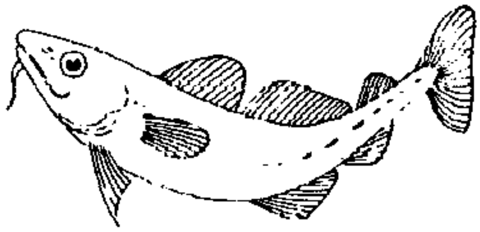
ISSN 0142-2499

AQUATIC ENVIRONMENT MONITORING REPORT
Number 38



Radioactivity in Surface and Coastal Waters of the British Isles, 1992

MAFF
Directorate of Fisheries Research
Lowestoft, 1993

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD
DIRECTORATE OF FISHERIES RESEARCH

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LOWESTOFT
1993

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Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft, (38): 66pp.

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1. INTRODUCTION

This report presents the results of the environmental monitoring programme carried out during 1992 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, 1993) supports statutory functions under the Radioactive Substances Act, 1960 (United Kingdom ¾ Parliament, 1960) (subsequently replaced by the Radioactive Substances Act, 1993 (United Kingdom ¾ Parliament, 1993)). 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 extensive 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 1992 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, 1993), the latest available data being for the year 1991. Details of the 1992 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 1992. 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, where periods shorter than one year are specified the annual equivalent has been used. 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 ¾ Parliament, 1986). The percentages of the authorised (or agreed) limits taken up in 1992 are also stated in Table 1.

For completeness, it should be noted that radiological safety for US Navy operations in the Holy Loch up to March 1992 was the responsibility of the US Navy in association with the Ministry of Defence; following the departure of the US Navy support facilities an extensive monitoring programme was carried out by the Ministry of Defence (Fuller *et al.*, 1993(a)) and results of further monitoring will continue to be published annually (e.g. Fuller *et al.*, 1993(b)).

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; none was carried out in 1992, and it was announced by the Secretary of State for Energy (United Kingdom — Parliament, 1988) that sea disposal of drummed radioactive wastes would not be resumed. Instead, such wastes will be prepared for eventual disposal in the National Radioactive Waste Centre to be developed by UK Nirex Ltd for both low- and intermediate-level radioactive wastes. However, the Government has not ruled out sea disposal for large items of low-level radioactive waste, such as boilers from decommissioned nuclear power stations, as a safe longer-term option, but will keep under review whether the option needs to be maintained. In the context of a new Convention on the Protection of the Marine Environment of the North-east Atlantic (OSPAR, 1992), the UK Government agreed a 15-year ban on the sea disposal of all radioactive waste to 1 January 2008. The Convention provides the possibility for the Government to agree to extend the ban for a further ten years.

Routine environmental monitoring does not provide an effective means of assessing radiation exposure from deep-sea disposal, as radionuclides from this practice are largely undetectable in environmental samples (OECD [NEA], 1990). International surveillance of the effects of these disposals is co-ordinated by the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development by means of a Co-ordinated Research and Environmental Surveillance Programme (CRESP) (OECD [NEA], 1981). This Programme is continuing (OECD [NEA], 1990). In the absence of readily detectable radioactivity from the disposal practice, radiation exposure is assessed mainly by the use of mathematical modelling. The emphasis of surveillance within CRESP has been to improve, by means of appropriate research, the data for modelling assessments. These assessments indicate that the environmental impact of these disposals is negligible (OECD [NEA], 1985).

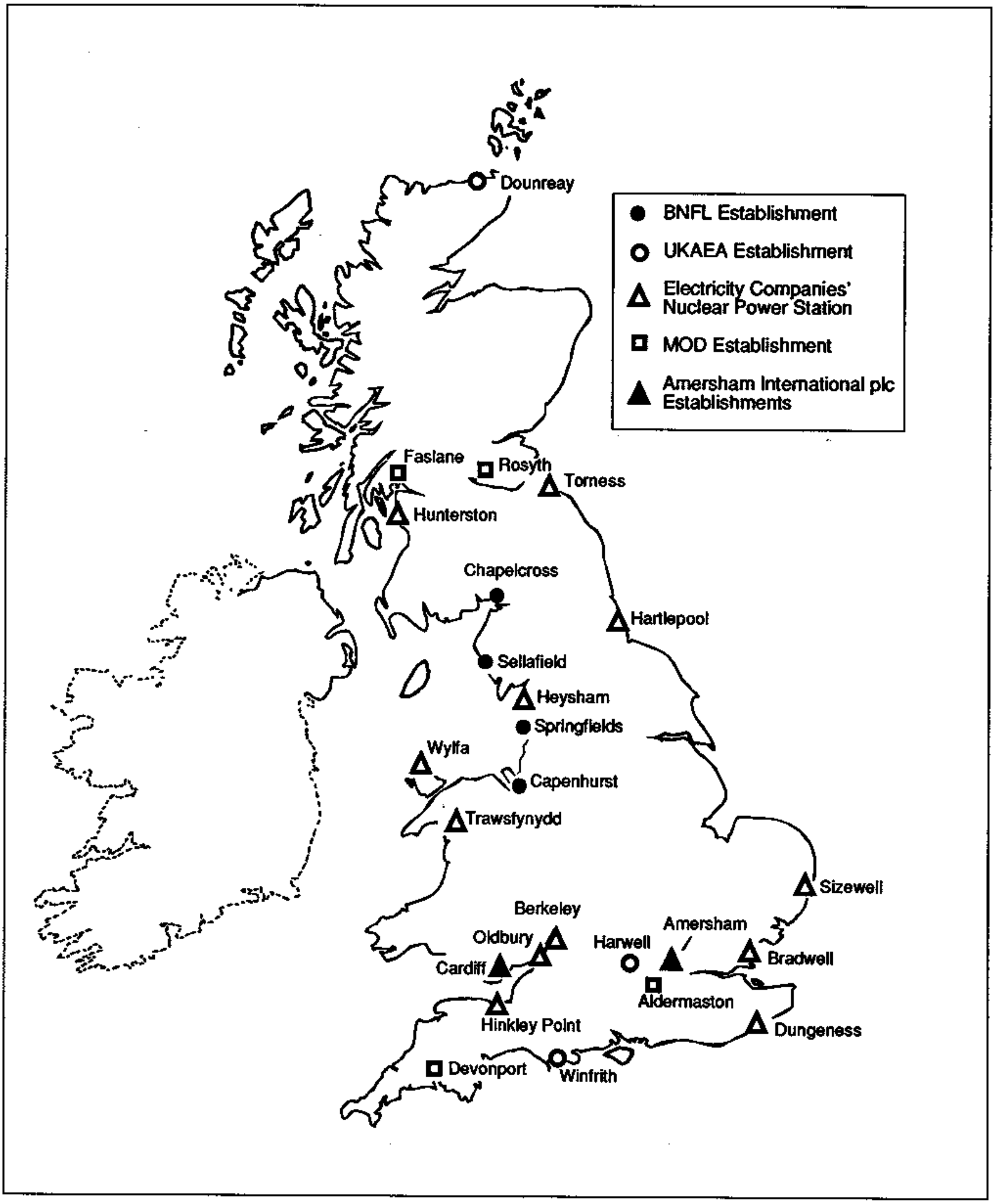

Figure 1. UK nuclear establishments giving rise to principal discharges of liquid radioactive waste

Table 1. Principal discharges of liquid radioactive waste from UK nuclear establishments, 1992

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1992	
			TBq[12]	% of limit [13]
British Nuclear Fuels plc				
Sellafield	Total alpha	10	1.55	16
Sea pipelines	Total beta[20]	500	57.2	11
	Tritium	3500	1200	34
	Carbon-14	4	0.804	20
	Cobalt-60	8	0.071	<1
	Strontium-90	35	4.14	12
	Zirconium-95+Niobium-95	180	10.2	5.7
	Technetium-99	10	3.18	32
	Ruthenium-106	170	12.6	7.4
	Iodine-129	0.4	0.068	17
	Caesium-134	10	0.834	8.3
	Caesium-137	110	15.2	14
	Cerium-144	22	1.73	7.9
	Plutonium alpha	7	0.935	13
	Plutonium-241	170	25.3	15
	Americium-241	3	0.542	18
Seaburn sewer	Total activity	0.148	0.000723	<1
Drigg				
Sea pipeline	Total alpha	0.1	0.000782	<1
	Total beta[1]	0.3	0.0278	9.3
	Tritium	120	3.0	2.5
Stream[17]	Total alpha	$9\ 10^{4}$	610	<1
	Total beta[1]	$1.2\ 10^{6}$	3400	<1
	Tritium	$6\ 10^{8}$	$1.8\ 10^{5}$	<1
Springfields	Total alpha	4	0.106	2.6
	Total beta	240	121	50
	Technetium-99	0.6	0.104	17
	Thorium-230	2	0.0306	1.5
	Thorium-232	0.2	0.0015	<1
	Neptunium-237	0.04	0.0002	<1
	Uranium	0.15	0.0597	40
Chapelcross	Total alpha	0.1	0.0002	<1
	Total beta[1]	25	0.07	<1
	Tritium	5.5	0.69	13
Capenhurst				
Rivacre Brook	Uranium	0.02	0.00161	8.0
	Uranium daughters	0.02	0.0069	35
	Non-uranic alpha	0.003	0.000068	2.3
	Technetium-99	0.1	0.00389	3.9
Meols outfall	Technetium-99	0.148	NIL	NIL
	Others	0.00148	“	“
United Kingdom Atomic Energy Authority				
Winfrith (inner pipeline)	Total alpha	0.3	0.00203	<1
	Tritium	650	13.8	2.1
	Cobalt-60	10	0.007	<1
	Zinc-65	6	0.0006	<1
	Other radionuclides	80	0.108	<1
Winfrith (outer pipeline)	Total alpha	0.004	0.000152	3.8
	Tritium	1	0.034	3.4
	Other radionuclides	0.01	0.00026	2.6
Harwell[2]	Total activity[1,3]	8.88	0.14	3.2
	Tritium	8.88	0.131	2.9
Harwell (pipeline)[2]	Total alpha	0.001	0.000063	13
	Total beta[1]	0.02	0.00161	16
	Tritium	4	0.0847	4.2
	Cobalt-60	0.007	0.000445	13
	Caesium-137	0.007	0.0006	17
Harwell (Lydebank Brook)[2]	Total alpha	0.0005	0.0000351	14
	Total beta[1]	0.002	0.00023	23
	Tritium	0.1	0.0438	88
Dounreay	Total alpha[4]	0.75	0.0259	3.5
	Total beta[1]	110	6.39	5.8
	Tritium	130	2.89	2.2
	Cobalt-60	1	0.0250	2.5
	Strontium-90	12	1.75	15
	Zirconium-95+Niobium-95	6	0.012	<1
	Ruthenium-106	12	0.499	4.2
	Silver-110m	0.4	0.006	1.5
	Caesium-137	50	3.08	6.2
	Cerium-144	12	0.0240	<1
	Plutonium-241	15	0.0442	<1
	Curium-242	1	0.0009	<1

Table 1. continued

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1992	
			TBq[12]	% of limit [13]
Nuclear Electric plc				
Berkeley	Total activity[1,7]	0.4	0.0902	23
	Tritium	8	0.156	2.0
	Caesium-137	0.2	0.0664	33
Bradwell	Total activity[1]	7.4	1.38	19
	Tritium	55.5	3.92	7.1
	Zinc-65	0.185	0.0012	<1
Dungeness				
'A' Station	Total activity[1]	7.4	0.507	6.8
	Tritium	74	0.451	<1
'B' Station	Total activity[1,5]	4	0.008	<1
	Tritium	650	93.3	14
	Sulphur-35	25	0.550	2.2
Hartlepool	Tritium	1850	277	15
	Sulphur-35	8	0.838	10
	Other radionuclides	4	0.0486	1.2
Heysham				
Station 1	Tritium	1850	272	15
	Sulphur-35	7.5	0.56	7.5
	Other radionuclides	4	0.0315	<1
Station 2	Tritium	1200	252	21
	Sulphur-35	7	0.0499	<1
	Cobalt-60	0.036	0.00135	3.8
	Other radionuclides	0.45	0.0223	5.0
Hinkley Point				
'A' Station	Total activity[1,7]	1	0.164	16
	Tritium	25	0.706	2.8
	Caesium-137	1.5	0.446	30
'B' Station	Total activity[1,5,8]	0.25	0.013	5.1
	Tritium	650	317	49
	Sulphur-35	2	1.27	63
	Cobalt-60	0.035	0.00295	8.4
Oldbury	Total activity[1,7]	1.3	0.397	31
	Tritium	25	0.215	<1
	Caesium-137	0.7	0.0246	3.5
Sizewell	Total activity[1]	7.4	0.383	5.5
	Tritium	111	5.08	4.6
Trawsfynydd	Total activity[1,7,16]	0.72	0.167	23
	Tritium	12	0.222	1.8
	Strontium-90	0.08	0.0536	67
	Caesium-137	0.05	0.0227	45
Wylfa[19]	Total activity[1]	2.405	0.0251	1.8
	Tritium	148	1.05	1.2
	Total activity[1]	0.15	0.0192	31
	Tritium	4.0	1.70	10
Scottish Nuclear Ltd				
Hunterston				
'A' Station	Total activity[1]	7.5	0.21	2.8
	Tritium	48	0.17	<1
'B' Station	Total activity[1,5]	3.7	0.02	<1
	Tritium	1480	245	17
	Sulphur-35	26	1.7	6.5
Torness	Total alpha	0.0045	0.000014	<1
	Beta activity[1,5,8]	0.45	0.011	2.4
	Tritium	1200	250	21
	Sulphur-35	10	0.048	<1
	Cobalt-60	0.05	0.0035	7.0

Table 1. continued

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1992	
			TBq[12]	% of limit [13]
Ministry of Defence (Procurement Executive)				
Aldermaston[6]	Total activity[1,3]	5.8	0.0288	<1
	Tritium	5.8	0.0171	<1
Aldermaston (pipeline)[6]	Alpha activity	0.00015	0.0000222	59
	Tritium	0.05	0.0103	82
	Plutonium-241	0.0006	0.0000888	59
	Other radionuclides	0.00015	0.0000108	29
Aldermaston (Silchester)[6]	Alpha activity	0.0001	0.000018	43
	Beta activity	0.0003	0.0000225	30
Ministry of Defence (Navy Department)				
Devonport[9,15]	Total beta		$2.21\ 10^{-5}$	
	Tritium		$2.62\ 10^{-5}$	
	Cobalt-60		$8.79\ 10^{-6}$	
Devonport[14,15] (sewer)	Total activity		0.000746	
	Cobalt-60		0.000599	
Devonport[14] (pipeline)	Total activity[1,8]	0.002	0.000341	17
	Tritium	0.12	0.0519	43
	Cobalt-60	0.016	0.00212	13
Faslane	Total activity[1]	0.037	0.000037	<1
Rosyth[10]	Total alpha	$1\ 10^{-6}$	$9.2\ 10^{-7}$	92
	Beta activity[1,8]	0.01	0.00038	3.8
	Tritium	0.01	0.0065	65
	Cobalt-60	0.055	0.0009	1.6
Amersham International plc				
Amersham[18]	Total activity[1,3]	2.7	0.245	33
	Tritium	14.8	0.00381	<1
	Total alpha	0.0003	0.000064	28
	Beta >0.4 MeV	0.1	0.00804	11
	Tritium	0.2	0.0336	23
	Iodine-125	0.2	0.038	25
	Caesium-137	0.005	0.000027	<1
	Other radionuclides	0.3	0.156	69
Cardiff	Beta/gamma activity[11]	0.096	0.019	19
	Tritium	1400	440	31
	Carbon-14	2	1.4	70

1. *Excluding tritium*
2. *Authorisation was revised with effect from 1 July 1992. The first block of data relates to the period 1 January 1992 to 30 June 1992; the data for the 'pipeline' and 'Lydebank Brook' relate to the period 1 July 1992 to 31 December 1992. '% of limit' refers to the equivalent limit for 6 months*
3. *Authorisation of agreement specifies a control formula in which the total effective activity is calculated to allow for the relative radiotoxicities of different nuclides. The sums of the actual discharges were lower than the values indicated.*
4. *Excluding curium-242*
5. *Excluding sulphur-35*
6. *Authorisation was revised with effect from 1 October 1992. The first block of data relates to the period 1 January 1992 to 30 September 1992; the data for the 'pipeline' and 'Silchester' relate to the period 1 October 1992 to 31 December 1992. '% of limit' refers to the equivalent limit for 9 months or 3 months respectively*
7. *Excluding caesium-137*
8. *Excluding cobalt-60*
9. *Discharges made by the Ministry of Defence*
10. *The operator of this site is 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 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 1992*
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 13 April 1992. The first block of data related to the period 1 January 1992 to 12 April 1992; the second block of data relates to the period 13 April 1992 to 31 December 1992. '% of limit' refers to the equivalent limit for 3 months 12 days, or 8 months 18 days respectively*
19. *Authorisation was revised with effect from 1 August 1992. The first block of data relates to the period 1 January 1992 to 31 July 1992; the second block of data relates to the period 1 August 1992 to 31 December 1992. '% limit' refers to the equivalent limit for 7 months or 5 months respectively*
20. *Excluding tritium, carbon-14 and plutonium-241*

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 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. 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.

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

With the exception of total beta analyses, radioactive decay of radionuclides is taken into account by correcting the activity measured at the time of counting to a value representing the activity in the sample at the time of collection. A decay correction for total beta analyses is not carried out because the activity measured is due to a mixture of several radionuclides each with different half-lives and samples are generally counted soon after collection as indicated above. For the relatively short-lived radionuclides protactinium-233 and thorium-234, the ingrowth of activity from their parent radionuclides is also taken into account when deriving the activity in the sample at the time of collection. In keeping with normal practice, the concentrations of very short-lived (< 3 days) radionuclides which are supported by their parents are not reported in the tables. However, the concentrations of parents are quoted and it can be assumed that the concentrations of the daughter products are approximately equal to those of the parents. Examples of such very short-lived radionuclides are yttrium-90, rhodium-103m, rhodium-106m, barium-137m and protactinium-234m which are formed by decay of strontium-90, ruthenium-103, ruthenium-106, caesium-137 and thorium-234 respectively.

Measurements of gamma dose in air over intertidal areas are made at 1 m above the ground using Mini Instruments * environmental radiation meters type 6-80 with compensated G-M tubes type MC-71. Thermoluminescent dosemeters are also used to measure integrated doses over a period of time in some situations. 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.

3.2 Methods of presentation of measurements

The tables of monitoring results generally 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, a sufficient number of individual animals is sampled and analysed 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 ¾ 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. This number again depends upon the radiological importance of the observation; 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*

* *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*

3.3 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 ¾ Parliament, 1986). The National Radiological Protection Board (NRPB) advises the UK Government on appropriate standards, including the recommendations of the ICRP. Current UK practice relevant to the general public is 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 our 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, 1989).

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 not for those based on monitoring data which may include the effects of several sources and past operations. Nevertheless, to provide further information to help with the process of interpreting the ICRP-60 recommendations, we have included in this report an assessment of the effects of current discharges from Sellafield and Springfields separately for comparison with the 0.3 mSv $year^{-1}$ constraint.

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.

Our 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, we have calculated the exposures for control purposes due to polonium intakes using the extant advice of a factor of 0.1 but have also considered the effect of the conservative assumption that the value of 0.8 applies to the total intake of polonium.

In the case of external exposure to penetrating gamma radiation, uniform whole body exposure has been assumed. The measured quantity is absorbed dose rate in air. When interpreting this in terms of radiological effect, an absorbed dose rate in air 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. 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. 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 our 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. We regularly monitor the environmental consequences of discharges of liquid radioactive waste from five BNFL sites, namely Sellafield, Drigg, Springfields, Capenhurst and, on behalf of departments of the Scottish Office, Chapelcross.

4.1 Sellafield and Drigg, Cumbria

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

Operations and facilities at Sellafield include fuel element storage and decanning, the Windscale nuclear fuel reprocessing plant 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 from the BNFL fuel element storage ponds and the reprocessing plant, through which pass all of the irradiated Magnox fuel from the UK nuclear power programme, and some fuel from abroad. 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). In 1992 BNFL applied for new discharge authorisations for the site, in part to account for the operation of new plant, the Thermal Oxide Reprocessing Plant (THORP) and the Enhanced Actinide Removal Plant (EARP). At the time of writing this report the applications were still under consideration.

Discharges from the Sellafield pipelines during 1992 are summarised in Table 1, and were within the limits set by the Authorising Departments. The site ion-exchange effluent plant (SIXEP) and the salt evaporator operated during 1992 and there was a period of two months when the reprocessing plant was shutdown. Site discharges continued at the low level typical of recent years. Total alpha discharges, at 1.55 TBq, declined as compared with 1991 (2.16 TBq) reflecting in part that the reprocessing plant was not operating throughout the year. Total beta discharges were slightly lower (1992: 57.2 TBq, 1991: 62.2 TBq) due to the shutdown combined with the continued cleaning of old storage ponds and associated areas prior to decommissioning.

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. On 1 January 1991 a Variation to the Authorisation for disposals came into effect which allowed for the discharge of leachate from the trenches through a new 1 km marine pipeline. Previously the leachate was discharged into a stream which runs across the site and enters the intertidal part of the River Irt. 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. Levels in 1992 were well within these limits.

The amounts of activity discharged from the pipeline 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 1992 above those due to Sellafield. Monitoring of the Drigg Stream is carried out by HMIP (HMIP, 1993).

Our regular monitoring of Sellafield continued during 1992. 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 1992, 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. An extensive research programme also continued. The aims of this programme are to improve our 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 our research programme are included where relevant.

4.1.1 The fish and shellfish consumption pathway

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, we also carry out specific surveys. 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 critical group is taken from this Area (Leonard and Hunt, 1985). Our 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. The ratios of caesium-137 to caesium-134 (half-lives 30 years and 2 years respectively) reflect the age of the radioactivity; up to 1985, these ratios increased with distance from Sellafield, but in 1986 they were perturbed by the addition of radiocaesium from Chernobyl which was relatively rich in caesium-134. This perturbation persisted in fish from Scottish waters and the North Sea until 1988 (Hunt, 1989) but is now difficult to detect due to decreasing concentrations of caesium-134. However, radiocaesium in fish from the Baltic 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 1992 were generally less than those in 1991, continuing the downward trend due to reductions in discharges during the 1980s.

Specific radionuclides, other than caesium-134 and -137, which were detected in fish in 1992, 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 our 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. The data for 1992 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 our own 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, 1992

Sampling area/ landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}		
			Total beta	^{134}Cs	^{137}Cs
Sellafield coastal area[1]	Cod	6	180	0.25	27
"	Plaice	3	140	0.17	16
"	Grey mullet	1	150	ND	25
"	Bass	1	170	"	48
Sellafield offshore area[1]	Cod	2	160	"	19
"	Plaice	4	120	"	15
"	Dab	4	150	0.06	17
"	Whiting	3	160	0.34	28
"	Lesser spotted dogfish	2	100	0.13	19
"	Ray	1	120	ND	21
Ravenglass[2]	Cod	19	150	0.22	22
"	Plaice	7	130	0.09	18
"	Flounder	2	140	0.45	28
"	Saithe	1	130	0.16	19
"	Salmon	1	93	ND	0.63
"	Hake	1	120	0.25	17
Whitehaven[2]	Cod	5	130	0.09	9.4
"	Plaice	4	100	0.07	13
"	Ray	4	94	0.03	13
Parton[2]	Cod	1	NA	0.17	26
Maryport[1]	Flounder	1	140	0.13	21
Morecambe Bay[1]	Flounder	4	130	0.18	40
"	Plaice	4	110	ND	17
"	Bass	2	140	0.27	32
"	Whitebait	1	100	ND	17
Cumbrian rivers[4]	Sea trout	3	130	0.12	15
"	Salmon	1	100	ND	5.3
Fleetwood[2]	Cod	4	120	0.07	12
"	Plaice	4	110	ND	9.7
"	Fish meal[5]	4	240	"	3.6
"	Fish oil[5]	4	NA	"	ND
Isle of Man[2]	Cod	5	120	0.03	6.4
"	Plaice	4	88	ND	4.8
"	Herring	5	110	0.09	6.9
Inner Solway[1]	Flounder	4	150	0.29	53
"	Salmon	1	79	ND	0.48
"	Sea trout	2	150	"	15
Kircudbright[2]	Plaice	2	93	"	4.1
North Anglesey[2]	Ray	5	98	"	4.0
"	Plaice	2	110	"	2.3
Ribble estuary	Plaice	1	110	"	18
"	Salmon	1	130	"	0.58
"	Sea trout	1	140	"	11
"	Eel	1	90	0.27	25
Northern Ireland[2]	Cod	5	130	ND	5.8
"	Whiting	8	120	0.04	9.6
"	Herring	4	120	ND	5.5
"	Spurdog	5	86	"	5.1
Sound of Mull[1]	Salmon	1	120	"	0.54
Minch[1]	Cod	3	120	"	1.0
"	Plaice	4	100	"	0.98
"	Mackerel	2	140	"	0.27
"	Haddock	4	120	"	0.64
"	Herring	3	100	"	0.86
West of Scotland[1]	Mackerel	2	120	"	0.31
Shetland[1]	Fish meal[5]	4	380	"	1.0
"	Fish oil	3	NA	"	ND

Table 4(a). continued

Sampling area/ landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}		
			Total beta	^{134}Cs	^{137}Cs
Northern North Sea[1]	Cod	6	130	ND	0.74
"	Plaice	4	110	"	0.70
"	Herring	6	130	"	0.66
"	Haddock	8	120	"	0.47
"	Whiting	1	NA	"	0.96
"	Mackerel	2	"	"	0.25
"	Saithe	4	"	"	0.71
Mid-North Sea[1]	Cod	8	140	"	1.0
"	Plaice	8	96	"	0.65
"	Haddock	3	NA	"	0.42
"	Herring	7	120	"	0.70
"	Mackerel	1	NA	"	0.49
"	Whiting	2	"	"	1.0
Southern North Sea[1]	Cod	6	110	"	0.61
"	Plaice	7	87	"	0.47
"	Herring	2	110	"	0.72
"	Whiting	1	NA	"	0.71
"	Mackerel	1	"	"	0.30
English Channel[1]	Cod	1	160	"	ND
"	Herring	1	100	"	0.48
"	Plaice	2	100	"	0.36
"	Sprat	2	110	"	0.63
"	Whiting	1	110	"	0.72
Skagerrak[1]	Herring	2	110	0.06	1.0
"	Cod	2	120	ND	1.1
Norwegian Sea[1]	Cod	1	130	"	0.64
Iceland area[1]	Cod	2	110	"	0.28
Icelandic processed[2]	Cod	2	120	"	0.30
Greenland area[1]	Cod	1	90	"	0.34
Barents Sea[1]	Cod	2	100	"	0.44
Baltic Sea[1]	Cod	3	140	1.6	21
"	Herring	3	120	0.94	11

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, 1992

Sampling area/ landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}				
			^{14}C	^{60}Co	^{90}Sr	^{99}Tc	^{147}Pm
Sellafield coastal area[1]	Cod	5	NA	0.04	NA	NA	NA
Sellafield offshore area[1]	Cod	3	75	ND	0.096	0.28	0.092
"	Plaice	4	76	"	0.068	0.57	0.027
Whitehaven[2]	Cod	4	34	"	0.029	NA	NA
"	Plaice	4	43	"	0.10	"	"
Morecambe Bay[1]	Flounder	4	32	"	NA	"	"
"	Plaice	2	44	"	"	"	"
"	Whitebait	1	NA	"	0.12	"	"
Fleetwood[2]	Fish meal[5]	4	"	"	0.22	"	"
"	Cod	4	40	"	NA	"	"
"	Plaice	4	33	"	"	"	"
Isle of Man[2]	Plaice	4	32	"	"	"	"
"	Cod	5	NA	0.01	"	"	"
Inner Solway[1]	Flounder	4	30	ND	"	"	"
North Anglesey[1]	Ray	5	52	"	"	"	"
"	Plaice	2	34	"	"	"	"
Northern Ireland[2]	Cod	5	32	"	"	"	"
Minch[1]	Mackerel	1	44	"	0.0057	"	"
West of Scotland[1]	"	2	75	"	NA	"	"
Shetland[1]	Fish meal[5]	4	NA	"	0.055	"	"
Northern North Sea[1]	Cod	1	"	"	0.0021	"	"
"	Haddock	1	25	"	NA	"	"
"	Herring	1	40	"	"	"	"
Mid-North Sea[1]	Cod	4	21	"	0.0045	"	"
"	Plaice	4	32	"	0.0037	"	"
Iceland area[1]	Cod	2	13	"	NA	"	"
Icelandic processed[2]	Cod	2	16	"	"	"	"

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, 1992

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	9	110	110	1.5	N D	0.52	N D	N D	1.8	N D	6.9	27
	Lobsters	9	280	150	0.62	"	0.29	"	"	170	"	1.3	28
"	Winkles[4]	12	240	57	2.6	"	8.0	2.9	1.8	24	0.09	34	40
"	" [5]	4	260	N A	3.9	"	N A	3.0	2.2	N A	N D	47	72
"	" [6]	1	210	"	3.5	"	"	N D	N D	"	"	25	57
"	Mussels[4]	4	190	"	1.9	"	"	4.3	4.4	"	0.33	31	3.1
"	" [8]	2	160	"	1.5	"	"	1.2	1.5	"	N D	41	8.6
"	Limpets[4]	5	240	"	1.7	0.06	"	1.1	0.53	"	"	28	28
St Bees[1]	Winkles	4	240	52	2.5	N D	8.0	2.2	1.6	15	"	37	41
"	Mussels	4	210	N A	2.2	"	N A	9.5	6.0	N A	"	54	24
"	Limpets	4	280	"	2.0	"	"	2.2	1.1	"	"	38	37
Nethertown[1]	Winkles	13	310	62	3.4	"	12	5.0	3.8	22	0.27	55	62
"	Mussels	4	220	N A	2.5	"	N A	12	0.39	75	N D	74	14
Drigg[1]	Winkles	4	310	80	4.1	"	6.9	2.0	0.34	40	"	52	75
Ravenglass[1]	Mussels	4	190	N A	2.4	"	N A	1.1	0.17	52	"	35	1.5
"	Cockles	4	170	"	4.3	"	"	3.4	0.66	N A	"	26	12
Ravenglass[2]	Crabs	4	110	76	1.3	"	0.53	N D	N D	2.0	"	6.3	25
"	Lobsters	4	230	98	0.24	"	0.19	"	"	110	"	0.40	21
"	Whelks	2	160	N A	2.5	"	N A	"	"	N A	"	19	37
Tarn Bay[1]	Winkles	4	210	"	2.6	"	"	2.9	2.2	"	"	28	39
Saltom Bay[1]	"	4	360	"	1.8	"	"	1.2	2.2	"	"	27	17
Whitehaven[2]	*Nephrops*	4	120	41	0.36	"	0.094	N D	N D	26	"	N D	0.66
"	Whelks	4	120	52	0.54	"	0.15	"	"	N A	"	1.5	3.6
Parton[1]	Winkles	4	210	N A	1.0	"	N A	0.71	0.53	"	"	21	14
"	Crabs	1	N A	"	N D	"	"	N D	N D	"	"	N D	8.2
"	Lobsters	1	"	"	"	"	"	"	"	"	"	"	11
Roosebeck[1]	Pacific oysters	4	92	"	0.18	"	"	"	"	"	"	0.91	19
Silloth[1]	Cockles	1	20	"	0.39	"	"	"	"	"	"	N D	11
Haverigg[2]	Cockles	2	150	"	1.9	"	"	5.1	8.6	"	"	18	3.5
Millom[1]	Mussels	2	110	"	0.57	"	"	0.28	0.27	"	0.09	13	0.20
Whitrigg Scar[1]	Shrimps	1	110	"	0.69	"	"	N D	N D	"	N D	7.5	15
Morecambe Bay[1]	"	4	95	48	0.04	"	0.051	"	"	"	"	N D	0.35
"	Cockles	4	92	29	0.89	"	0.72	"	"	4.4	"	1.6	0.52
Fleetwood[2]	Squid	1	83	N A	N D	"	N A	"	"	N A	"	N D	N D
"	Whelks	4	110	43	0.16	"	"	"	"	"	"	0.81	1.0
Isle of Man[2]	Scallops	4	90	N A	0.03	"	"	"	"	"	"	N D	0.47
Southerness[1]	Winkles	4	220	"	0.63	"	5.0	"	"	22	"	10	6.3
Kirkcudbright[2]	Scallops	2	110	"	N D	"	N A	"	"	N A	"	N D	N D
"	Queens	2	110	"	"	"	"	"	"	"	"	"	1.6
North Solway coast[1]	Winkles	4	130	"	0.61	"	"	0.12	0.32	"	"	3.9	6.0
"	Cockles	5	110	"	0.80	"	"	0.34	1.1	"	"	4.3	0.90
Wirral[1]	Shrimps	2	66	"	N D	"	"	N D	N D	1.6	"	N D	0.08
"	Cockles	4	62	"	0.18	"	"	"	"	0.65	"	0.17	N D
Conwy[2]	Mussels	2	44	"	N D	"	"	"	"	N A	"	N D	"
Northern Ireland[2]	*Nephrops*	8	110	"	"	"	"	"	"	"	"	"	"
"	Winkles	4	67	"	0.07	"	"	"	"	"	"	"	0.37
Minch[1]	*Nephrops*	4	90	"	N D	"	"	"	"	"	"	"	N D
Northern North Sea[1]	"	4	91	"	"	"	"	"	"	"	"	"	"
Mid North Sea[1]	Mussels[7]	2	38	"	0.53	"	"	"	"	"	"	"	"
Southern North Sea[1]	Cockles	4	37	"	0.97	"	"	"	"	"	"	"	"
"	Mussels	6	37	"	0.03	"	"	"	"	"	"	"	"

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	9	ND	ND	6.2	ND	1.0	ND	ND
	Lobsters	9	0.03	0.06	9.6	"	1.6	"	"
"	Winkles[4]	12	1.4	0.07	16	1.2	5.0	0.49	0.23
"	" [5]	4	2.5	0.16	19	2.0	NA	0.66	0.35
"	" [6]	1	1.6	ND	12	1.6	"	1.6	0.41
"	Mussels[4]	4	1.5	0.06	8.3	0.80	"	0.61	0.30
"	" [8]	2	2.1	ND	4.2	0.43	"	0.58	ND
"	Limpets[4]	5	3.1	0.02	13	0.42	"	0.26	0.09
St Bees[1]	Winkles	4	2.4	0.13	21	0.91	4.7	0.30	ND
"	Mussels	4	1.9	ND	8.9	1.8	NA	0.65	"
"	Limpets	4	4.5	0.09	27	0.70	"	0.67	0.21
Nethertown[1]	Winkles	13	2.9	0.10	25	1.9	6.4	0.93	0.23
"	Mussels	4	2.5	0.15	10	1.7	NA	0.56	0.08
Drigg[1]	Winkles	4	1.9	ND	16	0.56	5.6	ND	ND
Ravenglass[1]	Mussels	4	2.2	0.03	5.7	1.2	NA	0.49	0.35
"	Cockles	4	0.90	0.03	11	2.3	"	0.95	0.69
Ravenglass[2]	Crabs	4	0.18	ND	5.6	0.25	0.96	ND	ND
"	Lobsters	4	ND	0.03	7.4	ND	2.0	"	"
"	Whelks	2	0.62	ND	3.5	"	NA	"	"
Tarn Bay[1]	Winkles	4	1.4	0.20	18	0.54	"	0.81	0.22
Saltom Bay[1]	"	4	2.8	ND	19	0.88	"	0.29	0.45
Whitehaven[2]	*Nephrops*	4	ND	"	11	ND	"	ND	ND
"	Whelks	4	"	"	2.6	"	"	"	"
Parton[1]	Winkles	4	1.8	0.08	20	0.15	"	0.11	"
"	Crabs	1	ND	ND	4.0	ND	"	ND	"
"	Lobsters	1	"	"	6.2	"	"	"	"
Roosebeck[1]	Pacific oysters	4	"	"	4.1	"	"	"	"
Silloth[1]	Cockles	1	"	"	3.2	"	"	"	"
Haverigg[2]	Cockles	2	0.50	"	14	1.7	"	0.35	0.80
Millom[1]	Mussels	2	0.44	0.04	4.9	ND	"	ND	ND
Whitrigg Scar[1]	Shrimps	1	ND	ND	12	"	"	"	"
Morecambe Bay[1]	"	4	"	0.03	16	"	"	"	"
"	Cockles	4	0.30	ND	8.5	"	"	0.15	0.11
Fleetwood[2]	Squid	1	ND	"	2.5	"	"	ND	ND
"	Whelks	4	"	"	2.6	"	"	"	"
Isle of Man[2]	Scallops	4	"	"	1.4	"	"	"	"
Southerness[1]	Winkles	4	0.41	0.05	21	"	"	"	0.11
Kirkcudbright[2]	Scallops	2	ND	ND	0.63	"	"	"	ND
"	Queens	2	"	"	1.2	"	"	"	"
North Solway coast[1]	Winkles	4	0.93	"	9.5	"	"	0.15	0.08
"	Cockles	5	0.09	"	15	0.41	"	0.33	0.06
Wirral[1]	Shrimps	2	ND	0.05	4.9	ND	"	ND	ND
"	Cockles	4	0.03	ND	3.8	"	"	"	0.05
Conwy[1]	Mussels	2	ND	"	0.74	"	"	"	ND
Northern Ireland[2]	*Nephrops*	8	"	"	3.2	"	"	"	"
"	Winkles	4	"	"	0.79	"	"	"	"
Minch[1]	*Nephrops*	4	"	"	1.2	"	"	"	"
Northern North Sea[1]	"	4	"	"	0.41	"	"	"	"
Mid North Sea[1]	Mussels[7]	2	"	"	0.13	"	"	"	"
Southern North Sea[1]	Cockles	4	"	"	0.17	"	"	"	"
"	Mussels	6	"	"	0.30	"	"	"	"

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 311; [6]Samples collected by Consumer 460; [7]Landed in Denmark; [8]Samples collected by consumer 971

Concentrations of artificial radionuclides in shellfish, as with fish, diminish with increasing distance from Sellafield; the rate of reduction is least for nuclides which are relatively mobile in sea water, such as isotopes of caesium. There are substantial variations between species: for example, lobsters tend to concentrate more technetium-99 when compared with crabs. In addition, molluscs tend to concentrate the less mobile nuclides to a greater extent than crustaceans, which in turn tend to concentrate them more than fish. The reverse behaviour has also been true for mobile nuclides in the past. However, since the importance of caesium-137 associated with sediment has increased relative to the source of direct discharges, concentrations of this nuclide in molluscs have tended to be higher than those for crustaceans. Concentrations of beta/gamma-emitting radionuclides, particularly ruthenium-106, in shellfish in 1992 were generally less than those in 1991, with some evidence of small local increases of silver-110m in line with increases in discharge rates of this radionuclide at the end of 1991 and the beginning of 1992.

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 1992 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 1992, when compared with 1991, concentrations of transuranic nuclides in fish and shellfish generally showed small decreases in the vicinity of Sellafield and small fluctuations further afield in the Irish Sea. This may be due to the redistribution of such nuclides which have been associated with sediments near to Sellafield.

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

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 we have 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 1992. 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. We have included consideration of children's consumption rates 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. Our 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, it was noted that there was an increase in consumption of molluscs, particularly mussels, limpets and cockles, in 1992 to a rate of 11 kg year^{-1} compared with 8.3 kg year^{-1} in 1991 (Camplin, 1993). The consumption rates of the fish and crustacean sub-groups were unchanged and the rates of 37 kg year^{-1} fish, 6.0 kg year^{-1} crustaceans and 11 kg year^{-1} molluscs were therefore used in the assessment of doses to the critical group of fish and shellfish consumers.

Table 6. Transuranic radioactivity in fish and shellfish from the Irish Sea vicinity and further afield, 1992

Sampling area/ landing point	Sample	No. of sampling observations[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	1	NA	0.0021	0.0098	NA	0.016	ND	ND
"	Plaice	1	"	0.0017	0.0079	"	0.015	"	0.000036
"	Crabs	3	0.021	0.11	0.48	7.1	2.1	0.0017	0.0059
"	Lobsters	2	0.069	0.088	0.40	7.5	4.7	0.011	0.013
"	Winkles[4]	4	0.13	3.2	15	230	27	0.037	0.072
"	"[5]	2	NA	3.2	15	220	29	0.037	0.059
"	"[6]	1	"	3.1	15	210	25	0.050	0.059
"	Mussels[4]	1	"	3.1	1.5	220	26	ND	0.064
"	"[12]	2	0.32	2.3	10	170	17	0.037	0.041
"	Limpets[4]	1	NA	2.2	10	150	19	0.038	0.051
Sellafield offshore area[1]	Cod	1	0.00026	0.0024	0.011	NA	0.027	ND	0.000060
"	Plaice	1	0.00094	0.0077	0.036	0.57	0.056	0.00030	0.00015
St Bees[1]	Mussels	2	NA	2.7	12	190	20	0.021	0.043
"	Winkles	4	0.13	3.5	16	250	28	0.028	0.068
"	Limpets	1	NA	4.2	20	NA	33	0.13	0.084
Nethertown[1]	Winkles	5	0.19	4.9	22	350	38	0.046	0.10
"	Mussels	1	NA	3.0	14	NA	22	0.037	0.055
Whitrigg[1]	Shrimps	1	"	NA	NA	"	2.7	NA	NA
Drigg[1]	Winkles	4	0.15	3.6	17	250	31	0.037	0.073
Ravenglass[1]	Mussels	1	NA	3.1	13	210	26	0.044	0.084
"	Cockles	1	"	3.5	17	250	40	0.068	0.083
Ravenglass[2]	Cod[7]	1	"	0.0014	0.0060	NA	0.0098	ND	0.000026
"	Plaice[7]	1	"	0.0023	0.010	"	0.018	"	0.000063
"	Crabs[8]	1	0.024	0.012	0.51	9.1	2.2	0.0068	0.0063
"	Lobsters[8]	1	0.044	0.075	0.33	5.1	7.7	ND	0.015
"	Whelks[8]	1	NA	0.037	1.8	28	3.2	"	0.013
Tarn Bay[1]	Winkles	1	"	2.7	12	180	25	"	0.063
Whitehaven[2]	Cod	1	"	0.00059	0.0028	NA	0.0047	"	0.000054
"	Plaice	1	"	0.00092	0.0041	"	0.0072	"	ND
"	Rays	1	"	0.00060	0.0028	"	0.0048	"	0.000011
"	*Nephrops*	1	"	0.057	0.35	"	1.9	"	0.0020
"	Whelks	1	"	0.14	0.73	9.4	1.5	"	0.0036
Saltom Bay[1]	Winkles	4	"	NA	NA	NA	17	NA	NA
Parton[1]	Winkles	1	"	2.0	9.3	140	15	0.026	0.050
"	Crabs	1	"	NA	NA	NA	1.5	NA	NA
"	Lobsters	1	"	"	"	"	8.5	"	"
Roosebeck[1]	Pacific oysters	4	"	0.36	1.7	"	0.93	0.0024	0.0020
Haverigg[2]	Cockles	1	"	2.6	12	"	28	0.031	0.075
Millom[1]	Mussels	1	"	0.85	3.8	"	7.2	0.019	0.021
Silloth[1]	Cockles	1	"	0.17	0.83	"	2.5	0.0046	0.0060
Morecambe Bay[1]	Whitebait	1	"	NA	NA	"	0.72	NA	NA
"	Flounder	1	"	0.00042	0.0021	"	0.0041	ND	0.0000083
"	Shrimps	1	"	0.0085	0.044	0.59	0.066	"	0.00011
"	Cockles	1	"	0.59	3.0	40	7.9	"	0.015
Fleetwood[2]	Cod	1	"	0.00016	0.00081	NA	0.0014	"	ND
"	Plaice	1	"	0.00037	0.0017	"	0.0036	"	0.000012
"	Fishmeal[9]	1	"	0.0066	0.030	"	0.048	"	ND
"	Whelks	1	"	0.12	0.57	8.6	0.80	0.0043	0.0021
Isle of Man[2]	Cod	1	"	0.00018	0.00085	NA	0.0013	ND	ND
	Plaice	1	"	0.00025	0.0012	"	0.0021	"	"
	Herring	1	"	0.00027	0.0014	"	0.0019	"	"
	Scallops	1	"	0.029	0.14	"	0.072	"	0.00015
Inner Solway[1]	Sea trout	1	"	0.00062	0.0030	"	0.0044	"	0.0000067
Southerness[1]	Winkles	1	"	1.2	5.9	84	9.5	0.017	0.032

Table 6. continued

Sampling area/ landing point	Sample	No. of sampling observations[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	NA	0.00032	0.0015	NA	0.0028	ND	0.000011
"	Scallops	2	"	0.019	0.097	"	0.038	"	0.000075
"	Queens	1	"	0.024	0.14	"	0.15	"	0.00039
North Solway coast[1]	Winkles	1	"	0.93	4.5	67	7.2	"	0.012
"	Cockles	1	"	1.8	9.2	NA	19	0.054	0.037
Wirral[1]	Cockles	1	"	0.16	0.87	"	2.2	ND	0.0029
Conwy[2]	Mussels	1	"	0.042	0.20	"	0.34	"	0.00091
North Anglesey[2]	Rays	1	"	0.00038	0.0018	"	0.0030	"	0.0000078
Northern Ireland[2]	Whiting	1	"	0.00067	0.0033	"	0.0050	"	0.0000013
	Nephrops	1	"	0.0074	0.041	"	0.092	"	0.00027
	Winkles	1	"	0.040	0.21	"	0.11	0.0012	0.00049
Minch[1]	Cod	1	"	0.000049	0.00021	"	0.00027	ND	ND
"	Haddock	1	"	0.000092	0.00040	"	0.00039	"	"
"	Mackerel	1	"	0.000046	0.00014	"	0.00015	"	"
"	*Nephrops*	1	"	0.0012	0.0067	"	0.012	"	"
Shetland[1]	Fishmeal[13]	1	"	0.00035	0.0060	"	0.0050	"	"
Northern North Sea[1]	*Nephrops*	1	"	0.00083	0.0043	"	0.0049	"	0.000041
"	Cod	1	"	0.000049	0.00019	"	0.00025	"	ND
"	Haddock	1	"	0.000094	0.00044	"	0.00051	"	0.0000033
Mid-North Sea[1]	Mussels[10]	1	"	0.00015	0.0018	"	0.0013	"	0.000012
Southern North Sea[1]	Cockles	1	"	0.0026	0.0098	"	0.011	0.00074	0.0016
"	" [11]	1	"	0.0034	0.012	"	0.013	0.000093	0.0017
"	Mussels	1	"	0.0028	0.019	"	0.0060	0.0022	0.0016
Icelandic processed[2]	Cod	1	"	0.000021	0.00012	"	0.00016	ND	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 collected by Consumer 311; [7]Samples provided by Fisherman A; [8]Samples provided by Fisherman B; [9]Concentrations refer to weight as supplied; [10]Landed in Denmark; [11]Landed in Holland; [12]Samples provided by Consumer 971; [13]Concentrations refer to weight of samples as supplied

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. Comparison based on individual critical group members' exposures shows that this procedure is not excessively conservative (Leonard and Hunt, 1985). Plaice and cod are overwhelmingly the most popular fish eaten by the high-rate consumers, and the assessment of exposure of the critical group of local consumers was based upon 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 60% crabs and 40% 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 75% winkles and 25% other molluscs from the Coastal Area, including data from both our own sampling at specific locations within this Area and from samples collected by local consumers.

Table 7(a) summarises exposures in 1992 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 1992 was 0.19 mSv. This represents a small increase from 0.15 mSv reported on the same basis for 1991 (Camplin, 1993), mainly due to an increase 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, 1992

Exposed population	Consumption rate used in assessment (see text), kg year^{-1}		Nuclide	Exposure, mSv[#]	
				ICRP-26*	ICRP-60†
Consumers in local fishing community	Fish (plaice and cod):	37	^{14}C	0.002	0.002
	Crustaceans (crabs and lobsters):	6.0	^{90}Sr	0.004	0.003
	Molluscs (winkles and other molluscs):	11	^{106}Ru	0.003	0.005
			^{110m}Ag	0.002	0.002
			^{137}Cs	0.012	0.012
			^{238}Pu	0.009	0.005
			$^{239+240}Pu$	0.045	0.027
			^{241}Pu	0.013	0.008
			^{241}Am	0.094	0.056
			Total	0.19	0.12
Consumers associated with commercial fisheries: Whitehaven	Fish (plaice and cod):	49	^{137}Cs	0.009	0.009
	Crustaceans (*Nephrops*):	11	$^{239+240}Pu$	0.004	0.002
	Molluscs (whelks):	6	^{241}Am	0.015	0.009
			Total	0.03	0.02
Consumers in Dumfries and Galloway	Fish (plaice, cod and salmon):	40	^{137}Cs	0.005	0.005
	Crustaceans (crabs, lobsters and *Nephrops*):	13	^{238}Pu	0.007	0.004
	Molluscs (cockles and scallops):	16	$^{239+240}Pu$	0.038	0.022
			^{241}Pu	0.015	0.008
			^{241}Am	0.097	0.057
			Total	0.16	0.10
Consumers in Morecambe Bay area	Fish (flounders and plaice):	54	^{14}C	0.002	0.002
	Crustaceans (shrimps):	21	^{137}Cs	0.026	0.026
	Molluscs (cockles and mussels):	22	^{238}Pu	0.005	0.003
			$^{239+240}Pu$	0.025	0.015
			^{241}Pu	0.008	0.005
			^{241}Am	0.061	0.036
			Total	0.13	0.09
Consumers associated with commercial fisheries: Fleetwood	Fish (plaice and cod):	82	^{14}C	0.002	0.002
	Crustaceans (shrimps):	17	^{137}Cs	0.017	0.017
	Molluscs (cockles and whelks):	23	^{238}Pu	0.005	0.003
			$^{239+240}Pu$	0.025	0.015
			^{241}Pu	0.005	0.003
			^{241}Am	0.061	0.036
			Total	0.12	0.08
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	0.002	0.002

* *Committed effective dose equivalent using methodology of ICRP-26*
† *Committed effective dose calculated using methodology of ICRP-60*
\# *Due to artificial radionuclides; see text for exposures due to natural radionuclides*

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 1992, 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 1992 for comparison with the ICRP-60 dose limit

Nuclide	Committed effective dose*, mSv year^{-1}
^{90}Sr	0.002
^{106}Ru	0.012
^{137}Cs	0.003
$^{239+240}Pu$	0.004
^{241}Pu	0.003
^{241}Am	0.002
Total†	0.03

* *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 1992 was 0.12 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, we accept that 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 1992, the committed effective dose to the local criticial group of 0.12 mSv was substantially less than the 1 mSv limit.

In addition, to aid consideration of ICRP-60 in relation to practices, we have calculated the exposure of the local group of seafood consumers due to discharges during 1992. 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 0.03 mSv. This dose is much less than the constraint for practices of 0.3 mSv and is also a small fraction of the dose received in 1992 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 1992 was 0.17 mSv using the current recommendation on the choice of gut uptake factor for polonium (see section 3.3) (on the basis of ICRP-60: 0.09 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, 1989) and are less than the limit of 1 mSv.

Consumption rates in the wider fishing communities of Cumbria and northern Lancashire have been kept under review and a new survey of consumption on the south-west coast of Scotland has been carried out. 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. In comparison with the results for 1991, on the basis of the appropriate gut transfer factor, the committed effective dose equivalents to the groups at Whitehaven, Fleetwood and Morecambe Bay were slightly more in 1992 (1991: 0.02, 0.10 and 0.11 mSv respectively (Camplin, 1993)) because of small increases in concentrations of actinides in shellfish. However 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 1992 was 0.002 mSv, slightly less than for 1991 (Camplin, 1993).

Collective doses, received during 1992 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 (O'Grady *et al.*, in press; this report; Camplin, 1993). 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 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 1992 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 1991 (Camplin, 1993) have been revised to take account of updated landings statistics. The preliminary result of 7 man-Sv for the UK in 1991, given in the previous report (Camplin, 1993), has increased to 8 man-Sv due to a change in mollusc landings; the result for other European countries has been reduced from 25 to 24 man-Sv due to a general decrease in all landings.

Table 8. Collective doses from fish and shellfish, 1991 and 1992[a]

Population	Collective dose, man-Sv			
	ICRP-26*		ICRP-60+	
	1991	1992[a]	1991	1992[a]
UK	8	8	6	6
Other European countries	24	22	23	20

**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 1992 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; the contribution due to shellfish is generally minor. Also relatively small is the contribution, again mainly from radiocaesium, due to fish offal and industrial fisheries (Hunt and Jefferies, 1981). Other radionuclides which contribute to the collective dose, but in even smaller proportions, are strontium-90, through both fish and shellfish, and the transuranics, mainly through shellfish. It should be noted that for transuranics the doses per unit intake allow for the long body half-times, so that the small contributions estimated for the transuranics are committed in the future rather than already received. The contribution of pathways other than fish and shellfish consumption (e.g. external exposure) to the collective dose from Sellafield liquid discharges is relatively small (Hunt and Jefferies, 1981).

The preliminary result for 1992, of 8 man-Sv for the UK is the same as that reported for 1991 and represents a balance between decreasing radiocaesium concentrations and a small increase in actinide concentrations in molluscs in the Irish Sea. The result of 22 man-Sv for other European countries, is less than that reported for 1991 due to reductions in concentrations of radiocaesium in fish. It has not been possible to derive a direct estimate of the small Chernobyl contribution in coastal seas around the UK for 1992. 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*., 1992; Camplin, 1993; this report), it is estimated that the collective dose to other European countries from consumption of Baltic Sea fish was 80 man-Sv in both 1991 and 1992. The 1991 estimates are less than those made by Camplin (1993) because further catch data have become available for use in the assessment.

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 1992, the preliminary UK collective dose through the fish and shellfish pathway as a result of liquid radioactive waste disposal operations amounted to less than 0.01% of this level.

4.1.2 External exposure

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

We regularly monitor a range of coastal locations, 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. We increased the number of sampling positions in 1992 by providing a more complete coverage of locations far from Sellafield in order to monitor the possible redistribution of radioactivity within the Irish Sea. 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 departments 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

Table 9. Gamma radiation dose rates over intertidal areas of the Cumbrian coast and further afield, 1992

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	0.088
Burgh Marsh	"	4	0.10
Port Carlisle	Sandy mud	4	0.11
Greenend	Salt marsh	4	0.088
"	Muddy sand	4	0.079
Cardurnock Marsh	Salt marsh	4	0.12
Newton Arlosh	"	4	0.13
Silloth - silt pond	Mud	4	0.22
Allonby	Sand	2	0.081
Maryport - Christchurch	Mud	4	0.12
Siddick	Sand	4	0.074
Workington Harbour	Mud	4	0.18
Harrington Harbour	"	4	0.16
Whitehaven - outer harbour	Sandy mud	8	0.12
"	Muddy sand	4	0.13
"	Coal/sand	12	0.14
" - inner harbour	Muddy sand	8	0.19
"	Mud/sand/stones	4	0.19
" - yacht basin	Mud	14	0.29
St Bees	Sand	4	0.073
Nethertown	Winkle bed	4	0.10
Sellafield	Sand	4	0.086
Seascale	"	6	0.069
Drigg pipeline	"	8	0.066
Drigg Barn Scar	Mussel bed	4	0.089
Drigg Marsh	Grass	1	0.13
Saltcoats	Salt marsh	4	0.27
Ravenglass - Carleton Marsh	"	4	0.33
Ravenglass - salmon garth	Sandy mud	4	0.17
"	Sand/stones	3	0.094
"	Mussel bed	4	0.095
"	Sand	1	0.083
" - boat area	Sandy mud	12	0.11
" - "	Sand	4	0.067
" - ford	Muddy sand	4	0.12
" - River Mite	Salt marsh	4	0.27
" - Ravenvilla	Sandy mud	11	0.15
"	Muddy sand	1	0.13
"	Salt marsh	12	0.27
" - Eskmeals Nature Reserve	"	4	0.28
" - River Esk flooded pasture	"	4	0.27
Newbiggin	Sandy mud	4	0.25
"	Salt marsh	4	0.36
" - west of bridge	Sandy mud	3	0.13
"	Mud/sand/stones	1	0.12
"	Salt marsh	4	0.33
Silecroft	Sand	2	0.063
Haverigg - boat area	Sandy mud	4	0.11
" - river mouth	Muddy sand	4	0.071
Borwick Rails - Millom	"	4	0.11
Low Shaw	Salt marsh	4	0.12
Askham	"	4	0.19
Tummer Hill Marsh	"	4	0.20
Walney Channel	Sandy mud	2	0.12
"	Muddy sand	2	0.084
" - Vickers shore	"	4	0.085
" - west shore	Sand	4	0.060
Roa Island	Sandy mud	4	0.083
Greenodd	Salt marsh	2	0.089
Sand Gate Marsh - Holker	"	4	0.12
Flookburgh	Muddy sand	4	0.090
High Foulshaw	Salt marsh	4	0.10
Arnside	Muddy sand	4	0.073
Lancashire, Merseyside and North Wales			
Jenny Brown's Point	Salt marsh	4	0.078
Sunderland Point	Sandy mud	4	0.091
Sunderland	Mud/sand/stones	4	0.082
Colloway Marsh	Salt marsh	4	0.18

Table 9. continued

Location	Ground type	No. of sampling observations#	Mean gamma dose rate in air at 1 m, µGy h^{-1}
Lancaster	Saltmarsh	4	0.12
Aldcliffe Marsh	"	4	0.16
Conder Green	Sandy mud	5	0.12
"	Salt marsh	5	0.15
Cockerham Marsh	"	4	0.12
Heads - River Wyre	"	2	0.16
Height o' th' hill - River Wyre	"	4	0.19
Hambleton	Mud	4	0.13
"	Salt marsh	4	0.16
Fleetwood Docks	"	4	0.19
Skippool Creek	Mud	4	0.13
Fleetwood	Sand	4	0.067
Blackpool	"	4	0.052
Crossen Marsh	Mud	4	0.12
"	Salt marsh	4	0.12
Ainsdale	Sand	4	0.052
New Brighton	"	4	0.063
"	Mussel bed	1	0.062
West Kirby	Muddy sand	2	0.059
Rock Ferry	Mud	4	0.12
Runcorn	"	4	0.091
"	Salt marsh	4	0.11
Little Neston Marsh	Muddy sand	2	0.074
"	Salt marsh	3	0.085
Flint	Mud	4	0.097
"	Salt marsh	5	0.12
Prestatyn	Sand	2	0.056
Rhyl	Mud	4	0.077
Llandudno	Shingle	2	0.082
Caerhun	Salt marsh	2	0.11
Llanfairfechan	Mud	1	0.084
"	Salt marsh	3	0.10
Amlwch Harbour	Rock	4	0.090
South-west Scotland			
Garlieston	Sandy mud	4	0.099
Innerwell	"	4	0.092
Bladnoch	Mud	2	0.10
Creetown	Salt marsh	3	0.14
Carsluith	Sandy mud	4	0.087
Skyre burn Bay (Water of Fleet)	Salt marsh	3	0.089
Palnackie Harbour	Mud	4	0.11
Garden burn	Salt marsh	3	0.13
Kippford Slipway	Sandy mud	4	0.098
" Merse	Salt marsh	4	0.17
" Yacht Jetty	"	1	0.16
Carsethorn	Sandy mud	4	0.10
Glencaple Harbour	Muddy sand	3	0.088

 # See sub-section 3.2 for definition

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 1992 generally showed small reductions as compared with those in 1991 (Camplin, 1993).

We also regularly monitor radioactivity concentrations in sediments, 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 1991 (Camplin, 1993) shows general reductions of gamma radioactivity in line with the behaviour of dose rates.

To identify those members of the public subject to the highest external exposures, occupancies of different locations need to be considered. We keep under review the amounts of time spent by members of the public on intertidal areas of coastline bordering the north-eastern Irish Sea; activities leading to significant external exposures are sparse and our surveys cover a wide area including Cumbria, Lancashire (Doddington *et al.*, 1990) and the north Solway coast (Doddington *et al.*, 1989). In western Cumbria, combining dose rates and occupancy times, the maximum exposure in 1992 was 0.10 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 boats in the Ribble estuary are representative of those who

Table 10. Radioactivity in sediment from the Cumbrian coast and further afield, 1992

Sampling point and sediment type		No. of sampling observa-tions#	Mean radioactivity concentration (dry), Bq kg^{-1}							
			Total beta	^{60}Co	^{95}Zr	^{95}Nb	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs
Cumbria										
Newton Arlosh	Turf	4	1700	3.3	ND	ND	ND	ND	ND	5.1
Maryport - Christchurch	Mud	4	2800	11	39	16	370	7.5	15	6.4
Harrington Harbour	"	4	2800	10	71	99	370	14	21	4.1
Whitehaven - yacht basin	"	4	4800	9.8	38	36	320	8.0	18	5.4
St Bees	Sand	5	400	2.7	ND	ND	ND	ND	0.28	0.13
Sellafield	"	4	440	2.4	"	"	4.2	"	0.87	0.55
Seascale	"	4	460	2.0	"	"	3.8	"	0.45	0.45
Drigg pipeline	"	4	410	2.2	"	"	6.5	"	0.47	0.40
Drigg stream	Mud	2	5900	67	"	"	ND	"	ND	41
"	Muddy sand	1	2500	36	"	"	"	"	"	21
Carleton Marsh	Mud	2	2700	15	41	64	480	6.7	26	4.3
"	Turf	2	3200	40	ND	ND	240	ND	21	16
Rabbit Cat How	"	1	2000	22	"	"	240	"	15	3.2
Ravenglass - Ravenvilla	Sandy mud	4	1500	8.2	30	49	180	4.0	14	2.0
" - Ford	Mud	1	NA	11	12	58	160	ND	8.9	ND
Newbiggin	"	4	2000	14	31	ND	270	4.0	16	2.2
Millom	Sandy mud	4	830	2.7	20	29	67	1.3	2.2	0.78
Walney Channel	"	4	920	3.0	18	28	61	1.7	2.1	0.96
Low Shaw	Turf	4	2400	6.4	ND	ND	23	ND	ND	17
Flookburgh shore	Muddy sand	4	600	0.40	"	"	ND	"	"	ND
Sand Gate marsh	Turf	4	1300	1.7	"	"	"	"	"	3.8
Ainsdale	Sand	1	NA	ND	"	"	"	"	"	ND
Lancashire, Merseyside and north Wales										
Jenny Browns Point	Turf	1	600	"	"	"	"	"	"	1.3
Sunderland Point	Sandy mud	4	890	1.1	3.7	"	18	"	1.8	0.76
Conder Green	"	2	1100	1.7	13	"	28	"	2.8	2.4
"	Salt marsh	1	1300	1.9	20	"	39	"	9.3	2.5
"	Turf	4	2100	4.8	ND	"	20	"	ND	5.3
Cockerham Marsh	"	1	840	2.2	"	"	16	"	4.7	1.1
Hambleton	"	4	2800	4.0	"	"	ND	"	2.7	7.9
Skippool Creek	Mud	4	1800	4.0	6.8	4.2	44	"	2.5	3.4
Fleetwood	Sand	4	340	ND	ND	ND	ND	"	ND	ND
Blackpool	"	4	250	"	"	"	"	"	"	"
Crossens	"	1	270	"	"	"	"	"	"	"
New Brighton	"	4	350	"	"	"	"	"	"	"
West Kirby	Sandy mud	2	580	0.74	"	"	"	"	2.0	0.62
Rock Ferry	Mud	4	1200	0.42	"	"	"	"	1.8	1.1
Rhyl	"	1	770	ND	"	"	"	"	ND	ND
Caerhun	Turf	2	1100	0.61	"	"	"	"	"	5.5
Cemlyn Bay	Mud	2	1100	0.35	"	"	"	"	"	1.6
Llanfairfechan	"	1	860	0.55	"	"	7.0	"	"	ND
"	Turf	3	1400	0.73	"	"	ND	"	"	9.4
South-west Scotland										
Garlieston	Mud	4	1200	3.7	3.7	6.2	78	"	5.3	9.8
Innerwell	"	2	1000	2.4	ND	ND	27	"	2.0	1.2
Bladnoch	"	2	1500	4.1	"	"	59	"	ND	4.4
Carsluith	"	4	1200	3.1	3.7	6.3	57	1.4	3.8	2.0
Kippford Merse	Turf	4	2000	9.1	1.4	2.9	86	ND	5.3	9.8
" Slipway	Mud	4	1100	4.2	10	17	100	1.9	3.8	2.3
Palnackie Harbour	"	4	1400	5.8	14	17	130	2.4	4.9	2.3
Carsethorn	"	2	1500	4.0	14	22	150	3.7	4.6	1.8
Northern Ireland										
Lough Foyle	"	2	510	ND	ND	ND	ND	ND	ND	0.46
Portrush	Sand	2	200	"	"	"	"	"	"	ND
Larne Lough	Mud	2	800	"	"	"	"	"	"	1.5
Groomsport	Sand	2	270	"	"	"	"	"	"	ND
Ballymacormick	Mud	2	430	"	"	"	"	"	1.1	0.27
Strangford Lough - Island Hill	"	2	530	"	"	"	"	"	ND	ND
" - Nickey's Point	"	2	610	"	"	"	"	"	"	"
Dundrum Bay	"	2	650	"	"	"	"	"	"	"
Carlingford Lough	"	2	970	0.37	"	"	"	"	"	2.1
Oldmill Bay	"	2	820	ND	"	"	"	"	"	ND

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	1200	ND	5.9	1.2	NA	NA	NA	250	NA	NA
Maryport - Christchurch	Mud	4	950	31	22	7.0	130	590	〃	930	1.1	2.7
Harrington Harbour	〃	4	880	33	23	10	NA	NA	〃	1100	NA	NA
Whitehaven - yacht basin	〃	4	1300	36	27	14	160	730	〃	1100	1.5	2.3
St Bees	Sand	5	98	ND	3.6	2.2	NA	NA	〃	140	NA	NA
Sellafield	〃	4	170	〃	3.1	2.0	〃	〃	〃	220	〃	〃
Seascale	〃	4	100	〃	3.9	2.2	〃	〃	〃	170	〃	〃
Drigg pipeline	〃	4	81	0.48	5.2	2.2	〃	〃	〃	210	〃	〃
Drigg stream	Mud	2	4500	ND	ND	ND	〃	〃	〃	220	〃	〃
〃	Muddy sand	1	2600	〃	〃	〃	〃	〃	〃	160	〃	〃
Carleton Marsh	Mud	2	1100	34	39	17	200	940	〃	1400	ND	4.1
〃	Turf	2	2000	9.4	53	25	NA	NA	〃	2000	NA	NA
Rabbit Cat How	〃	1	750	30	22	10	〃	〃	〃	1100	〃	〃
Ravenglass - Ravenvilla	Sandy mud	4	460	23	17	8.4	〃	〃	〃	660	〃	〃
- Ford	Mud	1	430	13	18	9.2	〃	〃	〃	1100	〃	〃
Newbiggin	〃	4	670	23	26	12	150	710	11000	1100	ND	2.2
Millom	Sandy mud	4	270	7.2	5.8	2.9	NA	NA	NA	220	NA	NA
Walney Channel	〃	4	210	8.7	5.8	2.9	〃	〃	〃	210	〃	〃
Low Shaw	Turf	4	1500	ND	20	9.4	〃	〃	〃	760	〃	〃
Flookburgh shore	Muddy sand	4	150	〃	ND	1.1	〃	〃	〃	40	〃	〃
Sand Gate marsh	Turf	4	850	〃	4.6	0.93	〃	〃	〃	200	〃	〃
Ainsdale	Sand	1	19	〃	ND	ND	0.38	2.0	〃	2.5	0.0021	0.0043
Lancashire, Merseyside and north Wales												
Jenny Browns Point	Turf	1	120	〃	〃	〃	NA	NA	〃	23	NA	NA
Sunderland Point	Sandy mud	4	270	〃	1.4	2.1	〃	〃	〃	110	〃	〃
Conder Green	〃	2	430	〃	4.2	3.2	〃	〃	〃	140	〃	
〃	Salt marsh	1	480	〃	3.5	6.0	〃	〃	〃	160	〃	〃
〃	Turf	4	1400	〃	7.4	4.5	〃	〃	〃	310	〃	〃
Cockerham Marsh	〃	1	360	〃	3.7	ND	〃	〃	〃	150	〃	〃
Hambleton	〃	4	2100	〃	8.9	8.1	〃	〃	〃	400	〃	〃
Skippool Creek	Mud	4	900	〃	5.7	5.3	〃	〃	〃	320	〃	〃
Fleetwood	Sand	4	32	〃	ND	0.77	〃	〃	〃	12	〃	〃
Blackpool	〃	4	13	〃	〃	ND	〃	〃	〃	3.8	〃	〃
Crossens	〃	1	22	〃	〃	〃	〃	〃	〃	3.5	〃	〃
New Brighton	〃	4	18	〃	〃	0.19	〃	〃	〃	4.4	〃	〃
West Kirby	Sandy mud	2	140	〃	〃	0.68	〃	〃	〃	24	〃	〃
Rock Ferry	Mud	4	470	〃	〃	ND	〃	〃	〃	120	〃	〃
Rhyl	〃	1	130	〃	〃	〃	〃	〃	〃	33	〃	〃
Caerhun	Turf	2	300	〃	〃	1.3	〃	〃	〃	52	〃	〃
Cemlyn Bay	Mud	2	250	〃	〃	1.9	6.4	34	〃	49	ND	0.12
Llanfairfechan	〃	1	230	〃	〃	ND	NA	NA	〃	45	NA	NA
〃	Turf	3	700	〃	1.3	1.5	〃	〃	〃	120	〃	〃
South-west Scotland												
Garlieston	Mud	4	1000	〃	15	7.9	43	220	〃	320	ND	0.71
Innerwell	〃	2	200	〃	2.0	3.0	NA	NA	〃	140	NA	NA
Bladnoch	〃	2	670	〃	8.6	2.4	〃	〃	〃	150	〃	〃
Carsluith	〃	4	320	〃	3.3	1.8	26	130	〃	200	0.29	0.36
Kippford Merse	Turf	4	1000	〃	15	7.9	86	420	〃	640	ND	1.7
〃 Slipway	Mud	4	380	5.9	6.6	3.2	36	180	〃	270	〃	0.56
Palnackie Harbour	〃	4	570	11	9.4	4.9	61	290	〃	430	0.64	1.1
Carsethorn	〃	2	570	5.6	8.8	2.6	NA	NA	〃	310	NA	NA
Northern Ireland												
Lough Foyle	〃	2	9.1	ND	ND	ND	0.21	1.5	〃	1.7	ND	0.0043
Portrush	Sand	2	1.1	〃	〃	〃	NA	NA	〃	ND	NA	NA
Larne Lough	Mud	2	130	〃	〃	〃	〃	〃	〃	15	〃	〃
Groomsport	Sand	2	12	〃	〃	〃	〃	〃	〃	0.73	〃	〃
Ballymacormick	Mud	2	66	〃	〃	〃	2.5	14	190	18	ND	0.047
Strangford Lough - Island Hill	〃	2	19	〃	〃	〃	0.30	1.7	NA	1.0	〃	ND
〃 - Nickey's Point	〃	2	64	〃	〃	〃	1.7	10	〃	9.0	〃	0.0077
Dundrum Bay	〃	2	17	〃	〃	1.1	NA	NA	〃	1.5	NA	NA
Carlingford Lough	〃	2	160	〃	〃	2.1	2.7	16	〃	8.3	ND	0.0098
Oldmill Bay	〃	2	97	〃	〃	ND	2.5	13	〃	18	〃	0.043

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

receive the highest external exposures from the effects of discharges from Sellafield (see sub-section 4.2). Their occupancy of boats in 1992 was similar to that in 1991. Making an allowance for natural background, their external exposure in 1992 was 0.15 mSv, which is the same as that in 1991. 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.

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).

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. We regularly monitor fishing gear using portable beta dosemeters. Results for 1992 are presented in Table 11. Measured dose rates were similar to those for 1991 (Camplin, 1993). Our habits surveys keep under review the amounts of time spent by fishermen handling their gear; for those most exposed, 500 h year^{-1} is appropriate. The maximum exposure from handling of fishing gear in 1992, including a component due to natural radiation, would have been 0.21 mSv, which is well within 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 1992; this pathway has therefore remained

Table 11. Beta radiation dose rates on contact with fishing gear on vessels operating off Sellafield, 1992

Vessel	Type of gear	No. of sampling observations#	Mean beta dose rate in tissue, µSv h^{-1}
A	Nets	4	0.17
	Ropes	4	0.099
B	Nets	8	0.16
	Ropes	8	0.24
D	Gill nets	4	0.28
	Pots	1	0.42
E	Gill nets	4	0.36
	Nets	2	0.64
M	Nets	3	0.23
	Ropes	3	0.17
R	Nets	3	0.14
S	Pots	1	0.31
T	Gill nets	2	0.24
	Pots	1	0.45

 # See sub-section 3.2 for definition

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 1992 are presented in Table 12. Samples of laverbread from the major manufacturers are regularly collected from markets in South Wales and analysed. Results for 1992 are presented in Table 13. The exposure of critical laverbread consumers was less than 0.005 mSv, confirming the virtual abeyance of this exposure pathway.

4.1.5 Contact dose-rate monitoring of intertidal areas

We regularly monitor contact beta and gamma dose rates in intertidal areas to locate and remove any material with unusual levels of contamination. A summary of items detected during 1992 is presented in Table 14. The rate of detection increased as compared with 1991. In May and April, items found were associated with damage to a sea pipeline. This incident has been reported by BNFL (BNFL, 1993) and contaminated material, predominantly hydroids, were immediately removed from the beach. Other finds were typical of those in recent years. 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

Table 12. Radioactivity in Porphyra from UK shorelines of the Irish Sea, 1992

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	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb
Braystones South	4	200	N A	0.37	N A	1.3	0.97	N A	0.33	38	4.1	1.0
Seascale	49*	N A	"	0.16	"	1.5	1.5	"	0.45	46	3.5	2.0
St Bees	4	160	31	0.15	0.21	0.61	N D	0.92	0.14	33	2.0	1.5
Knock Bay	4	160	N A	N D	N A	N D	"	N A	N D	0.41	0.05	N D

Sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet), Bq kg^{-1}							
		^{134}Cs	^{137}Cs	^{144}Ce	^{238}Pu	^{239}Pu+^{240}Pu	^{241}Pu	^{241}Am	^{243}Cm+^{244}Cm
Braystones South	4	N D	4.8	0.25	0.80	3.7	53	6.1	0.0088
Seascale	49*	0.04	7.2	0.12	N A	N A	N A	8.8	N A
St Bees	4	N D	5.1	N D	0.63	3.0	44	5.4	0.012
Knock Bay	4	"	0.59	"	N A	N A	N A	0.30	N A

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, 1992

Manufacturer	No. of sampling observa-tions#	Mean radioactivity concentration (wet), Bq kg^{-1}			
		Total beta	^{110m}Ag	^{137}Cs	^{241}Am
A	4	59	0.04	0.37	0.09
C	3	34	N D	0.12	N D
D	4	78	0.04	0.43	0.07
E	1	88	N D	0.29	N D

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

Table 14. Summary of contact beta and gamma dose rate monitoring of intertidal areas of Cumbria, 1992

Month	No. of items detected (> 0.01 mGy h^{-1} but below 0.1 mGy h^{-1})	Location and dose rates (mGy h^{-1}) of items 0.1mGy h^{-1} and above
January	5	Pipeline to River Calder: 0.1
February	-	-
March	-	-
April	1	-
May	2	-
June	1	-
July	1	-
August	1	-
September	-	-
October	-	-
November	4	-
December	-	-

(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.

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, we undertake a number of further investigations. 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 1992 on marine plants from shorelines of the Irish Sea and further afield. Although small quantities of samphire and *Rhodymenia* may be eaten, 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 departments of the Scottish Office. Analyses of samples collected in Northern Ireland are carried out on behalf of the DOE(NI).

Table 15. Radioactivity in marine plants from shorelines of the Irish Sea and further afield, 1992

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	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb
Fucus vesiculosus												
Sellafield	4	970	NA	1.4	2.9	5.0	1.5	800	ND	10	26	1.7
St Bees	5	650	34	0.93	1.6	1.2	0.32	360	"	4.6	7.9	1.2
Port William	4	280	NA	0.09	NA	ND	ND	80	"	ND	0.05	0.17
Garlieston	4	440	"	0.43	"	0.15	"	NA	"	0.58	1.3	0.29
Auchencairn	4	340	"	0.38	"	0.22	"	"	"	0.39	1.1	0.50
Cape Wrath	1	270	"	ND	"	ND	"	25	"	ND	ND	0.20
Wick	1	130	"	"	"	"	"	9.2	"	"	"	ND
Ardglass	3	320	"	"	"	"	"	150	"	"	"	0.15
Portrush	2	210	"	"	"	"	"	NA	"	"	"	ND
Portmadog	1	160	"	"	"	"	"	"	"	"	"	"
Fishguard	1	180	"	"	"	"	"	6.6	"	"	"	"
Lavernock Point	1	220	"	"	"	"	"	NA	"	"	"	"
Isles of Scilly	1	200	"	"	"	"	"	1.1	"	"	"	"
Fucus serratus												
Portrush	2	190	"	"	"	"	"	NA	"	"	"	"
Fucus spiralis												
St Bees	1	480	"	1.1	"	"	"	"	"	7.3	12	1.6
Ardglass	1	160	"	ND	"	"	"	28	"	ND	ND	ND
Ascophyllum nodosum												
St Bees	1	NA	"	0.29	"	1.1	"	NA	"	2.1	3.5	1.2
Rhodymenia spp.												
St Bees	2	560	"	0.43	"	17	"	"	0.69	80	15	2.2
Strangford Lough	4	800	"	ND	"	ND	"	"	ND	ND	ND	ND
Samphire												
Rabbit Cat How, Ravenglass	1	26	"	0.19	"	"	"	0.13	"	2.1	"	"
Cockerham Marsh	1	40	"	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	^{147}Pm	^{155}Eu	^{238}Pu	^{239}Pu+^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+^{244}Cm
Fucus vesiculosus											
Sellafield	4	0.28	17	ND	1.5	ND	2.4	11	4.7	0.0092	0.011
St Bees	5	0.10	13	"	NA	"	1.6	7.1	4.0	ND	0.0078
Port William	4	0.04	4.9	"	"	"	NA	NA	0.45	NA	NA
Garlieston	4	ND	11	"	"	0.13	"	"	4.0	"	"
Auchencairn	4	0.08	13	"	"	0.06	"	"	2.8	"	"
Cape Wrath	1	ND	0.97	"	"	ND	"	"	ND	"	"
Wick	1	"	0.23	"	"	"	"	"	"	"	"
Ardglass	3	"	3.2	"	"	0.08	"	"	0.08	"	"
Portrush	2	"	0.31	"	"	ND	"	"	ND	"	"
Portmadog	1	"	1.7	"	"	"	"	"	"	"	"
Fishguard	1	"	0.50	"	"	"	"	"		"	"
Lavernock Point	1	"	0.36	"	"	"	"	"	"	"	"
Isles of Scilly	1	"	0.07	"	"	"	"	"	"	"	"
Fucus serratus											
Portrush	2	"	0.18	"	"	0.06	"	"	0.06	"	"
Fucus spiralis											
St Bees	1	0.21	10	"	"	0.25	"	"	5.5	"	"
Ardglass	1	ND	2.0	"	"	ND	"	"	ND	"	"
Ascophyllum nodosum											
St Bees	1	"	6.4	"	"	"	"	"	1.2	"	"
Rhodymenia spp.											
St Bees	2	0.52	37	1.8	"	"	1.6	7.6	16	0.045	0.044
Strangford Lough	4	ND	3.8	ND	"	"	0.074	0.37	0.41	ND	0.00081
Samphire											
Rabbit Cat How, Ravenglass	1	"	3.8	"	"	"	NA	NA	4.8	NA	NA
Cockerham Marsh	1	"	2.7	"	"	"	"	"	0.61	"	"

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

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 increased in 1992 (121 TBq) because uranium ore concentrate was processed for most of the year compared with 1991 when processing was limited to 4 months (38.4 TBq). 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 houseboats moored in muddy creeks of the Ribble estuary, and is the same group which is affected by discharges from Sellafield (sub-section 4.1.2).

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). We regularly monitor gamma and beta dose rates in relevant areas including muddy creeks where houseboats are moored, and some of these measurements are supported by analyses of sediments. In 1992, we continued to sample locally-obtained fish and shellfish, including analyses for isotopes of thorium, though there is little consumption of seafood from the estuary.

Results for 1992 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.

Table 16(a). Radioactivity in environmental materials near Springfields, 1992

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	^{154}Eu	^{155}Eu	^{228}Th	^{230}Th	^{232}Th
Chub	River Darwen	1	110	ND	ND	ND	ND	0.86	ND	ND	NA	NA	NA
Plaice	Ribble Estuary	1	110	"	"	"	"	18	"	"	0.0270	0.0021	0.0012
Salmon	"	1	130	"	"	"	"	0.58	"	"	0.0007	0.0008	0.0003
Sea trout	"	1	140	"	"	"	"	11	"	"	NA	NA	NA
Eel	"	1	90	"	"	"	0.27	25	"	"	0.0071	0.058	0.005
Shrimps	"	1	68	"	"	"	ND	8.7	"	"	0.0069	0.016	0.0039
Turf	Hesketh Bank	3	1600	3.2	27	4.7	3.2	650	4.4	4.1	NA	NA	NA
Mud	Becconsall	4	20000	1.0	14	1.2	1.3	480	2.6	ND	40	120	36
"	" (boat 2)	1	29000	3.2	37	6.5	4.2	980	9.6	"	NA	NA	NA
"	Pipeline	5	11000	2.2	19	2.0	1.7	380	2.8	0.63	40	110	34
Muddy sand	"	1	80000	ND	ND	ND	ND	160	ND	ND	NA	NA	NA
Mud	Deepdale Brook	4	2100	"	"	0.96	1.8	17	"	2.2	27	380	26
"	Savick Brook	2	380000	1.7	36	ND	3.0	390	2.7	1.7	NA	NA	NA
Sandy mud	Penwortham	1	6200	ND	ND	"	2.5	160	ND	ND	"	"	"
Mud	"	4	25000	2.1	14	2.1	1.1	370	1.4	2.1	42	180	34
"	Lower Penwortham	2	250000	2.7	41	ND	2.8	900	3.8	ND	NA	NA	NA

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
Chubb	River Darwen	1	ND	ND	NA	NA	NA	NA	NA	NA	ND	NA	NA
Plaice	Ribble Estuary	1	"	"	"	"	"	"	"	"	"	"	"
Salmon	"	1	"	"	"	"	"	"	"	"	"	"	"
Sea trout	"	1	"	"	"	"	"	"	"	"	"	"	"
Eel	"	1	"	"	"	"	"	"	"	"	"	"	"
Shrimps	"	1	"	"	"	"	"	"	0.0042	0.020	0.029	ND	ND
Turf	Hesketh Bank	3	570	"	"	"	"	"	NA	NA	220	NA	NA
Mud	Becconsall	4	33000	"	35	ND	35	"	"	"	310	"	"
"	" (boat 2)	1	36000	"	NA	NA	NA	"	"	"	320	"	"
"	Pipeline	5	53000	"	31	ND	34	"	100	570	440	0.20	0.24
Muddy sand	"	1	110000	"	NA	NA	NA	"	NA	NA	52	NA	NA
Mud	Deepdale Brook	4	850	5.2	910	34	810	3.4	"	"	ND	"	"
"	Savick Brook	2	750000	ND	NA	NA	NA	NA	"	"	280	"	"
Sandy mud	Penwortham	1	9900	"	"	"	"	"	"	"	59	"	"
Mud	"	4	140000	"	49	1.5	40	0.55	"	"	130	"	"
"	Lower Penwortham	2	270000	"	NA	NA	NA	NA	43	220	310	0.24	0.63

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, 1992

Location	Material	No. of sampling observations#	µGy h⁻¹
Gamma dose rates at 1 m over intertidal areas			
Lytham	Mud	4	0.15
"	Salt marsh	4	0.17
Lytham Boatyard	Mud	3	0.13
"	Sandy mud	1	0.11
Hesketh Bank	Mud	4	0.13
"	Sandy mud	1	0.15
"	Salt marsh	4	0.14
Freckleton	Mud	3	0.15
"	Sandy mud	1	0.12
River Douglas	Grass	4	0.20
Becconsall	Mud	7	0.12
"	Sandy mud	2	0.10
" (boat 2)	Cabin*	4	0.12
" (boat 2)	Mud	4	0.14
" (boat 3)	Cabin*	3	0.11
Longton Marsh	Mud	1	0.16
"	Salt marsh	3	0.17
Hutton Marsh	Mud	3	0.16
"	Salt marsh	3	0.14
Pipeline	Mud	4	0.12
"	Muddy sand	5	0.12
Pipeline (south bank)	Sandy mud	3	0.12
"	Salt marsh	3	0.17
Savick Brook	Mud	1	0.46
"	Grass	1	0.14
Penwortham	Muddy sand	2	0.078
"	Sandy mud	3	0.095
"	Mud	4	0.21
Lower Penwortham	"	3	0.19
"	Muddy sand	1	0.083
"	Sandy mud	2	0.086
"	Grass	5	0.091
Preston (Tramway Bridge)	"	1	0.063
River Darwen	Muddy sand	2	0.087
"	Mud/sand/stones	2	0.075
"	Grass	4	0.080
Beta dose rates			µSv h⁻¹
Lytham	Mud	4	4.0
Hesketh Bank	"	3	3.2
"	Sandy mud	1	8.7
River Douglas	Grass	4	1.5
Longton Marsh	Mud	1	8.2
"	Salt marsh	3	2.0
Hutton Marsh	Mud	3	11
Pipeline (south bank)	Sandy mud	3	6.6
Savick Brook	Mud	1	300
"	Grass	2	12
Penwortham	Mud	2	67
"	Sandy mud	1	11
"	Muddy sand	1	0.64
Lower Penwortham	Mud	2	52
"	Sandy mud	1	1.1
"	Muddy sand	1	2.1
"	Grass	4	7.9
Preston (Tramway Bridge)	"	1	0.31
River Darwen	Mud	1	0.72
"	Mud/sand/stones	1	0.53
"	Muddy sand	1	0.96
"	Grass	4	1.9
Ribble estuary	Gill net	3	1.3
"	Shrimp net	2	1.0
"	Fyke net	1	ND

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

Gamma dose rates over intertidal areas were generally similar to those for 1991. Beta dose rates were higher than those for 1991 because of increased discharges. Isolated high values for both beta and gamma dose rates were detected in the Savick Brook but the occupancy of the location where the measurement was made is extremely low. Exposure of the critical group of houseboat dwellers in 1992, including the Sellafield component, was 0.15 mSv, the same value as that for 1991. 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 1992 from Springfields has been calculated from appropriate models (HMIP and MAFF, 1991). The contribution is estimated to be 0.02 mSv. This dose, in addition to those considered below, is relevant for comparison with the dose constraint for practices of 0.3 mSv. It is also a small fraction of the dose received in 1992 due to the combined effects of past and current discharges.

The exposure of wildfowlers was assessed as being 0.03 mSv in 1992 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. Much of the dose is due to Springfields discharges and 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 wildfowlers with skin exposures, including a component due to natural radiation, of 1.6 mSv in 1992. This is 3% 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 1992 (see Table 1). We have established an environmental monitoring programme related to the pathways which could be of radiological significance due to both disposal routes. Aquatic plants are also sampled as indicator materials. It is to be noted that the programme is much more extensive than is technically justified by the potential radiological hazard from Capenhurst discharges.

Table 17. Radioactivity in environmental materials near Capenhurst, 1992

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	62	0.18	1.6	0.03	ND	3.9	ND	5.0
Fucus spiralis	Hoylake	1	190	ND	NA	ND	"	5.5	"	ND
Shrimps	"	2	66	"	0.65	"	0.05	4.9	"	"
Cladophoraceae rupestris	Rivacre Brook	2	560	"	250	"	ND	1.5	"	220
Mud	"	2	2100	0.42	2000	"	0.52	17	6.1	280

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	0.99	NA	0.16	0.87	2.2	0.0029
Fucus spiralis	Hoylake	1	"	"	"	ND	"	NA	NA	0.87	NA
Shrimps	"	2	"	"	"	"	"	"	"	ND	"
Cladophoraceae rupestris	Rivacre Brook	2	71	5.2	47	19	12	"	"	"	"
Mud	"	2	620	38	430	44	71	"	"	"	"

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

Results for 1992 are presented in Table 17. The concentrations of artificial radioactivity in marine samples are mainly due to Sellafield discharges and are consistent with values expected at this distance from Sellafield. Concentrations of technetium-99 were low, reflecting the low levels of discharges of this radionuclide from Sellafield. Exposure of shellfish consumers, a potential critical group, in the vicinity of the Wirral in 1992 amounted to 0.04 mSv, which is within the dose limit of 1 mSv year^{-1} for members of the public. The effective dose, calculated on the basis of ICRP-60, was 0.02 mSv. This exposure was mainly due to transuranic nuclides from Sellafield; only a tiny fraction was due to technetium-99, which was almost entirely from Sellafield discharges. Concentrations of radionuclides in materials from the Rivacre Brook in 1992 show the effects of Capenhurst discharges but these concentrations were of extremely low radiological significance.

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 by the Scottish Office. Our 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. Our 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 1992 are presented in Tables 18(a) and (b).

Table 18(a). Radioactivity in environmental materials near Chapelcross, 1992

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta	^{14}C	^{60}Co	^{95}Zr	^{106}Ru	^{110m}Ag	^{125}Sb
Flounder	4	150	30	ND	ND	ND	ND	ND
Salmon	1	79	NA	"	"	"	"	"
Sea trout	2	150	"	"	"	"	"	"
Shrimps	4	84	"	"	"	"	0.96	"
Fucus vesiculosus	4	350	"	0.40	0.08	0.98	0.11	0.19
Sandy mud	4	810	"	1.4	2.0	26	ND	1.2

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	0.29	53	ND	ND	NA	NA	ND	NA	NA
Salmon	1	ND	0.48	"	"	"	"	"	"	"
Sea trout	2	"	15	"	"	0.00062	0.0030	0.0044	ND	0.0000067
Shrimps	4	"	16	"	"	NA	NA	ND	NA	NA
Fucus vesiculosus	4	0.10	31	"	0.27	0.52	2.6	2.9	0.0048	0.0059
Sandy mud	4	1.2	330	1.8	1.4	11	52	78	ND	0.13

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, 1992

Location	Material	No. of sampling observations#	μSv h^{-1}
Beta dose rates on nets			
Seafield	Stake nets	2	0.21
Gamma dose rates at 1 m over intertidal areas			μGy h^{-1}
Seafield	Sandy mud	4	0.096
"	Saltmarsh	4	0.090
Battle Hill	Sandy mud	4	0.090
Browhouses	"	4	0.097
Dornoch Brow	Muddy sand	2	0.090
" "	Saltmarsh	4	0.100
Powfoot	"	4	0.079

 # See sub-section 3.2 for definition

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 1992 were generally similar to those in 1991. The exposure of the critical group of fishermen who consume seafood and are exposed to external radiation over intertidal areas was 0.02 mSv in 1992, which is 2% of the dose limit of 1 mSv year^{-1} for members of the public. The exposure of the skin of fishermen, including a component due to natural radiation, was 0.05 mSv which is much less than 1% of the dose limit appropriate for exposures to skin of members of the public. Wildfowlers received a dose of less than 0.005 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)

We have continued our regular monitoring of the environmental impact of liquid radioactive discharges from three UKAEA sites; namely Winfrith, Dounreay and Harwell. In common with such wastes from other nuclear establishments in the Thames Valley area, Harwell's liquid waste arisings are discharged into the River Thames catchment; whilst monitoring of the drinking water pathway is carried out by HMIP (HMIP, 1993), we have continued our small programme of monitoring of fish and other aquatic materials, and the results are presented in this section.

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 1992, we continued our small programme of monitoring of fish and other aquatic materials from the Thames catchment in surveillance of fisheries-related exposure pathways. In addition, sampling was carried out 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 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 monitoring are shown in Tables 19(a) and (b). 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. Gamma dose rates were indistinguishable from natural background. External exposures were calculated using a model based on concentrations of radionuclides in sediment (Hunt, 1984). The radiation dose to anglers in 1992 from fish consumption and external occupancy of the river bank would have been less than 0.005 mSv, or less than 0.5% of the dose limit of 1 mSv year^{-1}.

5.2 Winfrith, Dorset

The principal source of liquid radioactive wastes at this establishment in 1992 was decommissioning and decontamination of the Steam Generating Heavy Water Reactor (SGHWR) which ceased power production in September 1990. Discharges in 1992 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.

Table19(a). Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Harwell, 1992

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}									
			Total beta	^{14}C	^{57}Co	^{60}Co	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am
Pike	Outfall (Sutton Courtenay)	2	110	NA	ND	ND	0.08	3.0	ND	0.000044	0.00020	0.00032
	Newbridge	2	110	18	"	"	ND	ND	"	0.000013	0.000076	0.00012
	Staines	2	120	NA	"	"	"	0.38	"	NA	NA	ND
Nuphar lutea	Sutton Courtenay	1	46	"	"	0.99	0.03	0.71	"	"	"	"
	Sutton Pools	1	42	"	"	ND	ND	0.03	"	"	"	"
	Staines	1	39	"	0.23	0.06	"	0.20	"	"	"	"
Sandy mud	Sutton Courtenay	1	950	"	ND	26	0.95	570	2.7	"	"	6.2
	Staines	1	340	"	0.37	1.1	ND	21	0.51	"	"	ND
Mud	Newbridge	1	400	"	ND	ND	"	15	1.8	"	"	"

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

Table 19(b). Monitoring of gamma dose rates near Harwell, 1992

Location	Ground type	No. of sampling observations#	µGy h^{-1}
Gamma dose rates at 1 m over river bank			
Sutton Courtenay	Soil	1	0.069

 # See sub-section 3.2 for definition

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 our monitoring programme. External gamma radiation dose rates are monitored at Kimmeridge and in Poole Harbour where the intertidal sediment has the potential to adsorb radioactivity. In addition, monitoring of environmental materials and gamma dose rates at a number of locations along the south coast provides additional information on the distribution of radioactivity from all sources. 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 1992 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 (Smith and Hunt, 1989) reduced in 1992 to 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.

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 1992 were generally similar to those in 1991 reflecting the campaigns of reprocessing of reactor fuel. Our surveys near Dounreay are carried out on behalf of the Scottish Office. Monitoring in 1992 continued to include sampling of fish and shellfish from the area of the Dounreay outfall and other materials further afield, with associated gamma dose rate measurements. The results are presented in Tables 21(a) and (b).

Habits surveys have confirmed the existence of four potentially critical exposure pathways, three of which involve external irradiation. The first of these is due to radioactivity adsorbed mainly on fine particulate matter becoming entrained on fishing gear which is regularly handled. This results in skin dose, mainly from beta particles, to the hands and forearms of fishermen. The most exposed group is represented by a small number of people who operate a salmon fishery from Sandside Bay, close to Dounreay. The skin exposure of these fishermen has been assessed including a component due to natural radiation in this year's report in order to be consistent with assessments for other sites. Previously an estimate of the contribution due to natural radiation was subtracted. The dose in 1992 was 0.23 mSv, or less than 0.5% of the dose limit of 50 mSv year^{-1} for skin exposures (see sub-section 3.3).

Table 20(a). Radioactivity in environmental materials near Winfrith, 1992

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
			Total beta	^{14}C	^{60}Co	^{65}Zn	^{110m}Ag	^{125}Sb	^{137}Cs
Plaice	Weymouth Bay	2	85	30	ND	ND	ND	ND	ND
Whiting	"	2	94	NA	0.13	"	"	"	0.20
Crabs	"	4	70	"	3.3	2.4	"	"	ND
Lobsters	"	1	59	"	1.0	3.0	"	"	"
Pacific oysters	Poole	1	44	"	1.2	27	0.25	"	"
Mussels	"	1	52	"	3.5	ND	ND	"	"
"	Portland	1	44	"	4.2	"	"	"	"
Cockles	Poole	1	52	"	5.8	"	"	"	"
Scallops	Weymouth Bay	1	110	"	1.5	"	"	"	"
Squid	"	1	74	"	ND	"	"	"	"
Whelks	"	2	88	"	2.6	3.6	"	"	"
"	Poole	2	87	"	4.0	5.2	"	"	"
Fucus serratus	Arish Mell	1	220	"	15	ND	"	"	0.18
"	Kimmeridge	2	140	"	5.9	0.11	"	"	0.07
"	Bognor Rock	2	190	"	3.2	ND	"	"	0.11
"	Weymouth	2	130	"	5.1	"	"	"	0.09
Fucus spiralis	Arish Mell	1	130	"	1.6	"	"	"	ND
Sandy mud	Kimmeridge	2	430	"	5.4	"	"	"	2.0
Mud	Poole Harbour	2	290	"	8.7	"	"	0.54	3.0
"	Hardway	2	640	"	10	"	"	ND	3.7

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
			^{155}Eu	^{238}Pu	$^{239}Pu+{}^{240}Pu$	^{241}Pu	^{241}Am	^{242}Cm	$^{243}Cm+{}^{244}Cm$
Plaice	Weymouth Bay	2	ND	NA	NA	NA	ND	NA	NA
Whiting	"	2	"	"	"	"	"	"	"
Crabs	"	4	"	"	"	"	"	"	"
Lobsters	"	1	"	"	"	"	"	"	"
Pacific oysters	Poole	1	"	"	"	"	"	"	"
Mussels	"	1	"	"	"	"	"	"	"
"	Portland	1	"	"	"	"	"	"	"
Cockles	Poole	1	"	"	"	"	0.07	"	"
Scallops	Weymouth Bay	1	"	0.0012	0.0047	"	0.0024	ND	0.000041
Squid	"	1	"	NA	NA	"	ND	NA	NA
Whelks	"	2	"	0.0011	0.0047	"	0.0041	ND	0.00012
"	Poole	2	"	0.00079	0.0031	"	0.0028	"	0.00012
Fucus serratus	Arish Mell	1	"	NA	NA	"	ND	NA	NA
"	Kimmeridge	2	"	"	"	"	"	"	"
"	Bognor Rock	2	"	"	"	"	"	"	"
"	Weymouth	2	"	"	"	"	"	"	"
Fucus spiralis	Arish Mell	1	"	"	"	"	"	"	"
Sandy mud	Kimmeridge	2	1.5	"	"	"	"	"	"
Mud	Poole Harbour	2	1.4	0.12	0.56	5.7	0.40	ND	0.011
"	Hardway	2	1.6	NA	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, 1992

Location	Ground type	No. of sampling observations#	µGy h^{-1}
Gamma dose rates at 1 m over intertidal areas			
Kimmeridge	Sand	2	0.064
Poole Harbour	Mud	2	0.053
Hardway	"	2	0.065
Rye Harbour	"	2	0.060
Beta dose rates on fishing gear			µSv h^{-1}
Weymouth Bay	Pots	1	ND
"	Nets	1	"

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

Table 21(a). Radioactivity in environmental materials near Dounreay, 1992

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
Pipeline											
Cod	4	130	20	ND	ND	NA	ND	ND	ND	ND	1.0
Crabs	4	75	NA	"	"	"	"	1.0	"	"	0.19
Lobsters	4	76	"	"	0.03	"	"	9.8	"	"	0.38
Sandside Bay											
Winkles	4	93	"	0.15	1.5	"	"	58	"	"	0.19
Sand	4	430	"	0.06	0.25	"	"	ND	"	0.18	6.6
Fucus vesiculosus	4	280	"	1.1	1.7	38	0.38	1.7	"	ND	0.84
Oigins Geo											
Sludge	5	2300	"	15	36	NA	590	60	55	7.9	130
Brims Ness											
Winkles	4	100	"	0.01	1.3	"	ND	52	ND	ND	0.22
Fucus vesiculosus	3	280	"	1.2	1.7	"	"	1.7	"	0.02	0.75
Fucus spiralis	1	220	"	0.78	2.2	"	"	1.8	"	ND	0.46

Sampling point and 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	$^{243}Cm+^{244}Cm$
Pipeline										
Cod	4	ND	ND	ND	0.00029	0.0014	NA	0.0022	0.0000066	0.0000068
Crabs	4	"	"	"	0.0017	0.0073	"	0.0091	0.00031	0.00011
Lobsters	4	"	"	"	0.0051	0.018	"	0.10	0.0028	0.0028
Sandside Bay										
Winkles	4	"	"	"	0.12	0.34	3.5	0.53	0.027	0.011
Sand	4	"	0.87	2.1	2.4	8.8	NA	8.3	0.13	0.16
Fucus vesiculosus	4	0.19	ND	0.06	NA	NA	"	0.14	NA	NA
Oigins Geo										
Sludge	5	110	20	40	87	140	"	160	12	4.3
Brims Ness										
Winkles	4	0.12	ND	ND	0.12	0.36	"	0.59	0.032	0.013
Fucus vesiculosus	3	ND	"	"	NA	NA	"	ND	NA	NA
Fucus spiralis	1	"	"	"	"	"	"	"	"	"

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, 1992

Location	Ground type	No. of sampling observations#	µGy h^{-1}
Gamma dose rates at 1 m over intertidal areas			
Oigins Geo	Intertidal sediment	4	0.15
Sandside Bay	Sand	1	0.066
"	Winkle bed	4	0.15
Beta dose rates on fishing gear			µSv h^{-1}
Sandside Bay	Nets	1	0.35

See sub-section 3.2 for definition

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 1992, we carried out monitoring of sludge at Oigin's Geo; concentrations of radionuclides decreased compared with 1991. We also carried out measurements of gamma dose rates above areas of the foreshore. Public radiation exposure via this pathway remained low, at 0.005 mSv or 0.5% of the dose limit of 1 mSv year^{-1}.

The third potentially critical pathway involves internal exposure of consumers of locally-collected fish and crustaceans; we sample fish, crabs and lobsters from the outfall area 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 1992 were similar to or less than those for 1991. Exposures from consumption of fish and crustaceans 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 increased in 1992 but the radiation dose due to a combination of consumption of molluscs and external exposure during collection was low at 0.03 mSv or 3% of the dose limit of 1 mSv year^{-1}. This pathway was the critical one at Dounreay in 1992.

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; 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 our environmental monitoring. Our 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. We therefore analyse samples of fish and shellfish and monitor gamma dose rates over sediment. In addition, measurements of external exposure are supported by analyses of intertidal mud, and *Fucus vesiculosus* is collected as an indicator material.

Data for 1992 are presented in Tables 22(a) and (b). The only 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 is difficult at the low levels detected. 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 over intertidal mud continued to be indistinguishable from the natural background, thus a calculation based on concentrations of radionuclides in sediments has been used (Hunt, 1984) 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 0.005 mSv or 0.5% of the dose limit of 1 mSv year^{-1}.

Table 22(a). Radioactivity in environmental materials near Berkeley and Oldbury nuclear power stations, 1992

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}										
		Total beta	^{14}C	^{35}S	^{60}Co	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am	$^{243}Cm+^{244}Cm$
Dover sole	3	150	190	NA	ND	0.02	0.58	ND	NA	NA	ND	NA
Elvers	1	73	NA	"	"	ND	0.10	"	"	"	"	"
Shrimps	2	99	130	"	"	0.03	0.47	"	"	"	"	"
Fucus vesiculosus	2	240	NA	30	1.3	0.28	8.6	"	"	"	"	"
Mud: area of pipelines	7	790	"	NA	0.13	0.79	34	1.1	"	"	"	"
Lydney	2	690	"	"	ND	0.34	20	1.2	0.073	0.39	0.32	0.0094
Littleton Warth	2	900	"	"	"	0.77	42	2.1	NA	NA	ND	NA

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, 1992

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	0.072
2 km south west of Berkeley	"	2	0.066
Guscar Rocks	"	2	0.077
Lydney Locks	"	2	0.073
Berkeley pipeline	"	3	0.072
Sharpness	"	2	0.075
1 km north of Berkeley	"	1	0.067
Opposite Upper Framilode	Sandy mud	1	0.056
0.5 km south of Berkeley	Mud	1	0.073
Yacht club	"	1	0.078
Littleton Warth	"	2	0.069

 # See sub-section 3.2 for definition

6.2 Bradwell, Essex

Radioactive liquid effluent from this power station is discharged to the estuary of the River Blackwater. 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. Our environmental monitoring, therefore, reflects both these pathways. Gamma dose rate measurements are supported by analyses of intertidal sediment, and *Fucus vesiculosus* is analysed as an indicator material.

Measurements for 1992 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, however, small increases in caesium isotopes were detected corresponding in part to increases in discharges of these radionuclides. Gamma dose rates, as directly measured, were indistinguishable from the natural background. A calculation based on concentrations of radionuclides in sediments has been used (Hunt, 1984) 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}.

Table 23(a). Radioactivity in environmental materials near Bradwell nuclear power station, 1992

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}													
		Total beta	^{14}C	^{60}Co	^{65}Zn	^{99}Tc	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am	$^{243}Cm+^{244}Cm$
Cod	1	110	NA	ND	ND	NA	ND	ND	0.58	2.4	ND	NA	NA	ND	NA
Bass	1	110	"	"	"	"	"	"	0.71	3.0	"	"	"	"	"
Dab	1	110	32	"	"	"	"	"	0.21	1.4	"	"	"	"	"
Herring	1	100	NA	"	"	"	"	"	ND	0.84	"	"	"	"	"
Mullet	1	110	"	"	"	"	"	"	0.56	2.1	"	"	"	"	"
Crabs	2	71	"	0.37	"	"	"	"	0.24	0.64	"	"	"	"	"
Native oysters	4	62	"	0.19	1.5	"	"	"	0.26	1.0	"	0.00026	0.0012	0.0041	0.00029
Pacific oysters	1	60	"	0.08	2.2	"	0.09	"	0.10	0.41	"	NA	NA	ND	NA
Winkles	2	85	"	1.1	0.60	"	0.09	0.10	0.78	2.8	"	0.0032	0.013	0.011	0.00040
Fucus vesiculosus	2	250	"	0.74	0.18	4.1	ND	0.07	1.9	6.9	0.11	NA	NA	ND	NA
Mud	8	810	"	3.0	ND	NA	"	ND	8.9	46	1.7	"	"	"	"

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, 1992

Location	Ground type	No. of sampling observations#	μGy h^{-1}
Gamma dose rates at 1 m over intertidal areas			
Pipeline	Mud	2	0.076
1.5 km east of pipeline	"	2	0.066
Waterside	"	2	0.069
West Mersea	"	2	0.067
Maldon	"	2	0.059

 # See sub-section 3.2 for definition

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 our 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. Our 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 1992 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 and zinc-65 in some materials are likely to be due mainly to discharges from Winfrith rather than to Dungeness, as demonstrated by the indicator sampling programme described in sub-section 5.2. The small concentrations of transuranics in silt were similar to levels observed 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 (Hunt, 1984). The total exposure of the critical group for liquid discharges from Dungeness was low, at 0.007 mSv or 0.7% of the dose limit of 1 mSv year^{-1}.

Table 24(a). Radioactivity in environmental materials near Dungeness nuclear power stations, 1992

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}										
		Total beta	^{14}C	^{60}Co	^{65}Zn	^{125}Sb	^{137}Cs	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am	$^{243}Cm+^{244}Cm$
Plaice	2	110	22	ND	ND	ND	0.28	ND	NA	NA	ND	NA
Cod	3	130	NA	"	"	"	0.60	"	"	"	"	"
Bass	2	120	"	"	"	"	1.3	"	"	"	"	"
Shrimps	2	100	"	0.19	"	"	0.10	"	"	"	"	"
Whelks	2	54	"	0.72	0.27	"	0.07	"	"	"	"	"
Fucus serratus	2	270	"	2.5	ND	"	0.31	0.15	"	"	"	"
Mud	2	580	"	9.7	"	0.63	3.0	ND	0.16	0.59	0.48	0.052
Sand	3	230	"	1.6	"	ND	0.37	"	NA	NA	ND	NA

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, 1992

Location	Ground type	No. of sampling observations#	μGy h^{-1}
Gamma dose rates at 1 m over intertidal areas			
Camber Sands	Sand	2	0.051
Old Lifeboat Station	"	1	0.053
"	Shingle	1	0.045
Pilot Inn	Sand	1	0.064
"	Shingle	1	0.039
Rye Harbour	Mud	2	0.060

 # 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 our monitoring programme carried out in 1992 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. 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}.

Table 25(a). Radioactivity in environmental materials near Hartlepool nuclear power station, 1992

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg⁻¹										
		Total beta	^{14}C	^{60}Co	^{99}Tc	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Plaice	2	92	27	ND	NA	0.50	ND	NA	NA	ND	NA	NA
Cod	2	130	NA	"	"	1.1	"	"	"	"	"	"
Flounder	1	110	"	"	"	1.1	"	"	"	"	"	"
Whiting	1	130	"	"	"	1.4	"	"	"	"	"	"
Crabs	2	76	"	0.04	"	0.24	"	0.00083	0.0045	0.0060	0.000016	0.000024
Shrimps	1	78	"	ND	"	0.47	"	NA	NA	ND	NA	NA
Winkles	2	130	"	"	"	0.50	"	0.0049	0.026	0.013	0.000071	0.000035
Fucus vesiculosus	2	240	"	"	4.4	0.61	"	NA	NA	ND	NA	NA
Mud	4	710	"	"	NA	18	2.3	"	"	"	"	"
Coal/sand	2	220	"	"	"	3.2	0.86	"	"	"	"	"

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, 1992

Location	Ground type	No. of sampling observations#	μGy h⁻¹
Gamma dose rates at 1 m over intertidal areas			
Greatham Creek	Mud	2	0.073
Little Scar	Coal/sand	2	0.059
North Gare	Sand	2	0.055
Paddy's Hole	Mud	2	0.093

 # See sub-section 3.2 for definition

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 our 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. Our 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 1992 are given in Tables 26(a) and (b) showing fluctuations of zirconium-95, niobium-95, ruthenium-106 and silver-110m compared with 1991 (Camplin, 1993). These mainly reflect discharges from Sellafield; the effect of discharges from Heysham was not detectable above this background. The radiation exposure in 1992 to the critical group of fishermen was 0.13 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.

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 our 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 intertidal areas (Doddington *et al.*, 1988). Our 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.

The results for 1992, 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. Apportion-

Table 26(a). Radioactivity in environmental materials near Heysham nuclear power stations, 1992

Material	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	^{106}Ru	^{110m}Ag	^{125}Sb
Flounder	4	130	32	ND	NA	ND	ND	NA	ND	ND	ND
Plaice	4	110	44	"	"	"	"	"	"	"	"
Bass	2	140	NA	"	"	"	"	"	"	"	"
Whitebait	1	110	"	"	0.12	"	"	"	"	"	"
Cockles	4	86	"	0.84	NA	"	"	"	1.5	0.16	0.54
Mussels	4	75	35	0.35	"	"	"	"	2.1	0.22	0.41
Fucus vesiculosus	4	290	NA	0.33	"	0.32	"	150	0.32	0.38	0.63
Samphire	1	40	"	ND	"	ND	"	NA	ND	ND	ND
Sandy mud											
Half Moon Bay	4	960	"	1.9	"	11	16	"	28	1.2	2.8
Sunderland Point	4	890	"	1.1	"	3.7	ND	"	18	ND	1.8
Conder Green	2	1100	"	1.7	"	13	"	"	28	"	2.8
Morecambe Central Pier	4	930	"	1.9	"	5.6	2.7	"	22	"	1.8
Salt Marsh											
Conder Green	1	1300	"	1.9	"	20	ND	"	39	"	9.3
Turf											
Conder Green	4	2100	"	4.8	"	ND	"	"	20	"	ND
Cockerham	1	840	"	2.2	"	"	"	"	16	"	4.7

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	0.18	40	ND	ND	0.00042	0.0021	0.0041	ND	0.0000083
Plaice	4	ND	17	"	"	NA	NA	ND	NA	NA
Bass	2	0.27	32	"	"	"	"	"	"	"
Whitebait	1	ND	17	"	"	"	"	0.72	"	"
Cockles	4	"	8.8	"	0.05	0.65	3.2	7.4	ND	0.014
Mussels	4	"	3.7	"	ND	0.16	0.82	1.4	0.0040	0.0023
Fucus vesiculosus	4	0.03	13	"	"	NA	NA	0.84	NA	NA
Samphire	1	ND	2.7	"	"	"	"	0.61	"	"
Sandy mud										
Half Moon Bay	4	1.1	320	2.8	2.7	18	97	150	0.33	0.32
Sunderland Point	4	0.76	270	1.4	2.1	NA	NA	110	NA	NA
Conder Green	2	2.4	430	4.2	3.2	"	"	140	"	"
Morecambe Central Pier	4	1.0	300	2.1	2.4	"	"	120	"	"
Salt Marsh										
Conder Green	1	2.5	480	3.5	6.0	"	"	160	"	"
Turf										
Conder Green	4	5.3	1400	7.4	4.5	"	"	310	"	"
Cockerham	1	1.1	360	3.7	ND	"	"	150	"	"

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, 1992

Location	Material	No. of sampling observations#	$\mu Gy\ h^{-1}$
Gamma dose rates at 1 m over intertidal areas			
Morecambe Central Pier	Mussel bed	4	0.078
"	Muddy sand	3	0.085
Half Moon Bay	Sandy mud	4	0.095
Pipeline	Muddy sand	4	0.074
Red Nab Point	Sandy mud	4	0.091
Sunderland Point	"	4	0.091
Sunderland	Mud/sand/stones	4	0.082
Colloway Marsh	Salt marsh	4	0.18
Lancaster	"	4	0.12
Aldcliffe Marsh	"	4	0.16
Conder Green	Sandy mud	4	0.12
"	Salt marsh	4	0.15
Cockerham Marsh	"	4	0.12

 # See sub-section 3.2 for definition

ment 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 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 (Hunt, 1984) 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 $year^{-1}$.

Table 27(a). Radioactivity in environmental materials near Hinkley Point nuclear power stations, 1992

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	130	100	NA	ND	ND	0.14	1.2	ND	NA	NA	ND	NA
Shrimps	2	95	100	"	"	"	0.17	0.83	"	0.00039	0.0016	0.0022	0.000024
Fucus vesiculosus	2	230	NA	34	2.4	1.6	0.90	5.5	"	NA	NA	ND	NA
Sandy mud	4	630	"	NA	ND	0.66	3.4	37	0.52	"	"	"	"
Mud	2	880	"	"	"	0.77	5.4	55	1.6	"	"	"	"

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, 1992

Location	Ground type	No. of sampling observations#	µGy h^{-1}
Gamma dose rates at 1 m over intertidal areas			
0.8 km east of pipeline	Mud	2	0.087
0.8 km west of pipeline	Sandy mud	2	0.12
1.6 km east of pipeline	Mud	2	0.077
Pipeline	Sandy mud	2	0.085
River Parrett	Mud	2	0.072

 # See sub-section 3.2 for definition

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. 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. We 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 1992 are shown in Tables 28(a) and (b).

Table 28(a). Radioactivity in environmental materials near Hunterston nuclear power stations, 1992

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}													
		Total beta	^{14}C	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn	^{110m}Ag	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+^{244}Cm
Cod	2	120	26	ND	ND	ND	ND	ND	0.05	4.3	ND	NA	NA	ND	NA	NA
Saithe	2	140	NA	"	"	"	"	"	ND	11	"	"	"	"	"	"
Crabs	2	58	"	"	"	0.24	"	0.08	"	1.4	"	0.0028	0.016	0.013	0.00024	0.00030
Velvet swimming crabs	2	73	"	0.14	"	1.9	"	0.16	"	1.0	"	NA	NA	ND	NA	NA
Nephrops	2	110	"	ND	"	0.12	"	ND	"	4.5	"	"	"	"	"	"
Lobsters	1	86	"	"	"	0.36	"	"	"	1.6	"	"	"	"	"	"
Oysters	1	76	"	0.36	"	0.55	0.96	0.80	"	1.1	"	"	"	"	"	"
Winkles	4	98	"	4.0	0.20	8.6	0.15	1.3	"	1.6	"	0.059	0.27	0.12	0.00089	0.0021
Fucus spiralis	4	280	"	14	0.14	12	ND	0.14	0.08	4.8	"	NA	NA	ND	NA	NA
Sand	4	240	"	3.1	ND	1.8	"	ND	ND	16	0.20	"	"	"	"	"

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, 1992

Location	Ground type	No. of sampling observations#	µGy h^{-1}
Gamma dose rates at 1 m over intertidal areas			
0.5 km north of pipeline	Sand	2	0.057
0.5 km south of pipeline	Sand/stones	2	0.070

 # See sub-section 3.2 for definition

The concentrations of artificial radioactivity in this area are predominantly due to Sellafield discharges, the general values being consistent with those to be expected at this distance from Sellafield. Small increases in concentrations of manganese-54 were probably due to discharges from the site; however these were of negligible radiological significance. In 1992, 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 indistinguishable from the natural background, but a small contribution to the exposure of the critical group given above was included, based on a calculation (Hunt, 1984) using measured concentrations of radionuclides in sand.

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 habits survey in 1991 and 1992 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 1992 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 with the exception of measurements at one location close to the station which were affected by direct radiation. The above exposure of the critical group includes a small contribution for their external exposure based on a calculation (Hunt, 1984) using radionuclide concentrations in sediment.

Table 29(a). Radioactivity in environmental materials near Sizewell nuclear power station, 1992

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}										
		Total beta	^{14}C	^{60}Co	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+^{244}Cm
Cod	1	110	19	ND	0.17	2.3	ND	NA	NA	ND	NA	NA
Whiting	1	140	NA	"	ND	1.3	"	"	"	"	"	"
Sole	1	110	"	"	"	0.47	"	"	"	"	"	"
Crabs	2	68	"	0.18	"	0.33	"	0.00015	0.00062	0.0012	0.000020	0.000087
Shrimps	1	66	"	ND	0.27	0.83	"	0.00021	0.00075	0.0010	ND	ND
Pacific oysters	1	30	"	"	ND	0.13	"	NA	NA	ND	NA	NA
Whelks	1	99	"	0.40	"	0.31	"	"	"	"	"	"
Mud	2	760	"	2.0	"	18	1.5	"	"	"	"	"
Sand Dunwich	2	15	"	ND	"	0.40	ND	"	"	"	"	"
Aldeburgh	2	65	"	"	"	0.47	"	"	"	"	"	"
Pipeline	1	28	"	"	"	0.61	"	"	"	"	"	"

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, 1992

Location	Ground type	No. of sampling observations#	μGy h^{-1}
Gamma dose rates at 1 m over intertidal areas			
Pipeline	Sand/stone	1	0.059
"	Sand	2	0.088
Dunwich	"	2	0.045
Rifle range	"	2	0.044
Sizewell Hall	"	2	0.046
Aldeburgh	"	2	0.046
Southwold Harbour	Mud	2	0.068

\# *See sub-section 3.2 for definition*

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. Our 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. These pathways form the basis of our regular monitoring programme (Leonard and Hall, 1989). Samples of fish and shellfish are collected and analysed, and samples of *Fucus vesiculosus* are

Table 30(a). Radioactivity in environmental materials near Torness nuclear power station, 1992

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}													
		Total beta	^{14}C	^{54}Mn	^{99}Tc	^{60}Co	^{110m}Ag	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Cod	2	120	28	ND	NA	ND	ND	ND	1.6	ND	NA	NA	ND	NA	NA
Crabs	2	81	NA	"	"	0.09	"	"	0.32	"	"	"	"	"	"
Lobsters	1	61	"	"	"	ND	"	"	0.45	"	"	"	"	"	"
Nephrops	4	88	"	"	"	"	"	"	0.76	"	0.0010	0.0055	0.0057	0.000032	0.000029
Winkles	4	99	"	"	"	0.72	1.2	"	0.52	"	NA	NA	ND	NA	NA
Fucus vesiculosus	2	280	"	1.4	11	1.7	0.19	"	0.68	"	"	"	"	"	"
Mud															
Eyemouth Harbour	1	750	"	ND	NA	ND	ND	3.0	68	2.5	"	"	"	"	"
Muddy Sand															
Dunbar Inner Harbour	2	600	"	"	"	"	"	0.94	33	1.8	"	"	"	"	"
Barns Ness	1	410	"	"	"	"	"	ND	10	1.6	"	"	"	"	"
Sand															
Thornton Loch Beach	2	180	"	"	"	"	"	"	3.8	0.18	"	"	"	"	"

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, 1992

Location	Material	No. of sampling observations#	µSv h^{-1}
Beta dose rates on nets			
Cove	Pots	2	0.12
Dunbar Harbour	Nets	2	0.095
Gamma dose rates at 1 m over intertidal areas			µGy h^{-1}
Barns Ness	Mud/sand/stones	2	0.065
Skateraw Harbour	Sand	2	0.058
Thornton Loch Beach	"	2	0.054

 # See sub-section 3.2 for definition

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 1992 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 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 (Hunt, 1984); as directly measured, gamma dose rates remained indistinguishable from the natural background. This also applies to beta dose rates on contact with fishing gear.

6.10 Trawsfynydd, Gwynedd

Discharges from this station are made to the freshwater Lake Trawsfynydd under authorisation of the Welsh Office and HMIP. Because of the limited volume of water available for dispersion they are of greater radiological significance than those from other UK nuclear power stations which discharge to estuarine or coastal waters. 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, in 1992, 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 (Leonard, 1989).

Our 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. As part of our research programme, 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. The results of our monitoring are shown in Tables 31(a) and (b).

Table 31(a). *Radioactivity in environmental materials near Trawsfynydd nuclear power station, 1992*

Material	No. of sampling observations#	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	11	470	38	23	0.03	12	ND	ND	56	310
Rainbow trout	14	160	NA	17	ND	7.6	"	"	4.5	28
Rainbow trout (hatchery)	1	120	"	NA	"	5.8	"	"	0.85	3.9
Perch	8	980	"	28	"	8.4	"	"	150	880
Rudd	2	540	"	NA	"	NA	"	"	78	430
Eel	1	540	"	"	"	"	"	"	19	210
Grass carp	1	430	"	"	"	4.2	"	"	42	280
Fontinalis										
Afon Prysor	2	180	"	"	0.07	NA	"	"	0.87	15
Gwylan Stream	3	980	"	"	16	"	120	110	19	120
Afon Dywryd	1	660	"	"	ND	"	ND	6.8	ND	18
Mud										
Pipeline (bankside)	2	2700	"	"	40	"	210	290	200	1400
Hot lagoon	2	10000	"	"	120	"	1000	2200	600	6500
Nant Islyn Bay	1	8800	"	"	98	"	1000	1900	820	6500
Gwylan Stream	2	3500	"	"	19	"	64	180	150	2200
Peat										
Barrier Wall	1	14000	"	"	260	"	1600	2400	1000	9300
Near cooling water outlet	1	3700	"	"	37	"	550	1700	210	1200
Hot lagoon	2	2900	"	"	74	"	380	840	140	1000
South end of lake	2	1900	"	"	14	"	ND	41	42	1500
Cae Adda boat mooring	2	950	"	"	1.8	"	"	15	24	370
Bailey bridge	2	1400	"	"	3.2	"	"	50	52	690
Turf										
Afon Dywryd	8	1000	"	"	3.3	"	3.9	21	31	400
NE Promontory	1	2000	"	"	3.5	"	ND	18	15	1300
South end of lake	1	3100	"	"	ND	"	"	9.3	31	700
Water										
Bailey bridge	4	NA	"	"	NA	"	NA	NA	0.025	0.11
Cold lagoon	4	"	"	"	"	"	"	"	0.030	0.13

Material	No. of sampling observations#	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	11	ND	ND	ND	0.00022	0.00065	NA	0.0010	0.000086	0.000033
Rainbow trout	14	"	"	"	0.00055	0.0020	"	0.0033	0.00016	0.000071
Rainbow trout (hatchery)	1	"	"	"	0.000099	0.00042	"	0.00073	0.000054	0.0000087
Perch	8	"	"	"	0.00055	0.0022	"	0.0041	0.00017	0.000059
Rudd	2	"	"	"	NA	NA	"	ND	NA	NA
Eel	1	"	"	"	"	"	"	"	"	"
Grass carp	1	"	"	"	0.00011	0.00044	"	0.00077	ND	0.0000026
Fontinalis										
Afon Prysor	2	"	"	1.8	NA	NA	"	ND	NA	NA
Gwylan Stream	3	63	3.5	4.1	"	"	"	2.1	"	"
Afon Dywryd	1	ND	ND	11	"	"	"	ND	"	"
Mud										
Pipeline (bankside)	2	110	7.0	9.5	"	"	"	16	"	"
Hot lagoon	2	450	58	37	36	97	2700	140	10	7.2
Nant Islyn Bay	1	340	ND	35	NA	NA	NA	59	NA	NA
Gwylan Stream	2	18	"	ND	"	"	"	3.5	"	"
Peat										
Barrier wall	1	680	56	40	"	"	"	150	"	"
Near cooling water outlet	1	170	ND	ND	"	"	"	25	"	"
Hot lagoon	2	190	21	9.9	11	34	"	49	4.4	2.3
South end of lake	2	ND	ND	1.9	NA	NA	"	3.7	NA	NA
Cae Adda boat mooring	2	7.7	"	2.3	"	"	"	ND	"	"
Bailey bridge	2	12	"	ND	"	"	"	2.5	"	"
Turf										
Afon Dywryd	8	12	"	"	"	"	"	2.5	"	"
NE Promontory	1	ND	"	4.0	"	"	"	4.9	"	"
South end of lake	1	"	"	6.0	"	"	"	6.7	"	"
Water										
Bailey bridge	4	NA	NA	NA	"	"	"	NA	"	"
Cold lagoon	4	"	"	"	"	"	"	"	"	"

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, 1992

Location	Ground type	No. of sampling observations#	µGy h^{-1}
Gamma dose rates at 1 m over areas near lake shoreline			
Bailey Bridge	Grass	1	0.064
"	Peat	1	0.083
South end of lake	"	1	0.10
"	Grass	1	0.070
Cae Adda boat mooring	Mud	2	0.065
NE Promontory	Grass	1	0.075

 # See sub-section 3.2 for definition

Discharges of radiocaesium from the power station in 1992 decreased slightly as compared with 1991 (Table 1) whereas strontium-90 discharges increased. The concentrations of radiocaesium in lake water also decreased in 1992; these changes were generally reflected in concentrations in fish. In 1992, 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 1992, 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 slightly decreased when compared with that of 1991 (Camplin, 1993) and this was due to the decreased concentrations of radiocaesium in fish. Gamma dose rates, measured using portable instruments, were difficult to distinguish from values to be expected from the natural background with the exception of a single measurement at the south end of the lake. The exposure of the critical group given above includes a contribution due to lakeside external exposure based on a calculation (Hunt, 1984) 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 authorisation was revised in 1992 to set lower limits on discharges. 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 1992 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 1992 indicates that the radiation exposure of the critical group of high-rate fish and shellfish consumers was low, at 0.007 mSv, or 0.7% 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 (Hunt, 1984).

Table 32(a). Radioactivity in environmental materials near Wylfa nuclear power station, 1992

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}															
		Total beta	^{14}C	^{54}Mn	^{60}Co	^{65}Zn	^{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	110	34	ND	ND	ND	NA	ND	ND	ND	2.3	ND	NA	NA	NA	ND	NA	NA
Crabs	2	70	NA	"	"	"	2.2	0.16	"	"	1.6	0.10	0.0043	0.021	"	0.092	0.00010	0.00027
Winkles	1	74	"	"	"	"	NA	0.37	0.30	"	1.4	ND	0.026	0.14	0.82	0.18	ND	0.00031
Fucus vesiculosus	4	300	"	0.67	1.1	0.16	"	0.06	ND	"	4.1	"	NA	NA	NA	0.22	NA	NA
Mud	2	1100	"	ND	0.35	ND	"	ND	"	1.6	250	1.9	6.4	34	"	49	ND	0.12

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, 1992

Location	Ground type	No. of sampling observations#	µGy h^{-1}
Gamma dose rates at 1 m over intertidal areas			
Amlwch Harbour	Rock	4	0.090
Cemaes Bay	Sand	6	0.058
Cemlyn Bay	Mud	4	0.083

 # See sub-section 3.2 for definition

7. DEFENCE ESTABLISHMENTS

We have continued our regular monitoring of the effects of liquid radioactive waste discharges to sea from naval establishments, 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, 1993). In 1992, however, we continued our small programme of monitoring of fish and other aquatic materials 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 agreement and approval with MAFF and HMIP to the Thames catchment. In October 1992, the limits on discharges to the River Thames at Pangbourne were reduced and limits on discharges to the Silchester sewage works were introduced. As explained above, the drinking water pathway is investigated by HMIP but, in 1992, we continued a small programme of fisheries-related monitoring 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 identified anglers as a potential critical group which may be affected by 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.

Table 33(a). Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Aldermaston, 1992

Material	Sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}											
			Total beta	^{14}C	^{57}Co	^{60}Co	^{137}Cs	^{155}Eu	^{234}U	^{235}U	^{238}U	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am
Pike	Newbridge	2	110	18	ND	ND	ND	ND	NA	NA	NA	0.000013	0.000076	0.00012
	Pangbourne	2	120	NA	“	“	0.79	“	“	“	“	0.000024	0.00011	0.00024
	Staines	2	120	“	“	“	0.38	“	“	“	“	NA	NA	ND
Nuphar lutea	Pangbourne	1	35	“	“	0.16	0.47	“	“	“	“	“	“	“
	Staines	1	39	“	0.23	0.06	0.20	“	“	“	“	“	“	“
	Newbridge	1	42	“	ND	ND	0.03	“	“	“	“	“	“	“
Clay	Pangbourne	1	550	“	“	“	1.7	1.6	“	“	“	“	“	“
Sandy mud	Staines	1	340	“	0.37	1.1	21	0.51	“	“	“	“	“	“
Mud	Foundry Brook	1	490	“	ND	ND	7.0	2.1	17	0.54	18	“	“	“
	Newbridge	1	400	“	“	“	15	1.8	NA	NA	NA	“	“	“

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

Table 33(b). Monitoring of gamma dose rates near Aldermaston, 1992

Location	Ground type	No. of sampling observations#	µGy h^{-1}
Gamma dose rates at 1 m over river bank			
Pangbourne	Grass	1	0.061

 # See sub-section 3.2 for definition

The results of the monitoring are shown in Tables 33(a) and (b). The concentrations of artificial radioactivity detected were very low. Gamma dose rates were indistinguishable from natural background. External exposures were calculated using a model based on concentrations of radionuclides in sediment (Hunt, 1984). 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 Devonport, Faslane and Rosyth under authorisation/agreement with the relevant Authorising Departments (Table 1). We carry out monitoring programmes near all of these establishments and, in the case of Faslane and Rosyth, on behalf of departments of the Scottish Office. Monitoring is also carried out in the Holy Loch (sub-section 2.1). Monitoring near Chatham also continues in surveillance of the effects of past discharges.

Public radiation exposures due to the effects of any discharges from these establishments are primarily due to external radiation from sediments, the nuclide of main importance being cobalt-60. Our 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. We regularly carry out measurements of gamma dose rates near all establishments; these are supported by analyses of sediments. Marine foodstuffs and seaweed are also analysed where appropriate.

Results of monitoring in 1992 are presented in Tables 34(a) and (b). The small concentrations of cobalt-60 mainly reflect discharges from the establishments; levels of radiocaesium are mainly due to discharges from Sellafield. Gamma dose rates over intertidal sediments, directly measured using portable instruments, remained indistinguishable from the natural background, such that public radiation exposure has been estimated by calculation based on concentrations of radionuclides in sediments (Hunt, 1984) as well as on occupancy times from habits surveys. In 1992, 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 all of these naval establishments, at less than 0.01 mSv year^{-1}. This represents less than 1% of the dose limit of 1 mSv year^{-1}.

Table 34(a). Radioactivity in environmental materials near naval establishments, 1992

Establishment	Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}									
			Total beta	^{60}Co	^{125}Sb	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{243}Cm+ ^{244}Cm
Chatham	Mud	2	NA	3.8	ND	0.42	18	1.0	NA	NA	ND	NA
Devonport	Mussels	2	52	0.25	"	ND	0.09	ND	"	"	"	"
"	*Fucus vesiculosus*	2	NA	0.17	"	"	0.11	"	"	"	"	"
"	Mud	6	"	1.3	"	"	5.1	2.3	0.026	0.53	0.18	0.0016
Faslane	Mud	2	"	13	2.9	"	60	0.71	NA	NA	0.33	NA
Rosyth	Crabs	2	"	ND	ND	"	0.29	ND	"	"	ND	"
"	*Fucus vesiculosus*	2	"	"	"	"	0.51	"	"	"	"	"
"	Mud	6	940	0.27	"	0.39	52	2.2	"	"	"	"
"	Muddy sand	4	NA	0.22	"	ND	18	1.9	"	"	"	"
"	Sand	2	"	ND	"	"	1.1	ND	"	"	"	"
Holy Loch	Muddy sand	2	410	0.85	"	0.95	54	1.4	"	"	"	"
"	Mud/sand/stones	1	380	2.5	"	ND	19	ND	"	"	"	"
"	Sandy mud	1	NA	ND	"	1.2	49	"	"	"	"	"
"	Mud	2	"	1.2	"	ND	18	"	"	"	"	"
"	Winkles	2	96	ND	"	"	1.3	"	"	"	"	"

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, 1992

Establishment	Location	Ground type	No. of sampling observations#	µGy h^{-1}
Gamma dose rates at 1 m over intertidal areas				
Chatham	Letleys Yard	Mud	1	0.066
"	Commodores Hard	"	1	0.058
"	Hoo Marina	"	1	0.063
"	Medway Yacht Club	"	1	0.061
Devonport	Kinterbury	"	2	0.073
"	Brunel Bridge East	"	2	0.072
"	Torpoint Ferry East	"	3	0.074
"	Stonehouse	"	2	0.070
"	Torpoint South	"	2	0.078
"	Wearde Quay	Mussel bed	2	0.074
Faslane	Gareloch Head	Muddy sand	2	0.054
"	Gulley Bridge Pier	Sand/stones	2	0.067
"	Rhu Narrows	Mussel bed	1	0.054
"	"	Sand/stones	1	0.059
"	Rosneath	Sand/shingle	1	0.062
"	"	Mussel bed	1	0.057
"	Camban boatyard	Mud	2	0.089
Rosyth	Blackness Castle	Muddy sand	2	0.067
"	Burntisland Bay	Sand	2	0.057
"	East of Dockyard	"	2	0.065
"	Port Edgar	Mud	2	0.070
"	West of Dockyard	Muddy sand	2	0.081
Holy Loch	North Sandbanks	Mud/sand/stones	2	0.063
"	Ardnadam Pier	"	2	0.074
"	River Eachaig	Muddy sand	1	0.079
"	"	Salt marsh	1	0.065
"	Gibbs Point	Sand	2	0.060
"	West Kilmun	Muddy sand	2	0.061
"	Kilmun Pier	Sand	2	0.067
"	Mid-Loch	Muddy sand	1	0.055
"	"	Mussel bed	1	0.055
"	Sandbanks	Salt marsh	1	0.058
"	"	Grass	1	0.064

 # 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. As explained in section 5, environmental monitoring in respect of these discharges is carried out by the HMIP (HMIP, 1993). However, in 1992, we continued our 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. Our 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 Cross sewage works; releases enter the Grand Union Canal and the River Colne. The authorisation was revised in April 1992 to specify lower limits on discharges. In 1992, we continued our small programme of monitoring of fish and other aquatic materials 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 monitoring 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.

Table 35. Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Amersham, 1992

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}										
			Total beta	^{14}C	^{57}Co	^{58}Co	^{60}Co	^{65}Zn	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+^{240}Pu	^{241}Am
Pike	Newbridge	2	110	18	ND	ND	ND	ND	ND	ND	0.000013	0.000076	0.00012
	Grand Union Canal	1	110	76	0.17	"	"	"	0.90	"	NA	NA	ND
	Staines	2	120	NA	ND	"	"	"	0.38	"	"	"	"
Nuphar lutea	Grand Union Canal	1	59	"	0.88	0.31	"	0.08	0.03	"	"	"	"
	Staines	1	39	"	0.23	ND	0.06	ND	0.20	"	"	"	"
	Newbridge	1	42	"	ND	"	ND	"	0.03	"	"	"	"
Mud	Grand Union Canal	1	310	"	14	2.5	1.2	2.5	14	"	"	"	"
	Newbridge	1	400	"	ND	ND	ND	ND	15	1.8	"	"	"
Sandy mud	Staines	1	340	"	0.37	"	1.1	"	21	0.51	"	"	"

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

External exposures were calculated using a model based on concentrations of radionuclides in sediment (Hunt, 1984). 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.

Our 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 1992 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 1992; the presence of the other radionuclides was therefore due to the combined background effects noted above. The exposure of the critical group of fish and shellfish consumers including external irradiation was 0.01 mSv or 1% of the dose limit of 1 mSv year^{-1}. The external irradiation of the critical group was calculated on the basis of concentrations of radionuclides in sediment (Hunt, 1984). Gamma dose rates over sediment, as measured using portable instruments, were indistinguishable from those expected from the natural background.

Table 36(a). Radioactivity in environmental materials near Cardiff, 1992

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta^{x}	^{14}C	^{35}S	^{60}Co	^{131}I	^{134}Cs	^{137}Cs	^{155}Eu
Flounder	3	270	680	NA	ND	ND	ND	0.56	ND
Winkles	1	190	240	"	"	"	"	1.8	"
Limpets	1	100	NA	"	"	"	"	0.61	"
Fucus serratus	2	210	22	"	"	2.5	"	0.50	"
Fucus vesiculosus	2	220	23	"	"	3.5	0.02	0.40	"
Fucus spiralis	4	190	21	ND	"	3.1	ND	0.42	0.04
Mud	6	880	14	NA	0.18	ND	0.52	32	1.1

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, 1992

Location	Ground type	No. of sampling observations#	µGy h⁻¹
Gamma dose rates at 1 m over intertidal areas			
East of pipeline	Mud	2	0.076
West of pipeline	"	2	0.063
Mouth of Rhymney River	"	1	0.078
Rhymney River	"	1	0.068

 # See sub-section 3.2 for definition

9. CHANNEL ISLANDS MONITORING

We have continued to analyse marine environmental samples provided by the Channel Islands States, 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 1992 are given in Table 37. Concentrations of caesium-137 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 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 0.01 mSv in 1992 or 1% of the dose limit for members of the public. The concentrations of artificial radionuclides in the marine environment of the Channel Islands therefore continued to be of negligible radiological importance.

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

We continued surveillance of the effects of fallout from this accident in 1992, but at a reduced scale of effort. Parts of the freshwater environment continued to show the effect of fallout from Chernobyl. The results of our additional monitoring for 1992 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 1992, 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 1991 (Camplin, 1993) 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 1992 to those in 1991. Figure 2 shows a plot of mean total radiocaesium concentrations in brown trout from Ennerdale Water against time. In recent years, the rate of decline has reduced and it is likely that levels have now become more stable.

Radiation exposures have been estimated using a procedure based on cautious assumptions, as previously (Camplin, 1993). 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 1992, estimated exposures were less than 0.2 mSv on the basis of both ICRP-26 and ICRP-60 in all areas of the UK.

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

Table 37. Radioactivity in environmental materials from the Channel Islands, 1992

Material	Sampling area/ landing point	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
			Total beta	^{14}C	^{54}Mn	^{60}Co	^{65}Zn	^{90}Sr	^{99}Tc	^{106}Ru	^{110m}Ag
Rays	Guernsey[2]	1	120	NA	ND	ND	ND	NA	NA	ND	ND
Crabs	Guernsey[2]	1	45	"	"	0.98	"	"	"	"	0.22
	Jersey[2]	1	97	"	"	0.91	"	"	"	"	ND
	Alderney Casquets[1]	3	77	37	"	1.7	"	"	0.37	"	0.12
Lobsters	Guernsey[2]	1	97	NA	"	0.61	"	"	NA	"	ND
	Jersey[2]	1	91	"	"	ND	"	"	"	"	"
	Alderney Casquets[1]	1	95	"	"	0.38	"	"	"	" "	0.39
Oysters	Jersey[2]	1	81	"	"	0.67	0.14	"	"	"	0.99
Limpets	Guernsey[1]	1	93	"	"	ND	ND	"	"	"	ND
	Jersey[1] La Rozel	1	61	"	"	0.61	"	"	"	"	0.19
	Alderney East[1]	1	96	"	"	1.0	"	"	"	1.1	0.28
Ormers	Guernsey[1]	1	72	"	"	0.44	"	"	"	ND	ND
Toothed winkles	Alderney East [1]	1	61	"	"	2.3	"	"	"	3.0	0.64
Porphyra	Alderney[1] Quenard Point	3	210	"	"	0.26	"	"	"	ND	ND
	Guernsey[1] Fermain Bay	3	110	"	"	0.07	"	"	"	"	"
	Jersey[1] Greve de Lecq	4	200	"	"	0.40	"	"	"	0.53	"
Fucus serratus	Guernsey[1] Fermain Bay	3	210	"	"	1.6	"	0.18	"	ND	"
	Jersey[1] La Rozel	4	290	"	0.03	2.9	"	0.32	"	"	"
	Alderney[1] Quenard Point	3	230	"	ND	2.1	"	0.24	"	0.03	0.04
Fucus spiralis	Alderney[1] Quenard Point	1	210	"	"	2.1	"	NA	"	ND	ND
Fucus vesiculosus	Alderney[1]	2	NA	"	"	1.7	"	"	"	"	"
Laminaria digitata	Jersey[1] Verclut	4	340	"	"	0.17	"	"	"	"	"
Mud	Jersey[1] St Helier	1	610	"	1.6	32	"	"	"	16	"
Sand	Guernsey[1] Bordeaux Harbour	1	310	"	ND	1.3	"	"	"	ND	"
	Alderney[1] Little Crabbe Harbour	1	430	"	"	1.0	"	"	"	"	"

Material	Sampling area/ landing point	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			^{125}Sb	^{137}Cs	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm+^{244}Cm$
Rays	Guernsey[2]	1	ND	2	ND	0.00013	0.00049	0.00077	ND	0.000019
Crabs	Guernsey[2]	1	"	ND	"	0.0017	0.0027	0.0082	0.000072	0.0029
	Jersey[2]	1	"	"	"	0.00089	0.0018	0.0050	ND	0.0011
	Alderney Casquets[1]	3	"	1.0	"	0.0029	0.0038	0.0084	0.000047	0.0028
Lobsters	Guernsey[2]	1	"	ND	"	0.0013	0.0037	0.0056	ND	0.00076
	Jersey[2]	1	"	"	"	0.00042	0.0010	0.0039	"	0.00091
	Alderney Casquets[1]	1	"	"	"	0.0013	0.0017	0.025	0.00031	0.0095
Oysters	Jersey[2]	1	"	0.07	"	0.0074	0.013	0.014	0.00011	0.0038
Limpets	Guernsey[1]	1	"	ND	"	NA	NA	ND	NA	NA
	Jersey[1] La Rozel	1	"	"	"	0.0057	0.010	0.013	0.000081	0.0034
	Alderney East[1]	1	"	0.25	"	0.011	0.020	0.027	0.00022	0.0072
Ormers	Guernsey[1]	1	"	0.53	"	NA	NA	ND	NA	NA
Toothed winkles	Alderney East[1]	1	"	0.09	"	0.022	0.036	0.055	0.00040	0.018
Porphyra	Alderney[1] Quenard Point	3	"	ND	"	NA	NA	ND	NA	NA
	Guernsey[1] Fermain Bay	3	"	0.05	"	0.0038	0.012	0.0099	0.00014	0.0021
	Jersey[1] Greve de Lecq	4	0.02	0.11	"	NA	NA	ND	NA	NA
Fucus serratus	Guernsey[1] Fermain Bay	4	ND	0.03	"	0.018	0.035	0.017	0.00024	0.0044
	Jersey[1] La Rozel	4	0.14	0.11	0.04	0.043	0.069	0.035	ND	0.0094
	Alderney[1] Quenard Point	4	0.02	0.11	ND	0.021	0.035	0.014	"	0.0034
Fucus spiralis	Alderney[1] Quenard Point	1	ND	0.21	0.23	NA	NA	ND	NA	NA
Fucus vesiculosus	Alderney [1]	2	"	0.16	ND	"	"	"	"	"
Laminaria digitata	Jersey[1] Verclut	4	0.03	0.17	"	"	"	"	"	"
Mud	Jersey[1] St Helier	1	2.1	4.7	1.7	1.2	2.5	3.9	0.029	0.81
Sand	Guernsey[1] Bordeaux Harbour	1	ND	2.6	ND	0.16	0.42	0.51	0.0024	0.12
	Alderney[1] Little Crabbe Harbour	1	0.87	1.8	0.7	NA	NA	ND	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, 1992

Location	Species	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
			^{134}Cs	^{137}Cs
England				
Branthwaite	Rainbow trout	1	N D	0.30
Narborough	"	1	"	0.54
Ennerdale Water	Brown trout	14	"	36
"	Char	4	"	11
Devoke Water	Perch	1	65	880
"	Brown trout	11	3.2	50
River Teme	Chub	1	N D	0.13
Wales				
Llyn Goddionduon	Brown trout	16	1.0	46
Scotland				
Loch Dee	Brown trout	7	17	310

ND = not detected

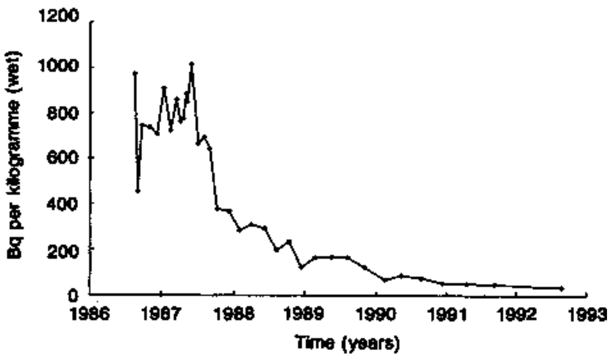

Figure 2. Radiocaesium in brown trout – Ennerdale Water

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) we have continued a programme of monitoring these radionuclides in the UK marine environment. Previous surveys (Rollo *et al.*, 1992) have established that an important source is 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 discharge is authorised by HMIP and contains low levels of natural radioactivity consisting mainly of thorium, uranium and their daughter products. Discharge rates at the end of 1992 were about one fifth of those in 1991 due to changes in waste treatment techniques and the reduction in use of phosphate ore.

The results of MAFF monitoring for natural radioactivity near the site in 1992 are shown in Table 39 with additional data for the Ribble estuary for completeness (see section 4.2). Analytical effort has focussed on polonium-210 which tends to concentrate in marine species. Concentrations of polonium-210 and other natural radionuclides are enhanced near Whitehaven but quickly reduce to background levels further away. Concentrations of polonium-210 in molluscan species were less than in 1991. 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 1992 and increased consumption of crustaceans was noted. The results of the assessment of exposures using the current NRPB

Table 39. Natural radioactivity in fish and shellfish from the Irish Sea, 1992

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	280	N A	N A	N A	N A	N A	N A	N A	N A
"	Parton	6	110	19	0.19	0.66	14	0.51	5.6	0.22	5.5
"	North Harrington	4	77	N A	N A	N A	N A	N A	N A	N A	N A
"	Fleswick Bay	4	44	"	"	"	"	"	"	"	"
"	Nethertown	4	30	"	"	"	"	"	"	"	"
"	Drigg	1	N A	"	"	0.78	1.5	0.58	"	"	"
"	Tarn Bay	4	19	"	"	N A	N A	N A	"	"	"
Mussels	Nethertown	4	87	"	"	"	"	"	"	"	"
Crabs	Parton	3	56	3.0	0.11	0.078	0.096	0.012	0.11	0.0033	0.10
"	St Bees	1	100	N A	N A	N A	N A	N A	N A	N A	N A
Lobsters	Parton	4	59	1.2	0.030	0.030	0.066	0.0068	0.051	0.0015	0.049
Shrimps	Ribble	1	N A	N A	N A	0.0069	0.016	0.0039	N A	N A	N A
Cod	Parton	3	2.5	0.05	"	N A	N A	N A	"	"	"
Salmon	Ribble	1	N A	N A	"	0.00070	0.00080	0.00030	"	"	"
Plaice	"	1	"	"	"	0.027	0.0021	0.0012	"	"	"

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

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 1992 was 0.64 mSv. This represents an increase from 0.52 mSv reported on the same basis for 1991 (Camplin, 1993), mainly due to increased consumption of crustaceans from 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 0.33 mSv in 1992, 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 $year^{-1}$.

We have increased our surveillance of concentrations in the area in 1993 and are now able to report on our preliminary findings based on results available at the time of writing this report. These indicate that, taking into account the expected seasonal variations in concentrations, the concentration of polonium-210 in 1993 in local winkles will be less than 100 Bq kg^{-1} (wet) or less than half the value for 1992. This decrease is due to the reduction in discharges from the site and the radioactive decay of polonium-210 in the environment. Further reductions in future years are expected.

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 approximately in proportion to the increase in gut uptake factor. This is because the contributions to dose from nuclides other than polonium-210 are relatively small.

12. SUMMARY AND CONCLUSIONS

A summary of estimated public radiation exposures in 1992, relating to liquid radioactive waste discharges, is presented in Table 41. The exposures are expressed on two bases. 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 on the basis of 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.

The concept of a 'constraint' on individual dose below the dose limit was introduced in ICRP-60 and developed by NRPB in their recent advice. NRPB recommend that the dose constraint for a single new source should not exceed 0.3 mSv $year^{-1}$ and believe that, in general, it should be possible for existing plant to be operated so that the dose from a controlled source does

Table 40. Individual radiation exposures from natural radionuclides due to consumption of fish and shellfish from the Whitehaven area, 1992

Exposed population	Nuclide	Effective dose equivalent, mSv		Effective dose, mSv	
		ICRP-26		ICRP-60	
		On the basis of current NRPB advice	Effect of polonium enhanced by a factor of 8 (see text)	On the basis of current NRPB advice	Effect of polonium enhanced by a factor of 8 (see text)
Consumers in Saltom Bay and Parton	^{210}Pb	0.13	0.13	0.08	0.08
	^{210}Po	0.49	4.0	0.24	1.9
	U, Th, Ra nuclides	0.02	0.02	0.01	0.01
	Total	0.64	4.1	0.33	2.0

Table 41. Summarised estimates of public radiation exposure from discharges of liquid radioactive waste in the UK, 1992

Establishment	Radiation exposure pathway	Critical group	Exposure, mSv ICRP-26=	ICRP-60+
British Nuclear Fuels plc				
Sellafield and Drigg[x]	Fish and shellfish consumption	Local fishing community	0.19	0.12
	External	Houseboat dwellers (River Ribble)	0.15	0.15
	External[d]	Fishermen (Whitehaven)	0.10	0.10
	Handling of fishing gear	Local fishing community	0.21[#]	0.21[#]
	Porphyra/laverbread consumption	Consumers in South Wales	<0.005	<0.005
Springfields	External	Houseboat dwellers (River Ribble)	0.15[a]	0.15[a]
	"	Wildfowlers	0.03[b]	0.04[b]
	" (skin)	"	1.6[#]	1.6[#]
Capenhurst	Shellfish consumption	Local fishing community	0.04[a]	0.02[a]
Chapelcross	Fish and shellfish consumption) External)	Local fishermen	0.02[a]	0.02[a]
	"	Wildfowlers	<0.005[a]	<0.005[a]
	Handling of fishing gear	Local fishermen	0.05[#a]	0.05[#a]
United Kingdom Atomic Energy Authority				
Harwell	Fish consumption) External)	Anglers	<0.005	<0.005
Winfrith	Fish and shellfish consumption	Local fishing community	<0.005	<0.005
Dounreay	Handling of fishing gear	Local fishermen	0.23[#b]	0.23[#b]
	External	Local community	0.005[b]	0.005[b]
	Fish and crustacean consumption	Local fishing community	<0.005[b]	<0.005[b]
	Mollusc consumption) External)	Mollusc collectors	0.03[b]	0.03[b]
Nuclear Power Stations Operated by the Electricity Companies				
Berkeley and Oldbury	Fish and shellfish consumption) External)	Local fishing community	0.005[b]	0.005[b]
Bradwell	Fish and shellfish consumption) External)	Houseboat dwellers	0.01[b]	0.01[b]
Dungeness	External) Fish and shellfish consumption)	Bait diggers	0.007	0.007
Hartlepool	Fish and shellfish consumption	Local fishing community	<0.005[a]	<0.005[a]
Heysham	Fish and shellfish consumption	Local fishermen	0.13[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]
Trawsfynydd	Fish consumption) External)	Local fishing community	0.08	0.08
Wylfa	Fish and shellfish consumption) External)	Local fishing community	0.007[a]	0.007[a]
Defence Establishments				
Aldermaston	Fish consumption) External)	Anglers	<0.005	<0.005
Chatham	External	Houseboat dwellers	0.007[b]	0.007[b]
Devonport	Fish and shellfish consumption) External)	Local community	<0.005	<0.005
Faslane	Fish and shellfish consumption) External)	Anglers	0.009[a]	0.009[a]
Rosyth	External	Dredgermen	0.006[a]	0.006[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	0.01	0.01
Albright and Wilson Ltd				
Whitehaven[c]	Fish and shellfish consumption	Local fishing community	0.64	0.33

= *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 1 mSv 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 1992 was 0.17 mSv (on the basis of ICRP-60: 0.09 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 1992 was 0.06 mSv (on the basis of ICRP-60: 0.04 mSv)*

d *Includes a small contribution due to consumption* not exceed this value. For Sellafield and Springfields we have calculated individual doses on the basis of discharges in 1992 and have shown that these are well within the 0.3 mSv constraint. Committed effective doses from discharges in 1992 at other sites would be less than or approximately equal to those in Table 41, depending upon the contribution due to radioactivity already in the environment. All licensed nuclear sites are being operated within the dose constraint for members of the public.

The more important contributions to exposures from the effects of discharges from Sellafield continued to be due to radiocaesium and transuranic radionuclides. Details are given in sub-section 4.1. Exposures of high-rate fish and shellfish consumers due to artificial radionuclides near Sellafield increased slightly in 1992, as compared with 1991, due to increases in consumption of molluscs. Exposures further afield in the commercial fisheries at Whitehaven, Fleetwood and Morecambe Bay were slightly more than in 1991. The small increases in these areas reflect fluctuations in the relatively low levels of actinides in shellfish. The long term trend in the reduction of such nuclides near Sellafield has however continued. Exposure of the externally-exposed group of houseboat dwellers in the area of the Ribble estuary was the same as 1991 at 0.15 mSv though, in general, there were small decreases in dose rates throughout the Irish Sea in 1992.

The maximum skin exposures in 1992 of 1.6 mSv were in the Ribble estuary. The dose limit for non-stochastic (deterministic) effects is 50 mSv $year^{-1}$. This exposure is therefore approximately 3% of the relevant dose limit.

Near Trawsfynydd, concentrations of radiocaesium in fish from the lake slightly decreased in 1992, following decreases in discharges. As a consequence, exposures of the high-rate fish consumers decreased from 0.11 mSv in 1991 to 0.08 mSv in 1992. These doses are well within the dose limit for members of the public.

In this year's report we have continued to provide an assessment of the exposures due to natural radioactivity which is enhanced above normal levels due to discharges from the Albright and Wilson factory at Whitehaven, Cumbria. Exposure of the critical group of fish and shellfish consumers, due to enhanced concentrations of natural radionuclides, on the basis of current recommendations for dose coefficients for ICRP-26 was 0.64 mSv. However, this would fall to 0.33 mSv on the basis of ICRP-60. These values represent small increases compared with exposures in 1991 (ICRP-26: 0.52 mSv; ICRP-60: 0.27 mSv) due to increases in consumption of crustaceans. These doses are within the 1 mSv limit for members of the public. Details are given in section 11. Discharge rates from Albright and Wilson have substantially reduced during 1992 due to changes in waste treatment techniques and the reduction in use of phosphate ore. These reductions have continued in 1993 and current indications are that levels of polonium-210 in molluscs have reduced by more than a factor of two in 1993 compared with 1992. Further reductions are expected. A recent experiment at this laboratory has provided evidence for a gut uptake factor for polonium eight times the currently recommended value. This result and data from other experiments are being considered by ICRP and NRPB in formulating their advice on human dosimetry. Until further advice is given, we have used the current recommendation for a gut uptake factor of 0.1 for control purposes. The implications of a higher factor are considered in section 11.

As in previous years, collective doses from artificial radionuclides have also been considered. The most significant radioactive waste discharges giving rise to collective dose were those from Sellafield, radiocaesium being the most significant component. Details are given in sub-section 4.1.1. The contribution to collective dose due to fallout from Chernobyl has been considered; this contribution is small except for fish from the Baltic Sea which are not widely eaten in the UK. Our preliminary assessment of the collective committed effective dose equivalent to the UK population in 1992 was 8 man-Sv, the same as the value for 1991. For the population of other European countries, excluding the effects of the Chernobyl accident on Baltic Sea fish, the preliminary collective committed effective dose equivalent was 22 man-Sv in 1992, slightly less than the value for 1991 (24 man-Sv). The decrease reflects the reductions in discharges from Sellafield over the past decade and the decreased contribution from Chernobyl. It is estimated that the effects of the Chernobyl accident on Baltic Sea fish could have added a further 80 man-Sv to the collective dose to other European countries in both 1991 and 1992.

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

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

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