharges, and the general levels of nuclides given in Table 18(a) are consistent with values expected at this distance from Sellafield. Concentrations of radiocaesium in 1993 were generally similar to those in 1992 despite the increase in discharges noted above. The exposure of the critical group of fishermen who consume seafood and are exposed to external radiation over intertidal areas was 0.04 mSv in 1993 (on the basis of ICRP-60: 0.04 mSv), which is 4% of the dose limit of 1 mSv year^{-1} for members of the public. This assessment takes into account the revised estimates of natural background dose rates (see sub-section 3.3). The exposure of the skin of local fishermen, including a component due to natural radiation, increased in 1993 to 0.11 mSv (0.05 mSv: 1992). However, the skin exposure was very small, corresponding to less than 1% of the dose limit appropriate for exposures to skin of members of the public. Wildfowlers received a dose of less than 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.

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 Thames catchment. In July 1992, the authorisation was revised to specify lower limits for discharges made directly to the River Thames at Sutton Courtenay and to introduce limits for discharges to the Lydebank Brook to the north of the site. During 1993, 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).

In addition, sampling was carried out in 1993 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 a potential critical group which may be 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^{-1} was assumed.

The results of the measurements of radioactivity concentrations are shown in Table 19. The gamma dose rate on the river bank at Sutton Courtenay was 0.081 μGy h^{-1} in 1993 (9 observations). The concentrations of artificial radioactivity detected were very low. 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 μGy h^{-1}. The radiation dose to anglers in 1993 from fish consumption and external occupancy of the river bank would have been 0.01 mSv, or 1% of the dose limit of 1 mSv year^{-1}.

Table 19. Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Harwell, 1993

Material	Sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			Total beta	^{57}Co	^{60}Co	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+^{240}Pu	^{241}Am
Pike	Outfall (Sutton Courtenay)	1	120	ND	ND	0.14	5.9	ND	0.000073	0.00027	0.00042
	Newbridge	1	93	"	"	ND	0.06	"	0.000066	0.00036	0.00047
	Staines	1	110	"	"	"	0.59	"	NA	NA	ND
Nuphar lutea	Sutton Courtenay	1	39	"	0.61	"	0.64	"	"	"	"
	Newbridge	1	30	"	ND	"	ND	"	"	"	"
	Staines	1	34	0.10	"	"	0.16	"	"	"	"
Mud and sand	Staines	1	280	ND	1.2	"	20	1.0	"	"	"
Mud	Newbridge	1	610	"	ND	"	19	2.8	"	"	"
	Sutton Courtenay	1	970	"	16	"	520	ND	"	"	"

NA = not analysed
ND = not detected
** Except for sediment where dry concentrations apply*
 # See sub-section 3.2 for definition

5.2 Winfrith, Dorset

The principal source of liquid radioactive wastes at this establishment in 1993 was decommissioning and decontamination of the Steam Generating Heavy Water Reactor (SGHWR) which ceased power production in September 1990. Discharges of radionuclides other than tritium in 1993 were substantially less than those prior to the SGHWR ceasing power production because regular decontamination of the primary coolant circuit was no longer needed. The wastes from decommissioning operations are disposed of under authorisation to deep water in Weymouth Bay. The radiological significance of the discharges from Winfrith is small and mainly due to activation products from decommissioning of the SGHWR. Concentration of activation products 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 20(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, particularly zinc-65, declined in 1993 as compared with previous years; this was due to the closure of the SGHWR noted above. The radiation dose to the critical group of fish and shellfish consumers remained low in 1993 at less than 0.005 mSv, or less than 0.5% of the dose limit of 1 mSv year^{-1}. External gamma radiation dose rates, and dose rates on fishing nets, measured using portable instruments, continued to be indistinguishable from levels typical of the natural background.

Table 20(a). Radioactivity in environmental materials near Winfrith, 1993

Material	Sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}											
			Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{131}I	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Plaice	Weymouth Bay	2	100	ND	ND	ND	ND	0.10	ND	NA	NA	ND	NA	NA
Whiting	“	2	130	“	“	“	“	0.52	“	“	“	“	“	“
Crabs	Chapmans Pool	2	81	“	2.3	0.50	“	ND	“	“	“	“	“	“
“	Lulworth Banks	2	79	“	3.8	0.67	“	0.05	“	“	“	“	“	“
Pacific oysters	Poole	1	56	“	0.25	0.49	“	ND	“	“	“	“	“	“
Cockles	“	1	68	“	5.0	ND	“	0.10	“	“	“	“	“	“
Scallops	Lulworth Banks	1	100	0.13	1.7	0.51	“	0.13	“	“	“	“	“	“
Whelks	Weymouth Bay	2	74	ND	3.3	1.4	“	ND	“	“	“	“	“	“
“	Poole	2	110	“	2.1	1.6	“	“	“	0.00097	0.0041	0.0045	ND	0.00013
Fucus serratus	Arish Mell	2	200	“	5.1	ND	“	0.07	“	NA	NA	ND	NA	NA
“	Kimmeridge	2	190	“	3.6	“	“	0.13	“	“	“	0.076	“	“
“	Bognor Rock	2	240	“	3.2	“	0.39	0.12	0.05	“	“	ND	“	“
“	Weymouth	2	180	“	3.2	“	ND	0.11	ND	“	“	“	“	“
Mud and sand	Kimmeridge	3	300	“	2.7	“	“	1.1	“	“	“	“	“	“
“	Poole Harbour	2	88	“	4.2	“	“	1.5	“	0.08	0.41	0.33	“	0.0049
Mud	“	1	360	“	9.1	“	“	3.2	1.6	0.16	0.72	0.55	0.0019	0.0091
“	Hardway	2	760	“	10	“	“	3.9	1.5	NA	NA	ND	NA	NA

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 radiation dose rates near Winfrith, 1993

Location	Ground type	No. of sampling observa-tions#	µGy h^{-1}
Gamma dose rates at 1 m over intertidal areas			
Kimmeridge	Mud and sand	2	0.067
Poole Harbour	Mud	2	0.051
Hardway	“	2	0.067
Beta dose rates on fishing gear			µSv h^{-1}
Weymouth Bay	Gill nets	1	ND

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

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 the Ministry of Defence (Procurement Executive). Discharges from Dounreay in 1993 were generally similar to those in 1992 reflecting the campaigns of reprocessing of reactor fuel. DFR surveys near Dounreay are carried out on behalf of the Scottish Office. Monitoring in 1993 continued to include sampling of fish and shellfish from the area of the Dounreay outfall and other materials further afield, with associated beta and gamma dose rate measurements. The results are presented in Tables 21(a) and (b).

Table 21(a). Radioactivity in environmental materials near Dounreay, 1993

Sampling point and material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, $Bq\ kg^{-1}$										
		Total beta	^{14}C	^{54}Mn	^{60}Co	^{99}Tc	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
Pipeline												
Cod	4	130	26	ND	ND	NA	ND	ND	ND	ND	0.69	ND
Crabs	4	80	NA	"	0.06	"	"	1.1	"	"	0.32	"
Lobsters	4	70	"	"	ND	"	"	4.9	"	"	0.24	"
Sandside Bay												
Winkles	4	90	"	0.03	0.91	"	2.4	18	0.16	0.05	0.53	0.13
Sand	4	320	"	ND	0.10	"	ND	ND	ND	ND	5.7	ND
Fucus vesiculosus	4	300	"	0.54	1.3	64	1.5	1.4	0.12	0.17	1.7	0.13
Oigins Geo												
Sludge	4	3900	"	13	42	NA	1500	110	140	8.0	150	190
Brims Ness												
Winkles	4	91	"	ND	0.97	"	2.1	18	ND	ND	0.62	0.16
Fucus vesiculosus	2	270	"	0.39	1.6	"	2.3	2.0	0.11	0.22	1.5	0.62
Fucus spiralis	1	180	"	0.15	0.83	"	ND	0.48	ND	0.07	0.40	ND

Sampling point and material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, $Bq\ kg^{-1}$							
		^{154}Eu	^{155}Eu	^{238}Pu	$^{239}Pu+$ ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	$^{243}Cm+$ ^{244}Cm
Pipeline									
Cod	4	ND	ND	0.000068	0.00028	NA	0.00039	ND	ND
Crabs	4	"	"	0.0033	0.011	"	0.015	0.0014	0.00044
Lobsters	4	"	"	0.0050	0.015	"	0.062	0.0021	0.0013
Sandside Bay									
Winkles	4	ND	0.05	0.16	0.43	7.4	0.32	0.018	0.0067
Sand	4	1.3	1.6	2.7	9.8	NA	9.8	0.14	0.14
Fucus vesiculosus	4	ND	0.08	NA	NA	"	0.10	NA	NA
Oigins Geo									
Sludge	4	23	52	260	610	"	230	25	6.1
Brims Ness									
Winkles	4	ND	ND	0.15	0.41	"	0.31	0.017	0.0058
Fucus vesiculosus	2	"	0.20	NA	NA	"	0.24	NA	NA
Fucus spiralis	1	"	ND	"	"	"	ND	"	"

NA = not analysed
ND = not detected
** Except for sediment where dry concentrations apply*
 # See sub-section 3.2 for definition

Table 21(b). Monitoring of dose rates near Dounreay, 1993

Location	Ground type	No. of sampling observa-tions#	$\mu Gy\ h^{-1}$
Gamma dose rates at 1 m over intertidal areas			
Oigins Geo	Intertidal sediment	5	0.15
Sandside Bay	Sand	1	0.060
"	Winkle bed	4	0.10
Beta dose rates on fishing gear			$\mu Sv\ h^{-1}$
Sandside Bay	Nets	1	0.21
"	Gill nets	1	ND
Pipeline offshore	Pots	1	"
"	Ropes	1	0.20
Strathy Point	Gill nets	1	ND
"	Ropes	1	0.14

 # See sub-section 3.2 for definition

A recent habits survey has 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 1993 was 0.13 mSv, or less than 0.5% of the dose limit of 50 mSv $year^{-1}$ 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 1993, monitoring of sludge at Oigin's Geo was carried out;

concentrations of radionuclides increased compared with 1992. However, measurements of gamma dose rates above areas of the foreshore were also carried out and the results remained unchanged. Public radiation exposure via this pathway remained low, at 0.008 mSv or 0.8% of the dose limit of 1 mSv $year^{-1}$.

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, as in previous years, seaweed was sampled as an indicator material. Concentrations of radionuclides in 1993 were similar to those for 1992. 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 $year^{-1}$.

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 decreased in 1993 and the radiation dose due to a combination of consumption of molluscs and external exposure during collection was low at 0.02 mSv or 2% of the dose limit of 1 mSv $year^{-1}$. This pathway was the critical one at Dounreay in 1993.

6. NUCLEAR POWER STATIONS OPERATED BY THE ELECTRICITY COMPANIES

All but two of these sites are in England or Wales and are operated by Nuclear Electric plc. The power stations at Hunterston and Torness are 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; indeed discharges increased in 1993 due to these operations. In addition there is a component to these wastes from the adjoining Berkeley Technology Centre. Liquid radioactive wastes from both Berkeley and Oldbury are discharged to the same stretch of the Severn Estuary. The stations are therefore considered together for the purpose of DFR environmental monitoring. Habits surveys have confirmed that the two potentially 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.

Data for 1993 are presented in Tables 22(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. 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

Table 22(a). Radioactivity in environmental materials near Berkeley and Oldbury nuclear power stations, 1993

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}											
		Total beta	^{14}C	^{54}Mn	^{60}Co	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm+^{244}Cm$
Dover sole	2	150	250	ND	ND	ND	0.52	ND	NA	NA	ND	NA	NA
Flounder	2	100	120	"	"	"	0.76	"	"	"	"	"	"
Elvers	1	38	NA	"	"	"	0.21	"	"	"	"	"	"
Shrimps	2	130	180	"	"	"	0.61	"	0.00088	0.0048	0.0041	0.000034	0.000091
Fucus vesiculosus	2	230	NA	1.0	1.9	0.23	11	"	NA	NA	ND	NA	NA
Mud and sand													
area of pipelines	2	600	"	ND	0.23	0.79	49	2.0	"	"	1.5	"	"
Mud													
area of pipelines	1	940	"	"	ND	ND	42	2.9	"	"	0.88	"	"
Lydney	2	780	"	"	"	"	30	2.0	"	"	ND	"	"
Littleton Warth	2	970	"	"	"	1.6	44	0.94	"	"	"	"	"
1 km south of Oldbury	2	980	"	"	"	1.1	44	ND	"	"	"	"	"

NA = not analysed
ND = not detected
** Except for sediment where dry concentrations apply*
 # See sub-section 3.2 for definition

Table 22(b). ***Monitoring of gamma dose rates near Berkeley and Oldbury nuclear power stations, 1993***

Location	Ground type	No. of sampling observa-tions#	µGy h-1
Gamma dose rates at 1 m over intertidal areas			
1 km south of Oldbury	Mud	2	0.075
2 km south west of Berkeley	"	2	0.075
Guscar Rocks	"	2	0.085
Lydney Locks	"	2	0.074
Berkeley pipeline	"	1	0.073
"	Mud and sand	1	0.075
Sharpness	Mud	2	0.072
Littleton Warth	"	2	0.073

 # See sub-section 3.2 for definition

natural background, thus a calculation based on concentrations of radionuclides in sediments has been used to estimate the external exposure of the critical group of fish and shellfish consumers. Their total exposure due to liquid waste discharges was low, at 0.006 mSv or 0.6% of the dose limit of 1 mSv year^{-1}.

6.2 Bradwell, Essex

Radioactive liquid effluent from this power station is discharged to the estuary of the River Blackwater. The authorisation for discharge was revised in 1993 and limits were reduced. The 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.

Table 23(a). ***Radioactivity in environmental materials near Bradwell nuclear power station, 1993***

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg-1											
		Total beta	^{60}Co	^{65}Zn	^{99}Tc	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm+^{244}Cm$
Whiting	1	110	ND	ND	NA	0.18	1.1	ND	NA	NA	ND	NA	NA
Bass	1	110	"	"	"	0.98	4.6	"	"	"	"	"	"
Sole	2	110	"	"	"	0.26	1.4	"	"	"	"	"	"
Mullet	1	120	"	"	"	0.16	1.1	"	"	"	"	"	"
Native oysters	2	93	"	0.88	"	0.18	0.81	"	0.00083	0.0037	0.0078	0.000018	0.00031
Pacific oysters	1	57	"	1.1	"	0.25	0.86	"	NA	NA	ND	NA	NA
Winkles	2	80	1.0	0.48	"	0.38	2.0	"	"	"	"	"	"
Fucus vesiculosus	2	200	0.51	ND	1.90	0.63	2.7	"	"	"	"	"	"
Mud													
Pipeline	2	780	0.55	"	NA	4.1	17	4.3	"	"	"	"	"
West Mersea	2	650	2.0	"	"	2.3	19	1.9	"	"	"	"	"
Maldon	2	930	2.7	"	"	12	84	1.2	"	"	"	"	"
Burnham-on-Crouch	2	840	6.0	"	"	1.3	23	0.95	"	"	"	"	"

NA = not analysed
ND = not detected
** Except for sediment where dry concentrations apply*
 # See sub-section 3.2 for definition

Table 23(b). ***Monitoring of gamma dose rates near Bradwell, 1993***

Location	Ground type	No. of sampling observa-tions#	µGy h-1
Gamma dose rates at 1 m over intertidal areas			
Pipeline	Mud	2	0.10
1.5 km east of pipeline	"	2	0.067
Waterside	"	2	0.064
West Mersea	"	2	0.064
Maldon	"	2	0.056

 # See sub-section 3.2 for definition

Measurements for 1993 are summarised in Tables 23(a) and (b). Low concentrations of artificial radioactivity were detected due to the combined effects of discharges 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 1992 (Camplin, 1993(a)). Gamma dose rates, as directly measured, were indistinguishable 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 critical group of houseboat dwellers. This exposure, including the effects of consumption pathways, was small, amounting to 0.01 mSv or 1% of the dose limit of 1 mSv year^{-1}.

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. There are two potentially 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. *Fucus serratus* is analysed as an indicator material. The results for 1993 are given in Tables 24(a) and (b).

Concentrations of radiocaesium are attributable to discharges from the stations and from Sellafield, with a small contribution due to weapons-test fallout. 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 comprises local bait diggers who also eat fish and shellfish. Gamma dose rates over intertidal sediments, measured using portable instruments, were indistinguishable 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 0.005 mSv or 0.5% of the dose limit of 1 mSv $year^{-1}$.

Table 24(a). Radioactivity in environmental materials near Dungeness nuclear power stations, 1993

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}											
		Total beta	^{60}Co	^{90}Sr	^{125}Sb	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Plaice	2	120	ND	NA	ND	ND	0.27	ND	NA	NA	ND	NA	NA
Cod	2	120	"	"	"	"	0.47	"	"	"	"	"	"
Sprat	1	59	"	"	"	"	0.44	"	"	"	"	"	"
Bass	1	95	"	"	"	"	1.5	"	"	"	"	"	"
Shrimps	2	110	0.21	"	"	0.08	0.47	"	"	"	"	"	"
Whelks	2	110	0.76	0.010	"	ND	0.06	"	0.0012	0.0041	0.0043	ND	0.00044
Fucus serratus	2	240	1.9	NA	"	"	0.18	"	NA	NA	0.08	NA	NA
Mud													
Rye Harbour	2	560	6.7	"	"	"	2.7	1.7	0.14	0.61	0.49	0.0026	0.043
Sand													
Camber Sands	2	180	0.98	"	0.28	"	0.24	0.28	NA	NA	ND	NA	NA
Pilot Inn	2	280	1.4	"	ND	0.18	0.83	1.1	"	"	"	"	"

NA = not analysed
ND - not detected
** Except for sediment where dry concentrations apply*
 # See sub-section 3.2 for definition

Table 24(b). Monitoring of gamma dose rates near Dungeness nuclear power stations, 1993

Location	Ground type	No. of sampling observa-tions#	µGy h^{-1}
Gamma dose rates at 1 m over intertidal areas			
Camber Sands	Sand	2	0.050
Old Lifeboat Station	Shingle	2	0.042
Pilot Inn	Sand	2	0.054
Rye Harbour	Mud and sand	2	0.059

 # See sub-section 3.2 for definition

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 1993 are shown in Tables 25(a) and (b). Concentrations of radiocaesium and transuranics were mainly due to discharges from Sellafield and to weapons-test fallout. Iodine-131 was detected this year in winkles and seaweed at low levels. The most likely source of this nuclide is local hospitals. 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 year^{-1}.

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. The potentially critical radiation exposure pathways are due to internal irradiation following consumption of locally-caught shellfish 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 *Fucus vesiculosus* is monitored as an indicator material. Samphire is also collected and analysed because of its use as a foodstuff.

The results for 1993 are given in Tables 26(a) and (b) showing similar levels to those for 1992 (Camplin, 1993(a)). 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; the effect of discharges from Heysham was not detectable above this background from these data. The radiation exposure in 1993 to the critical group of fishermen was 0.14 mSv (on the basis of ICRP-60: 0.09 mSv) which is well within the dose limit of 1 mSv year^{-1}. Concentrations of radioactivity in samphire were of negligible radiological significance.

Table 25(a). Radioactivity in environmental materials near Hartlepool nuclear power station, 1993

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}									
		Total beta	^{14}C	^{99}Tc	^{131}I	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{243}Cm+ ^{244}Cm
Plaice	3	94	39	NA	ND	0.43	ND	NA	NA	ND	NA
Cod	2	120	NA	"	"	0.92	"	"	"	"	"
Crabs	2	74	"	"	"	0.21	"	0.00044	0.0024	0.0017	0.000014
Shrimps	1	72	"	"	"	0.39	"	NA	NA	ND	NA
Winkles	2	100	"	"	0.18	0.27	"	0.0041	0.021	0.015	0.000040
Fucus vesiculosus	2	200	"	4.5	4.5	0.28	"	NA	NA	ND	NA
Mud											
Greatham Creek	2	690	"	NA	ND	11	2.1	"	"	"	"
Paddy's Hole	2	890	"	"	"	20	1.5	"	"	"	"
Coal & sand											
Little Scar	2	240	"	"	"	2.2	ND	"	"	"	"

NA = not analysed
ND = not detected
** Except for sediment where dry concentrations apply*
 # See sub-section 3.2 for definition

Table 25(b). Monitoring of gamma dose rates near Hartlepool nuclear power station, 1993

Location	Ground type	No. of sampling observa-tions#	µGy h^{-1}
Gamma dose rates at 1 m over intertidal areas			
Greatham Creek	Mud	2	0.073
Little Scar	Coal and sand	2	0.055
North Gare	Sand	2	0.055
Paddy's Hole	Mud	2	0.097

 # See sub-section 3.2 for definition

Table 26(a). Radioactivity in environmental materials near Heysham nuclear power stations, 1993

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}										
		Total beta	^{14}C	^{54}Mn	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{99}Tc	^{106}Ru	^{110m}Ag	^{125}Sb
Flounder (Flookburgh)	4	140	37	ND	ND	NA	ND	ND	NA	ND	ND	ND
Plaice	4	100	NA	“	“	“	“	“	“	“	“	“
Bass	2	140	“	“	“	“	“	“	“	“	“	“
Whitebait	1	100	“	“	“	0.084	“	“	“	“	“	“
Cockles (Middleton Sands)	4	78	“	“	0.67	NA	“	“	“	2.7	0.09	0.30
“ (Flookburgh)	4	90	47	“	0.60	0.84	“	“	6.7	1.7	0.12	0.43
Pacific oysters	4	94	NA	“	0.27	NA	“	“	NA	2.4	13	ND
Shrimps	4	78	47	“	ND	0.080	“	“	“	ND	0.06	“
Mussels	4	79	34	“	0.29	NA	“	“	“	5.9	0.04	0.12
Fucus vesiculosus	4	390	NA	“	0.19	“	“	“	180	ND	0.07	0.49
Samphire	1	46	“	“	ND	“	“	“	NA	“	ND	ND
Mud and sand												
Flookburgh	4	670	“	“	0.37	“	“	“	“	4.3	“	“
Half Moon Bay	4	1000	“	0.28	2.3	“	3.8	3.8	“	42	“	5.2
Sunderland Point	4	880	“	ND	1.1	“	ND	ND	“	12	“	1.8
Morecambe Central Pier	4	920	“	“	1.6	“	“	“	“	24	“	1.8
Turf												
Conder Green	4	1600	“	“	2.7	“	“	“	“	13	“	3.1
Sand Gate Marsh	4	980	“	“	1.2	“	“	“	“	ND	“	ND

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}										
		^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Pu	^{241}Am	^{242}Cm	$^{243}Cm+^{244}Cm$
Flounder (Flookburgh)	4	0.26	46	ND	ND	ND	0.00043	0.0022	NA	0.0042	0.000013	0.000010
Plaice	4	0.02	11	“	“	“	NA	NA	“	ND	NA	NA
Bass	2	0.22	33	“	“	“	“	“	“	“	“	“
Whitebait	1	ND	14	“	“	“	“	“	“	“	“	“
Cockles (Middleton Sands)	4	“	8.1	0.09	0.05	“	0.64	3.3	“	7.9	ND	0.016
“ (Flookburgh)	4	“	9.0	ND	0.08	0.04	0.56	2.9	38	7.7	“	0.023
Pacific oysters	4	“	3.9	“	ND	ND	0.26	1.3	NA	0.68	“	0.0018
Shrimps	4	0.03	15	“	“	“	0.0048	0.025	0.40	0.040	“	0.00013
Mussels	4	ND	2.4	“	“	“	0.35	1.7	NA	2.9	“	0.0058
Fucus vesiculosus	4	0.13	15	“	“	“	NA	NA	“	0.78	NA	NA
Samphire	1	ND	1.9	“	“	“	“	“	“	0.50	“	“
Mud and sand												
Flookburgh	4	0.51	170	“	“	“	“	“	“	40	“	“
Half Moon Bay	4	1.0	380	3.1	2.7	3.3	21	100	“	150	ND	0.36
Sunderland Point	4	1.0	310	ND	0.82	0.63	NA	NA	“	100	NA	NA
Morecambe Central Pier	4	0.57	250	“	0.68	2.8	“	“	“	89	“	“
Turf												
Conder Green	4	2.9	1100	“	3.2	2.6	“	“	“	290	“	“
Sand Gate Marsh	4	1.8	490	“	1.8	0.73	“	“	“	120	“	“

NA = not analysed
ND = not detected
**Except for sediment where dry concentrations apply*
#See sub-section 3.2 for definition

Table 26(b). Monitoring of gamma dose rates near Heysham nuclear power stations, 1993

Location	Material	No. of sampling observa-tions#	μGy h^{-1}
Gamma dose rates at 1 m over intertidal areas			
Greenodd	Salt marsh	2	0.078
Sand Gate marsh	“	4	0.12
Flookburgh	Mud and sand	3	0.084
“	Sand	1	0.078
High Foulshaw	Salt marsh	4	0.095
Arnside	Mud and sand	4	0.072
Jenny Brown’s Point	Salt marsh	4	0.079
Morecambe Central Pier	Mussel bed	4	0.074
“	Mud and sand	4	0.080
Half Moon Bay	“	4	0.10
Pipeline	“	4	0.073
Red Nab Point	“	4	0.086
Sunderland Point	“	4	0.089
Sunderland	Mud, sand and stones	4	0.078
Colloway Marsh	Salt marsh	4	0.18
Lancaster	“	4	0.12
Aldcliffe Marsh	“	4	0.16
Conder Green	Mud	1	0.10
“	Mud and sand	3	0.12
“	Salt marsh	4	0.14
Cockerham 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 silty inter-tidal 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, *Fucus* seaweed is monitored as an indicator material.

Table 27(a). Radioactivity in environmental materials near Hinkley Point nuclear power stations, 1993

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}										
		Total beta	^{14}C	^{35}S	^{54}Mn	^{60}Co	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{243}Cm+ ^{244}Cm
Flounder	2	140	140	NA	ND	ND	0.05	0.75	ND	NA	NA	ND	NA
Shrimps	2	84	120	"	"	"	0.13	0.71	0.06	0.00016	0.00069	0.00070	0.000028
Fucus vesiculosus	2	240	NA	57	0.47	0.91	0.69	3.8	ND	NA	NA	ND	NA
Mud & sand													
Pipeline	2	420	"	NA	ND	0.38	1.5	14	"	"	"	"	"
Mud													
1.6 km east of pipeline	2	770	"	"	"	1.6	2.7	37	2.3	"	"	"	"
River Parrett	2	940	"	"	"	ND	0.99	44	ND	"	"	"	"

NA = not analysed
ND = not detected
** Except for sediment where dry concentrations apply*
 # See sub-section 3.2 for definition

Table 27(b). Monitoring of gamma dose rates near Hinkley Point nuclear power stations, 1993

Location	Ground type	No. of sampling observa-tions#	µGy h^{-1}
Gamma dose rates at 1 m over intertidal areas			
0.8 km east of pipeline	Mud	1	0.070
"	Mud & sand	1	0.092
0.8 km west of pipeline	Mud	2	0.16
1.6 km east of pipeline	"	2	0.074
Pipeline	Mud & sand	1	0.099
"	Sand & stones	1	0.16
River Parrett	Mud	2	0.072

 # See sub-section 3.2 for definition

The results for 1993, presented in Tables 27(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 difficult at the low levels detected. 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. A calculation based on concentrations of radionuclides in sediments has been used to estimate the external exposure of the high-rate fish and shellfish consumers. Their total exposure due to liquid waste discharges was low, at 0.008 mSv or 0.8% of the dose limit of 1 mSv year^{-1}.

6.7 Hunterston, Ayrshire

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 by the Scottish Office. Discharge limits for the 'A' station were reduced in 1993 to account for recent operating experience. 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 *Fucus* seaweed is analysed as an indicator material. The results of monitoring in 1993 are shown in Tables 28(a) and (b).

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 1993, the exposure of members of the critical group of fish and shellfish consumers near Hunterston was low, at 0.01 mSv or 1% of the dose limit of 1 mSv year^{-1}. Gamma radiation dose rates directly measured over intertidal sediments were difficult to distinguish from the natural background, but a small contribution to the exposure of the critical group given above was included, based on a calculation using measured concentrations of radionuclides in sand.

Table 28(a). Radioactivity in environmental materials near Hunterston nuclear power stations, 1993

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{51}Cr	^{54}Mn	^{58}Co	^{59}Fe	^{60}Co	^{65}Zn	^{110m}Ag
Cod	1	150	ND	ND	ND	ND	ND	ND	ND
Saithe	2	140	"	"	"	"	"	"	"
Crabs	2	64	"	"	"	"	0.07	"	"
Velvet swimming crabs	1	81	"	0.41	"	"	3.0	"	0.33
Nephrops	2	100	"	ND	"	"	ND	"	ND
Lobsters	1	87	"	"	"	"	"	"	"
Oysters	1	67	"	0.10	"	"	0.33	0.35	0.58
Winkles	4	110	9.3	3.1	0.28	0.15	4.8	0.22	1.0
Fucus spiralis	4	240	ND	6.6	0.17	ND	5.0	0.10	ND
Sand	4	240	"	1.6	ND	"	1.1	ND	"

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Cod	1	ND	4.7	ND	NA	NA	ND	NA	NA
Saithe	2	0.07	7.8	"	"	"	"	"	"
Crabs	2	ND	0.97	"	0.0057	0.031	0.023	ND	0.000074
Velvet swimming crabs	1	"	0.96	"	NA	NA	ND	NA	NA
Nephrops	2	"	3.4	"	"	"	"	"	"
Lobsters	1	"	1.3	"	"	"	"	"	"
Oysters	1	"	0.78	"	"	"	"	"	"
Winkles	4	0.11	2.4	0.07	0.056	0.23	0.11	0.0014	0.0036
Fucus spiralis	4	0.16	5.3	ND	NA	NA	ND	NA	NA
Sand	4	0.19	25	0.39	"	"	0.38	"	"

NA = not analysed
ND = not detected
** Except for sand where dry concentrations apply*
 # See sub-section 3.2 for definition

Table 28(b). Monitoring of gamma dose rates near Hunterston nuclear power stations, 1993

Location	Ground type	No. of sampling observa-tions#	μGy h^{-1}
Gamma dose rates at 1 m over intertidal areas			
0.5 km north of pipeline	Sand	2	0.060
0.5 km south of pipeline	Sand & stones	2	0.073

 # 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, is under construction. Radioactive liquid effluent from the 'A' station is discharged under authorisation to the North Sea. A recent habits survey has established that consumption of fish and shellfish and occupancy of intertidal areas remain the two critical radiation exposure pathways. The results of monitoring in the area in 1993 are shown in Tables 29(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 year^{-1}. Directly-measured gamma dose rates were indistinguishable from the natural background. The above exposure of the critical group therefore 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. DFR investigations, on behalf of the Scottish Office, have 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.

Table 29(a). Radioactivity in environmental materials near Sizewell nuclear power station, 1993

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{60}Co	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Cod	1	140	ND	0.69	ND	NA	NA	ND	NA	NA
Plaice	1	100	“	0.19	“	“	“	“	“	“
Crabs	2	60	0.05	0.26	“	0.0013	0.0059	0.010	0.000031	0.000075
Pacific oysters	1	71	ND	0.11	“	NA	NA	ND	NA	NA
Whelks	1	93	“	ND	“	“	“	“	“	“
Mud										
Southwold	2	790	1.3	13	1.1	“	“	“	“	“
Sand										
Rifle Range	2	58	ND	0.38	ND	“	“	“	“	“
Aldeburgh	2	40	“	0.15	“	“	“	“	“	“

NA = not analysed
ND = not detected
** Except for sediment where dry concentrations apply*
 # See sub-section 3.2 for definition

Table 29(b). Monitoring of gamma dose rates near Sizewell nuclear power station, 1993

Location	Ground type	No. of sampling observa-tions#	µGy h^{-1}
Gamma dose rates at 1 m over intertidal areas			
Pipeline	Sand	2	0.048
Dunwich	“	2	0.045
Rifle range	“	2	0.045
Sizewell Hall	“	2	0.044
Aldeburgh	Sand & shingle	2	0.045
Southwold Harbour	Mud	2	0.060

 # See sub-section 3.2 for definition

These pathways form the basis of the regular monitoring programme. Samples of fish and shellfish are collected and analysed, and samples of *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 1993 are shown in Tables 30(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. Radiation exposure of the critical group of fish and shellfish consumers was low, at less

Table 30(a). Radioactivity in environmental materials near Torness nuclear power station, 1993

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}										
		Total beta	^{54}Mn	^{60}Co	^{99}Tc	^{110m}Ag	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{243}Cm+ ^{244}Cm
Cod	2	120	ND	ND	NA	ND	ND	0.98	ND	NA	NA	ND	NA
Crabs	2	71	“	“	“	0.07	“	0.17	“	“	“	“	“
Lobsters	1	79	“	“	“	ND	“	ND	“	“	“	“	“
Nephrops	4	92	“	“	“	“	“	0.55	“	0.00068	0.0039	0.0042	0.000031
Winkles	4	83	“	0.44	“	4.3	“	0.43	“	NA	NA	ND	NA
Fucus vesiculosus	2	250	0.35	0.69	5.6	0.78	0.16	0.44	“	“	“	“	“
Mud													
Eyemouth Harbour	1	710	ND	ND	NA	ND	1.5	42	“	“	“	“	“
Mud and sand													
Dunbar Inner Harbour	2	690	“	“	“	“	ND	24	0.79	“	“	“	“
Barns Ness	1	470	“	“	“	“	“	9.6	ND	“	“	“	“
Sand													
Thornton Loch Beach	2	160	“	“	“	“	“	2.7	0.29	“	“	“	“

NA = not analysed
ND = not detected
** Except for sediment where dry concentrations apply*
 # See sub-section 3.2 for definition

Table 30(b). Monitoring of radiation dose rates near Torness, 1993

Location	Material	No. of sampling observa-tions#	μSv h^{-1}
Beta dose rates on nets			
Cove	Pots	2	0.22
Dunbar Harbour	Nets	2	0.12
Gamma dose rates at 1 m over intertidal areas			μGy h^{-1}
Barns Ness	Mud, sand & stones	2	0.063
Skateraw Harbour	Sand	2	0.060
Thornton Loch Beach	"	2	0.055
Eyemouth Harbour	"	1	0.079

 # See sub-section 3.2 for definition

than 0.005 mSv, or 0.5% of the dose limit of 1 mSv year^{-1}. This exposure includes a small contribution due to external radiation, calculated on the basis of radionuclide concentrations in sediment; as directly measured, gamma dose rates remained difficult to distinguish from the natural background. The skin exposure of fishermen handling nets and pots was 0.24 mSv including natural background or less than 0.5% of the dose limit of 50 mSv year^{-1} for skin exposures (see sub-section 3.3).

6.10 Trawsfynydd, Gwynedd

Discharges from this station are made to the freshwater Lake Trawsfynydd under authorisation of the Welsh Office and HMIP. In 1993, Nuclear Electric announced that the station would no longer be used to generate electricity and would be decommissioned. Cessation of power production has resulted in discharges reducing substantially compared with previous years. The critical groups are 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 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 and peat from the lake bed are 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. In this year's report, results of analyses of water which flows into the lake have been included for comparison purposes. The results of DFR monitoring are shown in Tables 31(a) and (b).

The concentrations of radiocaesium in lake water decreased in 1993 as a result of decreasing discharges. However, levels in fish were similar to previous years reflecting the lag time to be expected for the fish to come to equilibrium with their environment. In 1993, 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.

It is estimated that, in 1993, members of the critical group of fish consumers received 0.08 mSv, which is well within the dose limit of 1 mSv year^{-1}. The exposure has remained the same when compared with that of 1992 (Camplin, 1993(a)). Gamma dose rates, measured using portable instruments, were difficult to distinguish from values to be expected from the natural background. The exposure of the critical group given above includes a contribution due to lakeside external exposure based on a calculation using radionuclide concentrations in sediment.

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 potentially 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 indicator seaweed *Fucus vesiculosus* is also sampled. The results of monitoring in 1993 are presented in Tables 32(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 1993 indicates 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 year^{-1}. The magnitude of discharges from the station indicate 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; this contribution was based on a calculation using concentrations of radionuclides in sediments.

Table 31(a). Radioactivity in environmental materials near Trawsfynydd nuclear power station, 1993

Material	No. of sampling observa-tions+	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{14}C	^{35}S	^{60}Co	^{90}Sr	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs
Brown trout	5	510	54	20	ND	25	ND	ND	43	310
Rainbow trout	8	130	NA	24	“	2.9	“	“	1.2	10
Perch	6	960	“	18	0.06	10	“	“	110	880
Rudd	1	560	“	NA	ND	NA	“	“	64	440
Eel	1	NA	“	“	“	“	“	“	19	150
Fontinalis										
Afon Prysor	2	190	“	“	“	“	“	“	ND	14
Gwylan Stream	2	980	“	“	20	“	110	67	14	140
Mud										
Pipeline (bankside)	2	3300	“	“	43	“	360	190	150	1800
Hot lagoon	2	8600	“	“	80	“	690	1300	400	5900
End of Barrier Wall	1	9700	“	“	98	“	510	1000	520	7200
Barrier Wall	2	9900	“	“	170	“	720	1200	380	6600
Mud, sand and stones										
Gwylan Stream	2	2800	“	“	32	“	74	220	120	2100
Peat										
Near cooling water outlet	1	8000	“	“	110	“	590	1400	310	3300
Cae Adda boat mooring	2	580	“	“	ND	“	ND	7.1	20	160
Below Maent. HEP Stn.	2	11000	“	“	620	“	810	1100	290	3400
Water										
South end of lake	1	NA	“	“	NA	“	NA	NA	0.010	0.052
Bailey bridge	4	“	“	“	“	“	“	“	0.015	0.076
Cold lagoon	4	“	“	“	“	“	“	“	0.017	0.082
Afon Prysor	3	“	“	“	“	“	“	“	ND	0.0066
Ardudwy Leet	1	“	“	“	“	“	“	“	“	0.0039
Inlet stream SW of dam	1	“	“	“	“	“	“	“	“	0.0035
Trout hatchery	1	“	“	“	“	“	“	“	“	0.0023
Islyn	1	“	“	“	“	“	“	“	“	0.0026

Material	No. of sampling observa-tions+	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Brown trout	5	ND	ND	ND	0.00024	0.0010	NA	0.0013	0.000021	0.000028
Rainbow trout	8	“	“	“	0.00027	0.00094	“	0.0014	0.000017	0.000016
Perch	6	“	“	“	0.00016	0.00058	“	0.0010	ND	0.000049
Rudd	1	“	“	“	NA	NA	“	ND	NA	NA
Eel	1	“	“	“	“	“	“	“	“	“
Fontinalis										
Afon Prysor	2	“	“	1.5	“	“	“	“	“	“
Gwylan Stream	2	40	3.8	4.4	“	“	“	5.5	“	“
Mud										
Pipeline (bankside)	2	110	20	15	“	“	“	30	“	“
Hot lagoon	2	260	47	29	35	89	2400	120	5.0	7.9
End of Barrier Wall	1	150	38	30	NA	NA	NA	72	NA	NA
Barrier wall	2	250	51	37	“	“	“	160	“	“
Mud, sand and stones										
Gwylan Stream	2	25	6.1	3.5	“	“	“	5.1	“	“
Peat										
Near cooling water outlet	1	220	36	25	“	“	“	67	“	“
Cae Adda boat mooring	2	ND	ND	ND	“	“	“	ND	“	“
Below Maent. HEP Stn.	2	180	66	40	“	“	“	73	“	“
Water										
South end of lake	1	NA	NA	NA	“	“	“	NA	“	“
Bailey bridge	4	“	“	“	“	“	“	“	“	“
Cold lagoon	4	“	“	“	“	“	“	“	“	“
Afon Prysor	3	“	“	“	“	“	“	“	“	“
Ardudwy Leet	1	“	“	“	“	“	“	“	“	“
Inlet Stream SW of dam	1	“	“	“	“	“	“	“	“	“
Trout Hatchery	1	“	“	“	“	“	“	“	“	“
Islyn	1	“	“	“	“	“	“	“	“	“

NA = not analysed
ND = not detected
** Except for mud and peat where dry concentrations apply*
+ *See sub-section 3.2 for definition*

Table 31(b). Monitoring of gamma dose rates near Trawsfynydd nuclear power station, 1993

Location	Ground type	No. of sampling observa-tions#	μGy h^{-1}
Gamma dose rates at 1 m over areas near lake shoreline			
Bailey Bridge	Peat	2	0.077
South end of lake	“	2	0.070
Cae Adda boat mooring	“	2	0.063

 # See sub-section 3.2 for definition

Table 32(a). Radioactivity in environmental materials near Wylfa nuclear power station, 1993

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}														
		Total beta	^{14}C	^{54}Mn	^{60}Co	^{99}Tc	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Pu	^{241}Am	^{242}Cm	$^{243}Cm+^{244}Cm$
Plaice	2	90	39	ND	ND	NA	ND	ND	ND	4.7	ND	NA	NA	NA	ND	NA	NA
Crabs	2	76	NA	“	“	0.41	0.34	“	“	1.3	“	0.0076	0.038	“	0.12	ND	0.00039
Winkles	2	70	“	“	0.09	NA	0.08	0.07	“	1.4	“	0.036	0.19	3.8	0.27	“	ND
Mud	2	1100	“	“	1.1	“	ND	ND	1.9	270	1.4	7.6	39	NA	55	0.060	0.12
Fucus vesiculosus																	
Cemaes Bay	2	260	“	“	0.09	“	“	0.11	ND	4.2	ND	NA	NA	“	0.33	NA	NA
Cemlyn Bay	2	280	“	“	ND	“	“	0.12	0.06	3.9	“	“	“	“	0.27	“	“
Wylfa Head West	2	210	“	0.38	1.4	“	“	ND	ND	4.3	“	“	“	“	0.71	“	“

NA = not analysed
ND = not detected
** Except for sediment where dry concentrations apply*
 # See sub-section 3.2 for definiton

Table 32(b). Monitoring of gamma dose rates near Wylfa nuclear power station, 1993

Location	Ground type	No. of sampling observa-tions#	μGy h^{-1}
Gamma dose rates at 1 m over intertidal areas			
Cemaes Bay	Sand	8	0.059
Cemlyn Bay	Mud	4	0.084

 # 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 1993, 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 Thames catchment. DFR monitoring in the Thames catchment continued including sampling in Foundry 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 of pike, 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 potential critical group which may be 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^{-1}.

The results of measurements of radioactivity concentrations are shown in Table 33. The concentrations of artificial radioactivity detected were very low. The gamma dose rate on the river bank at Pangbourne was 0.062 µGy h^{-1} in 1993 (1 observation) and 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 year^{-1}.

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 Authorising Departments (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. The site at Barrow was licensed by the Nuclear Installations Inspectorate in 1993 and was granted an authorisation jointly by MAFF and HMIP. A revised discharge agreement took effect at Faslane in July 1993.

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 and seaweed are also analysed where appropriate.

Results of monitoring in 1993 are presented in Tables 34(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. 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 1993, 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^{-1}. This represents less than 3% of the dose limit of 1 mSv year^{-1}.

Table 33. Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Aldermaston, 1993

Material	Sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}										
			Total beta	^{57}Co	^{60}Co	^{137}Cs	^{155}Eu	^{234}U	^{235}U	^{238}U	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am
Pike	Newbridge	1	93	ND	ND	0.06	ND	NA	NA	NA	0.000066	0.00036	0.00047
	Pangbourne	1	110	“	“	0.97	“	“	“	“	0.000090	0.00038	0.00048
	Staines	1	110	“	“	0.59	“	“	“	“	NA	NA	NA
Nuphar lutea	Pangbourne	1	31	“	0.05	0.18	“	“	“	“	“	“	“
	Staines	1	34	0.10	ND	0.16	“	“	“	“	“	“	“
	Newbridge	1	30	ND	“	ND	“	“	“	“	“	“	“
Clay	Pangbourne	1	460	“	“	0.50	1.7	“	“	“	“	“	“
Mud & sand	Staines	1	280	“	1.2	20	1.0	“	“	“	“	“	“
Mud	Foundry Brook	1	470	“	ND	4.6	1.5	23	0.97	25	“	“	“
	Newbridge	1	610	“	“	19	2.8	NA	NA	NA	“	“	“

NA = not analysed
ND = not detected
** Except for sediment where dry concentrations apply*
 # See sub-section 3.2 for definition

Table 34(a). Radioactivity in environmental materials near naval establishments, 1993

Establishment	Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, $Bq\ kg^{-1}$						
			Total beta	^{60}Co	^{95}Zr	^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs
Barrow	Mud - Walney Channel (outfall)	2	990	2.1	ND	ND	44	ND	ND
	Mud and sand - " (Vickerstown Church)	4	930	2.1	7.7	5.8	55	4.0	0.43
Chatham	Mud - Commodores Hard	1	NA	3.3	ND	ND	ND	ND	1.1
	" - Hoo Marina	1	"	3.5	"	"	"	"	1.3
Devonport	Mussels	2	"	0.15	"	"	"	"	ND
	Fucus vesiculosus	2	"	0.15	"	"	"	"	"
	Mud - Torpoint Ferry East	2	"	1.8	"	"	"	"	"
	" - Kinterbury	2	"	0.74	"	"	"	"	"
	" - Torpoint South	2	"	0.76	"	"	"	"	"
Faslane	Mud - Carnban boatyard	1	"	ND	"	"	"	"	"
	Mud and sand - "	1	"	7.5	"	"	"	"	"
Rosyth	Crabs	2	"	ND	"	"	"	"	"
	Fucus vesiculosus	2	"	"	"	"	"	"	"
	Mud - Blackness Castle	2	"	"	"	"	"	0.51	0.42
	" - Dockyard dredger	2	800	"	"	"	"	ND	0.64
	" - East of dockyard	2	NA	"	"	"	"	"	ND
	" - Port Edgar	2	"	"	"	"	"	"	"
	Mud and sand - West of dockyard	2	"	0.62	"	"	"	"	"
	Sand - Burntisland Bay	2	"	ND	"	"	"	"	"
Holy Loch	Mud and sand - mid-Loch	1	"	1.4	"	"	"	0.84	"

Establishment	Material	No of sampling observa-tions#	Mean radioactivity concentration (wet)*, $Bq\ kg^{-1}$						
			^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am
Barrow	Mud - Walney Channel (outfall)	2	250	ND	6.4	2.2	NA	NA	250
	Mud and sand - " (Vickerstown Church)	4	190	7.0	4.8	3.4	"	"	220
Chatham	Mud - Commodores Hard	1	17	ND	ND	1.7	"	"	ND
	" - Hoo Marina	1	21	"	"	1.7	"	"	"
Devonport	Mussels	2	0.06	"	"	ND	"	"	"
	Fucus vesiculosus	2	0.12	"	"	"	"	"	"
	Mud - Torpoint Ferry East	2	8.8	"	"	1.8	"	"	"
	" - Kinterbury	2	5.3	"	"	1.8	0.029	0.55	0.18
	" - Torpoint South	2	3.0	"	"	1.7	NA	NA	ND
Faslane	Mud - Carnban boatyard	1	8.5	"	"	ND	"	"	1.7
	Mud and sand - "	1	40	"	"	"	"	"	ND
Rosyth	Crabs	2	0.20	"	"	"	"	"	"
	Fucus vesiculosus	2	0.51	"	"	"	"	"	"
	Mud - Blackness Castle	2	31	"	"	1.8	"	"	"
	" - Dockyard dredger	2	46	"	"	1.1	"	"	"
	" - East of dockyard	2	29	"	"	2.1	"	"	0.99
	" - Port Edgar	2	37	"	"	0.55	"	"	ND
	Mud and sand - West of dockyard	2	11	"	"	1.5	"	"	"
	Sand - Burntisland Bay	2	1.2	"	"	ND	"	"	"
Holy Loch	Mud and sand - mid-Loch	1	32	"	"	1.2	"	"	"

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 naval establishments, 1993

Establishment	Location	Ground type	No. of sampling observa-tions#	μGy h^{-1}
Gamma dose rates at 1 m over intertidal areas				
Barrow	Walney Channel (1 km south of outfall)	Mud and sand	4	0.088
"	" (Vickerstown church)	"	4	0.11
Chatham	Commodores Hard	Mud	1	0.054
"	Hoo Marina	"	1	0.061
"	Medway Yacht Club	"	1	0.055
Devonport	Kinterbury	"	2	0.070
"	Brunel Bridge East	"	2	0.078
"	Torpoint Ferry East	"	2	0.069
"	Stonehouse	"	2	0.071
"	Torpoint South	"	2	0.074
"	Wearde Quay	Mussel bed	1	0.078
"	"	Stones	1	0.073
Faslane	Gareloch Head	Mud, sand and stones	2	0.053
"	Gulley Bridge Pier	Sand and stones	2	0.063
"	Rhu Narrows	"	2	0.051
"	Rosneath	Mussel bed	2	0.057
"	Carnban boatyard	Mud, sand and stones	2	0.10
Rosyth	Blackness Castle	Mud and sand	1	0.069
"	"	Mud	1	0.070
"	Burntisland Bay	Sand	2	0.058
"	East of Dockyard	"	1	0.069
"	"	Sand and stones	1	0.062
"	Port Edgar	Mud	2	0.071
"	West of Dockyard	Mud, sand and stones	2	0.078
Holy Loch	Ardnadam Pier	"	1	0.062
"	River Eachaig	"	1	0.069
"	Gibbs Point	Sand and stones	1	0.058
"	West Kilmun	Sand	1	0.052
"	Kilmun Pier	Sand and stones	1	0.067
"	Mid-Loch	Mussel bed	1	0.049

 # 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 1993, 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 1993, 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 a potential critical group which may be 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^{-1} was assumed.

The results of the measurements of radioactivity concentrations are presented in Table 35. 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 0.051 μGy h^{-1}

Table 35. Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Amersham, 1993

Material	Sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}											
			Total beta	^{14}C	^{54}Mn	^{57}Co	^{58}Co	^{60}Co	^{65}Zn	^{137}Cs	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am
Pike	Newbridge	1	93	NA	ND	ND	ND	ND	ND	0.06	ND	0.000066	0.00036	0.00047
	Grand Union Canal	1	130	98	“	0.07	“	“	“	0.81	“	NA	NA	ND
	Staines	1	110	NA	“	ND	“	“	“	0.59	“	“	“	“
Nuphar lutea	Grand Union Canal	1	55	“	0.09	1.9	0.25	“	0.28	ND	“	“	“	“
	Staines	1	34	“	ND	0.10	ND	“	ND	0.16	“	“	“	“
	Newbridge	1	30	“	“	ND	“	“	“	ND	“	“	“	“
Mud	Grand Union Canal	1	410	“	“	38	7.1	“	14	14	“	“	“	“
	Newbridge	1	610	“	“	ND	ND	“	ND	19	2.8	“	“	“
Mud and sand	Staines	1	280	“	“	“	“	1.2	“	20	1.0	“	“	“

NA = not analysed
ND = not detected
** Except sediment where dry concentrations apply*
 # See sub-section 3.2 for definition

in 1993 (1 observation) and was 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 year^{-1}.

8.2 Cardiff Laboratory

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 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 potentially 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, and *Fucus* seaweed is collected as an indicator material. 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.

The results of monitoring in 1993 are presented in Tables 36(a) and (b). Of the separate radionuclides listed, only carbon-14 and sulphur-35 were discharged by this establishment in 1993; the presence of the other radionuclides was therefore due to the combined

Table 36(a). Radioactivity in environmental materials near Cardiff, 1993

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta^{x}	^{14}C	^{35}S	^{131}I	^{134}Cs	^{137}Cs	^{155}Eu
Flounder	4	330	1000	NA	ND	ND	0.53	ND
Mussels	2	260	850	“	“	“	ND	“
Fucus vesiculosus	1	200	22	“	4.6	“	0.56	0.12
Fucus spiralis	3	160	20	49	0.62	0.02	0.40	ND
Mud	3	790	18	NA	ND	0.35	29	0.43
Mud & sand	1	350	15	“	“	ND	7.6	2.4

NA = not analysed
ND = not detected
** Except sediment where dry concentrations apply*
 # See sub-section 3.2 for definition
^{x} Includes contribution from carbon-14 at low counting efficiency due to the low energy of beta particles emitted by this radionuclide

Table 36(b). Monitoring of gamma dose rates near Cardiff, 1993

Location	Ground type	No. of sampling observa- tions#	µGy h^{-1}
Gamma dose rates at 1 m over intertidal areas			
East of pipeline	Mud	2	0.078
West of pipeline	Mud & sand	2	0.064

 # See sub-section 3.2 for definition

background effects noted above. The exposure of the critical group of fish and shellfish consumers including external irradiation was 0.02 mSv or 2% of the dose limit of 1 mSv $year^{-1}$. 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. Seaweeds are sampled as indicator materials and because of their use as fertilisers.

The results for 1993 are given in Table 37. 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. The presence of transuranics, antimony-125 and ruthenium-106 in environmental materials may be attributed to discharges from the plant at Cap de la Hague. A theoretical assessment based on a pessimistic choice of consumption rates and occupancy (110, 7 and 18 kg $year^{-1}$ for fish, crustaceans and molluscs respectively and 1000 hours $year^{-1}$ for intertidal occupancy) gives an estimated exposure of 0.02 mSv in 1993 or 2% 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 importance.

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 1993. Parts of the freshwater environment continued to show the effect of fallout from Chernobyl. The results of monitoring for 1993 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 38 presents concentrations of caesium-134 and -137 in fish, giving the averaged results of all analyses carried out at each location on samples taken during the year. Artificial radionuclides, other than those of radiocaesium, in 1993, were no longer detectable from the Chernobyl accident.

Concentrations of radiocaesium in freshwater fish varied widely between locations, reflecting the areas of deposition of radioactivity from Chernobyl and the number of samples obtained. Most samples analysed were of brown trout, in recognition of the potential radiological significance of this species. 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 1992 (Camplin, 1993(a)) there are still likely to be fluctuations, such as those due to sample size or to the contribution of hatchery-reared fish, but concentrations of radiocaesium were generally similar in 1993 to those in 1992. Figure 7 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.

Radiation exposures have been estimated using a procedure based on cautious assumptions, as previously (Camplin, 1993(a)). A consumption rate of brown trout of 37 kg $year^{-1}$, sustained for one year, was taken to be representative of 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. Exposures of children and infants would be likely to be lower than those for adults. In 1993, estimated exposures were less than 0.2 mSv on the basis of both ICRP-26 and ICRP-60 in all areas of the UK.

Table 37. Radioactivity in environmental materials from the Channel Islands, 1993

Material	Sampling area/ landing point	No. of sampling observa- tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			Total beta	^{54}Mn	^{60}Co	^{90}Sr	^{106}Ru	^{110m}Ag	^{125}Sb	^{137}Cs
Rays	Guernsey[2]	1	110	ND	ND	NA	ND	ND	ND	0.75
Crabs	Guernsey[2]	1	88	“	1.0	“	“	0.19	“	0.09
	Jersey[2]	1	95	“	0.27	“	“	0.31	“	ND
Lobsters	Guernsey[2]	1	50	“	0.22	“	“	ND	“	“
	Jersey[2]	1	82	“	0.69	“	“	2.1	“	“
Oysters	Jersey[2]	1	70	“	0.46	“	“	0.34	“	0.05
Limpets	Guernsey[1]	1	110	“	0.25	“	“	ND	“	0.15
	Jersey[1] La Rozel	1	78	“	0.61	“	“	0.26	“	ND
Ormers	Guernsey[1]	1	95	“	1.2	“	0.36	ND	“	0.07
Porphyra	Guernsey[1] Fermain Bay	2	110	“	0.23	“	ND	“	“	0.19
Fucus serratus	Guernsey[1] Fermain Bay	2	230	“	1.1	0.17	“	“	“	0.10
	Jersey[1] La Rozel	3	270	“	1.9	0.39	“	“	0.04	0.30
Laminaria digitata	Jersey[1] Verclut	4	310	“	0.23	NA	“	“	ND	0.18
Mud	Jersey[1] St Helier	1	650	2.2	46	“	11	“	1.2	6.8
Mud & sand	Guernsey[1] Bordeaux Harbour	2	470	ND	0.96	“	ND	“	0.44	2.3
Sand	Alderney[1] Little Crabbe Harbour	1	630	0.43	8.1	“	2.7	“	1.8	3.7

Material	Sampling area/ landing point	No. of sampling observa- tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
			^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Rays	Guernsey[2]	1	ND	ND	0.000061	0.00025	0.00033	ND	ND
Crabs	Guernsey[2]	1	“	“	0.0010	0.0020	0.0056	0.000027	0.0018
	Jersey[2]	1	“	“	0.00075	0.0019	0.0044	0.000029	0.00078
Lobsters	Guernsey[2]	1	“	“	0.00073	0.0016	0.015	0.000087	0.0040
	Jersey[2]	1	“	“	0.00067	0.0011	0.0032	ND	0.00076
Oysters	Jersey[2]	1	“	“	0.0063	0.012	0.011	0.000085	0.0029
Limpets	Guernsey[1]	1	“	“	NA	NA	ND	NA	NA
	Jersey[1] La Rozel	1	“	“	0.0079	0.016	0.025	0.00013	0.0052
Ormers	Guernsey[1]	1	“	“	NA	NA	ND	NA	NA
Porphyra	Guernsey[1] Fermain Bay	2	“	“	0.0040	0.0096	0.013	0.000090	0.0028
Fucus serratus	Guernsey[1] Fermain Bay	2	“	“	0.012	0.028	0.012	0.000060	0.00029
	Jersey[1] La Rozel	3	“	“	0.028	0.049	0.021	0.00053	0.0057
Laminaria digitata	Jersey[1] Verclut	4	“	“	NA	NA	ND	NA	NA
Mud	Jersey[1] St Helier	1	3.1	2.7	1.5	3.1	5.0	0.041	1.0
Mud & sand	Guernsey[1] Bordeaux Harbour	2	ND	0.80	0.11	0.37	0.34	0.0015	0.056
Sand	Alderney[1] Little Crabbe Harbour	1	0.63	0.69	NA	NA	1.3	NA	NA

[1] = Sampling area
[2] = Landing point
NA = not analysed
ND = not detected
** Except for sediment where dry concentrations apply*
 # See sub-section 3.2 for definition

Table 38. Caesium radioactivity in freshwater fish, 1993

Location	Species	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
			^{134}Cs	^{137}Cs
England				
Branthwaite	Rainbow trout	1	ND	0.32
Narborough	“	1	“	0.31
Ennerdale Water	Brown trout	9	“	41
Devoke Water	Perch	7	29	600
“	Brown trout	11	2.8	73
River Teme	Chub	1	ND	0.09
Wales				
Llyn Hiraethlyn	Perch	10	6.6	170
Llyn Bala	Brown trout	2	1.2	16
“	Pike	6	0.95	15
“	Grayling	1	0.45	7.2
“	Gwyniad	5	0.42	7.3
“	Rainbow trout	3	ND	0.91
“	Roach	11	0.56	6.81
Scotland				
Loch Dee	Brown trout	1	14	320

ND = not detected

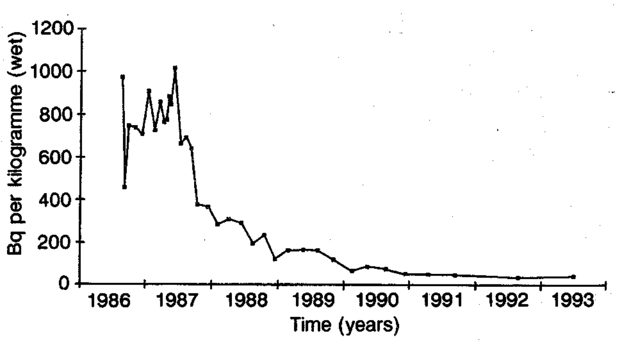

Figure 7. Radiocaesium in brown trout — Ennerdale Water

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), a small programme of monitoring these radionuclides in the UK marine environment has continued. Previous surveys (Rollo *et al*., 1992) have established that an 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 1993 were much less than those in 1992 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 1993 are shown in Table 39. 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.

Table 39. Natural radioactivity in fish and shellfish from the Irish Sea, 1993

Material	Sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet), Bq kg^{-1}								
			^{210}Po	^{210}Pb	^{226}Ra	^{228}Th	^{230}Th	^{232}Th	^{234}U	^{235}U	^{238}U
Winkles	Saltom Bay	4	41	7.7	NA	NA	NA	NA	NA	NA	NA
“	Parton	4	50	6.8	0.2	1.5	4.7	1.1	4.5	0.22	4.4
“	North Harrington	4	37	NA	NA	NA	NA	NA	NA	NA	NA
“	Fleswick Bay	4	22	“	“	“	“	“	“	“	“
“	Nethertown	4	16	2.9	“	“	“	“	“	“	“
“	Drigg	4	NA	NA	“	0.57	0.91	0.43	“	“	“
“	Tarn Bay	4	13	“	“	NA	NA	NA	“	“	“
Mussels	Parton	1	67	“	“	“	“	“	“	“	“
“	Nethertown	4	50	4.8	“	“	“	“	“	“	“
Crabs	Parton	4	32	6.4	“	0.10	0.053	0.019	0.15	0.0064	0.14
“	St Bees	4	15	9.1	“	NA	NA	NA	NA	NA	NA
“	Sellafield coastal area	3	14	NA	“	“	“	“	“	“	“
Lobsters	Parton	4	17	0.33	“	0.035	0.041	0.0063	0.033	0.0014	0.031
“	St Bees	4	16	0.39	“	NA	NA	NA	NA	NA	NA
Cod	Parton	4	0.80	0.025	“	0.024	0.013	0.0051	0.0049	0.00026	0.0044

NA = not analysed
 # See sub-section 3.2 for definition

Table 40. Individual radiation exposures from natural radionuclides due to consumption of fish and shellfish from the Whitehaven area, 1993

Exposed population	Nuclide	Effective dose equivalent, mSv ICRP-26: On the basis of current NRPB advice	Effective dose equivalent, mSv ICRP-26: Effect of polonium enhanced by a factor of 8 (see text)	Effective dose, mSv ICRP-60: On the basis of current NRPB advice	Effective dose, mSv ICRP-60: Effect of polonium enhanced by a factor of 8 (see text)
Consumers in Saltom Bay and Parton	^{210}Pb	0.22	0.22	0.14	0.14
	^{210}Po	0.088	0.70	0.042	0.33
	U, Th, Ra nuclides	0.0096	0.0096	0.0053	0.0053
	Total	0.32	0.93	0.19	0.48

Concentrations of polonium-210 were much lower than in 1992 due to reductions in discharges and radioactive decay of activity already in the environment. 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 Parton. Consumption rates were reviewed in 1993 and decreased consumption of molluscs was noted. The results of the assessment of exposures using the current NRPB advice for a gut transfer factor of 0.1 for polonium are shown in Table 40 with the contributions of individual radionuclides. On the basis of ICRP-26 the committed effective dose equivalent to the critical group in 1993 was 0.32 mSv. This represents a substantial decrease from 0.64 mSv reported on the same basis for 1992 (Camplin, 1993(a)), mainly due to the decreased concentrations of polonium-210 in the area. 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 0.19 mSv in 1993, is less than that for ICRP-26. On both bases the estimated exposures are less than the dose limit for members of the public of 1 mSv $year^{-1}$.

As discussed in section 3.3, a recent 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. NRPB and ICRP are considering this and data from other research in formulating their recommendations on human dosimetry. Until such a time as their advice is available we have used the extant factor of 0.1 for control purposes but have also considered the effect of the conservative assumption that the value of 0.8 applies to the total intake of polonium as shown in Table 40. These data show that exposures would increase, but by less than the increase in gut uptake factor. This is because the contribution to dose from lead-210 is significant.

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 sub-section 4.1. In 1993 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

Area of work	Staff
1. Inspection of nuclear sites	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 D R P Leonard 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 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

APPENDIX 2. Dosimetric data

Radionuclide†	Half-life (years)	Mean γ energy (MeV per disintegration)	Dose* per unit intake by ingestion using the following methodology (Sv Bq^{-1})	
			ICRP-26	ICRP-60
Hydrogen-3	$1.24\ 10^{1}$	0.0	$1.60\ 10^{-11}$	$1.80\ 10^{-11}$
Carbon-14	$5.73\ 10^{3}$	0.0	$5.60\ 10^{-10}$	$5.60\ 10^{-10}$
Sulphur-35	$2.39\ 10^{-1}$	0.0	$6.95\ 10^{-10}$	$7.00\ 10^{-10}$
Manganese-54	$8.56\ 10^{-1}$	$8.364\ 10^{-1}$	$7.24\ 10^{-10}$	$7.30\ 10^{-10}$
Iron-55	2.7	$1.691\ 10^{-3}$	$4.46\ 10^{-10}$	$3.40\ 10^{-10}$
Cobalt-57	$7.42\ 10^{-1}$	$1.25\ 10^{-1}$	$3.10\ 10^{-10}$	$1.00\ 10^{-9}$
Cobalt-58	$1.94\ 10^{-1}$	$9.976\ 10^{-1}$	$9.40\ 10^{-10}$	$1.00\ 10^{-9}$
Cobalt-60	5.27	2.500	$7.04\ 10^{-9}$	$7.20\ 10^{-9}$
Zinc-65	$6.67\ 10^{-1}$	$5.845\ 10^{-1}$	$3.90\ 10^{-9}$	$3.80\ 10^{-9}$
Strontium-90†	$2.91\ 10^{1}$	$3.163\ 10^{-3}$	$3.77\ 10^{-8}$	$3.22\ 10^{-8}$
Zirconium-95†	$1.75\ 10^{-1}$	1.505	$1.72\ 10^{-9}$	$2.06\ 10^{-9}$
Niobium-95	$9.62\ 10^{-2}$	$7.660\ 10^{-1}$	$6.80\ 10^{-10}$	$7.70\ 10^{-10}$
Technetium-99	$2.13\ 10^{5}$	0.0	$3.46\ 10^{-10}$	$6.70\ 10^{-10}$
Ruthenium-103†	$1.07\ 10^{-1}$	$4.685\ 10^{-1}$	$8.10\ 10^{-10}$	$1.10\ 10^{-9}$
Ruthenium-106†	1.01	$2.049\ 10^{-1}$	$7.50\ 10^{-9}$	$1.10\ 10^{-8}$
Silver-110 m†	$6.84\ 10^{-1}$	2.740	$2.89\ 10^{-9}$	$3.00\ 10^{-9}$
Antimony-125	2.77	$4.312\ 10^{-1}$	$7.02\ 10^{-10}$	$9.80\ 10^{-10}$
Iodine-129	$1.57\ 10^{7}$	$2.463\ 10^{-2}$	$6.40\ 10^{-8}$	$1.10\ 10^{-7}$
Caesium-134	2.06	1.550	$1.90\ 10^{-8}$	$1.90\ 10^{-8}$
Caesium-137†	$3.00\ 10^{1}$	$5.651\ 10^{-1}$	$1.30\ 10^{-8}$	$1.30\ 10^{-8}$
Barium-140†	$3.49\ 10^{-2}$	2.502	$4.41\ 10^{-9}$	$6.50\ 10^{-9}$
Cerium-144†	$7.78\ 10^{-1}$	$5.282\ 10^{-2}$	$5.80\ 10^{-9}$	$8.80\ 10^{-9}$
Promethium-147	2.62	$4.374\ 10^{-6}$	$2.55\ 10^{-10}$	$4.40\ 10^{-10}$
Europium-154	8.80	1.237	$2.47\ 10^{-9}$	$3.10\ 10^{-9}$
Europium-155	4.96	$6.062\ 10^{-2}$	$3.68\ 10^{-10}$	$5.30\ 10^{-10}$
Lead-210†	$2.23\ 10^{1}$	$4.810\ 10^{-3}$	$2.03\ 10^{-6}$	$1.30\ 10^{-6}$
Bismuth-210	$1.37\ 10^{-2}$	0.0	$1.56\ 10^{-9}$	$2.10\ 10^{-9}$
Polonium-210 (c)	$3.79\ 10^{-1}$	0.0	$4.35\ 10^{-7}$	$2.10\ 10^{-7}$
Polonium-210 (d)			$3.48\ 10^{-6}$	$1.64\ 10^{-6}$
Radium-226†	$1.60\ 10^{3}$	1.765	$2.96\ 10^{-7}$	$2.20\ 10^{-7}$
Thorium-228†	1.91	1.567	$3.42\ 10^{-7}$	$2.32\ 10^{-7}$
Thorium-230	$7.7\ 10^{4}$	$1.553\ 10^{-3}$	$3.45\ 10^{-7}$	$1.80\ 10^{-7}$
Thorium-232	$1.41\ 10^{10}$	$1.332\ 10^{-3}$	$1.83\ 10^{-6}$	$9.20\ 10^{-7}$
Uranium-238†	$4.47\ 10^{9}$	$2.235\ 10^{-2}$	$6.67\ 10^{-8}$	$4.17\ 10^{-8}$
Neptunium-237†	$2.14\ 10^{6}$	$2.382\ 10^{-1}$	$5.40\ 10^{-7}$	$3.20\ 10^{-7}$
Plutonium-238 (a)	$8.77\ 10^{1}$	$1.812\ 10^{-3}$	$4.30\ 10^{-7}$	$2.60\ 10^{-7}$
Plutonium-238 (b)			$1.70\ 10^{-7}$	$1.10\ 10^{-7}$
Plutonium-240 (a)	$6.54\ 10^{3}$	$1.731\ 10^{-3}$	$4.80\ 10^{-7}$	$2.80\ 10^{-7}$
Plutonium-240 (b)			$1.90\ 10^{-7}$	$1.20\ 10^{-7}$
Plutonium-241 (a)	$1.44\ 10^{1}$	$2.546\ 10^{-6}$	$9.30\ 10^{-9}$	$5.30\ 10^{-9}$
Plutonium-241 (b)			$3.70\ 10^{-9}$	$2.20\ 10^{-9}$
Americium-241 (a)	$4.32\ 10^{2}$	$3.253\ 10^{-2}$	$4.90\ 10^{-7}$	$2.90\ 10^{-7}$
Americium-241 (b)			$2.00\ 10^{-7}$	$1.20\ 10^{-7}$
Curium-242	$4.46\ 10^{-1}$	$1.832\ 10^{-3}$	$1.80\ 10^{-8}$	$1.60\ 10^{-8}$
Curium-243	$2.85\ 10^{1}$	$1.347\ 10^{-1}$	$3.40\ 10^{-7}$	$2.00\ 10^{-7}$
Curium-244	$1.81\ 10^{1}$	$1.700\ 10^{-3}$	$2.70\ 10^{-7}$	$1.70\ 10^{-7}$

† *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 x 10^{-4} for consumption of all foodstuffs except Irish Sea winkles

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

(c) Gut transfer factor 0.1

(d) Gut transfer factor 0.8. Dose coefficients from Phipps, A. (1993). Personal communication, NRPB

APPENDIX 3. Radioactivity in surface and coastal waters of the British Isles, 1989 to 1993

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 five year period 1989 to 1993. All of the data have been taken from this report, Hunt (1990) and Camplin (1992, 1993(a) and (b)). 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 five 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.

References

CAMPLIN, W.C., 1992. Radioactivity in Surface and Coastal Waters of the British Isles, 1990. Aquat. Environ. Monit. Rep., MAFF. Direct. Fish. Res., Lowestoft, ***(29)***: 1-68.

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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
Tritium	2144.02	1698.62	1800	1200	2310
Carbon-14	2.03	1.97	2.44	0.804	2.03
Cobalt-60	0.17	0.17	0.087	0.071	0.087
Strontium-90	9.17	4.22	4.09	4.14	17.1
Zirconium-95+Niobium-95	11.11	6.82	12.4	10.2	9.61
Technetium-99	6.07	3.82	3.86	3.18	6.06
Ruthenium-106	24.96	16.54	18.7	12.6	17.1
Iodine-129	0.17	0.11	0.159	0.068	0.161
Caesium-134	1.73	1.15	0.765	0.834	1.19
Caesium-137	28.60	23.46	15.6	15.2	21.9
Cerium-144	3.78	2.01	1.73	1.73	2.51
Plutonium alpha	1.21	1.14	1.08	0.935	1.33
Plutonium-241	30.24	31.61	29.5	25.3	37.5
Americium-241	1.06	0.75	0.744	0.542	0.873

Table 3.3. Monitoring of radioactivity in fish due to Sellafield discharges†

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

NA = not analysed
ND = not detected
† *Data may include contributions from sources other than Sellafield*

Table 3.4. Monitoring of radioactivity in crustaceans due to Sellafield discharges[†]

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

NA = not analysed
ND = not detected
[†] *Data may include contributions from sources other than Sellafield*

Table 3.5. Monitoring of radioactivity in molluscs due to Sellafield discharges†

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

* *Including niobium-95*
ND = not detected
NA = not analysed
† *Data may include contributions from sources other than Sellafield*

Table 3.6. Monitoring of radioactivity in seaweed due to Sellafield discharges†

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

NA = not analysed
ND = not detected
* *Including niobium-95*
† *Data may include contributions from sources other than Sellafield*

Table 3.7. Monitoring of radioactivity in sediments due to Sellafield discharges†

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

** Including Niobium-95*
ND = not detected
† Data may include contributions from sources other than Sellafield
[1] Salt marsh in 1993

Table 3.8. Monitoring of gamma dose rates due to Sellafield discharges†

Material or ground type	Sampling point or landing area	Radionuclide or dose measurement	Gamma dose rate, µGy h^{-1}				
			1989	1990	1991	1992	1993
Sand	Sellafield	Gamma dose	0.096	0.087	0.083	0.086	0.079
Mud	Whitehaven yacht basin	Gamma dose	0.33	0.32	0.30	0.29	0.27
Salt marsh	Newbiggin	Gamma dose	0.43	0.41	0.41	0.36	0.33
Salt marsh	Kippford merse	Gamma dose	0.21	0.18	0.17	0.17	0.16

† *Data may include contributions from sources other than Sellafield*

Table 3.9. Monitoring of beta dose rates due to Sellafield discharges†

Material or ground type	Sampling point or landing area	Radionuclide or dose measurement	Beta dose rate, µSv h^{-1}				
			1989*	1990	1991	1992	1993
Nets	Vessel A	Beta dose	0.28	0.22	0.25	0.17	0.13
Nets	Vessel B	Beta dose	0.28	0.39	0.24	0.16	0.20
Pots	Vessel D	Beta dose	0.44	0.39	0.42	0.42	0.36

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

Material or ground type	Sampling point or landing area	Radionuclide or dose measurement	Discharge, TBq, concentration of activity*, Bq kg^{-1} or gamma dose rate, $\mu Gy\ h^{-1}$				
			1989	1990	1991	1992	1993
Liquid waste	Sea pipeline	Total alpha			$5\ 10^{-4}$	$7.82\ 10^{-4}$	$6.71\ 10^{-4}$
		Total beta(2)			0.014	0.0278	0.0206
		Tritium			2.2	3.0	2.4
Winkles	Drigg	Carbon-14	94	59	73	80	74
		Manganese-54	0.1	ND	ND	ND	ND
		Colbalt-60	12	8.5	5.3	4.1	3.7
		Strontium-90	14	7.5	7.5	6.9	NA
		Zirconium-95	62(1)	1.9	5.7	2.0	14
		Niobium-95		1.6	10	0.34	12
		Technetium-99	97	150	110	40	48
		Ruthenium-103	3.2	0.4	0.53	ND	0.69
		Ruthenium-106	330	130	130	52	120
		Silver-110m	14	8.7	39	75	65
		Antimony-125	6.5	5.9	4.0	1.9	4.0
		Caesium-134	0.7	ND	ND	ND	0.06
		Caesium-137	40	23	18	16	15
		Cerium-144	19	4.3	3.1	0.56	11
		Promethium-147	52	16	11	5.6	9.7
		Europium-154	2.8	0.5	1.2	ND	0.47
		Europium-155	1.6	0.5	0.52	ND	ND
		Neptunium-237	1.6	0.31	0.40	0.15	0.42
		Plutonium-238	12	6.3	4.7	3.6	4.0
		Plutonium-239+240	50	27	21	17	18
		Plutonium-241	980	470	350	250	280
		Americium-241	84	54	40	31	34
		Curium-242	0.33	0.11	0.10	0.037	0.063
		Curium-243+244	0.22	0.16	0.10	0.073	0.076
Sand	Drigg pipeline	Gamma dose	0.080	0.076	0.071	0.066	0.072
Mussel bed	Drigg Barn Scar	Gamma dose	0.12	0.10	0.094	0.089	0.10

ND = not detected
† *Environmental data may include contributions from sources other than Drigg*
* *Concentrations in wet material*
1 *Including niobium-95*
2 *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	Sampling point or landing area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity, Bq kg^{-1} wet † or gamma dose rate, µGy h^{-1}				
			1989	1990	1991[(1)]	1992	1993
Liquid waste		Total alpha	0.38	0.20	0.170	0.106	0.0773
		Total beta	114	92	38.4	121	62.5
		Technetium-99			0.0192	0.104	0.0947
		Thorium-230			0.0042	0.0306	0.0194
		Thorium-232			0.0003	0.0015	0.00078
		Neptunium-237			0.0003	0.0002	0.00025
		Uranium			0.0184	0.0597	0.049
Shrimps	Ribble Estuary	Caesium-134	0.3	ND	ND	ND	ND
		Caesium-137	9.9	6.7	7.6	8.7	7.5
		Thorium-228	0.0086	0.0084	0.013	0.0069	NA
		Thorium-230	0.039	0.0085	0.018	0.016	NA
		Thorium-232	0.0057	0.0040	0.0047	0.0039	NA
		Plutonium-238	NA	NA	0.0070	0.0042	NA
		Plutonium-239+240	NA	NA	0.033	0.020	NA
		Americium-241	ND	ND	ND	0.029	ND
		Curium-243+244	NA	NA	0.000080	ND	NA
Mud	Becconsall	Cobalt-60	5.6	5.5	4.4	1.0	0.95
		Ruthenium-106	45	34	51	14	12
		Antimony-125	ND	2.3	5.9	1.2	ND
		Caesium-134	11	6.8	5.4	1.3	0.43
		Caesium-137	980	870	800	480	380
		Cerium-144	ND	ND	ND	ND	3.0
		Europium-154	9.8	6.5	1.3	2.6	0.36
		Europium-155	9.9	1.9	ND	ND	0.36
		Thorium-228	60	46	46	40	33
		Thorium-230	460	290	500	120	86
		Thorium-232	75	50	47	36	30
		Thorium-234	51000	81000	61000	33000	17000
		Protactinium-233	5.4	ND	ND	ND	ND
		Uranium-234	NA	41	43	35	38
		Uranium-235 + 236	NA	1.9	1.7	ND	2.0
		Uranium-238	NA	40	39	35	36
		Americium-241	270	280	270	310	130
Mud	Pipeline	Gamma dose	0.14	0.15	0.10	0.12	0.11
Mud	Becconsall	Gamma dose	0.15	0.16	0.13	0.12	0.11
Mud	Penwortham	Gamma dose	0.15	0.16	0.17	0.21	0.16

NA = not analysed
ND = not detected
* *Environmental data may include contributions from sources other than Springfields*
† *dry for sediments*
[1] *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	Sampling point or landing area	Radionuclide	Discharges, TBq and concentration of activity, Bq kg^{-1} wet†				
			1989	1990	1991	1992	1993
Liquid waste	Rivacre Brook	Uranium	0.00067	0.0030	0.00293	0.00161	0.00158
		Uranium daughters	0.0077	0.010	0.0077	0.0069	0.0068
		Non-uranic alpha	0.000032	0.00013	0.000136	0.000068	0.0000994
		Technetium-99	0.00087	0.0066	0.00767	0.00389	0.0049
Water weed *(Cladophora rupestris)*	Rivacre Brook	Cobalt-60	0.4	0.2	0.04	ND	ND
		Technetium-99	27	450	770	250	300
		Antimony-125	NA	NA	0.13	ND	ND
		Caesium-134	ND	ND	0.15	ND	ND
		Caesium-137	0.5	0.6	1.8	1.5	1.3
		Europium-155	0.4	0.7	0.86	ND	ND
		Thorium-234	NA	430	810	220	170
		Protactinium-233	ND	140	5.9	19	16
		Uranium-234	NA	NA	170	71	62
		Uranium-235+236	NA	NA	14	5.2	3.8
		Uranium-238	NA	NA	130	47	37
		Neptunium-237	NA	NA	55	12	10
Mud(1)	Rivacre Brook	Cobalt-60	2.7	0.4	0.51	0.42	0.15
		Technetium-99	360	2500	1900	2000	1200
		Caesium-134	12	3.6	1.4	0.52	0.56
		Caesium-137	52	31	17	17	18
		Europium-155	4.7	11	2.7	6.1	0.64
		Thorium-234	5800	1900	640	280	410
		Protactinium-233	30	130	68	44	66
		Uranium-234	NA	810	500	620	290
		Uranium-235+236	NA	47	34	38	20
		Uranium-238	NA	530	300	430	180
		Neptunium-237	2.8	180	90	71	43

ND = not detected
NA = not analysed
* *Environmental data may include contributions from sources other than Capenhurst*
† *dry for sediments*
1 *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†

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

NA = not analysed
ND = not detected
† *Environmental data may include contributions from sources other than Chapelcross*
* *Dry concentrations for sediments; wet for other materials*
1 *Excluding tritium*
2 *Mud and sand in 1993*

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

Material or ground type	Sampling point or landing area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg^{-1} or gamma dose rate, µGy h^{-1}				
			1989	1990	1991	1992(2)	1993
Liquid waste	Sutton Courtenay	Total activity(1)	0.24	0.17	0.231	0.14	
		Total alpha				0.000063	0.000104
		Total beta(1)				0.00161	0.00199
		Tritium	1.6	1.0	0.444	0.2157	0.48
		Cobalt-60				0.000445	0.000514
		Caesium-137				0.0006	0.000348
Pike	Outfall	Cobalt-60		0.09	ND	ND	ND
		Caesium-134		0.1	0.29	0.08	0.14
		Caesium-137		5.8	16	3.0	5.9
		Plutonium-238		0.00003	0.000040	0.000044	0.000073
		Plutonium-239+240		0.00012	0.00024	0.00020	0.00027
		Americium-241		0.00023	0.00018	0.00032	0.00042
Mud, or sand and mud	Sutton Courtenay	Cobalt-60		57	32	26	16
		Antimony-125		6.6	ND	ND	ND
		Caesium-134		3.3	1.9	0.95	ND
		Caesium-137		190	650	570	520
		Europium-155		ND	ND	2.7	ND
		Americium-241		ND	ND	6.2	ND
Soil	Sutton Courtenay	Gamma dose			0.078	0.069	0.081

NA = not analysed
ND = not detected
† *Environmental data may include the effects of sources other than Harwell*
* *Dry concentrations for sediments; wet for other materials*
1 *Excluding tritium*
2 *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†

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

ND = not detected
NA = not analysed
† *Environmental data may include contributions from sources other than Winfrith*
1 *Inner pipeline*
* *Dry concentrations for sediments; wet for other materials*
2 *Lulworth Banks in 1993*
3 *Mud and sand in 1993*

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

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

NA = not analysed
ND = not detected
† *Environmental data may include contributions from sources other than Dounreay*
* *Dry concentrations for sediments; wet for other materials*
1 *Excluding curium-242*
2 *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†

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

NA = not analysed
ND = not detected
* *Dry concentrations for sediments; wet for other materials*
1 *Excluding tritium and caesium-137*
2 *Excluding tritium*
† *Environmental data may include the effects of sources other than Berkeley and Oldbury*
3 *Dover sole in 1992*
4 *Discharged quantities may not be for a whole calendar year. Further details can be found in annual report*

Table 3.18 Discharges of liquid waste from Bradwell, and radioactivity in environmental materials and radiation dose rates near Bradwell†

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

NA = not analysed
ND = not detected
* *Dry concentrations for sediment; wet for other materials*
1 *Excluding Tritium*
2 *Mixed fish*
3 *Several locations near the site prior to 1993*
† *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†

Material or ground type	Sampling point or landing area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg^{-1} or gamma dose rate, $\mu Gy\ h^{-1}$				
			1989	1990	1991	1992	1993
Liquid waste	'A' Station	Total activity(1)	0.23	0.39	0.374	0.507	1.03
		Tritium	0.20	0.71	0.492	0.451	4.43
	'B'Station	Total activity(1)(2)	0.0025	0.0091	0.0103	0.008	0.019
		Tritium	16	7.20	76.1	93.3	269
		Sulphur-35	0.25	0.05	0.379	0.550	0.652
Cod		Caesium-137	0.7	1.0	0.92	0.60	0.47
Shrimps		Cobalt-60	ND	0.5	0.37	0.19	0.21
		Zinc-65	ND	0.2	0.11	ND	ND
		Ruthenium-106	ND	0.9	ND	ND	ND
		Caesium-134	ND	ND	ND	ND	0.08
		Caesium-137	ND	0.3	0.16	0.10	0.47
Mud	Rye Harbour	Manganese-54	1.2	0.6	ND	ND	ND
		Cobalt-60	16	22	8.3	9.7	6.7
		Ruthenium-106	9.4	4.3	ND	ND	ND
		Antimony-125	2.4	ND	ND	0.63	ND
		Caesium-137	4.5	4.2	3.0	3.0	2.7
		Europium-155	ND	1.0	2.0	ND	1.7
		Plutonium-238	0.23	0.14	0.10	0.16	0.14
		Plutonium-239+240	0.83	0.64	0.49	0.59	0.61
		Americium-241	0.60	0.42	0.34	0.48	0.49
		Curium-242	ND	ND	ND	ND	0.0026
		Curium-243+244	0.048	0.038	0.029	0.052	0.043
Sand	Old lifeboat station	Gamma dose		0.050	0.047	0.053	0.042(4)
Sand	Pilot Inn	Gamma dose		0.045	0.053	0.064	0.054
Mud	Rye Harbour	Gamma dose	0.078	0.063	0.066	0.060	0.059(3)

NA = not analysed
ND = not detected
1 *Excluding tritium*
2 *Excluding sulphur-35*
† *Environmental data may include contributions from sources other than Dungeness*
* *Dry concentrations for sediments; wet for other materials*
3 *Mud and sand*
4 *Shingle*

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

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

NA = not analysed
ND = not detected
* *Dry concentrations for sediments; wet for other materials*
† *Environmental data may include contributions from sources other than Hartlepool*
1 *Paddy's Hole*

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

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

NA = not analysed
ND = not detected
* *Dry concentrations for sediments; wet for other materials*
† *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†

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

NA = not analysed
ND = not detected
† *Environmental data may include the effects of sources other than Hinkley Point*
* *Dry concentrations for sediments; wet for other materials*
1 *Excluding tritium and caesium-137*
2 *Excluding tritium, sulphur-35 and cobalt-60*
3 *Excluding tritium and sulphur-35*
4 *Discharge quantities may not be for a whole calendar year. Further details can be found in annual report*

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

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

NA = not analysed
ND = not detected
† *Environmental data may include the effects of sources other than Hunterston*
* *Dry concentrations for sediments; wet for other materials*
1 *Excluding tritium*
2 *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	Sampling point or landing area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg^{-1} or gamma dose rate, $\mu Gy\ h^{-1}$				
			1989	1990	1991	1992	1993
Liquid waste		Total activity(1)	0.36	0.43	0.47	0.383	0.275
		Tritium	2.1	5.0	5.6	5.08	2.79
Cod		Carbon-14	NA		22	19	NA
		Caesium-134	ND		ND	0.17	ND
		Caesium-137	2.5		1.1	2.3	0.69
Shrimps		Caesium-134	0.2	0.3	0.54	0.27	
		Caesium-137	1.4	1.6	1.2	0.83	
		Plutonium-238	0.00003	0.00017	0.0010	0.00021	
		Plutonium-239+240	0.00023	0.00085	0.0045	0.00075	
		Americium-241	0.00013	0.0016	0.0078	0.0010	
		Curium-243+244	ND	ND	0.000050	ND	
Pacific oysters		Zinc-65	0.8	0.5	ND	ND	ND
		Silver-110m	1.7	ND	ND	ND	ND
		Caesium-137	0.2	0.5	0.56	0.13	0.11
Whelks		Cobalt-60	ND		0.92	0.40	ND
		Silver-110m	1.3		ND	ND	ND
		Caesium-137	ND		ND	0.31	ND
Mud		Cobalt-60	3.3	6.2	2.8	2.0	1.3
		Ruthenium-106	6.8	ND	ND	ND	ND
		Caesium-134	1.5	0.6	ND	ND	ND
		Caesium-137	28	24	22	18	13
		Europium-155	1.5	1.1	0.86	1.5	1.1
Sand	Pipeline	Gamma dose		0.046	0.047	0.088	0.048
Sand, or sand and stones	Aldeburgh	Gamma dose		0.041	0.044	0.046	0.045
Mud	Southwold Harbour	Gamma dose		0.059	0.062	0.068	0.060

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*
1 *Excluding tritium*

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

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

NA = not analysed
ND = not detected
† *Environmental data may include the effects of sources other than Torness*
* *Dry concentrations for sediments; wet for other materials*
1 *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†

Material or ground type	Sampling point or landing area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg^{-1} or gamma dose rate, μGy h^{-1}				
			1989	1990	1991(3)	1992	1993
Liquid waste		Total activity(2)			0.0250	0.167	0.0267
		Total activity(1)	0.28	0.33	0.271		
		Caesium-137	0.036	0.041	0.03376	0.0227	0.00848
		Tritium	0.49	2.5	0.3567	0.222	0.075
		Strontium-90			0.00232	0.0536	0.00603
Brown trout		Carbon-14	NA	38	51	38	54
		Sulphur-35	34	110	64	23	20
		Cobalt-60	0.1	0.05	0.03	0.03	ND
		Strontium-90	9.2	8.4	9.0	12	25
		Caesium-134	45	73	100	56	43
		Caesium-137	230	340	420	310	310
		Plutonium-238	0.00021	0.00033	0.00036	0.00022	0.00024
		Plutonium-239+240	0.00082	0.0013	0.0013	0.00065	0.0010
		Americium-241	0.0013	0.0020	0.0019	0.0010	0.0013
		Curium-242	0.00008	0.00023	0.00020	0.000086	0.000021
		Curium-243+244	0.00002	0.00003	0.000035	0.000033	0.000028
Perch		Carbon-14	NA	49	43	NA	NA
		Sulphur-35	100	280	75	28	18
		Cobalt-60	0.4	ND	ND	ND	0.06
		Strontium-90	5.1	5.0	5.4	8.4	10
		Caesium-134	110	160	180	150	110
		Caesium-137	600	740	870	880	880
		Plutonium-238	0.00017	0.00014	0.00011	0.00055	0.00016
		Plutonium-239+240	0.00061	0.00044	0.00045	0.0022	0.00058
		Americium-241	0.0012	0.00064	0.00074	0.0041	0.0010
		Curium-242	0.00012	0.00014	0.00017	0.00017	ND
		Curium-243+244	0.00003	0.00002	0.000040	0.000059	0.000049
Mud	Hot lagoon	Manganese-54	ND	ND	4.7	ND	ND
		Cobalt-60	120	170	150	120	80
		Zirconium-95	ND	45	11	ND	ND
		Niobium-95	ND	180	51	ND	ND
		Ruthenium-106	57	890	1200	1000	690
		Antimony-125	480	1300	1900	2200	1300
		Caesium-134	190	660	690	600	400
		Caesium-137	6900	6700	7100	6500	5900
		Cerium-144	33	620	690	450	260
		Europium-154	50	54	50	58	47
		Europium-155	34	36	35	37	29
		Plutonium-238	34	NA	35	36	35
		Plutonium-239+240	140	NA	100	97	89
		Plutonium-241	NA	ND	ND	2700	2400
		Americium-241	210	140	150	140	120
		Curium-242	2.2	NA	23	10	5.0
		Curium-243+244	5.2	NA	7.4	7.2	7.9
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	Strontium-90	0.22	0.16	NA	NA	NA
		Caesium-134	0.055	0.10	0.050	0.025	0.015
		Caesium-137	0.19	0.27	0.16	0.11	0.076
Peat	Bailey Bridge	Gamma dose		0.098	0.085	0.083	0.077
Peat	South end of lake	Gamma dose		0.088	0.084	0.10	0.070
Mud or peat	Cae Adda boat mooring	Gamma dose		0.069	0.064	0.065	0.063

NA = not analysed
ND = not detected
† *Environmental data may include the effects of sources other than Trawsfynydd*
* *Dry concentrations for sediments; wet for other materials*
1 *Excluding tritium*
2 *Excluding tritium, strontium-90 and caesium-137*
3 *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†

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

NA = not analysed
ND = not detected
† *Environmental data may include the effects of sources other than Wylfa*
* *Dry concentrations for sediments; wet for other materials*
1 *Excluding tritium*

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

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

NA = not analysed
ND = not detected
† *Environmental data may include the effects of sources other than Aldermaston*
* *Dry concentrations for sediments; wet for other materials*
1 *Excluding tritium*
2 *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 †

Material or ground type	Sampling point or landing area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg^{-1} or gamma dose rate, $\mu Gy\ h^{-1}$				
			1989	1990	1991	1992	1993
Liquid waste		Tritium					$1.82\ 10^{-3}$
		Manganese-54					$3.32\ 10^{-9}$
		Cobalt-58					$1.55\ 10^{-9}$
		Cobalt-60					$1.47\ 10^{-8}$
		Tin-113					$1.47\ 10^{-9}$
		Antimony-124					$1.81\ 10^{-9}$
		Other radionuclides					$5.88\ 10^{-8}$
Mud and sand		Cobalt-60					2.1
		Zirconium-95					7.7
		Niobium-95					5.8
		Ruthenium-106					55
		Antimony-125					4.0
		Caesium-134					0.43
		Caesium-137					190
		Cerium-144					7.0
		Europium-154					4.8
		Europium-155					3.4
		Americium-241					220
Mud and sand	1 km south of outfall	Gamma dose					0.088

NA = not analysed
ND = not detected
† *Environmental data may include the effects of sources other than Barrow*
* *Dry concentrations for sediments; wet for other materials*

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

Material or ground type	Sampling point or landing area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg^{-1} or gamma dose rate, $\mu Gy\ h^{-1}$				
			1989	1990	1991	1992	1993
Liquid waste		Total activity(1)	0.000115	0.000009	0.000151	0.000341	0.000365
		Tritium	0.064	0.049	0.0432	0.00212	0.0684
		Cobalt-60	0.0039	0.0014	0.00116	0.0519	0.00135
Mussels		Cobalt-60	0.1	0.2	0.21	0.25	0.15
		Caesium-137	ND	0.3	0.50	0.09	0.06
Mud		Cobalt-60	1.3	ND	0.55	1.3	1.1
		Caesium-137	5.7	3.3	5.2	5.1	5.7
		Europium-155	ND	0.6	1.4	2.3	1.8
		Plutonium-238	NA	NA	0.024	0.026	0.029
		Plutonium-239+240	NA	NA	0.50	0.53	0.55
		Americium-241	ND	ND	0.16	0.18	0.18
		Curium-243+244	NA	NA	ND	0.0016	ND
Mud	Kinterbury	Gamma dose				0.073	0.070
Mud	Brunel Bridge	Gamma dose				0.072	0.078

NA = not analysed
ND = not detected
† Environmental data may include the effects of sources other than Devonport
** Dry concentrations for sediments; wet for other materials*
1 Excluding tritium and cobalt-60

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

Material or ground type	Sampling point or landing area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg^{-1} or gamma dose rate, $\mu Gy\ h^{-1}$				
			1989	1990	1991	1992	1993(2)
Liquid waste		Total activity(1)	0.000032	0.000084	0.00011	0.000037	0.0000552
		Alpha activity					$7.27\ 10^{-6}$
		Beta activity(3)					$5.90\ 10^{-5}$
		Tritium					0.0219
		Cobalt-60					$4.50\ 10^{-5}$
Mud		Cobalt-60	16	14	45	13	ND
		Silver-110m	ND	ND	1.5	ND	ND
		Antimony-125	2.7	2.8	4.9	2.9	ND
		Caesium-134	4.2	1.8	1.8	ND	ND
		Caesium-137	100	76	77	60	8.5
		Cerium-144	ND	ND	2.2	ND	ND
		Europium-155	ND	ND	1.5	0.71	ND
		Americium-241	ND	ND	0.49	0.33	1.7
Mud and sand, or mud, sand and stones	Gareloch Head	Gamma dose				0.054	0.053
Mud, or mud, sand and stones	Carnban	Gamma dose				0.089	0.10

ND = not detected
NA = not analysed
† *Environmental data may include the effects of sources other than Faslane*
* *Dry concentrations for sediments; wet for other materials*
1 *Excluding tritium*
2 *Discharge quantities may not be for a whole calendar year. Further details can be found in annual report*
3 *Excluding tritium and cobalt-60*

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

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

NA = not analysed
ND = not detected
* *Dry concentrations for sediments; wet for other materials*
[1] *Excluding tritium and cobalt-60*
† *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†

Material or ground type	Sampling point or landing area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg^{-1} or gamma dose rate, $\mu Gy\ h^{-1}$				
			1989	1990	1991	1992(1)	1993
Liquid waste		Total activity(2)	0.79	1.07	0.9	0.245	
		Total alpha				0.000064	0.0000712
		Beta > 0.4 MeV				0.00804	0.00887
		Tritium	0.055	0.032	0.013	0.03741	0.0263
		Iodine-125				0.038	0.0408
		Caesium-137				0.000027	0.0000726
		Other radionuclides				0.156	0.112
Pike	Grand Union Canal	Carbon-14		130	96	76	98
		Sulphur-35		9.1	31	NA	NA
		Cobalt-57		ND	0.02	0.17	0.07
		Caesium-137		0.7	0.56	0.90	0.81
Mud	Grand Union Canal	Cobalt-57	ND	ND	25	14	38
		Cobalt-58	9.7	5.2	4.5	2.5	7.1
		Cobalt-60	ND	2.1	0.79	1.2	ND
		Zinc-65	11	5.0	3.6	2.5	14
		Caesium-134	2.6	ND	0.61	ND	ND
		Caesium-137	20	8.4	12	14	14
		Europium-155	ND	3.2	0.67	ND	ND
Grass	Grand Union Canal	Gamma dose			0.044		0.051

NA = not analysed
ND = not detected
† *Environmental data may include the effects of sources other than Amersham*
* *Dry concentrations for sediments; wet for other materials*
1 *Discharge quantities may not be for a whole calendar year. Further details can be found in annual report*
2 *Excluding tritium*

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

Material or ground type	Sampling point or landing area	Radionuclide or dose measurement	Discharges, TBq, concentration of activity*, Bq kg^{-1} or gamma dose rate, $\mu Gy\ h^{-1}$				
			1989	1990	1991	1992	1993
Liquid waste		Beta/gamma activity[1]	0.021	0.022	0.018	0.019	0.0158
		Tritium	601	609	555	440	397
		Carbon-14	1.53	1.57	1.33	1.4	1.3
Flounder		Carbon-14	940	790	810	680	1000
		Sulphur-35	ND	30	12	NA	NA
		Caesium-137	0.8	0.6	0.47	0.56	0.53
Mud		Carbon-14	12	14	13	14	18
		Cobalt-60	ND	ND	ND	0.18	ND
		Caesium-134	2.2	1.5	1.4	0.52	0.35
		Caesium-137	35	31	41	32	29
		Europium-155	1.7	1.0	ND	1.1	0.43
Mud	East of pipeline	Gamma dose			0.071	0.076	0.078
Mud and sand	West of pipeline	Gamma dose			0.061	0.063	0.064

NA = not analysed
ND = not detected
[1] *Excluding tritium, carbon-14 and radioisotopes of calcium and strontium*
* *Dry concentrations for sediments; wet for other materials*
† *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	Sampling point or landing area	Radionuclide or dose measurement	Concentration of activity*, Bq kg^{-1}				
			1989	1990	1991	1992	1993
Ray	Guernsey	Carbon-14	19	NA	NA	NA	NA
		Caesium-137	0.7	1.3	0.78	2	0.75
		Plutonium-238	0.00017	0.00039	0.00014	0.00013	0.000061
		Plutonium-239+240	0.00024	0.0015	0.00050	0.00049	0.00025
		Americium-241	0.00036	0.0017	0.00093	0.00077	0.00033
		Curium-243+244	ND	ND	0.000020	0.000019	ND
Crabs	Guernsey	Cobalt-60	0.4	1.4	3.0	0.98	1.0
		Zinc-65	ND	0.9	ND	ND	ND
		Ruthenium-106	ND	1.8	ND	ND	ND
		Silver-110m	0.5	0.6	0.57	0.22	0.19
		Caesium-137	ND	0.2	0.14	ND	0.09
		Plutonium-238	0.0016	0.0012	0.0011	0.0017	0.0010
		Plutonium-239+240	0.0033	0.0019	0.0016	0.0027	0.0020
		Americium-241	0.0047	0.0048	0.0060	0.0082	0.0056
		Curium-242	0.00007	ND	0.000050	0.000072	0.000027
		Curium-243+244	0.0017	0.0020	0.0021	0.0029	0.0018
Oysters	Jersey	Cobalt-60	1.1	1.0	0.62	0.67	0.46
		Zinc-65	1.6	0.8	ND	0.14	ND
		Ruthenium-106	4.9	5.9	2.0	ND	ND
		Silver-110m	2.5	3.4	2.1	0.99	0.34
		Caesium-137	ND	0.2	0.11	0.07	0.05
		Plutonium-238	0.0093	0.011	0.012	0.0074	0.0063
		Plutonium-239+240	0.014	0.018	0.019	0.013	0.012
		Americium-241	0.014	0.017	0.021	0.014	0.011
		Curium-242	0.00023	0.00017	0.00016	0.00011	0.000085
		Curium-243+244	0.0049	0.0050	0.0046	0.0038	0.0029
Sand, or mud and sand	Guernsey Bordeaux Harbour	Cobalt-60	1.6	1.6	1.4	1.3	0.96
		Ruthenium-106	4.7	3.3	ND	ND	ND
		Antimony-125	1.1	1.2	ND	ND	0.44
		Caesium-137	2.4	2.6	2.3	2.6	2.3
		Europium-155	ND	0.6	ND	ND	0.80
		Plutonium-238	0.10	0.12	0.096	0.16	0.11
		Plutonium-239+240	0.37	0.37	0.36	0.42	0.37
		Americium-241	0.30	0.34	0.31	0.51	0.34
		Curium-242	ND	ND	0.0027	0.0024	0.0015
		Curium-243+244	0.050	0.075	0.065	0.12	0.056

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	Sampling point or landing area	Radionuclide or dose measurement	Concentration of activity, Bq kg^{-1} wet				
			1989	1990	1991	1992	1993
Brown trout	Ennerdale Water	Caesium-134	24	5.5	1.6	ND	ND
		Caesium-137	130	66	49	36	41

ND = not detected

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

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

** 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^{-1} (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		12.6	5.2		19.3	47.5
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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