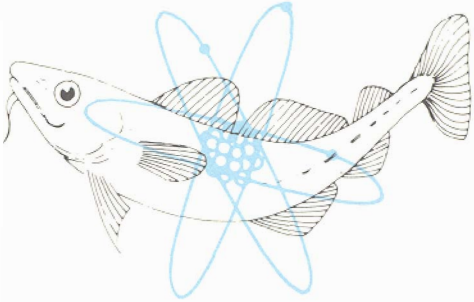
ISSN 0142-2499

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD
DIRECTORATE OF FISHERIES RESEARCH

AQUATIC ENVIRONMENT MONITORING REPORT



Number 23

Radioactivity in surface and coastal waters of the British Isles, 1989

Lowestoft 1990

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD

DIRECTORATE OF FISHERIES RESEARCH

AQUATIC ENVIRONMENT MONITORING REPORT

NUMBER 23

Radioactivity in surface and coastal waters of the British Isles, 1989

Lowestoft 1990

The author:
G J Hunt, MA PhD C Phys F Inst P MSRP is a Senior Principal Scientific Officer at the Directorate of Fisheries Research at Lowestoft. He is Head of the Fisheries Radiological Inspectorate of the Aquatic Environment Protection Division, Section 1.

Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft, (23), 66 pp.

CONTENTS

1. INTRODUCTION

This report presents the results of the environmental monitoring programme carried out during 1989 by staff of the Ministry of Agriculture, Fisheries and Food's (MAFF's) Directorate of Fisheries Research (DFR), Lowestoft. The monitoring programme complements the Ministry's Terrestrial Radioactivity Monitoring Programme (TRAMP) (MAFF, 1990) in supporting the Ministry's functions under the Radioactive Substances Act, 1960 (Great Britain - Parliament, 1960). The DFR programme is set up to verify the satisfactory control of liquid radioactive waste discharges to the aquatic environment, and to ensure that the resulting public radiation exposure is within nationally-accepted limits. The monitoring is independent of similar programmes carried out by nuclear site operators as a condition of their authorisations to discharge radioactive wastes. This report also includes results of monitoring carried out on behalf of departments of the Scottish Office, the Welsh Office, the Department of the Environment for Northern Ireland and the Channel Islands States. Where appropriate, the information presented is supplemented by results from our extensive programme of research into the behaviour of radioactivity in the aquatic environment. During 1989, the special programme of monitoring of the freshwater environment was continued in connection with the accident at Chernobyl, USSR on 26 April 1986, and the results are presented in this report.

To set the monitoring results from our regular programme in context, liquid radioactive discharges from UK nuclear establishments to the aquatic environment in 1989 are first summarised. Before the results are presented, an explanatory section gives details of methods of analysis and presentation and 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 Environment Departments (Department of the Environment, 1990; Scottish Development Department, 1988), the latest available data being for the year 1988. Data for 1989 are being prepared for publication but, to enable the results of environmental monitoring presented in this report to be considered readily in the context of relevant discharges, a summary is included here.

2.1 Liquid radioactive waste

Table 1 lists the principal discharges of liquid radioactive waste from UK nuclear establishments during 1989. 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 limits are usually very much lower than the 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 (Great Britain - Parliament, 1986). The percentages of the authorised (or agreed) limits taken up in 1989 are also stated in Table 1.

For completeness it should be noted that radiological safety for US Navy operations in the Holy Loch is the responsibility of the US Navy in association with the Ministry of Defence who publish information annually (Fuller and Casey, 1990).

2.2 Solid radioactive waste

In addition to receiving most of the above liquid discharges, the marine environment has also received low specific activity packaged solid waste, disposed of mainly in an area of the deep Atlantic Ocean. The most recent such disposal was in 1982; none was carried out in 1989, and it was announced by the Secretary of State for Energy (Great Britain - Parliament, 1988) that sea dumping 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. The Government has not ruled out sea disposal for large items such as boilers from decommissioned power stations, but will keep under review whether this disposal option needs to be maintained.

Routine environmental monitoring does not provide an effective means of assessing radiation exposure from sea dumping, as radionuclides from this practice are largely undetectable in deep-sea samples (OECD (NEA), 1985). International surveillance of the effects of these disposals is coordinated by the Nuclear Energy Agency of the Organisation for Economic Cooperation and Development by means of a Coordinated Research and Environmental Surveillance Programme (CRESP) (OECD (NEA), 1981). This Programme is continuing. In the absence of ready detectability of radioactivity from the dumping 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).

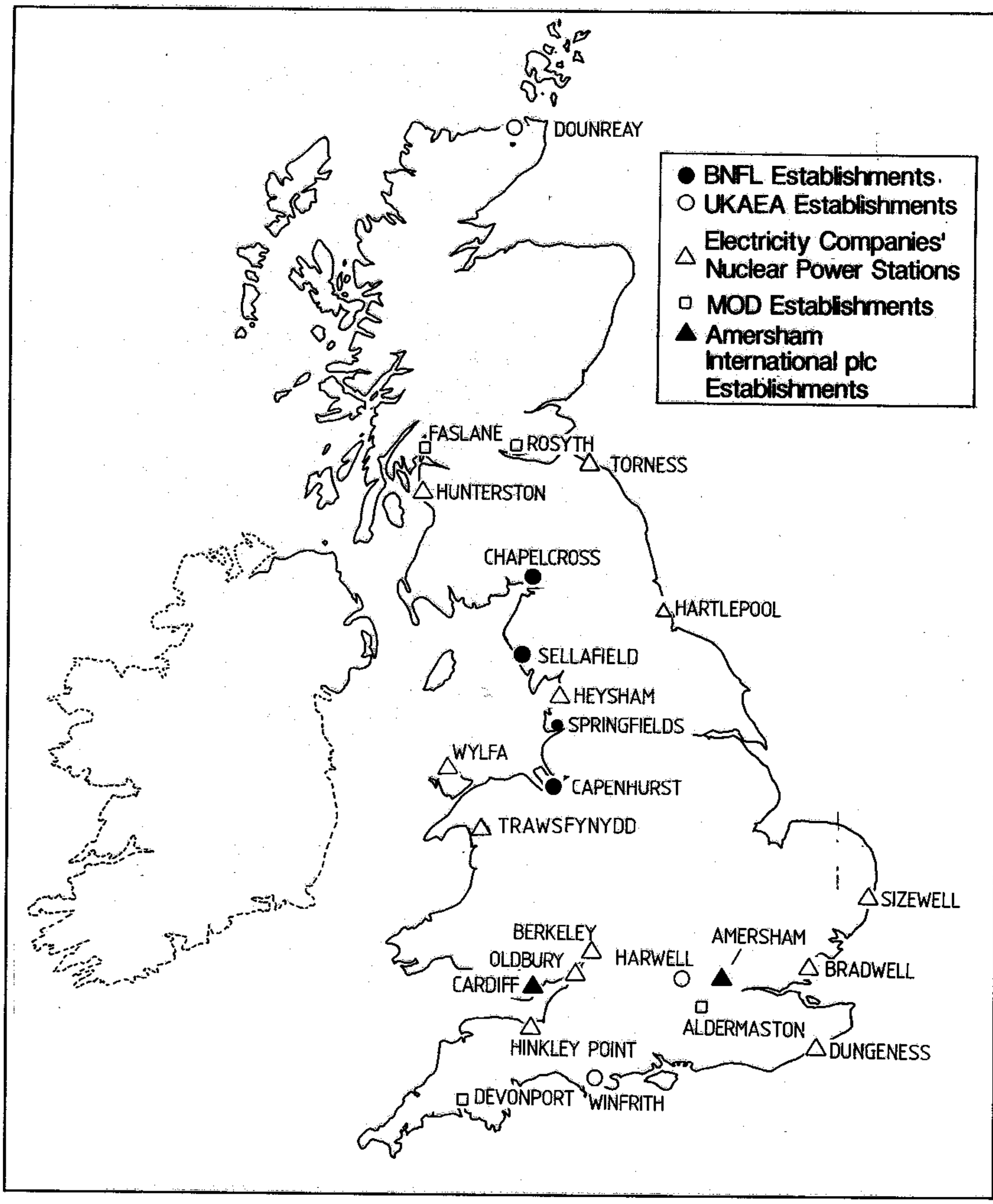


Figure 1. UK nuclear establishments giving rise to principal discharges of liquid radioactive waste.

Table 1. Principal discharges of liquid radioactive waste from UK nuclear establishments, 1989.

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1989	
			TBq	% of limit
British Nuclear Fuels plc				
Sellafield Sea pipelines	Total beta	950	101.04	11
	Total alpha	14	2.70	19
	Ruthenium-106	370	24.96	6.8
	Strontium-90	60	9.17	15
	Americium-241	3.3	1.06	32
	Caesium-134	25	1.73	6.9
	Caesium-137	200	28.60	14
	Carbon-14	4	2.03	51
	Cerium-144	40	3.78	9.5
	Cobalt-60	9	0.17	1.9
	Iodine-129	0.4	0.17	41
	Plutonium alpha	10	1.21	12
	Plutonium-241	350	30.24	8.6
	Technetium-99	10	6.07	61
	Tritium	3500	2144.02	61
	Zirconium-95 plus Niobium-95	250	11.11	4.4
Seaburn sewer	Total activity	0.148	0.0012	0.8
Springfields	Total alpha	13.32	0.38	2.9
	Total beta	444	114	26
Chapelcross	Total alpha	0.1	0.00323	3.2
	Total beta[1]	25	0.215	<1
	Tritium	5.5	0.63	11
Capenhurst				
Rivacre Brook[2]	Uranium	0.02	0.00067	5.0
	Uranium daughters	0.02	0.0077	58
	Non-uranic alpha	0.003	0.000032	1.6
	Technetium-99	0.1	0.00087	1.3
Meols outfall	Technetium-99	0.148	NIL	NIL
United Kingdom Atomic Energy Authority				
Winfrith[3]	Tritium	650	149.1	17
	Cobalt-60	10	1.422	7.0
	Zinc-65	6	0.388	4.0
	Total alpha	0.3	<0.0045	1.4
	Other radionuclides	80	6.53	8.3
Harwell	Total activity[1,4]	8.88	0.24	2.7
	Tritium	8.88	1.6	18
Dounreay[5]	Total alpha[6]	0.75	0.0268	3.6
	Total beta[1]	110	6.46	5.9
	Tritium	130	0.51	<1
	Cobalt-60	1.0	<0.031	<3.1
	Strontium-90	12	1.27	11
	Zirconium-95 + Niobium-95	6.0	<0.036	<1
	Ruthenium-106	12	<0.733	<6.1
	Silver-110m	0.4	0.00381	<1
	Caesium-137	50	3.1	6.2
	Cerium-144	12	0.0177	<1
	Plutonium-241	15	0.542	3.6
	Curium-242	1.0	<0.00353	<1
Nuclear Electric plc				
Berkeley	Total activity[1]	7.4	0.23	3.1
	Tritium	55.5	3.53	6.4
Bradwell	Total activity[1]	7.4	0.39	5.3
	Zinc-65	0.185	0.0016	<1
	Tritium	55.5	0.96	1.7
Dungeness "A" Station	Total activity[1]	7.4	0.23	3.2
	Tritium	74	0.20	<1
"B" Station	Total activity[1,7]	4	0.0025	<1
	Sulphur-35	25	0.25	1.0
	Tritium	650	16	2.5
Hartlepool	Total activity[1,7]	4	0.021	<1
	Sulphur-35	7.5	0.43	5.7
	Tritium	1850	112	6.1

Table 1. Continued.

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1989	
			TBq	% of limit
Heysham				
Station 1	Total activity[1,5]	4	0.058	1.4
	Sulphur-35	7.5	0.48	6.3
	Tritium	1850	195	11
Station 2	Tritium	1200	106	8.8
	Sulphur-35	7	0.086	1.2
	Cobalt-60	0.036	0.000007	<1
	Other radionuclides	0.45	0.0058	1.3
Hinkley Point[8]				
"A" Station	Total activity[1,7]	7.4	0.90	12
	Sulphur-35	3.7	0.16	4.3
	Tritium	74	1.1	1.5
"B" Station	Total activity[1,7]	3.7	0.031	<1
	Sulphur-35	22.2	0.99	4.5
	Tritium	666	266	40
Oldbury	Total activity[1]	3.7	0.41	11
	Tritium	74	0.72	<1
Sizewell	Total activity[1]	7.4	0.36	4.9
	Tritium	111	2.1	2.9
Trawsfynydd	Total activity[1]	1.48	0.28	19
	Caesium-137	0.259	0.036	14
	Tritium	74	0.49	<1
Wylfa	Total activity[1]	2.045	0.063	2.6
	Tritium	148	3.0	2.0
Scottish Nuclear Ltd				
Hunterston				
"A" Station	Total activity[1]	7.5	0.62	8.3
	Tritium	48	0.76	1.6
"B" Station	Total activity[1,7]	3.7	0.039	1.1
	Sulphur-35	25.9	1.2	4.3
	Tritium	1480	333	21
Torness	Tritium	1200	92.3	7.7
	Sulphur-35	10	0.168	1.7
	Cobalt-60	0.05	0.000043	<1
	Beta activity[1,3,7]	0.45	0.0156	3.5
	Total alpha	0.0045	0.000015	<1
Ministry of Defence (Procurement Executive)				
Aldermaston	Total activity[1,4]	5.8	0.049	<1
	Tritium	5.8	0.022	<1
Ministry of Defence (Navy Department)				
Devonport[10]	Total activity[1,9]	0.002	0.000115	5.7
	Cobalt-60	0.016	0.0039	24
	Tritium	0.12	0.064	53
Faslane	Total activity[1]	0.037	0.000032	<1
Rosyth[11]	Beta activity[1,9]	0.01	0.000248	2.4
	Cobalt-60	0.055	0.000788	1.4
	Tritium	0.01	0.0060	60
	Total alpha	1×10^{-6}	0.75×10^{-6}	75
Amersham International plc				
Amersham	Total activity[1,4]	2.7	0.79	29
	Tritium	14.8	0.055	<1
Cardiff	Beta/gamma activity[12]	0.096	0.021	22
	Carbon-14	2	1.53	77
	Tritium	1400	601	43

1 Excluding tritium.
2 Authorisation was varied with effect from 1 May 1989. Discharges are given for the period from 1 May to 31 Dec 1989. "% of limit" refers to this period on a pro rata basis.
3 Authorisation was revised with effect from 1 April 1989. The new discharge limits are given together with discharges in these categories for the whole of 1989. "% of limit" refers only to discharges in the period 1 April-31 December 1989 on a pro rata basis of the new limits, following introduction of the new authorisation.
4 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.
5 Authorisation was revised with effect from 1 June 1989. The new discharge limits are given together with discharges in these categories for the whole of 1989. "% of limit" refers to discharges for the whole of 1989 as a percentage of the new limits.
6 Excluding curium-242.
7 Excluding sulphur-35.
8 A single site authorisation applies at Hinkley Point. The table format represents the way in which it has been agreed that the authorisation should be apportioned in practice.
9 Excluding cobalt-60.
10 The operator of this site is Devonport Management Ltd.
11 The operator of this site is Babcock Thorn Ltd.
12 Excluding tritium, carbon-14 and radioisotopes of calcium and strontium.

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

3.1 SI units

In this report, data are presented using the Système Internationale (SI) radiological units recommended for use in the UK by the British Committee on Radiation Units and Measurements (BCRU, 1978). Table 2 summarises the radiological units used in this report, and provides relevant conversion factors to relate SI units to the old radiological units.

3.2 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 3. 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 3; however, these conditions may vary, sometimes significantly.

Pure beta emitters, such as carbon-14, strontium-90, technetium-99 and promethium-147, are chemically separated from samples before beta counting (Harvey *et al.*, 1989). Transuranic nuclides are chemically separated and analysed by alpha spectrometry using silicon surface-barrier detectors (Harvey and Thurston, 1988; Lovett *et al.*, 1990) or, in the case of plutonium-241, by liquid scintillation counting. 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 3.3). Detection limits are usually much lower for radionuclides analysed using these procedures than for gamma-emitting radionuclides.

Table 2. Radiological units used in this report.

Quantity	New SI unit and symbol	Definition	Old unit and symbol	Definition	Conversion data
Radioactivity	Becquerel (Bq)	Disintegration per second	Curie (Ci)	3.7×10^{10} disintegrations per second	1 Ci = 3.7 10^{10} Bq 1 Bq ≃ 2.7 10^{-11} Ci = 27 pCi
Notes: 1	The terabecquerel (TBq) is used in this report for radioactive discharges:				1 TBq = 10^{12} Bq ≃ 27 Ci
2	Radioactivity concentrations are given in becquerels per kilogram (Bq kg^{-1}):				1 Bq kg^{-1} = 1 mBq g^{-1} ≃ 27 pCi kg^{-1} 1 pCi g^{-1} = 37 Bq kg^{-1}
Absorbed dose	Gray (Gy)	J kg^{-1} (joule per kilogram)	Rad (rad)	10^{-2} J kg^{-1}	1 rad = 10^{-2} Gy 1 Gy = 10^{2} rad
Dose equivalent	Sievert (Sv)	J kg^{-1} x (modifying factors)	Rem (rem)	10^{-2} J kg^{-1} x (modifying factors)	1 rem = 10^{-2} Sv = 10 mSv 1 Sv = 10^{2} rem

Table 3. 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 plus Niobium-95	1.0
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.

3.3 Methods of presentation of measurements

The tables of monitoring results generally contain summarised values of observations obtained during the year under review. 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 dispersion 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 3.4. 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. This procedure takes account of corrections for radioactive decay which are made to the time of sampling.

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 sampled within an observation varied - by up to several hundred for fish and molluscs from near Sellafield. For external beta and gamma dose rates, which are measured using portable instruments calibrated against reference standards, 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 3.4).

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 unless otherwise stated.

Measurements on biota are given in terms of concentrations 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 radioactivity concentrations 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. For both types of measurement, however, experience is also useful. Table 4 lists representative values to be expected from natural sources. It should be noted that concentrations of alpha-emitting radioactivity can be due to natural radionuclides. For example, concentrations of polonium-210, a decay

Table 4. 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: $\mu Gy\ h^{-1}$

Sand, shingle	0.03 to 0.05
Mud	0.05 to 0.1

*Except sediments for which dry concentrations apply.

product of radon, of up to 4 $Bq\ kg^{-1}$ (wet), have been observed in fish and up to 250 $Bq\ kg^{-1}$ (wet) in shellfish from a variety of locations (Pentreath *et al.*, 1979; McDonald *et al.*, 1986; Pentreath and Allington, 1988; Pentreath *et al.*, 1989(a)). Radiation exposures from natural sources are in most cases greater than those from artificial radioactivity. For example, natural polonium-210 alone can result in dose rates of up to 0.5 mSv $year^{-1}$ to high-rate consumers of fish and shellfish (Pentreath and Allington, 1988). However, the ICRP dose limits (sub-section 3.4) do not apply to natural and medical irradiation.

3.4 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 (Great Britain - 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); at present, these recommendations are under review. 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 Publication 26, as are the Basic Safety Standards for Radiation Protection promulgated by the International Atomic Energy Agency (IAEA, 1982). In this report, results have been interpreted also on the basis of the recommendations of ICRP Publication 26, taking account of recent explanatory statements by the ICRP (ICRP, 1987) and advice from the NRPB (NRPB, 1987).

The effects of accidental releases of radioactivity strictly do not fall within the scope of the ICRP dose limitation system, which applies to controlled sources. However, because the effects of the release of radioactivity from Chernobyl on the UK aquatic environment near nuclear sites were minor (Camplin *et al.*, 1986), and in many cases difficult to separate from the effects of site operation, the total exposures due to artificial radionuclides, including those from Chernobyl, have conservatively been considered when comparing exposures with ICRP dose limits.

The ICRP dose limitation system includes, 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 is 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 (Hughes *et al.*, 1988).

ICRP Publication 26 recommends that doses should meet the ALARA objective, 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 (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. Exposures from intakes of radioactivity can continue for a number of years, depending upon body retention time. The committed effective dose equivalent represents the integrated exposure over 50 years following an intake. The ICRP (ICRP, 1985) recommends that the principal limit for the committed effective dose equivalent received by a member of the public is 1 mSv in a year. However, it is permissible 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 $^{-1}$. The ICRP-recommended dose limits apply to the sum of the effective dose equivalent resulting from external exposure during 1 year and the committed effective dose equivalent incurred from that year's intake of radionuclides. For members of the public, the dose limitation criteria apply at each site to the appropriate 'critical group', who are that small group of people who, because of their habits and other aspects of behaviour which affect the doses received, are likely to be the most exposed.

The ICRP is currently revising its basic recommendations in the light of improved risk estimates. In the meantime, it is recommended (ICRP, 1987) that it would be prudent to follow the present recommendations on dose limitation as they were intended to be interpreted. This includes the use of the ALARA principle in keeping doses well below the dose limits. In advance of the review by the ICRP, the NRPB has given interim guidance (NRPB, 1987), suggesting a criterion of 0.5 mSv year $^{-1}$ for the effective dose equivalent to the critical group from current discharges of radioactive effluents from a given site. The UK Government has already accepted the 0.5 mSv year $^{-1}$ level as a target in connection with authorised limits (Great Britain - Parliament, 1986), and this level is now interpreted as applying to the committed effective dose equivalent to members of a critical group, due to all current radioactive waste discharges. The total exposures received by critical groups are likely to be affected by past discharges. Thus, while the recommendations of the ICRP are under review, the committed effective dose equivalents to critical groups presented in this report are compared with the principal ICRP-recommended dose limit of 1 mSv year $^{-1}$. As regards non-stochastic effects due to intakes of radionuclides, the ICRP has indicated (ICRP, 1984a) 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 limits are appropriate. For example, the ICRP continues to recommend (ICRP, 1985) the limit for skin of 50 mSv year $^{-1}$; this limit is applicable in the case of handling of fishing gear.

Values for committed effective dose equivalents following intakes by members of the public of some radionuclides have been provided by the ICRP (ICRP, 1989). In this report, results are based on these values and, for other nuclides, data derived by the NRPB using ICRP principles (NRPB, 1987). 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 recently made recommendations on gut transfer factors for a range of radionuclides (NRPB, 1990). These recommendations include endorsement of the results of recent 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; Hunt *et al.*, 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 molluscs from the north-east Irish Sea, both gut transfer factors of 0.0002 and 0.0005 are used for plutonium and americium. For other foods, and remote from Sellafield, the factor of 0.0005 is used for these radioelements.

In the case of external exposure to penetrating 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 $\mu Gy\ h^{-1}$ has been taken as producing an effective dose equivalent rate of 0.87 $\mu Sv\ h^{-1}$ (Spiers *et al.*, 1981).

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). 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, 1984(a)) and on seabirds (Woodhead, 1984(b)) have confirmed the applicability of the general assumption in these cases. In addition, the wider context of the work of the DFR (MAFF, 1989) includes research programmes which are designed to keep under close scrutiny the health of fish and shellfish stocks.

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 nuclear power plant supplying electricity to the national grid. We regularly monitor the environmental consequences of discharges of liquid radioactive waste from four BNFL sites, namely Sellafield, Springfields, Capenhurst and, on behalf of departments of the Scottish Office, Chapelcross.

4.1 Sellafield, Cumbria

Operations and facilities at this establishment 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 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-east Irish Sea through pipelines which terminate 2.1 km beyond low-water mark. In 1989, these wastes were discharged under an authorisation which took effect from 1 July 1986, specifying lower limits to radioactivity in discharges than previously and limiting more nuclides specifically, maintaining controls on releases of solvents and particulates (Great Britain - Parliament, 1986). A further condition requires BNFL to use the 'best practicable means' (BPM) to control discharges. This condition 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 3.4. This condition also has the effect of applying the principle of 'best available technology'. From 1 January 1990, the authorisation was varied to specify even lower limits to radioactivity in the discharges, whilst maintaining the BPM condition.

Discharges from the Sellafield pipelines during 1989 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 throughout 1989. There was no period of plant shutdown for refurbishment in 1989 and more fuel was reprocessed than in previous recent years, thus there were slight increases in discharges of some radionuclides to sea. Discharges of total beta activity were 101 TBq (1988: 81 TBq). Caesium-137 discharges in 1989 totalled 28.6 TBq (1988: 13.3 TBq), the increase being due to cleaning of old plants as well as to greater fuel reprocessing. Discharges of alpha-emitting radionuclides in 1989 totalled 2.7 TBq (1988: 2.1 TBq).

Our regular monitoring continued during 1989. 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 1989, 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 5(a). Data are listed by location of sampling or landing point, in approximate order of increasing distance from Sellafield. 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.

Table 5(a). Beta/gamma radioactivity in fish from the Irish Sea vicinity and further afield, 1989.

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	4	200	0.9	41
	Plaice	2	160	0.8	23
	Bass	1	160	1.1	50
	Grey mullet	1	160	1.1	34
	Sole	1	210	0.5	29
Sellafield offshore area[1]	Cod	2	180	0.5	26
	Plaice	4	160	0.4	22
	Flounder	1	170	1.4	86
	Dab	3	140	0.3	19
	Whiting	2	150	0.3	33
	Spurdog	1	83	ND	9.6
Ravenglass[2]	Cod	16	160	0.7	33
	Plaice	10	120	0.3	14
	Whitebait	1	150	0.9	24
	Sea trout	1	140	0.6	15
	Salmon	1	120	ND	0.8
Whitehaven[2]	Cod	4	150	0.5	19
	Plaice	4	110	0.3	15
	Rays	2	100	0.4	18
Morecambe Bay[1]	Cod	1	130	3.4	16
	Flounder	5	160	0.8	64
	Plaice	3	120	0.3	28
	Bass	1	170	1.1	68
Cumbrian rivers[4]	Brown trout	1	150	4.8	34
	Sea trout	5	130	0.5	17
Fleetwood[2]	Cod	4	150	0.3	17
	Plaice	4	120	0.2	13
	Fish meal[5]	4	290	0.2	11
	Fish oil[5]	4	NA	ND	ND
Isle of Man[2]	Cod	4	140	0.2	8.7
	Plaice	4	97	0.1	5.0
	Herring	3	130	0.4	9.1
Inner Solway[1]	Salmon	1	130	ND	1.0
	Sea trout	1	150	"	11
	Flounder	4	170	1.1	69
Kirkcudbright[2]	Plaice	4	120	0.4	13
North Anglesey[1]	Plaice	2	130	0.1	2.8
	Spurdog	3	99	0.4	9.6
Northern Ireland[2]	Cod	8	130	0.2	10
	Whiting	9	120	0.2	10
	Herring	4	140	ND	7.8
	Spurdog	5	99	0.3	9.1
Ayr[2]	Cod	4	130	0.3	8.9
	Plaice	4	100	0.2	6.9
Loch Leven[1]	Salmon	1	160	ND	2.0
Minch[1]	Cod	3	130	0.1	4.0
	Plaice	4	110	0.1	2.9
	Haddock	4	120	0.06	2.0
	Herring	4	130	0.1	5.2
	Mackerel	5	100	0.05	1.3
Shetland[1]	Fish meal[5]	2	570	ND	1.1
Northern North Sea[1]	Plaice	4	110	0.1	1.5
	Cod	5	130	ND	2.2
	Haddock	6	130	"	1.1
	Saithe	2	NA	"	1.4
	Herring	4	78	"	0.8
	Norway pout	1	NA	"	0.4
	Mackerel	1	"	"	0.9
	Whiting	2	"	"	1.8
Mid-North Sea[1]	Plaice	7	94	0.05	1.5
	Cod	8	130	0.08	2.4
	Haddock	3	NA	ND	1.4
	Whiting	2	"	"	2.2
	Herring	5	110		1.3
Southern North Sea[1]	Plaice	3	92		1.1
	Cod	3	120	0.04	1.5
	Whiting	1	NA	0.2	1.9
	Herring	2	110	ND	1.0
	Mackerel	1	NA	"	0.5
Norwegian Sea[1]	Cod	1	110	0.1	1.2
Iceland area[1]	Cod	2	110	ND	0.3
Icelandic processed	Cod	2	120	"	0.3

ND = not detected; NA = not analysed; [1]Sampling area; [2]Landing point; [3]See sub-section 3.3 for definition; [4]Samples collected from a number of rivers by North West Water; [5]Concentrations refer to weight of sample as supplied.

The results 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 in previous years because of the significant reductions in discharges. 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 was difficult to detect in 1989 due to decreasing concentrations of caesium-134. Concentrations of radiocaesium in fish from Icelandic waters remained typical of those from weapons-test fallout, at a value of about 0.1-0.4 Bq kg^{-1} for caesium-137 in fish. In the Irish Sea, the ratios of caesium-137 to caesium-134 were generally higher than in recent discharges from Sellafield, even allowing for residence time in the water and uptake into fish; this suggests that a 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 feeding habits. To obtain representative results for dose estimation, samples include large numbers of individual fish (sub-section 3.3).

Concentrations of radiocaesium in fish in 1989 were generally less than in 1988 in all sea areas, continuing the trend due to the significant overall reductions in radiocaesium discharges from Sellafield beginning in the late 1970s and sustained following the operation of SIXEP from May 1985. In Scottish waters and the North Sea, this trend was also due to continued dispersion from these areas of radioactivity originating from the Chernobyl accident.

Near Sellafield, the effects of the overall reductions in radiocaesium discharges continued, despite the small increases in discharges that occurred in 1988 and 1989. However, it appears that the rate of decrease in concentrations of radiocaesium in fish from the Irish Sea is now diminishing.

Specific radionuclides, other than caesium-134 and -137, which were detected in fish in 1989 are listed in Table 5(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 1989 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 6 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 5(b). Other beta/gamma radioactivity in fish from the Irish Sea vicinity, 1989.

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	^{106}Ru	^{147}Pm
Sellafield offshore area[1]	Plaice	1	150	0.09	0.13	1.7	ND	0.066
	Cod	1	86	ND	0.087	0.27	"	0.020
Ravenglass[2]	Whitebait	1	NA	0.3	0.52	NA	1.2	NA
Whitehaven[2]	Plaice	1	"	ND	0.056	"	ND	"
	Cod	1	"	"	0.046	"		
Fleetwood[2]	Fish meal[4]	1	"	"	0.52	"		
Shetland[1]	Fish meal[4]	1	"	"	0.050	"		

NA = not analysed; ND = not detected; [1]Sampling area; [2]Landing point; [3]See sub-section 3.3 for definition; [4]Concentrations refer to weight of sample as supplied.

Table 6. Beta/gamma radioactivity in shellfish from the Irish Sea vicinity and further afield,1989.

Sampling area/ landing point	Sample	No. of sampling observa-tions[3]	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
			Total beta	^{14}C	^{54}Mn	^{60}Co	^{65}Zn	^{90}Sr	$^{95}Zr+^{95}Nb$	^{99}Tc	^{103}Ru
Sellafield coastal area[1]	Crab	1	150	120	ND	6.7	ND	1.5	ND	8.4	ND
	Lobster	2	480	NA	"	2.7	"	NA	"	NA	"
	Winkles[4]	12	350	66	"	7.1	"	6.8	3.8	64	0.2
	Winkles[5]	4	420	NA	"	8.5	"	NA	8.1	NA	1.2
	Winkles[6]	4	350	"	"	4.5	"	"	5.9	"	ND
	Mussels[4]	4	200	"	"	4.1	0.1	"	0.8	"	0.3
	Limpets[4]	4	410	"	"	6.2	ND	"	2.4	"	ND
Sellafield offshore area[1]	Whelks	1	300	"	"	10	"	"	ND	"	"
St Bees[1]	Winkles	4	390	59	0.05	7.8	"	12	11	49	0.2
	Mussels	4	310	NA	ND	5.5	"	NA	13	NA	ND
	Limpets	4	560	"	"	6.9	"	"	8.8	"	"
Nethertown[1]	Winkles	12	460	79	"	7.6	"	12	17	36	0.9
Drigg[1]	Winkles	4	720	94	0.1	12	"	14	62	97	3.2
Ravenglass[1]	Cockles	4	260	NA	ND	14	"	NA	11	NA	ND
	Mussels	4	230	"	"	5.3	"	"	3.8	"	"
Ravenglass[2]	Crabs	2	120	"	"	4.0	"	"	ND	"	"
	Lobsters	3	270	"	"	1.3	"	"	"	"	"
	Whelks	2	170	"	"	4.8	0.2	"	0.2	"	"
Tarn Bay[1]	Winkles	4	380	"	"	6.4	ND	"	10	"	0.8
Whitehaven[2]	*Nephrops*	4	140	"	"	0.03	"	"	ND	"	ND
	Whelks	4	120	"	"	0.6	"	"	"	"	"
Parton[1]	Winkles	11	310	"	"	3.2	"	"	1.3	"	"
Roosebeck[1]	Oysters	4	75	"	"	0.2	0.1	"	ND	"	"
Morecambe Bay[1]	Shrimps	4	96	"	"	ND	ND	0.098	"	"	"
	Cockles	4	100	"	"	1.6	"	1.0	"	"	"
Heysham[1]	Mussels	4	65	"	"	0.7	"	NA	"	"	"
	Cockles	4	75	"	"	1.4	"	"	"	"	"
Fleetwood[2]	Squid	1	80	"	"	ND	"	"	"	"	"
	Whelks	4	100	"	"	0.5	"	"	"	"	"
Isle of Man[2]	Scallops	4	110	"	"	ND	"	"	"	"	"
	Queens	1	71	"	"	"	"	"	"	"	"
Inner Solway[1]	Shrimps	4	100	"	"	"	"	"	"	"	"
Southerness[1]	Cockles	3	150	"	"	3.0	"	"	"	"	"
	Winkles	4	240	"	"	1.5	"	"	0.2	"	"
Kirkcudbright[2]	Scallops	4	49	"	"	ND	"	"	ND	"	"
	Queens	4	71	"	"	0.1	"	"	"	"	"
North Solway coast[1]	Winkles	4	150	"	"	1.7	"	"	"	"	"
Wirral[1]	Shrimps	2	59	"	"	ND	"	"	"	0.53	"
	Cockles	2	63	"	"	0.3	"	"	"	1.1	"
Conwy[2]	Mussels	2	49	"	"	ND	"	"	"	"	"
North Anglesey[1]	Crabs	2	86	"	"	0.2	"	"	"	"	"
	Winkles	2	87	"	"	0.4	"	"	"	"	"
Northern Ireland[2]	*Nephrops*	8	100	"	"	ND	"	"	"	"	"
	Winkles	5	96	"	"	0.2	"	"	"	"	"
Minch[1]	*Nephrops*	4	110	"	"	ND	"	"	"	"	"
Northern North Sea[1]	*Nephrops*	4	90	"	"	"	"	"	"	"	"
Mid-North Sea[1]	Queens	1	88	"	"	"	"	"	"	"	"
	Mussels	1	43	"	"	"	"	"	"	"	"
	Mussels[7]	2	25	"	"	0.03	"	"	"	"	"
Southern North Sea[1]	Cockles	2	34	"	"	2.3	"	"	"	"	"
	Cockles[8]	2	53	"	"	0.7	"	"	"	"	"
	Mussels	3	39	"	"	ND	"	"	"	"	"

Table 6. Continued.

Sampling area/ landing point	Sample	No. of sampling observa-tions[3]	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
			^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{147}Pm	^{154}Eu	^{155}Eu
Sellafield coastal area[1]	Crab	1	37	8.3	ND	ND	7.6	ND	4.1	ND	ND
	Lobster	2	6.6	10	"	"	14	"	NA	"	"
	Winkles[4]	12	91	7.5	1.8	0.1	20	1.9	17	"	0.5
	Winkles[5]	4	170	14	3.3	0.2	19	3.7	NA	1.0	0.2
	Winkles[6]	4	83	7.5	1.7	ND	22	4.3	"	ND	0.4
	Mussels[4]	4	64	ND	0.7	0.1	8.4	1.9	"	0.4	1.0
	Limpets[4]	4	59	4.8	2.8	ND	23	2.3	"	ND	1.0
Sellafield offshore area[1]	Whelks	1	82	17	1.0	"	6.1	1.6	"	1.3	1.3
St Bees[1]	Winkles	4	130	10	2.7	0.2	28	7.1	25	0.2	ND
	Mussels	4	120	4.6	1.7	ND	11	5.3	NA	0.9	0.7
	Limpets	4	92	6.9	3.2	0.1	27	4.8	"	0.8	0.7
Nethertown[1]	Winkles	12	170	12	4.8	0.6	34	7.8	29	1.4	0.9
Drigg[1]	Winkles	4	330	14	6.5	0.7	40	19	52	2.8	1.6
Ravenglass[1]	Cockles	4	86	0.6	0.8	0.5	20	6.0	NA	3.4	1.8
	Mussels	4	83	ND	1.4	ND	8.2	2.0	"	1.4	ND
Ravenglass[2]	Crabs	2	13	6.7	ND	"	8.2	ND	"	ND	"
	Lobsters	3	ND	5.4	0.3	0.1	12	"	"	"	0.2
	Whelks	2	38	8.8	0.3	ND	5.0	"	"	"	ND
Tarn Bay[1]	Winkles	4	110	7.2	2.5	0.3	26	4.4	"	0.8	0.6
Whitehaven[2]	*Nephrops*	4	ND	ND	ND	0.2	15	ND	"	ND	ND
	Whelks	4	4.8	2.1	"	0.05	3.9	"	"	"	"
Parton[1]	Winkles	11	48	3.4	2.0	0.3	30	1.3	"	0.2	0.1
Roosebeck[1]	Oysters	4	4.5	2.6	ND	ND	5.7	ND	"	ND	ND
Morecambe Bay[1]	Shrimps	4	ND	ND	"	0.2	20	"	"	"	"
	Cockles	4	4.4	"	0.4	0.2	15	"	"	"	"
Heysham[1]	Mussels	4	2.4	"	ND	0.2	6.8	"	"	"	"
	Cockles	4	4.1	"	0.2	0.1	9.7	"	"	"	"
Fleetwood[2]	Squid	1	ND	"	ND	ND	4.6	"	"	"	"
	Whelks	4	3.0	0.5	"	"	2.9	"	"	"	"
Isle of Man[2]	Scallops	4	ND	0.3	"	"	1.4	"	"	"	"
	Queens	1	4.0	2.0	"	"	1.4	"	"	"	"
Inner Solway[1]	Shrimps	4	ND	ND	"	0.2	27	"	"	"	"
Southerness[1]	Cockles	3	7.6	"	"	0.1	18	"	"	"	0.4
	Winkles	4	14	5.2	0.8	0.5	28	"	"	0.3	ND
Kirkcudbright[2]	Scallops	4	ND	ND	ND	ND	0.5	"	"	ND	"
	Queens	4	"	0.2	"	"	1.5	"	"	"	"
North Solway coast[1]	Winkles	4	7.3	3.0	"	0.2	12	"	"	"	"
Wirral[1]	Shrimps	2	ND	ND	"	ND	6.2	"	"	"	"
	Cockles	2	"	"	"	"	8.3	"	"	"	"
Conwy[2]	Mussels	2	"	"	"	"	1.5	"	"	"	"
North Anglesey[1]	Crabs	2	"	1.0	"	"	1.6	"	"	"	"
	Winkles	2	"	0.8	"	"	2.5	"	"	"	"
Northern Ireland[2]	*Nephrops*	8	"	ND	"	"	3.4	"	"	"	"
	Winkles	5	"	1.9	0.3	0.03	1.6	"	"	"	"
Minch[1]	*Nephrops*	4	"	0.07	ND	0.04	3.8	"	"	"	"
Northern North Sea[1]	*Nephrops*	4	"	0.4	"	ND	0.7	"	"	"	"
Mid-North Sea[1]	Queens	1	"	ND	"	"	0.4	"	"	"	"
	Mussels	1	"	"	"	"	ND	"	"	"	"
	Mussels[7]	2	"	"	"	"	0.2	"	"	"	"
Southern North Sea[1]	Cockles	2	1.1	0.4	"	"	0.1	"	"	"	0.06
	Cockles[8]	2	ND	ND	"	"	0.5	"	"	"	ND
	Mussels	3	"	"	"	"	0.4	"	"	"	"

NA = not analysed; ND = not detected; [1]Sampling area; [2]Landing point; [3]See sub-section 3.3 for defintion; [4]Samples collected by Consumer 116; [5]Samples collected by Consumer 460; [6]Samples collected by Consumer 311; [7]Landed in Denmark; [8]Landed in Holland.

Concentrations of artificial radionuclides in shellfish, as with fish, diminish with increasing distance from Sellafield; the rate of reduction is least for nuclides which are relatively mobile in sea water, such as isotopes of caesium. There are substantial variations between species: in general, molluscs tend to concentrate the less mobile nuclides to a greater extent than do crustaceans, which in turn tend to concentrate them more than fish; the reverse behaviour is generally observed for mobile nuclides. Concentrations of beta/gamma-emitting radionuclides in shellfish in 1989 were generally similar to those in 1988, and reflect the recent behaviour of the Sellafield discharges.

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 3.3). The data for 1989 are presented in Table 7. 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. A gradual slowing down in the rate of decrease in these concentrations is consistent with our model predictions (Hunt, 1986; Pentreath *et al.*, 1989(b)). It is to be noted that environmental factors are likely to cause fluctuations in measured concentrations. In 1989, compared with 1988, concentrations of transuranic nuclides in fish and shellfish showed small increases in many areas, including areas outside the Irish Sea. These increases were minor in terms of their effect on doses to the public.

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 quantities 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 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 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 1989. 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 estimation of doses to consumers it is not sufficient to determine only the total consumption rates of fish and shellfish together. Our experience (illustrated by Tables 5-7) 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, these sub-groups' consumption rates of fish and shellfish in 1989 were not significantly different from those in 1988 (Hunt, 1989), and the same rates of 36.5 kg year $^{-1}$ fish, 6.0 kg year $^{-1}$ crustaceans and 8.3 kg year $^{-1}$ molluscs have been used in the assessment of doses to the critical group of fish and shellfish consumers.

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).

Table 7. Transuranic radioactivity in fish and shellfish from the Irish Sea vicinity and further afield, 1989.

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]	Plaice	1	NA	0.0092	0.038	NA	0.036	ND	0.00022
	Cod	1	"	0.0061	0.033	"	0.041	"	ND
	Crab	1	0.11	0.39	1.6	34	3.5	"	0.0097
	Lobster	1	NA	0.14	0.64	NA	5.4	"	0.023
	Winkles[4]	4	0.21	4.1	18	330	31	0.052	0.11
	Winkles[5]	2	NA	4.3	20	380	36	0.11	0.12
	Winkles[6]	4	"	4.2	18	350	26	0.054	0.085
	Mussels[4]	1	"	3.7	16	NA	24	0.073	0.073
	Limpets[4]	1	"	5.1	22	"	37	ND	0.15
Sellafield offshore area[1]	Plaice	1	0.0017	0.020	0.087	1.7	0.12	0.00028	0.00042
	Cod	1	0.0003	0.0017	0.0074	NA	0.016	ND	0.00004
	Whelks	1	NA	1.9	7.9	"	27	0.048	0.094
St Bees[1]	Winkles	4	0.48	6.2	27	490	41	0.11	0.13
	Mussels	2	NA	5.3	23	440	34	0.11	0.094
	Limpets	1	"	5.3	24	NA	37	0.12	0.088
Nethertown[1]	Winkles	4	0.58	6.6	28	540	45	0.13	0.15
Drigg[1]	Winkles	4	1.6	12	50	980	84	0.33	0.22
Ravenglass[1]	Whitebait	1	NA	0.14	0.68	22	0.93	0.0012	0.0032
	Cockles	1	"	6.1	25	480	57	0.21	0.19
	Mussels	1	"	4.4	19	360	31	0.087	0.071
Ravenglass[2]	Cod[7]	1	"	0.0027	0.012	NA	0.017	ND	ND
	Plaice[7]	1	"	0.0031	0.013	"	0.025	"	0.00010
	Crab[8]	1	"	0.26	1.1	"	4.1	"	0.012
	Lobster[8]	1	"	0.13	0.56	"	8.0	"	0.014
	Whelks[8]	1	"	0.60	2.6	48	4.9	"	0.0084
Tarn Bay[1]	Winkles	1	"	5.1	23	410	36	"	0.088
Whitehaven[2]	Plaice	1	"	0.0011	0.0055	NA	0.0099	0.00005	0.00002
	Cod	1	"	0.0017	0.0077	"	0.0067	0.00007	0.00003
	Rays	1	"	0.0015	0.0075	"	0.011	0.00003	0.00002
	Nephrops	1	"	0.050	0.24	"	0.86	ND	0.0019
	Whelks	1	"	0.18	0.83	13	1.4	0.0029	0.0030
Parton[1]	Winkles	1	"	3.0	14	240	20	0.052	0.078
Roosebeck[1]	Oysters	1	"	0.24	1.2	NA	0.90	ND	0.0031
Morecambe Bay[1]	Shrimps	1	"	0.0065	0.035	0.67	0.054	0.00028	0.00012
	Cockles	1	"	0.65	3.2	52	7.6	0.019	0.022
Heysham[1]	Mussels	1	"	0.37	1.8	NA	3.3	ND	0.0067
	Cockles	1	"	0.71	3.4	"	7.2	"	0.021
Fleetwood[2]	Cod	1	"	0.00033	0.0016	"	0.0023	"	ND
	Plaice	1	"	0.00071	0.0031	"	0.0055	"	"
	Fish meal[9]	1	"	0.018	0.086	"	0.13	"	0.00037
	Whelks	1	"	0.11	0.51	8.5	0.64	0.0021	0.0015

Table 7. Continued.

Sampling area/ landing point	Sample	No. of sampling observa-tions[3]	Mean radioactivity concentration (wet), Bq kg^{-1}						
			^{237}Np	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Pu	^{241}Am	^{242}Cm	$^{243}Cm+^{244}Cm$
Isle of Man[2]	Cod	1	NA	0.00013	0.00065	NA	0.0012	ND	ND
	Plaice	1	"	0.00050	0.0022	"	0.0031	0.00001	0.00001
	Herring	1	"	0.00030	0.0014	"	0.0014	ND	ND
	Scallops	1	"	0.043	0.21	"	0.065	"	"
Inner Solway[1]	Sea trout	1	"	0.00033	0.0014	"	0.0022	"	"
Southerness[1]	Cockles	1	"	1.3	6.1	"	12	0.031	0.033
	Winkles	1	"	1.4	7.2	"	10	ND	0.034
Kirkcudbright[2]	Plaice	1	"	0.00071	0.0035	"	0.0067	"	ND
	Scallops	1	"	0.014	0.064	"	0.024	0.00012	0.00004
	Queens	1	"	0.020	0.099	"	0.11	ND	ND
North Solway coast[1]	Winkles	1	"	1.1	5.4	"	7.5	0.013	0.018
Ayr[2]	Cod	1	"	0.00016	0.00084	"	0.0010	ND	ND
	Plaice	1	"	0.00033	0.0016	"	0.0027	"	"
Wirral[1]	Cockles	1	"	0.32	1.6	"	3.4	0.0089	0.0089
Conwy[2]	Mussels	1	"	0.059	0.29	"	0.49	ND	0.0011
North Anglesey[1]	Spurdog	1	"	0.00005	0.00018	"	0.00033	"	ND
	Winkles	1	"	0.075	0.36	"	0.43	"	0.0017
Northern Ireland[2]	Whiting	1	"	0.00069	0.0035	"	0.0054	"	0.00001
	Nephrops	1	"	0.0032	0.017	"	0.055	"	0.00009
	Winkles	1	"	0.067	0.32	"	0.18	"	0.00032
Minch[1]	Cod	1	"	0.00006	0.00032	"	0.00032	"	ND
	Haddock	1	"	0.00014	0.00072	"	0.00074	"	"
	Mackerel	1	"	0.00003	0.00017	"	0.00018	"	"
	Nephrops	1	"	0.0016	0.0082	"	0.0086	0.00003	0.00003
Shetland[1]	Fish meal[9]	1	"	0.00021	0.0033	"	0.00083	ND	ND
Northern North Sea[1]	Cod	1	"	0.00008	0.00035	"	0.00029	"	"
	Haddock	1	"	0.00004	0.00033	"	0.00026	"	"
	Nephrops	1	"	0.00070	0.0036	"	0.0046	"	"
Mid-North Sea[1]	Mussels	1	"	0.024	0.13	"	0.016	"	"
	Mussels[10]	1	"	0.00033	0.0048	"	0.0021	"	0.00004
Southern North Sea[1]	Mussels	1	"	0.0022	0.012	"	0.0042	"	ND
	Cockles	1	"	0.0028	0.011	"	0.012	"	0.0014
	Cockles[11]	1	"	0.0028	0.016	"	0.0070	"	0.00015
Icelandic processed	Cod	1	"	0.00001	0.00005	"	0.00005	"	ND

ND = not detected.
NA = not analysed.
[1]Sampling area; [2]Landing point; [3]See sub-section 3.3 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.

Table 8. Individual radiation exposures due to consumption of Irish Sea fish and shellfish, 1989.

Exposed population	Consumption rate used in assessment (see text), kg year $^{-1}$		Nuclide	Committed effective dose equivalent, mSv year $^{-1}$, on basis of following gut transfer factors for Pu, Am in molluscs (see text)	
				0.0002	0.0005
Consumers in local fishing community	Fish (plaice and cod):	36.5	^{90}Sr	0.004	0.004
	crustaceans (crabs and lobsters):	6.0	^{106}Ru	0.010	0.010
	molluscs (winkles):	8.3	^{137}Cs	0.015	0.015
			^{238}Pu	0.009	0.022
			^{239}Pu+^{240}Pu	0.045	0.107
			^{241}Pu	0.017	0.040
			^{241}Am	0.084	0.188
			Total	0.19	0.40
Consumers associated with commercial fisheries: Whitehaven	Fish (plaice and cod):	49	^{137}Cs	0.013	0.013
	crustaceans (*Nephrops*):	11	^{239}Pu+^{240}Pu	0.002	0.004
	molluscs (whelks):	6	^{241}Am	0.006	0.009
			Total	0.03	0.03
Consumers in Morecambe Bay area	Fish (flounders and plaice):	54	^{137}Cs	0.040	0.040
	crustaceans (shrimps):	21	^{239}Pu+^{240}Pu	0.011	0.028
	molluscs (cockles and mussels):	22	^{241}Am	0.024	0.058
			Total	0.09	0.15
Consumers associated with commercial fisheries: Fleetwood	Fish (plaice and cod):	82	^{137}Cs	0.022	0.022
	crustaceans (shrimps):	17	^{239}Pu+^{240}Pu	0.009	0.021
	molluscs (cockles and whelks):	23	^{241}Am	0.018	0.044
			Total	0.06	0.11
Typical member of the fish-eating public consuming fish landed at Whitehaven/Fleetwood	Fish (plaice and cod):	15	^{137}Cs	0.003	0.003
			Total	0.004	0.004

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, following the 1989 review of consumption rates, was calculated on the basis of a mix of two-thirds crabs and one-third lobsters from the Coastal Area and landings at Ravenglass, combined equally. The exposure from consumption of molluscs was calculated on the basis of averaged radionuclide concentrations in winkles 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 8 summarises exposures in 1989. For each exposed group considered, the committed effective dose equivalent (sub-section 3.4) is given together with the contributions of individual radionuclides. 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. The gut transfer factor for plutonium and americium in fish and crustaceans was taken to be 0.0005; for molluscs the effect of applying gut transfer factors of 0.0002 and 0.0005 is shown in the last two columns. Recent work at this laboratory (Hunt *et al.*, 1990) has suggested that a gut transfer factor of 0.0002 may be used for these elements in realistic assessments of dose from eating winkles from near Sellafield, and this procedure has now been endorsed by the NRPB (NRPB, 1990). On this basis, the committed effective dose equivalent to the local critical group in 1989 was 0.19 mSv. This represents a small increase from 0.15 mSv reported for 1988 (Hunt, 1989), due to small differences in the revised values used for dose per unit intake (see sub-section 3.4) and to the small increases noted above in the concentrations of transuranics in shellfish. These committed effective dose equivalents are within the ICRP-recommended principal dose limit for members of the public of 1 mSv year $^{-1}$.

The exposure of the critical group has also been considered in comparison with the ICRP recommendation on lifetime exposure (sub-section 3.4). In 1989, and in previous recent 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 ICRP-recommended 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).

Consumption rates in the wider fishing communities of Cumbria and north Lancashire have been kept under review. Consumption rates of groups associated with commercial fisheries in Whitehaven, Fleetwood and the Morecambe Bay area are given in Table 8, 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 received by the groups are given in Table 8. The results for Whitehaven were less than those for Morecambe Bay or Fleetwood, mainly because of lower consumption rates and radioactivity concentrations in molluscs. In comparison with the results for 1988 on the basis of the more conservative gut transfer factor of 0.0005 for plutonium and americium in non-winkle species, the committed collective dose equivalents to the groups at Whitehaven and Fleetwood were slightly lower in 1989 (1988: 0.05 mSv year $^{-1}$ and 0.12 mSv year $^{-1}$ respectively) and in the Morecambe Bay area was slightly higher in 1989 (1988: 0.11 mSv year $^{-1}$). The changes from 1988 are small in relation to the associated variabilities, including environmental fluctuations. Doses were well within the ICRP-recommended principal dose limit for members of the public of 1 mSv year $^{-1}$.

The effective dose appropriate to a consumption rate of 15 kg year $^{-1}$ of fish from landings at Whitehaven and Fleetwood is also given in Table 8. This consumption rate represents an average for typical fish-eating members of the public. The committed effective dose equivalent in 1989 was 0.004 mSv, which represents a decrease from 0.005 mSv reported for 1988 (Hunt, 1989), due to the reduced concentrations of radiocaesium in Irish Sea fish.

Comparison of the exposures reported in Table 8 with those due to ingestion of natural polonium-210 in fish and shellfish is of interest although this source of exposure is not subject to the ICRP-recommended dose limits. For the high consumption rate groups, dose rates up to 0.5 mSv year $^{-1}$ could be received (Pentreath and Allington, 1988; Pentreath *et al.*, 1989(a)). The exposures reported here may also be compared with the average dose of approximately 2.2 mSv year $^{-1}$ to members of the UK public from all natural sources of radiation (Hughes *et al.*, 1988).

Collective doses received during 1989, 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. This method differs from that based on modelling of water movements and a usually fixed catch rate for different sea areas; this 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 included the Irish Sea, Scottish waters, the North Sea, Baltic Sea, Norwegian Sea, Spitzbergen/Bear Island area and 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 9. The results for 1989 are preliminary, being

Table 9. Collective doses from fish and shellfish, 1988 and 1989*.

Population	Size of population	Collective committed effective dose equivalent, man-Sv	
		1988	1989*
UK	5.6×10^7	30	20
Other European countries	6.5×10^8	50	30

* Preliminary data

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. Data for 1988 have been revised to take account of updated landings statistics as well as revised data on doses per unit intake, mainly leading to reductions in calculated exposures due to plutonium and americium (sub-section 3.4). The preliminary result of 40 man-Sv for the UK in 1988 given in the previous report (Hunt, 1989) has been reduced to 30 man-Sv on this basis; there has been no change to the preliminary result of 50 man-Sv for other European countries because only a very small component of this dose is due to plutonium and americium.

Liquid radioactive waste discharges from Sellafield up to the end of 1989 are the main source of collective dose reported in Table 9; by comparison, the effect of liquid discharges from other establishments is very small. The contribution due to fallout from the Chernobyl reactor accident in 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 (sub-section 3.4). 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 results for 1989 of 20 man-Sv for the UK and 30 man-Sv for other European countries are less than the respective results now reported for 1988. This was mainly due to reductions in concentrations in fish of radiocaesium both from Sellafield discharges and from Chernobyl. It has not been possible to derive a direct estimate of the Chernobyl contribution for 1989 because most concentrations of caesium-134 in fish from the North Sea and further afield are below detection limits. However, based on the contribution estimated in the past, in 1989 this would have amounted to no more than about 10% of the totals for the UK population and for other countries, excluding the effect of fish from the Baltic Sea. The contribution to the collective dose to the UK population from Baltic Sea fish would have been minimal. On the basis of

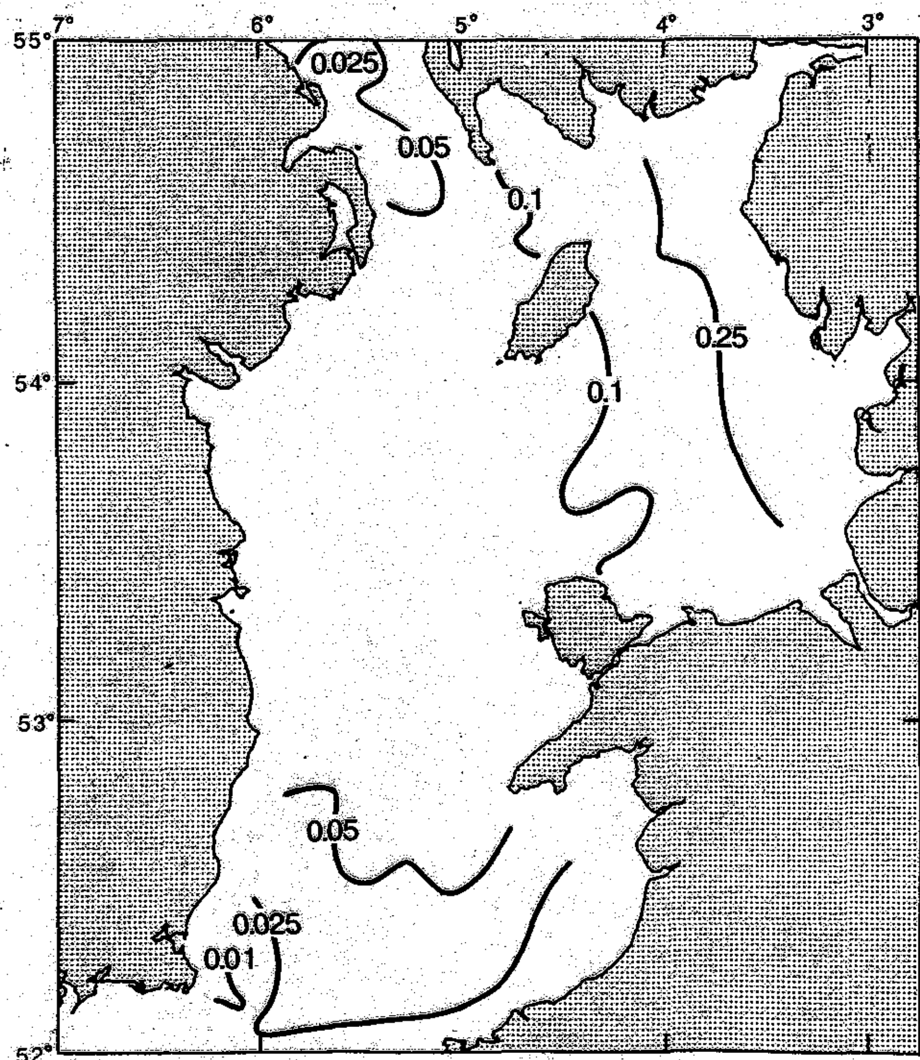


Figure 2. Concentrations (Bq kg^{-1}) of caesium-137 in filtered water from the Irish Sea, March 1989.

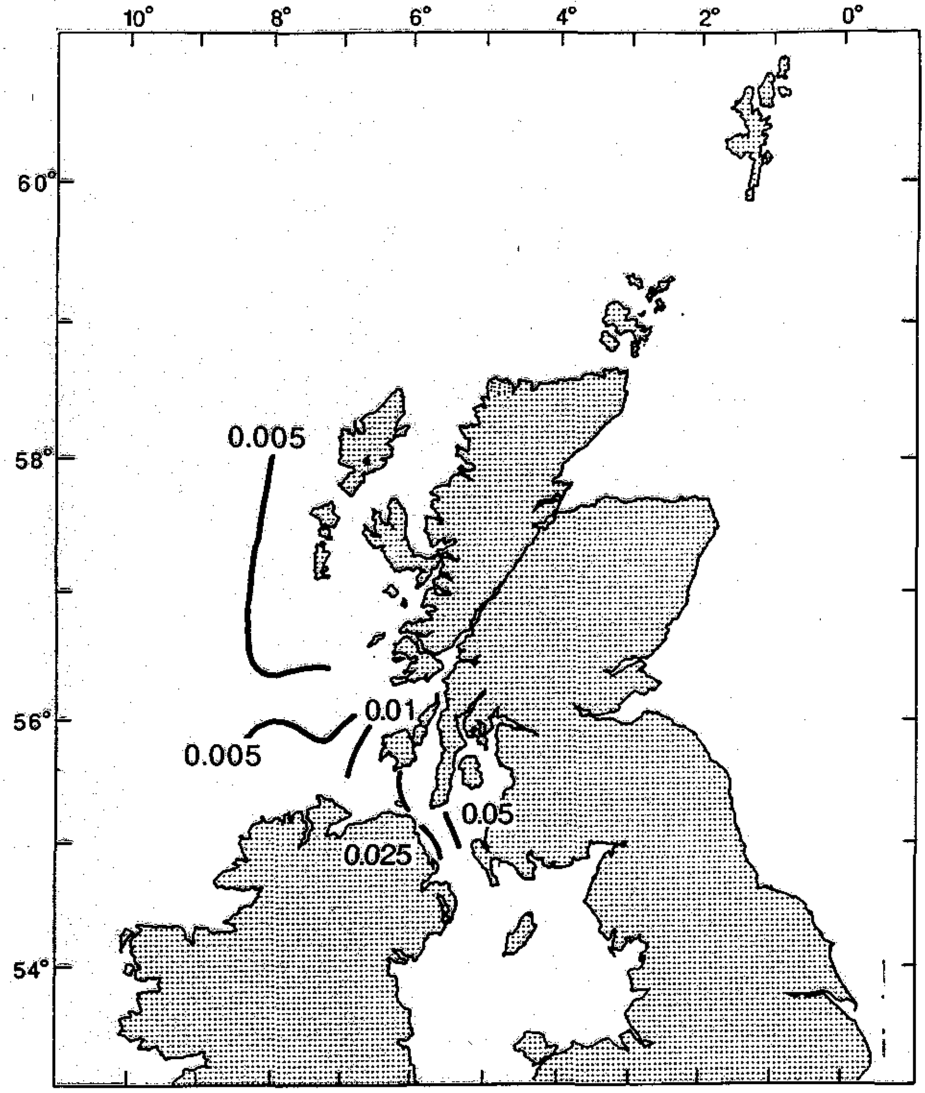


Figure 3. Concentrations (Bq kg⁻¹) of caesium-137 in filtered water from the west of Scotland, March 1989.

concentrations of radioactivity in fish from the Baltic Sea (Saxen *et al.*, 1989), it is estimated that the collective dose to other European countries due to the effects of the Chernobyl accident on Baltic Sea fish could have been as much as 30 man-Sv in both 1988 and 1989.

The collective dose for the UK, given in Table 9, 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 3.4). In 1989, the preliminary UK collective dose through the fish and shellfish pathway as a result of liquid radioactive waste disposal operations amounted to less than 0.02% of this level.

It is clear from the statements above, which compare the 1988 and 1989 results for both critical group and collective dose rates, that an important factor determining exposures is the distribution of radioactivity in the marine environment. We maintain a continuing programme of research on marine behaviour and distribution (including budget assessments) of significant radionuclides. Data on the distribution of caesium-137 in sea water are regularly collected by research vessel cruises; the distribution observed in the Irish Sea in March 1989 is shown in Figure 2. Comparison with the data for March 1988 (Hunt, 1989) shows that concentrations of caesium-137 in sea water of the eastern Irish Sea were generally similar, and those in the western Irish Sea decreased, continuing in that area to reflect the reductions in discharges from Sellafield since 1985, following operation of SIXEP. Our cruise programme in March 1989 included collection of data on the distribution of caesium-137 in sea water west of Scotland; the data are shown in Figure 3. Comparison with the data for March 1988 (Hunt, 1989) shows continuing reductions in concentrations of caesium-137 in Scottish waters. Data for the North Sea during August and September 1989 are shown in Figure 4. Comparison with the distribution observed in August and September 1988 (Hunt, 1989) shows a continuing reduction in concentrations of caesium-137 in most areas of the North Sea, particularly off the east coast of Scotland. Some of the caesium-137 in the North Sea, particularly in the north and east, is due to the effect of fallout from Chernobyl (Mitchell and Steele, 1988);

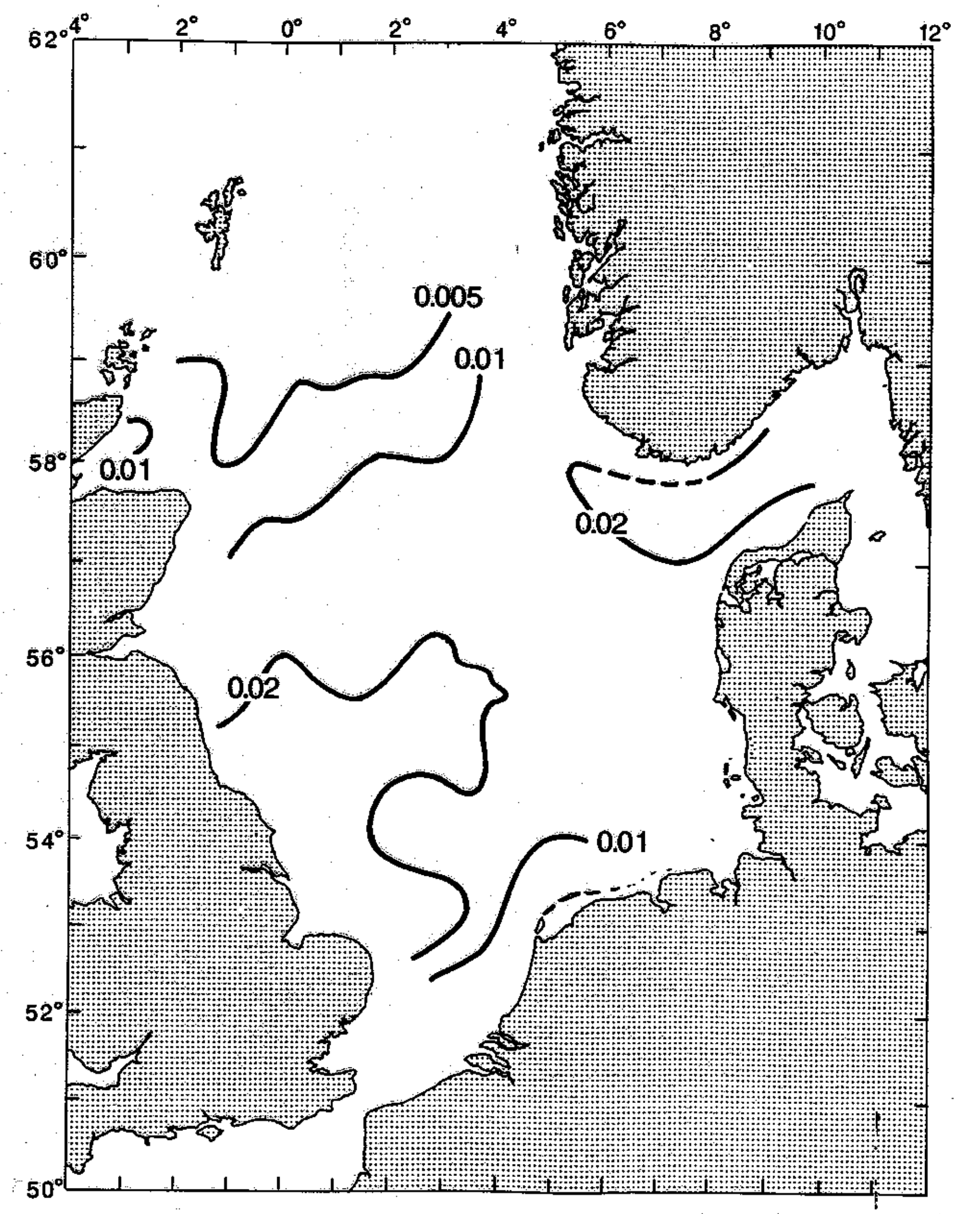


Figure 4. Concentrations (Bq kg⁻¹) of caesium-137 in filtered water from the North Sea, August-September 1989.

the distribution for 1989 continues to show the introduction of water from the Baltic Sea which is slightly richer in caesium-137 from Chernobyl than water of the North Sea.

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. Table 10 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, 4.3, 4.4, 6.5, 6.11). Variations in sediment type account for the quite marked fluctuations in dose rate, superimposed on a general decrease with increasing distance from Sellafield. Dose rates over intertidal areas in 1989 showed general reductions as compared with 1988 (Hunt, 1989).

Table 10. Gamma radiation dose rates over intertidal areas of the Cumbrian coast and further afield, 1989.

Location	Ground type	No. of sampling observa-tions#	Mean gamma dose rate in air at 1m, µGy h^{-1}
Cumbria			
Burgh marsh	Salt marsh	4	0.11
Greenend	" "	4	0.10
"	Muddy sand	4	0.080
Maryport Christchurch	Mud	4	0.14
" shore	Sand	4	0.099
Workington harbour	Mud	4	0.19
Harrington harbour	"	4	0.19
Whitehaven outer harbour	Sandy mud	12	0.17
" " "	Coal/sand	12	0.16
" inner "	Sandy mud	12	0.24
" yacht basin	Mud	13	0.33
St Bees	Sand	4	0.077
Nethertown winkle beds	Rock	4	0.12
Sellafield	Sand	4	0.096
Seascale	"	4	0.089
Drigg pipeline	"	4	0.080
" beach	"	4	0.080
" Barn Scar	Mussel bed	4	0.12
Ravenglass - salmon garth	Sandy mud	4	0.22
" " "	Sand/stones	4	0.11
" " "	Mussel bed	4	0.12
" - boats area	Sandy mud	12	0.14
" - " "	Sand	4	0.079
" - ford area	Sandy mud	4	0.15
" - Ravenvilla	Sandy mud	12	0.20
" "	Salt marsh	12	0.38
Newbiggin	Sandy mud	4	0.32
" - west of bridge	Sandy mud	4	0.16
" " " "	Salt marsh	4	0.43
Haverigg	Muddy sand	4	0.081
"	Sandy mud	4	0.15
Millom	Sandy mud	4	0.13
Tummer Hill Marsh	Salt marsh	4	0.26
Walney Channel	Sandy mud	4	0.14
" Vickers shore	Sandy mud	4	0.098
" west shore	Sand	4	0.067
Low Shaw	Salt marsh	4	0.14
Flookburgh	Muddy sand	4	0.11
Lancashire, Merseyside and North Wales			
Jenny Brown's Point	Salt marsh	4	0.095
Sunderland Point	Sandy mud	4	0.11
Skippool Creek	Mud	4	0.16
Fleetwood	Sand	4	0.074
Blackpool	"	4	0.061
Lytham Creek	Mud	4	0.14
Freckleton	"	4	0.16
Becconsall	Mud	4	0.15
Ainsdale	"	4	0.061
New Brighton	"	4	0.072
Mersey (Rock Ferry)	Mud	4	0.14
Llandudno	Gravel	4	0.083
Prestatyn	Sandy gravel	4	0.059
South-west Scotland			
Garlieston	Sandy mud	4	0.10
Innerwell	Mud	4	0.12
Kippford - slipway	Sandy mud	4	0.11
" - jetty	Sandy mud	4	0.10
" - merse	Salt marsh	4	0.21
Palnackie harbour	Mud	4	0.15
Carsethorn	Sandy mud	4	0.12

See sub-section 3.3 for definition.

We also regularly monitor radioactivity concentrations in sediments. This is 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 11. Variations similar in cause to those of the dose rates are observed, and comparison with results for 1988 (Hunt, 1989) shows general reductions 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-east 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 west Cumbria, combining dose rates and occupancy times, it is considered that bait diggers are representative of those who receive the highest external exposures, because of the occupancy times involved, which are greater than for other activities on intertidal areas. The maximum external exposure in 1989 was 0.079 mSv (Doddington *et al.*, 1990); addition of dose due to other pathways including fish and shellfish consumption increases this to 0.24 mSv. This total is within the distribution of individual doses for the critical group of consumers of fish and shellfish from the Cumbrian Coastal Area, and the radiological impact in

Table 11. Radioactivity in sediment from the Cumbrian coast and further afield, 1989.

Sampling point and sediment type		No. of sampling observations#	Mean radioactivity concentration (dry), Bq kg^{-1}								
			Total beta	^{54}Mn	^{60}Co	$^{95}Zr+^{95}Nb$	^{103}Ru	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs
Cumbria											
Maryport shore	(sand)	4	800	ND	3.1	ND	ND	10	4.8	2.3	320
Maryport Christchurch	(mud)	4	3700	"	21	110	"	610	20	12	1100
Harrington	(")	4	4000	"	18	120	"	550	17	11	1100
Whitehaven	(")	4	6200	"	18	91	2.1	430	21	18	1900
St Bees	(sand)	4	490	"	3.4	ND	ND	6.2	ND	1.1	110
Sellafield	(")	4	690	"	4.5	1.8	"	18	"	1.8	270
Seascale	(")	4	570	"	3.5	ND	"	16	1.0	1.3	170
Ravenglass-Ravenvilla	(sandy mud)	4	2100	"	23	56	"	370	16	7.2	690
Newbiggin	(mud)	4	3000	0.5	37	45	"	480	35	10	990
Millom	(sandy mud)	4	1500	ND	9.7	33	"	200	8.8	5.7	530
Walney Island	(mud)	4	1100	"	6.5	11	"	110	3.2	3.1	340
Flookburgh	(muddy sand)	4	660	"	0.7	ND	"	2.5	1.3	1.7	210
Lancashire and Merseyside											
Heysham	(mud)	4	1200	"	6.3	12	"	95	6.3	4.9	560
Sunderland Pt	(")	4	1200	0.5	3.2	0.9	"	37	2.9	4.4	430
Skippool Creek	(")	4	2200	ND	7.3	ND	"	88	3.8	13	1200
Fleetwood	(sand)	4	380	"	ND	"	"	ND	ND	0.5	41
Blackpool	(")	4	230	"	"	"	"	"	"	0.1	17
New Brighton	(")	4	280	"	"	"	"	"	"	ND	25
Rock Ferry	(mud)	4	1600	"	3.6	"	"	3.1	"	7.0	700
South-west Scotland											
Garlieston	(mud)	4	1200	"	6.3	1.6	"	72	2.8	9.7	390
Innerwell	(")	2	1400	"	9.0	ND	"	97	5.6	6.3	440
Kippford slipway	(")	4	1500	0.3	8.9	5.6	"	100	4.1	7.9	560
Kippford merse	(marsh)	4	2600	ND	18	4.1	"	180	2.8	33	1300
Palnackie	(mud)	4	1900	"	11	6.3	"	130	3.7	9.5	750
Carsethorn	(")	2	1200	"	5.8	ND	"	69	2.4	5.4	480
Northern Ireland											
Strangford Lough*	(mud)	2	720	"	ND	"	"	ND	ND	2.0	110
Strangford Lough**	(")	2	570	"	"	"	"	"	"	0.3	21
Groomsport	(sand)	2	320	"	"	"	"	"	"	0.3	14
Carlingford Lough	(mud)	2	990	"	"	"	"	"	"	7.3	240
Dundrum Bay	(sandy mud)	2	700	"	"	"	"	"	"	0.8	23
Larne Lough	(mud)	2	950	"	"	"	"	3.4	"	5.1	190

Table 11. Continued.

Sampling point and sediment type		No. of sampling observa-tions#	Mean radioactivity concentration (dry), Bq kg^{-1}								
			^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Pu	^{241}Am	^{242}Cm	$^{243}Cm+^{244}Cm$
Cumbria											
Maryport shore	(sand)	4	ND	2.4	1.5	18	92	NA	130	0.51	0.39
Maryport Christchurch	(mud)	4	66	30	20	160	740	"	1100	ND	2.6
Harrington	(")	4	63	30	19	NA	NA	"	860	NA	NA
Whitehaven	(")	4	47	34	22	180	810	"	1100	ND	2.6
St Bees	(sand)	4	ND	4.5	2.7	NA	NA	"	150	NA	NA
Sellafield	(")	4	2.8	6.9	4.0	"	"	"	230	"	"
Seascale	(")	4	0.9	5.7	2.7	"	"	"	190	"	"
Ravenglass-Ravenvilla	(sandy mud)	4	50	29	17	"	"	"	810	"	"
Newbiggin	(mud)	4	69	43	23	240	1100	19000	1300	1.8	4.7
Millom	(sandy mud)	4	25	15	10	NA	NA	NA	420	NA	NA
Walney Island	(mud)	4	13	9.1	5.9	"	"	"	260	"	"
Flookburgh	(muddy sand)	4	ND	0.6	0.8	"	"	"	44	"	"
Lancashire and Merseyside											
Heysham	(mud)	4	4.6	7.6	6.3	38	180	"	210	0.77	0.65
Sunderland Pt	(")	4	1.7	3.2	4.4	NA	NA	"	110	NA	NA
Skippool Creek	(")	4	ND	11	7.5	"	"	"	330	"	"
Fleetwood	(sand)	4	"	ND	ND	"	"	"	12	"	"
Blackpool	(")	4	"	"	"	"	"	"	3.6	"	"
New Brighton	(")	4	"	"	"	"	"	"	3.4	"	"
Rock Ferry	(mud)	4	4.1	5.3	5.3	"	"	"	150	"	"
South-west Scotland											
Garlieston	(mud)	4	1.7	6.6	5.9	36	170	"	250	ND	0.54
Innerwell	(")	2	8.4	9.4	7.7	NA	NA	"	250	NA	NA
Kippford slipway	(")	4	8.7	10	7.2	45	210	"	290	ND	0.89
Kippford merse	(marsh)	4	ND	19	15	110	500	"	650	"	2.7
Palnackie	(mud)	4	8.6	15	9.7	68	310	"	430	0.85	1.7
Carsethorn	(")	2	ND	7.4	5.7	NA	NA	"	190	NA	NA
Northern Ireland											
Strangford Lough*	(mud)	2	"	ND	ND	1.4	7.2	"	5.6	ND	ND
Strangford Lough**	(")	2	"	"	"	0.18	1.1	"	0.57	"	0.0015
Groomsport	(sand)	2	"	"	"	NA	NA	"	0.55	NA	NA
Carlingford Lough	(mud)	2	"	"	1.8	2.5	15	"	7.2	ND	ND
Dundrum Bay	(sandy mud)	2	"	"	ND	NA	NA	"	ND	NA	NA
Larne Lough	(mud)	2	"	"	2.0	"	"	"	14	"	"

NA = not analysed.
ND = not detected.
* Nickey's Point
** Island Hill
# see sub-section 3.3 for definition.

west Cumbria of liquid waste discharges from Sellafield is adequately represented by this critical group. 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 receive the highest external exposures from the effects of discharges from Sellafield (see sub-section 4.2). Their occupancy of boats in 1989 was nearly full-time but, taking account of the time that the boats are shielded from the mud by tidal effects and the shielding afforded by the boats themselves, this occupancy was equivalent to that from spending 3000 h year $^{-1}$ over unshielded mud. Making an allowance for natural background, their external exposure in 1989 was 0.17 mSv. This was less than in 1988 (0.27 mSv), due to reduced equivalent occupancy times and to reduced dose rates following declining concentrations of radiocaesium in sediments. The exposure was within the ICRP-recommended principal 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.

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 except in the case of the bait digger described above, 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 11) 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 1989 are presented in Table 12. 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

Table 12. Beta radiation dose rates on contact with fishing gear on vessels operating off Sellafield, 1989.

Vessel	Type of gear	No. of sampling observations#	Mean beta dose rate in tissue, $\mu Gy\ h^{-1}$
A	Nets	4	0.05
	Ropes	4	0.03
B	Nets	8	0.05
	Ropes	8	0.05
D	Gill nets	4	0.09
	Pots	4	0.08
E	Nets	4	0.10
	Gill nets	2	0.07
M	Nets	4	0.06
	Ropes	4	0.04
N	Nets	1	0.10
	Gill nets	4	0.04
	Pots	2	0.06
P	Nets	4	0.04
Q	Gill nets	11	0.14
	Pots	2	0.07
R	Nets	4	0.04

See sub-section 3.3 for definition.

Table 13. Radioactivity in Porphyra from UK shorelines of the Irish Sea, 1989.

Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet), $Bq\ kg^{-1}$									
		Total beta	^{60}Co	^{65}Zn	^{90}Sr	^{95}Zr+ ^{95}Nb	^{99}Tc	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb
Braystones South	4	380	1.2	ND	NA	3.4	NA	1.4	190	0.1	3.0
Seascale	52*	NA	1.9	0.05	"	4.4	"	1.8	180	0.04	5.7
St Bees	4	300	0.8	ND	0.97	5.7	2.3	1.2	130	0.1	4.5
Knock Bay	4	140	ND	"	NA	ND	NA	ND	1.1	ND	ND

Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet), $Bq\ kg^{-1}$									
		^{134}Cs	^{137}Cs	^{144}Ce	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Braystones South	4	0.05	6.6	1.6	ND	1.6	7.4	130	12	0.026	0.039
Seascale	52*	0.02	13	1.8	0.1	NA	NA	NA	20	NA	NA
St Bees	4	0.05	9.3	2.2	0.1	2.2	9.8	180	17	0.074	0.033
Knock Bay	4	ND	0.9	ND	ND	NA	NA	NA	0.58	NA	NA

NA = not analysed.
ND = not detected.
# See sub-section 3.3 for definition.
* These samples are counted wet to provide a rapid result.

of fishing gear in 1989 would have been less than 0.1 mSv, which is well within 1% of the ICRP-recommended dose limit appropriate for exposures to skin of members of the public, based on non-stochastic effects (sub-section 3.4). 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 1989; this pathway has therefore remained essentially dormant. However, monitoring has continued in view of its potential importance and the value of *Porphyra* as an indicator material. Samples of *Porphyra* are regularly collected from selected locations along UK shorelines of the Irish Sea. Results of analyses for 1989 are presented in Table 13. Samples of laverbread from the major manufacturers are regularly collected from markets in South Wales and analysed. Results for 1989 are presented in Table 14. The exposure of critical laverbread consumers was less than 0.01 mSv, confirming the virtual abeyance of this exposure pathway.

Table 14. Radioactivity in laverbread from South Wales, 1989.

Manufacturer	No. of sampling observations#	Mean radioactivity concentration (wet), Bq kg^{-1}			
		Total beta	^{60}Co		
A	4	70	0.2	ND	0.7
C	4	55	ND	0.3	0.4
D	4	51	"	ND	0.4
E	1	80	"	"	0.2

ND = not detected.
# See sub-section 3.3 for definition.

Table 15. Summary of contact beta and gamma dose rate monitoring of intertidal areas of Cumbria, 1989.

Month	No. of items detected (> 0.01 mGy h^{-1}) but below 0.1 mGy h^{-1}	Locations and dose rates (mGy h^{-1}) of items 0.1 mGy h^{-1} and above
January	0	
February	2	Drigg : 2.0
March	0	
April	1	Sellafield : 0.14
May	0	
June	1	
July	0	
August	0	
September	3	
October	2	
November	1	
December	1	

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 1989 is presented in Table 15. The rate of detection has continued to decline. The presence of contaminated items only represents a pathway for exposure of the public in the unlikely event of prolonged contact with them. The appropriate standard with which to compare the dose rates is the ICRP-recommended dose limit of 50 mSv year^{-1} for exposures to skin of members of the public (sub-section 3.4). It is not considered likely that anyone has received a dose to skin in excess of this 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 16 presents the results of measurements in 1989 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).

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 are of low radiological significance, consisting mainly of thorium and uranium and their decay products; liquid discharges are made by pipeline to the Ribble estuary. Public radiation exposure in this vicinity, as a result of these discharges, is very low; there is, however, a greater contribution due to Sellafield discharges. The critical pathway is external

Table 16. Radioactivity in marine plants from shorelines of the Irish Sea and further afield, 1989.

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	^{134}Cs
Fucus vesiculosus												
Sellafield	4	1700	NA	8.1	4.6	9.2	1800	0.07	35	4.1	4.0	0.9
St Bees	4	1100	29	3.3	5.9	4.6	1000	ND	16	1.6	2.5	0.6
Heysham	4	460	NA	0.5	NA	ND	NA	"	0.8	ND	1.0	0.3
Porthmadog	1	250	"	ND	"	"	"	"	ND	"	ND	ND
Port William	4	300	"	0.3	"	"	"	"	"	"	"	"
Garlieston	3	340	"	1.4	"	"	"	"	0.9	"	0.6	0.3
Auchencairn	4	440	"	1.5	"	0.3	"	"	0.3	"	0.6	0.3
Ardglass	3	340	"	0.06	"	ND	"	"	ND	"	ND	ND
Portrush	4	260	"	ND	"	"	"	"	"	"	"	"
Scilly Isles	1	220	"	"	"	"	"	"	"	"	"	"
Cape Wrath	1	270	"	"	"	"	"	"	"	"	"	"
Fishguard	1	210	"	"	"	"	"	"	"	"	"	"
Wick	1	210	"	"	"	"	"	"	"	"	"	"
Shetlands	1	74	"	"	"	"	"	"	"	"	"	"
Fucus spiralis												
Garlieston	1	310	"	1.1	"	"	"	"	"	"	"	0.4
Samphire												
Ravenglass	1	22	"	ND	"	"	"	"	1.1	"	"	ND
Heysham	1	73	"	"	"	"	"	"	ND	"	"	0.1
Rhodymenia												
St Bees	2	600	"	0.4	"	5.1	"	1.0	85	0.4	0.9	0.9
Strangford Lough	4	750	"	ND	"	ND	"	ND	ND	ND	ND	0.1
Alaria esculenta												
Isle of Man	1	350	"	"	"	"	"	"	"	"	"	ND

Type of seaweed and sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet), Bq kg^{-1}									
		^{137}Cs	^{144}Ce	^{147}Pm	^{154}Eu	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm+^{244}Cm$
Fucus vesiculosus											
Sellafield	4	34	1.6	8.3	0.3	0.4	4.8	20	9.7	0.044	0.031
St Bees	4	23	0.3	NA	ND	ND	2.3	10	5.4	ND	ND
Heysham	4	22	ND	"	"	0.2	0.57	2.7	1.1	0.0010	0.0020
Porthmadog	1	2.2	"	"	"	ND	NA	NA	ND	NA	NA
Port William	4	6.7	"	"	"	"	"	"	0.86	"	"
Garlieston	3	15	"	"	"	"	"	"	5.3	"	"
Auchencairn	4	26	"	"	"	0.1	"	"	3.2	"	"
Ardglass	3	4.5	"	"	"	ND	"	"	ND	"	"
Portrush	4	0.8	"	"	"	"	"	"	"	"	"
Scilly Isles	1	0.2	"	"	"	"	"	"	"	"	"
Cape Wrath	1	1.0	"	"	"	"	"	"	"	"	"
Fishguard	1	0.3	"	"	"	"	"	"	"	"	"
Wick	1	0.4	"	"	"	"	"	"	"	"	"
Shetlands	1	ND	"	"	"	"	"	"	"	"	"
Fucus spiralis											
Garlieston	1	7.5	"	"	"	"	"	"	3.5	"	"
Samphire											
Ravenglass	1	2.1	"	"	"	"	"	"	2.4	"	"
Heysham	1	10	"	"	"	"	"	"	1.9	"	"
Rhodymenia											
St Bees	2	39	1.7	"	0.4	0.2	1.3	6.0	11	0.035	0.044
Strangford Lough	4	5.3	ND	"	ND	ND	0.11	0.52	0.43	ND	ND
Alaria esculenta											
Isle of Man	1	1.7	"	"	"	NA	NA	ND	NA	NA	NA

NA = not analysed.
ND = not detected.
# See sub-section 3.3 for definition.

Table 17(a). Radioactivity in environmental materials near Springfields, 1989.

Material	Sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
			Total beta	^{60}Co	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu
Bass	Ribble estuary	1	150	ND	ND	ND	1.0	42	ND	ND	ND
Eel	" "	1	98	"	"	"	0.6	24	"	"	"
Grey mullet	" "	1	150	"	"	"	0.4	21	"	"	"
Sea trout	" "	1	140	"	"	"	0.5	22	"	"	"
Shrimp	" "	1	78	"	"	"	0.3	9.9	"	"	"
Cockles	" "	1	150	"	"	"	ND	12	"	"	"
Mud	Pipeline outlet	4	33000	3.7	19	3.3	8.3	680	"	2.9	2.0
	Becconsall	4	40000	5.6	45	ND	11	980	"	9.8	9.9
	Penwortham	4	140000	6.2	28	1.7	9.0	820	5.7	5.3	1.8
	Freckleton	1	110000	5.3	53	10	11	1100	ND	13	4.9
	Lytham Creek	1	42000	8.0	86	ND	12	1200	"	14	8.3
	Skippool Creek	4	2200	7.3	88	3.8	13	1200	"	11	7.5
	Rock Ferry	4	1600	3.6	3.1	ND	7.0	700	4.1	5.3	5.3
Sand	Lytham	1	350	ND	ND	"	ND	37	"	ND	ND

Material	Sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
			^{228}Th	^{230}Th	^{232}Th	^{233}Pa	^{234m}Pa	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am	$^{243}Cm+^{244}Cm$
Bass	Ribble estuary	1	0.0011	0.0015	0.00060	NA	ND	NA	NA	ND	NA
Eel	" "	1	NA	NA	NA	"	"	"	"	"	"
Grey mullet	" "	1	"	"	"	"	"	"	"	"	"
Sea trout	" "	1	"	"	"	"	"	"	"	"	"
Shrimp	" "	1	0.0086	0.039	0.0057	"	"	"	"	"	"
Cockles	" "	1	0.41	0.79	0.28	"	"	"	"	6.0	"
Mud	Pipeline outlet	4	51	300	62	1.3	46000	27	130	180	0.76
	Becconsall	4	60	460	75	5.4	51000	NA	NA	270	NA
	Penwortham	4	64	840	90	3.7	180000	"	"	220	"
	Freckleton	1	NA	NA	NA	5.0	140000	"	"	330	"
	Lytham Creek	1	"	"	"	ND	50000	"	"	330	"
	Skippool Creek	4	43	88	47	ND	170	"	"	330	"
	Rock Ferry	4	49	62	53	"	ND	"	"	150	"
Sand	Lytham	1	6.9	13	7.3	"	"	"	"	13	"

NA = not analysed.
ND = not detected.
* Except for sediment where dry concentrations apply.
# See sub-section 3.3 for definition.

Table 17(b). Gamma dose rates in air at 1m over intertidal areas near Springfields, 1989.

Location	No. of sampling observa-tions#	µGy h^{-1}
Pipeline outlet	4	0.14
Freckleton	4	0.16
Becconsall	4	0.15
Lytham	4	0.14
Penwortham	4	0.15

See sub-section 3.3 for definition.

exposure, due to adsorption of radioactivity on the muddy areas of river banks. The amounts of time for which members of the public are subject to such exposure is 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). We regularly monitor dose rates in relevant areas including muddy creeks where house-boats are moored, and some of these measurements are supported by analyses of sediment. In 1989, we continued to investigate the fish and shellfish consumption pathway by analysing locally-obtained samples, including analyses for isotopes of thorium.

Results for 1989 are shown in Table 17(a) and (b). Radionuclides detected which were due to Springfields discharges were isotopes of thorium and protactinium and their decay products. The concentrations of these radionuclides in environmental materials were of low radiological significance; other radionuclides present were mainly from Sellafield. Exposure of the critical group of houseboat dwellers in 1989, including the Sellafield component, was about 0.17 mSv, less than for 1988 (0.27 mSv), due to reduced equivalent occupancy times which allow for shielding by the boats themselves and to declining dose rates following reduced discharges from Sellafield. The contribution to exposures due to Springfields discharges would have been a small fraction of the total. Exposures were within the ICRP-recommended principal dose limit of 1 mSv year $^{-1}$ for members of the public. Concentrations of thorium isotopes in fish from the Ribble estuary were not significantly different from those expected from natural sources. Any exposures due to Springfields-derived radionuclides in shellfish would have been a small fraction of the total, most of which is due to Sellafield discharges, as considered in sub-section 4.1.1. The concentrations of thorium isotopes in silt in areas outside the Ribble estuary were consistent with natural sources, as were concentrations of thorium isotopes in sand from Lytham.

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 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. In May 1989, the Rivacre Brook authorisation was varied (see Table 1) to control more radionuclides specifically, prior to operation of a new decontamination plant. This plant commenced active operation in August 1989, leading

Table 18. Radioactivity in environmental materials in the vicinity of the Wirral, 1989.

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			Total beta	^{60}Co	^{99}Tc	^{106}Ru	^{134}Cs	^{137}Cs	^{155}Eu	^{233}Pa
Shrimps	Hoylake	2	59	ND	0.53	ND	ND	6.2	ND	NA
Cockles	Dee estuary	2	63	0.3	1.1	"	"	8.3	"	"
Fucus spiralis	Hoylake	2	200	ND	25	"	0.3	13	"	"
Fucus serratus	Little Orme	2	260	0.2	45	"	0.06	5.9	"	"
Water weed *Cladophora rupestris*	Rivacre Brook	2	150	0.4	27	"	ND	0.5	0.4	"
Mud	Hoylake	1	1300	2.6	NA	25	5.0	450	ND	"
	Rivacre Brook	2	1200	2.7	360	ND	12	52	4.7	30

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			^{234m}Pa	Total U	^{237}Np	^{238}Pu	^{239}Pu+^{240}Pu	^{241}Am		^{244}Cm
Shrimps	Hoylake	2	ND	NA	NA	NA	NA	ND	NA	NA
Cockles	Dee estuary	2	"	"	"	0.32	1.6	3.4	0.0089	0.0089
Fucus spiralis	Hoylake	2	"	"	"	NA	NA	1.3	NA	NA
Fucus serratus	Little Orme	2	"	"	"	"	"	ND	"	"
Water weed *Cladophora rupestris*	Rivacre Brook	2								
Mud	Hoylake	1	"	"	"	"	"	90	"	
	Rivacre Brook	2	5800	710	2.8	"	"	ND	"	

ND = not detected.
NA = not analysed.
* Except for sediment where dry concentrations apply.
# See sub-section 3.3 for definition.

to small increases in discharges in technetium-99 to the Rivacre Brook. No discharges from Capenhurst took place via Meols in 1989 (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.

Results for 1989 are presented in Table 18. 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. Technetium-99 concentrations were low, reflecting in seaweeds the much reduced discharges of technetium-99 from Sellafield because decay-stored liquors were not being released. Exposure of potentially critical shellfish consumers in the vicinity of the Wirral in 1989 amounted to less than 0.1 mSv, which is within the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$ for members of the public. 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. The small increases in discharges of technetium-99 to the Rivacre Brook were reflected in the concentrations of this nuclide in water weed and mud, but these concentrations were of negligible 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 of the Scottish Development Department. There are two pathways leading to public radiation exposures which are of potential importance. These are internal irradiation from consumption of locally-caught fish and shellfish and external exposure from use of intertidal areas by fishermen and turf cutters. Our monitoring, which is carried out on behalf of departments of the Scottish Office, continued to reflect these pathways. Samples of *Fucus* seaweeds, as useful indicators, are also analysed. The results of monitoring in 1989 are presented in Table 19(a) and (b).

Concentrations of artificial radionuclides in the Chapelcross vicinity are mostly due to Sellafield discharges, and the general levels of nuclides given in Table 19(a) are consistent with values expected at this distance from Sellafield. Concentrations of radiocaesium in 1989 were generally less than those in 1988, reflecting overall reductions in Sellafield discharges over the last few years. A reassessment of exposures was carried out for 1989, and this showed that fishermen continue to constitute the critical group in view of their regular occupancy of intertidal areas and consumption of local seafood. In 1989 their exposure was less than 0.1 mSv, which is within the ICRP-recommended principal

Table 19(a). Radioactivity in environmental materials in the vicinity of Chapelcross, 1989.

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			Total beta	^{54}Mn	^{60}Co	$^{95}Zr+{}^{95}Nb$	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs
Flounder	Seafield	4	170	ND	ND	ND	ND	ND	1.1	69
Salmon	"	1	130	"	"	"	"	"	ND	1.0
Sea trout	"	1	150	"	"	"	"	"	"	11
Shrimps	"	4	100	"	"	"	"	"	0.2	27
Fucus vesiculosus	"	4	400	0.3	0.8	"	0.8	0.2	0.6	53
Mud	"	4	1300	ND	3.4	"	52	2.1	6.0	610
Sand	"	4	690	"	0.4	0.7	5.5	ND	1.6	170

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
			^{154}Eu	^{155}Eu	^{238}Pu	$^{239}Pu+{}^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm+{}^{244}Cm$
Flounder	Seafield	4	ND	ND	NA	NA	ND	NA	NA
Salmon	"	1						"	"
Sea trout	"	1		"	0.00033	0.0014	0.0022	ND	ND
Shrimps	"	4		"	NA	NA	ND	NA	NA
Fucus vesiculosus	"	4		0.2	0.69	3.3	3.2	ND	0.0095
Mud	"	4	4.4	4.2	21	97	140	0.048	0.51
Sand	"	4	ND	0.7	1.8	9.3	13	ND	ND

ND = not detected; NA = not analysed.

* Except for sediment where dry concentrations apply.

\# See sub-section 3.3 for definition.

Table 19(b). Gamma dose rates in air at 1m over intertidal areas in the vicinity of Chapelcross, 1989.

Location	Ground type	No. of sampling observations#	µGy h^{-1}
Seafield	Mud/sand	4	0.10
Seafield	Salt marsh	4	0.11
Battle Hill	Mud/sand	4	0.11
Browhouses	Mud/sand	4	0.11
Dornoch Brow	Sand/mud	2	0.094
Dornoch Brow	Salt marsh	4	0.12

See sub-section 3.3 for definition

dose limit of 1 mSv year $^{-1}$ for members of the public. The magnitude of the Chapelcross discharges indicate that the local contribution would have been a tiny fraction of this exposure, 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 the Winfrith Technology Centre and from AEA Technology, Dounreay. Liquid radioactive wastes also arise at the UKAEA Harwell Laboratory. In common with such wastes from other nuclear establishments in the Thames Valley area, these are discharged into the River Thames catchment; whilst the critical exposure pathway is likely to be from drinking water, and monitoring is carried out by the DOE (DOE, 1990), 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 Laboratory, Oxfordshire

At this establishment the UKAEA operates research facilities, including in 1989 low-power nuclear reactors. Liquid radioactive waste arisings are small and discharges are made under authorisation to the River Thames at Sutton Courtenay. The critical exposure pathway is likely to be from drinking water, as stated above. During 1989, we continued our small programme of monitoring of fish and other aquatic materials from the Thames catchment in surveillance of fisheries-related exposure pathways. This included monitoring at locations remote from nuclear establishments. Analyses were carried out of available fish species, with *Nuphar lutea* (yellow water lily) and sediments as indicator materials.

The results of this monitoring are shown in Table 20. The concentrations of artificial radioactivity detected were very low. Concentrations of some nuclides, most notably caesium-137 in sediment, were enhanced close to the outfall, but the levels were very small in terms of any radiological effect. If any fish were eaten, even at rates typical of enthusiastic trout consumers, the radiation dose in 1989, including that due to occupancy of the river bank near the outfall for times typical of enthusiastic anglers, would have been less than 0.01 mSv, or less than 1% of the ICRP-recommended principal dose limit of 1 mSv year $^{-1}$.

Table 20. Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Harwell, 1989.

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}				
			Total beta	^{35}S	^{60}Co	^{65}Zn	^{137}Cs
Rainbow trout	East Hendred (Ginge Brook)	1	140	NA	ND	ND	0.4
Chub	Staines	1	110	ND	"	"	ND
Nuphar lutea	Sutton Courtenay	1	44	NA	6.5	0.2	2.1
	Staines	1	39	"	0.1	ND	0.3
Mud	Sutton Courtenay	1	580	"	10	"	150

NA = not analysed.
ND = not detected.
* Except for sediment where dry concentrations apply.
# See sub-section 3.3 for definition.

5.2 Winfrith Technology Centre, Dorset

The principal source of liquid radioactive wastes at this establishment is the Steam Generating Heavy Water Reactor. Most of the activity in these wastes (Table 1) is due to tritium from the moderator and coolant, but small amounts of activation products, including manganese-54, cobalt-60 and zinc-65, are removed during decontamination of the reactor's pressure circuit. These wastes are disposed of under authorisation to deep water in Weymouth Bay. In April 1989, the authorisation was revised, setting more stringent limits and controlling more radionuclides specifically, as well as requiring limitation of discharges by the best practicable means.

In 1989, the wastes continued to be subjected to treatment and storage, mainly to allow the short-lived zinc-65 to decay before release. The radiological significance of the discharges from Winfrith is small and mainly due to the activation products rather than to tritium. Reconcentration 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 Table 21.

The impact of Winfrith discharges, as in previous years, was mainly observed in the concentrations of activation product radionuclides. The concentrations of the shorter-lived of these radionuclides, particularly zinc-65, continued to decline in 1989 as compared with previous years; this was likely to have been due to the treatment procedures noted above. The radiation dose to the critical group of fish and shellfish consumers (Smith and Hunt, 1989) was about 0.03 mSv, or 3% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$. External gamma radiation dose rates, measured using portable instruments, continued to be indistinguishable from levels typical of the natural background.

Table 21. Radioactivity in environmental materials and gamma dose rates from the vicinity of Winfrith, 1989.

Material	Sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
			Total beta	^{54}Mn	^{55}Fe	^{58}Co	^{60}Co	^{65}Zn	^{99}Tc	^{106}Ru	^{110m}Ag
Plaice	Weymouth Bay	2	95	ND	0.6	ND	ND	0.3	NA	ND	ND
Pout whiting	Weymouth Bay	1	110	"	0.6	"	"	0.3	"	"	"
Squid	Weymouth Bay	2	93	"	NA	"	"	2.6	"	"	"
Crabs	Weymouth Bay	8	79	0.8	29	0.7	21	100	3.0	"	0.3
	Old Harry	1	66	ND	12	ND	11	65	NA	"	ND
Lobsters	Weymouth Bay	3	88	0.4	1.5	ND	13	76	3.6	"	0.2
Oysters	Poole	2	58	ND	2.5	"	0.8	92	NA	"	ND
Cockles	Poole	1	57	"	2.0	0.4	9.9	2.4	"	"	"
Scallops	Weymouth Bay	4	110	12	40	1.1	8.4	51	"	"	"
Whelks	Weymouth Bay	1	120	ND	2.7	ND	5.6	26	"	"	"
	Poole Bay	2	96	0.4	6.9	"	10	93	"	"	"
Fucus serratus	Arish Mell	1	270	8.0	1.9	5.2	60	17	"	"	"
	Kimmeridge	3	270	8.8	3.8	2.7	72	21	"	1.8	"
	Swanage	2	280	1.8	2.6	1.7	43	11	"	ND	"
	Hengistbury Head	2	200	0.7	0.6	0.8	22	4.5	"	"	"
	Bognor Rock	2	270	0.2	0.4	ND	8.4	0.4	"	0.6	"
	Sandgate	1	300	0.2	NA	"	7.3	0.7	"	ND	"
	Weymouth	2	220	2.8	1.0	1.2	24	6.1	"	"	"
	Chesil	2	210	ND	NA	ND	2.5	ND	"	"	"
	Lyme Regis	2	310	"	0.3	"	1.7	"	"	"	"
Mud	Kimmeridge	3	590	1.5	60	1.3	31	21	"	"	"
	Poole Harbour	2	770	2.1	92	ND	22	2.3	"	"	"
	Hardway	2	720	1.7	NA	"	21	1.6	"	"	"
	Rye Harbour	2	570	1.2	NA	"	16	ND	"	9.4	"
Muddy Sand	Kimmeridge	1	320	1.8	NA	0.8	31	15	"	ND	"

Table 21. Continued.

Material	Sampling 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
Plaice	Weymouth Bay	2	ND	0.4	ND	NA	NA	ND	NA	NA
Pout whiting	Weymouth Bay	1	"	0.3	"			"		
Squid	Weymouth Bay	2	"	ND	"					
Crabs	Weymouth Bay	8	"	0.03	"	0.00040	0.0013	0.0021	0.00004	0.00021
	Old Harry	1	"	ND	"	0.00016	0.00082	0.0015	ND	ND
Lobsters	Weymouth Bay	3	"	0.2	"	0.00045	0.0016	0.010	"	0.00053
Oysters	Poole	2	"	ND	"	NA	NA	ND	NA	NA
Cockles	Poole	1	"	0.2	"	"	"	"	"	"
Scallops	Weymouth Bay	4	"	0.05	"	0.0063	0.017	0.0049	0.00045	0.00021
Whelks	Weymouth Bay	1	"	ND	"	0.00074	0.0028	0.0020	ND	0.00022
	Poole Bay	2	"	"	"	0.0013	0.0044	0.0042	"	0.00030
Fucus serratus	Arish Mell	1	"	"	"	NA	NA	ND	NA	NA
	Kimmeridge	3	"	"	"	"	"	"	"	"
	Swanage	2	"	0.2	"	"	"	"	"	"
	Hengistbury Head	2	"	ND	"	"	"	"	"	"
	Bognor Rock	2	"	0.3	"	"	"	"	"	"
		1	"	0.3	"	"	"	"	"	"
	Weymouth	2	"	ND	"	"	"	"	"	"
	Chesil	2	"	0.09	"	"	"	"	"	"
	Lyme Regis	2	"	0.1	"	"	"	"	"	"
Mud	Kimmeridge	3	"	2.6	0.9	"	"	"	"	"
	Poole Harbour	2	"	5.6	ND	0.19	0.87	0.66	ND	ND
	Hardway	2	0.8	4.5	1.1	NA	NA	ND	NA	NA
	Rye Harbour	2	2.4	4.5	ND	0.23	0.83	0.60	ND	0.048
Muddy Sand	Kimmeridge	1	ND	3.4	1.2	NA	NA	NA	NA	NA

Mean gamma dose rate in air at 1m over intertidal sediments:

Kimmeridge (2 sampling observations): 0.085 µGy h^{-1}
Poole Harbour (2 sampling observations): 0.068 µGy h^{-1}
Hardway (2 sampling observations): 0.073 µGy h^{-1}
Rye Harbour (2 sampling observations): 0.078 µGy h^{-1}

NA = not analysed.
ND = not detected.
* Except for sediment where dry concentrations apply.
# See sub-section 3.3 for definition.

5.3 AEA Technology, Dounreay, Caithness

Liquid radioactive waste discharges from this establishment are made to the Pentland Firth under authorisation of the Scottish Development Department. 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). In June 1989, the authorisation was revised, setting more stringent limits and controlling more radionuclides specifically, as well as requiring reduction of discharges by the best practicable means. Discharges from Dounreay in 1989 were less than in 1988 reflecting the campaigns of reprocessing of reactor fuel. All discharges remained well within the new authorised limits. Our surveys near Dounreay are carried out on behalf of departments of the Scottish Office. Monitoring in 1989 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 Table 22.

Table 22. Radioactivity in environmental materials and gamma dose rates from the vicinity of Dounreay, 1989.

Sampling point and material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{54}Mn	^{58}Co	^{60}Co	^{95}Zr+ ^{95}Nb	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs
Area of outfall										
Cod	4	140	ND	ND	ND	ND	ND	ND	ND	0.2
Crabs	4	79	"	"	"	"	"	4.9	"	ND
Lobsters	4	85	"	"	"	"	3.2	18	"	"
Sandside Bay										
Winkles	4	120	"	"	1.5	"	24	85	"	"
Fucus vesiculosus	4	310	4.1	"	3.2	"	0.3	5.5	"	0.03
Sand	4	500	ND	"	0.3	"	ND	ND	"	0.3
Oigins Geo										
Sludge	3	11000	140	"	100	130	6100	800	250	160
Brims Ness										
Winkles	4	130	ND	"	2.4	ND	17	89	ND	ND
Fucus vesiculosus	4	310	5.8	0.1	5.3	"	3.2	11	"	0.08

Sampling point and material	No. of sampling observations#	Mean radioactive concentration (wet)*, Bq kg^{-1}								
		^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Area of outfall										
Cod	4	2.6	ND	ND	ND	0.00008	0.00035	0.00048	ND	ND
Crabs	4	0.3	"	"	"	0.0020	0.0079	0.013	0.0015	0.00044
Lobsters	4	0.3	"	"	"	0.0029	0.011	0.057	0.0038	0.0016
Sandside Bay										
Winkles	4	0.2	1.1	"	"	0.093	0.22	0.27	0.037	0.0088
Fucus vesiculosus	4	1.5	0.2	"	"	NA	NA	ND	NA	NA
Sand	4	7.9	4.4	2.2	3.2	4.0	14	15	0.36	0.23
Oigins Geo										
Sludge	3	1200	710	54	170	140	390	250	60	12
Brims Ness										
Winkles	4	0.4	ND	ND	ND	0.092	0.23	0.33	0.030	0.011
Fucus vesiculosus	4	1.6	"	"	"	NA	NA	ND	NA	NA

Mean gamma dose rate in air at 1m over intertidal sediment : Oigins Geo (4 sampling observations): 0.15 µGy h^{-1}

Mean gamma dose rate in air at 1m over intertidal sediment : Sandside (3 sampling observations): 0.080 µGy h^{-1}

ND = not detected.
NA = not analysed.
* Except for sediment where dry concentrations apply.
# See sub-section 3.3 for definition.

Recent habits surveys have confirmed the existence of three potentially critical exposure pathways, two 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. Our regular measurements in previous years have shown that, at current rates of discharge, the average dose rates on nets would be low. Monitoring by the UKAEA in 1989 has confirmed that the exposure of these fishermen remained low, at less than 0.1 mSv, or less than 1% of the ICRP-recommended dose limit of 50 mSv year^{-1} for skin exposures (see sub-section 3.4).

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 1989, we carried out monitoring of sludge at Oigin's Geo; concentrations of radioactivity were less than in 1988 and consistent with the range of levels expected due to normal Dounreay operations. We also carried out measurements of gamma dose rates above areas of the foreshore. Public radiation exposure via this pathway remained low, at less than 0.01 mSv or less than 1% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$.

The third potentially critical pathway involves internal exposure of consumers of locally-collected fish and shellfish; we sample fish, crabs and lobsters from the outfall area and winkles from Sandside Bay and Brims Ness to enable this pathway to be kept under review. Additionally, as in previous years, seaweed was sampled as an indicator material. Radionuclide concentrations in 1989 were less than in 1988, reflecting the lower discharges from Dounreay and, for radiocaesium, the trend of discharges from Sellafield over the past few years. Exposures from fish and shellfish consumption continued to be low: for high-rate consumers the radiation dose was less than 0.01 mSv or 1% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$.

6. NUCLEAR POWER STATIONS OPERATED BY THE ELECTRICITY COMPANIES

All but two of these power stations 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 Nuclear Laboratories. 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. 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.

Table 23. Radioactivity in environmental materials and gamma dose rates near Berkeley and Oldbury nuclear power stations, 1989.

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}											
		Total beta	^{14}C	^{54}Mn	^{60}Co	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm+^{244}Cm$
Flounders	2	97	73	ND	ND	ND	0.8	ND	NA	NA	ND	NA	NA
Grey mullet	1	120	NA	"	"	"	1.2	"	"	"	"	"	"
Salmon	1	110	"	"	"	"	ND	"	"	"	"	"	"
Shad	1	150	"	"	"	"	"	"	"	"	"	"	"
Sole	1	150	"	"	"	"	0.6	"	"	"	"	"	"
Eel	1	91	"	"	"	"	ND	"	"	"	"	"	"
Shrimps	2	110	"	"	"	0.06	0.7	"	"	"	"	"	"
Fucus vesiculosus	2	170	"	"	"	0.1	1.1	"	"	"	"	"	"
Mud:													
Area of outfalls	4	900	"	0.3	0.4	2.1	51	1.2	"	"	"	"	"
Lydney	2	840	"	ND	0.8	1.8	45	1.0	0.16	0.80	0.66	0.011	0.016

Mean gamma dose rate at 1m over intertidal mud (13 sampling observations): 0.076 μGy h^{-1}

NA = not analysed.
ND = not detected.
* Except for sediment where dry concentrations apply.
\# See sub-section 3.3 for definition.

Data for 1989 are presented in Table 23. 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 exposure of the critical group of fish and shellfish consumers. Their total exposure due to liquid waste discharges was low, at less than 0.01 mSv or 1% of the ICRP-recommended principal dose limit of 1 mSv year $^{-1}$.

6.2 Bradwell, Essex

Radioactive liquid effluent from this power station is discharged to the estuary of the River Blackwater. A reassessment of pathways for radiation exposure of the public has shown that the critical pathway is external exposure of people who live in houseboats moored in muddy areas of the estuary, because of the amounts of time spent on board. Consumption of locally-caught fish and shellfish is of lesser importance. Our environmental monitoring, however, 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 1989 are summarised in Table 24. In fish and shellfish, artificial radioactivity was detected due to the combined effects of discharges from the station, Sellafield discharges, and fallout. Apportionment of the effects of these sources is difficult because of the low levels detected. Concentrations of artificial radionuclides in sediment and seaweed were also low. Gamma dose rates, as directly measured, were 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 houseboat dwellers. This exposure was small, amounting to less than 0.02 mSv or 2% of the ICRP-recommended principal dose limit of 1 mSv year $^{-1}$. Exposures of high-rate fish and shellfish consumers were lower than those of houseboat dwellers.

Table 24. Radioactivity in environmental materials and gamma dose rates near Bradwell nuclear power station, 1989.

Material	No. of observations#	Mean radioactivity concentration (wet)*, Bq kg $^{-1}$						
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{106}Ru	^{110m}Ag	^{125}Sb
Mixed fish	2	91	ND	ND	ND	ND	ND	ND
Oysters	2	82	"	"	12	"	1.4	"
Whelks	2	72	"	"	ND	"	2.5	"
Fucus vesiculosus	2	190	"	1.0	0.2	"	ND	0.2
Sediment	6	830	0.2	5.3	ND	5.3	"	1.4

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg $^{-1}$						
		^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{243}Cm+ ^{244}Cm
Mixed fish	2	ND	0.9	ND	NA	NA	ND	NA
Oysters	2	"	0.3	"	0.00047	0.0019	0.0068	0.00029
Whelks	2	"	"	"	NA	NA	ND	NA
Fucus vesiculosus	2	"	1.5	"	"	"	"	"
Sediment	6	1.1	21	1.6	"	"	"	"

Mean gamma dose rate in air at 1m over intertidal sediment (7 sampling observations): 0.77 μGy h $^{-1}$

NA = not analysed.
ND = not detected.
* Except for sediment where dry concentrations apply.
# See sub-section 3.3 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. Seaweed is analysed as an indicator material. The results for 1989 are given in Table 25.

Concentrations of radiocaesium are attributable to discharges from the stations and from Sellafield, with a small contribution due to weapons-test fallout and perhaps from the Chernobyl accident. Apportionment is difficult at these low levels. Trace levels of manganese-54, 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. Trace amounts of ruthenium-106 were also detected in whelks, sediment and seaweed. Our monitoring programme in the Channel Islands (section 9) shows that the French reprocessing plant at Cap de la Hague may be the source of this radionuclide. The small concentrations of transuranics in silt were similar to levels observed at other sites remote from Sellafield.

A review of exposure pathways has shown that 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 due to liquid discharges from Dungeness was low, at about 0.01 mSv or 1% of the ICRP-recommended principal dose limit of 1 mSv year $^{-1}$.

6.4 Hartlepool, Cleveland

This station is powered by twin AGRs. Discharges of liquid radioactive wastes are made under authorisation to the North Sea. Potentially critical pathways for radiation exposure of the public near the station are internal irradiation following consumption of local fish and shellfish and external exposure from occupancy in intertidal areas. 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 1989 are shown in Table 26. Concentrations of radiocaesium and transuranics were mainly due to discharges from Sellafield and to fallout including, for radiocaesium, a contribution due to the Chernobyl accident. The radiation exposure of the critical group of local fish and shellfish consumers was low, at less than 0.01 mSv or 1% of the ICRP-recommended principal dose limit of 1 mSv year $^{-1}$. Gamma radiation dose rates over intertidal sediments, as directly measured, continued to be indistinguishable from the natural background; a calculation based on measured concentrations of radionuclides in coal/sand (Hunt, 1984) confirmed that the external exposure of coal collectors in 1989 would have been less than those of high-rate fish and shellfish consumers, at less than 0.001 mSv.

Table 25. Radioactivity in environmental materials and gamma dose rates near Dungeness nuclear power stations, 1989.

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}												
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+^{240}Pu	^{241}Am	^{243}Cm+^{244}Cm
Cod	1	130	ND	ND	ND	ND	ND	ND	0.7	ND	NA	NA	ND	NA
Dab	2	100	"	"	0.2	"	"	0.06	0.5	"	"	"	"	"
Plaice	2	120	"	"	ND	"	"	ND	0.4	"	"	"	"	"
Shrimp	1	83	"	"	"	"	"	"	ND	"	"	"	"	"
Whelks	2	91	"	1.7	1.1	1.1	"	"	"	"	"	"	"	"
Fucus serratus	1	300	0.2	7.3	0.7	ND	"	"	0.3	"	"	"	"	"
Porphyra	1	240	ND	1.1	0.6	5.2	"	"	0.2	"	"	"	"	"
Sand	2	350	"	3.7	ND	ND	"	"	0.6	2.0	"	"	"	"
Mud	2	570	1.2	16	"	9.4	2.4	"	4.5	ND	0.23	0.83	0.60	0.048

Mean gamma dose rate in air at 1m over intertidal sand (7 sampling observations): 0.066 µGy h^{-1}

Mean gamma dose rate in air at 1m over intertidal silt in Rye Harbour (2 sampling observations): 0.078 µGy h^{-1}

NA = not analysed.
ND = not detected.
* Except for sediment where dry concentrations apply.
# See sub-section 3.3 for definition.

Table 26. Radioactivity in environmental materials and gamma dose rates near Hartlepool nuclear power station, 1989.

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}									
		Total beta	^{110m}Ag	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+^{244}Cm
Plaice	2	100	ND	ND	0.9	ND	NA	NA	ND	NA	NA
Cod	2	140	"	0.2	3.1	"	"	"	"	"	"
Crabs	2	63	0.3	ND	0.4	"	0.00040	0.0017	0.0013	ND	ND
Shrimp	1	100	ND	"	1.1	"	NA	NA	ND	NA	NA
Winkles	2	120	"	0.05	1.0	"	0.010	0.050	0.020	0.00009	0.00007
Fucus vesiculosus	2	240	"	ND	0.9	"	NA	NA	ND	NA	NA
Sand	1	450	"	1.4	8.5	"	"	"	"	"	"
Coal/sand	1	190	"	ND	2.8	"	"	"	"	"	"
Mud	2	870	"	1.8	44	1.9	"	"	"	"	"

Mean gamma dose rate in air at 1m over intertidal sediment (6 sampling observations): 0.072 µGy h^{-1}

NA = not analysed.
ND = not detected.
* Except for sediment where dry concentrations apply.
# See sub-section 3.3 for definition.

Table 27. Radioactivity in environmental materials and gamma dose rates near Heysham nuclear power stations, 1989.

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{54}Mn	^{60}Co	^{95}Zr+^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs
Cod	1	130	ND	ND	ND	ND	ND	3.4	16
Plaice	3	120	"	"	"	"	"	0.3	28
Bass	1	170	"	"	"	"	"	1.1	68
Flounder	1	160	"	"	"	"	"	0.7	59
Whitebait	1	130	"	"	"	"	"	0.5	29
Cockles	4	75	"	1.4	"	4.1	0.2	0.1	9.7
Mussels	4	65	"	0.7	"	2.4	ND	0.2	6.8
Fucus vesiculosus	4	460	"	0.5	"	0.8	1.0	0.3	22
Samphire	1	73	"	ND	"	ND	ND	0.1	
Sediment									
Sunderland Point	4	1200	0.5	3.2	0.9	37	2.9	4.4	430
Half Moon Bay	4	1200	ND	6.3	12	95	6.3	4.9	560

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}Am	^{242}Cm	^{243}Cm+^{244}Cm
Cod	1	ND	ND	ND	NA	NA	ND	NA	NA
Plaice	3								
Bass	1								
Founder	1								
Whitebait	1				0.047	0.23	0.31	ND	0.00084
Cockles	4				0.71	3.4	7.2	"	0.021
Mussels	4	"	"	"	0.37	1.8	3.3	"	0.0067
Fucus vesiculosus	4	"	"	0.2	0.57	2.7	1.1	0.0010	0.0020
Samphire	1	"	"	ND	NA	NA	1.9	NA	NA
Sediment									
Sunderland Point	4	1.7	3.2	4.4	"	"	110	"	"
Half Moon Bay	4	4.6	7.6	6.3	38	180	210	0.77	0.65

Mean gamma dose rate in air at 1m over intertidal sediment:
Heysham vicinity (24 sampling observations): 0.097 µGy h^{-1}
Sunderland Point (4 sampling observations): 0.11 µGy h^{-1}

NA = not analysed.
ND = not detected.
* Except for sediment where dry concentrations apply.
# See sub-section 3.3 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 fish and 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 1989 are given in Table 27. These mainly reflect discharges from Sellafield; the effect of discharges from Heysham was not detectable above this background. The radiation exposure in 1989 of members of the critical group of fish and shellfish consumers in the Morecambe Bay area was about 0.15 mSv, as given in sub-section 4.1.1. External exposure of members of the public was less than 0.1 mSv. The groups of people to which these exposures apply are independent, thus summation is not necessary; both exposures are within the ICRP-recommended principal 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 1989, presented in Table 28, indicate concentrations of radionuclides representing the combined effect of releases from the stations, from other establishments which discharge to the Bristol Channel, from Sellafield, and from fallout. Apportionment is difficult at the low levels detected. The concentrations in shrimps of transuranic nuclides from the station and from Sellafield were of negligible radiological significance. Gamma radiation dose rates over intertidal sediment, measured using portable instruments, were 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 high-rate fish and shellfish consumers. Their total exposure due to liquid waste discharges was low, at less than 0.01 mSv or 1% of the ICRP-recommended principal dose limit of 1 mSv year $^{-1}$.

Table 28. Radioactivity in environmental materials and gamma dose rates near Hinkley Point nuclear power stations, 1989.

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}										
		Total beta	^{14}C	^{54}Mn	^{60}Co	^{90}Sr	^{110m}Ag	^{134}Cs	^{137}Cs	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am
Flounders	2	120	86	ND	ND	NA	ND	0.1	1.5	NA	NA	ND
Shrimps	2	96	NA	"	"	0.13	"	0.1	0.7	0.00018	0.00088	0.00074
Fucus vesiculosus	2	270	"	2.2	1.0	NA	0.1	0.9	5.0	NA	NA	ND
Sediment	2	390	"	ND	0.5	"	ND	4.1	25	"	"	"

Mean gamma dose rate in air at 1m over intertidal sediment (8 sampling observations): 0.083 uGy h^{-1}

NA = not analysed.

ND = not detected.

* Except for sediment where dry concentrations apply.

\# See sub-section 3.3 for definition.

6.7 Hunterston, Ayrshire

This establishment comprises 'A' and 'B' stations; the 'A' station is powered by magnox-type reactors and the 'B' station by AGRs. Liquid radioactive waste discharges are made to the Firth of Clyde under authorisation of the Scottish Development Department. 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 departments 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 1989 are shown in Table 29.

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. Concentrations of radiocaesium generally declined in 1989 following the overall reductions in Sellafield discharges over the past few years. In 1989, the exposure of members of the critical group of fish and shellfish consumers near Hunterston was low, at less than 0.02 mSv or 2% of the principal ICRP-recommended dose limit of 1 mSv year $^{-1}$. Radiocaesium concentrations detected in fish from farms which are supplied by station cooling water were generally lower than in fish caught in the open sea; this is because the farmed fish are fed on manufactured food which has a lower radioactivity concentration. The small amounts of activation products observed in molluscs, seaweed and sand were mainly due to discharges from the 'B' station. However, they gave rise to but a small fraction of the above exposure and their radiological significance was negligible. 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. Our monitoring reflects the two potentially critical radiation exposure pathways of fish and shellfish consumption leading to internal irradiation, and occupancy of intertidal areas giving rise to external exposure (Leonard and Smith, 1982). The results of this monitoring in 1989 are shown in Table 30.

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, zinc-65 and ruthenium-106 in some shellfish

Table 29. Radioactivity in environmental materials and gamma dose rates near Hunterston nuclear power stations, 1989.

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg $^{-1}$												
		Total beta	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn	^{110m}Ag	^{134}Cs	^{137}Cs	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Cod	1	140	ND	ND	ND	ND	ND	0.4	7.7	NA	NA	ND	NA	NA
Grey mullet	1	160	"	"	0.4	"	"	0.9	10	"				
Saithe	4	140	"	"	ND	"	"	0.5	13	"				
Turbot (fish farm)	4	120	"	"	"	"	"	0.6	4.8	"				
Lobster	1	110	"	"	"	"	"	ND	2.3	"				
Nephrops	2	85	"	"				"	4.6	"				"
	1	39	"	"	"	3.1	1.9	"	0.9	"			"	
Winkles	4	100	4.7	0.6	7.5	3.2	4.4	0.2	2.4	0.033	0.13	0.056	0.0021	0.0034
Fucus spiralis	4	270	9.1	0.5	7.9	3.9	1.3	1.1	8.2	0.10	0.47	0.066	0.0025	0.0025
Sand	4	260	2.8	ND	1.9	ND	ND	1.4	37	NA	NA	ND	NA	NA

Mean gamma dose rate in air at 1m over intertidal sediment (8 sampling observations): 0.085 μGy h $^{-1}$

NA = not analysed.
ND = not detected.
* Except for sand where dry concentrations apply.
# See sub-section 3.3 for definition.

Table 30. Radioactivity in environmental materials and gamma dose rates near Sizewell nuclear power station, 1989.

Material	No. of sampling observa-vations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}										
		Total beta	^{60}Co	^{65}Zn	^{106}Ru	^{110m}Ag	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+^{240}Pu	^{241}Am
Cod	1	140	ND	ND	ND	ND	ND	2.5	ND	NA	NA	ND
Plaice	1	110	"	"	"	"	"	0.9	"	"	"	"
Lobster	1	59	0.7	"	"	1.3	"	0.4	"	"	"	"
Shrimp	1	110	ND	"	"	ND	0.2	1.4	"	0.00003	0.00023	0.00013
Crab	1	68	0.2	"	"	1.3	ND	0.4	"	NA	NA	ND
Oysters	2	68	ND	0.8	"	1.7	"	0.2	"	"	"	"
Whelk	1	80	"	ND	"	1.3	"	ND	"	"	"	"
Mud	2	800	3.3	"	6.8	ND	1.5	28	1.5	"	"	"

Mean gamma dose rate in air at 1m over intertidal sand/shingle (10 sampling observations): 0.056 µGy h^{-1}

Mean gamma dose rate in air at 1m over intertidal mud in Southwold Harbour (2 sampling observations): 0.070 µGy h^{-1}

NA = not analysed.
ND = not detected.
* Except for mud where dry concentrations apply.
# See sub-section 3.3 for definition.

Table 31. Radioactivity in environmental materials and gamma dose rates near Torness nuclear power station, 1989.

Material	No. of sampling observa-vations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}									
		Total beta	^{106}Ru	^{110m}Ag	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{243}Cm+^{244}Cm
Cod	2	140	ND	ND	ND	1.6	ND	NA	NA	ND	NA
Crabs	2	93	"	1.5	"	0.5	"	"	"	"	"
Lobster	1	69	"	1.2	"	0.5	"	"	"	"	"
Nephrops	4	98	"	0.2	"	1.2	"	0.00089	0.0051	0.0041	0.00001
Winkles	3	96	"	1.9	"	0.5	"	NA	NA	ND	NA
Fucus spiralis	1	360	"	ND	"	1.6	"	"	"	"	"
Fucus vesiculosus	2	290	"	"	"	1.7	"	"	"	"	"
Mud											
Dunbar Inner Harbour	2	710	6.2	"	5.0	66	"	"	"	"	"
Eyemouth Harbour	1	880	ND	"	8.3	80	"	"	"	"	"
Aberlady Bay	1	480	"	"	1.1	22	"	"	"	"	"
Sand											
Thornton Loch Beach	2	160	"	"	ND	3.2	0.4	"	"	"	"

Mean gamma dose rate in air at 1m over intertidal sediment (10 sampling observations): 0.064 µGy h^{-1}

NA = not analysed.
ND = not detected.
* Except for sediment where dry concentrations apply.
# See sub-section 3.3 for definition.

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 0.003 mSv or 0.3% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}. Directly-measured gamma dose rates, as in previous years, were indistinguishable from the natural background; however, 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.

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 Development Department. Our investigations, on behalf of departments 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 seaweed are monitored as indicator materials. Measurements are also made of gamma dose rates over intertidal areas, supported by analyses of sediment.

Results of this monitoring in 1989 are shown in Table 31. Concentrations of artificial radionuclides were mainly due to the distant effects of Sellafield discharges and to fallout, including a contribution from the Chernobyl accident. Radiation exposure of the critical group of fish and shellfish consumers was low, at less than 0.003 mSv, or 0.3% of the ICRP-recommended principal 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.

6.10 Trawsfynydd, Gwynedd

Discharges from this station are made to the freshwater Lake Trawsfynydd under authorisation of the Welsh Office. 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 radiation exposure pathway is due to consumption of fish caught in the lake; the important radionuclides are those of caesium and, to a lesser extent, strontium-90. Species of fish regularly consumed are brown trout and rainbow trout; negligible amounts of perch were eaten by high-rate trout consumers in 1989. Perch and most brown trout are indigenous to the lake but rainbow trout, and sometimes brown 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.

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. Our enhanced monitoring programme, which was increased in 1986 following the Chernobyl accident, continued. The results of our additional monitoring are reported in section 10. Our regular programme of monitoring of fish at Trawsfynydd continued during 1989, and is reported here to present a balanced picture of public radiation exposures for the whole year. The results of our regular monitoring are shown in Table 32.

Table 32. Radioactivity in environmental materials and gamma dose rates near Trawsfynydd nuclear power station, 1989.

Material	No. of observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{35}S	^{54}Mn	^{60}Co	^{90}Sr	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs
Brown trout	13	380	34	ND	0.1	9.2	ND	ND	45	230
Rainbow trout	15	140	3.8	"	ND	3.9	"	"	3.8	20
Rainbow trout (hatchery)	1	97	NA	"	"	7.6	"	"	ND	1.2
Perch	8	760	100	"	0.4	5.1	"	"	110	600
Rudd	3	460	NA	"	ND	NA	"	"	72	380
Fontinalis										
Afon Prysor	3	230	"	0.2	"	"	"	"	4.4	23
Gwylan Stream	2	950	"	8.3	110	"	60	150	26	240
Mud										
Near cooling water outfall	2	2100	"	ND	60	"	57	250	100	1300
Hot lagoon	2	7900	"	"	120	"	57	480	190	6900
South end of lake	1	1900	"	"	9.6	"	ND	35	39	1100
Cae Adda boat mooring	1	480	"	"	1.4	"	"	ND	10	83
Bailey bridge	1	1100	"	"	5.2	"	"	9.5	20	300
Gwylan Stream	2	4200	"	1.5	41	"	28	73	100	2500
Peat										
Near cooling water outfall	1	1400	"	"	22	"	50	250	31	200
Hot lagoon	2	3300	"	"	96	"	25	250	70	2100
South end of lake	1	500	"	"	ND	"	ND	6.5	1.8	220
Cae Adda boat mooring	1	750	"	"	"	"	"	7.3	40	220
	1	1800	"	"	42	"	49	99	59	530
Water										
Bailey bridge	12	NA	"	NA	NA	0.22	NA	NA	0.055	0.19
Cold lagoon	12	"	"	"	"	0.20	"	"	0.046	0.17

Table 32. Continued.

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}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Brown trout	13	ND	ND	ND	0.00021	0.00082	0.0013	0.00008	0.00002
Rainbow trout	15	"	"	"	0.00013	0.00047	0.0007	0.00006	0.00001
Rainbow trout (hatchery)	1	"	"	"	0.00010	0.00057	0.00077	ND	ND
Perch	8	"	"	"	0.00017	0.00061	0.0012	0.00012	0.00003
Rudd	3	"	"	"	NA	NA	ND	NA	NA
Fontinalis									
Afon Prysor	3	"	"	1.8	"	"	"		
Gwylan Stream	2	19	0.9	4.2	"	"	0.62		
Mud									
Near cooling water outfall	2	12	7.4	7.4	"	"	15	"	"
Hot lagoon	2	33	50	34	34	140	210	2.2	5.2
South end of lake	1	ND	ND	ND	NA	NA	ND	NA	NA
Cae Adda boat mooring	1	"	"	"	"	"	"	"	"
Bailey bridge	1	"	"	"	"	"	"		
Gwylan Stream	2	6.9	"	"	"	"	1.5		
Peat									
Near cooling water outfall	1	25	"	"	"	"	4.3	"	"
Hot lagoon	2	20	25	14	17	69	97	1.2	1.9
South end of lake	1	ND	ND	ND	NA	NA	ND	NA	NA
Cae Adda boat mooring	1	"	"	"	"	"	"	"	"
Bailey bridge	1	"	"	"	"	"	"	"	"
Water									
Bailey bridge	12	NA	NA	NA	"	"	NA		
Cold lagoon	12	"	"	"	"	"	"		

Mean gamma dose rate in air at 1m over areas near lake shoreline (7 sampling observations): 0.078 µGy h^{-1}

NA = not analysed.
ND = not detected.
* Except for mud and peat where dry concentrations apply.
\# See sub-section 3.3 for definition

Discharges of radiocaesium from the power station in 1989 decreased to levels more typical of 1986 and 1987 as compared with somewhat greater discharges in 1988 (Table 1). All discharges have remained within authorised limits. There were consequent decreases as compared with 1988 in concentrations of radiocaesium in the water of the hot lagoon, and the lake water reflected the ratio of caesium-137 to caesium-134 in the discharges. Despite the changes in discharges and lake water, however, concentrations of radiocaesium in trout, averaged over the whole year, were higher than those in 1988 (Hunt, 1989). This is thought to be due to the time required for fish to respond to the higher concentrations in lake water in 1988 as compared with 1987 (Hunt, 1988). In 1989, 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 1989 members of the critical group of fish consumers received about 0.09 mSv, which is within the ICRP-recommended principal dose limit of 1 mSv year^{-1}. This increased exposure, as compared with 0.07 mSv in 1988 (Hunt, 1989), was mainly due to the greater concentrations of radiocaesium in trout. Gamma dose rates, measured using portable instruments, were not significantly different from values to be expected from the natural background. However, the exposure of the critical group given above includes a small contribution due to lakeside external exposure based on a calculation (Hunt, 1984) using radionuclide concentrations in sediment.

6.11 Wylfa

Liquid radioactive wastes from this station are discharged to the Irish Sea under authorisation of the Welsh Office. 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 1989 are presented in Table 33.

Table 33. Radioactivity in environmental materials and gamma dose rates near Wylfa nuclear power station, 1989.

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}										
		Total beta	^{60}Co	^{106}Ru	^{110m}Ag	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{243}Cm+ ^{244}Cm
Plaice	2	130	ND	ND	ND	0.1	2.8	ND	NA	NA	ND	NA
Spurdog	3	99	"	"	"	0.4	9.6	"	0.00005	0.00018	0.00033	ND
Crabs	2	86	0.2	"	1.0	ND	1.6	"	NA	NA	ND	NA
Winkles	2	87	0.4	"	0.8	"	2.5	"	0.075	0.36	0.43	0.0017
Mussels	2	49	ND	"	ND	"	1.5	"	0.059	0.29	0.49	0.0011
Fucus vesiculosus	2	290	"	"	"	0.09	5.1	"	NA	NA	0.32	NA
Sediment:												
Cemlyn Bay	2	1200	1.8	4.4	"	8.3	350	1.8	7.5	39	52	0.14

Mean gamma dose rate in air at 1m over intertidal sediment (12 sampling observations): 0.087 µGy h^{-1}

NA = not analysed.
ND = not detected.
* Except for sediment where dry concentrations apply.
\# See sub-section 3.3 for definition.

Any effects of discharges from this station are masked by Sellafield-derived radioactivity. Concentrations of artificial radionuclides in environmental materials were consistent with those expected at this distance from Sellafield, and generally decreased in 1989, following the overall reductions in Sellafield discharges in recent years. Data for 1989 confirmed that the critical group consisted of high-rate fish and shellfish consumers, and that their radiation exposure was about 0.01 mSv, which is within the ICRP-recommended principal 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 indistinguishable 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).

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 River Thames; The critical public radiation exposure pathway is likely to be from drinking water, and monitoring is carried out by the DOE (DOE, 1990). In 1989, 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 with Authorising Departments to the River Thames at Pangbourne. As explained above, the critical exposure pathway is likely to be from drinking water, but in 1989 we continued a small programme of fisheries-related monitoring. This included monitoring at locations in the Thames catchment remote from nuclear establishments. Analyses were carried out of available fish species, with *Nuphar lutea* (yellow water lily) and sediments as indicator materials.

The results of this monitoring are shown in Table 34. The concentrations of artificial radioactivity detected were very low. Concentrations of plutonium were not significantly different from the level expected due to fallout. The overall effect was of very low radiological significance: if any fish were eaten, even at rates typical of enthusiastic trout consumers, the radiation dose, together with that due to occupancy of the river bank near the outfall for times typical of enthusiastic anglers, would have been less than 0.002 mSv or less than 0.2% of the ICRP-recommended principal dose limit of 1 mSv year $^{-1}$.

Table 34. Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from the Atomic Weapons Establishment, Aldermaston, 1989.

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
			Total beta	^{60}Co	^{134}Cs	^{137}Cs	^{155}Eu	^{239}Pu+ ^{240}Pu	^{241}Am
Chub	Pangbourne	1	95	ND	ND	0.8	ND	0.00017	0.00047
	Staines	1	110	"	"	ND	"	NA	ND
Nuphar lutea	Pangbourne	1	34	0.5	"	0.4	"	"	"
	Staines	1	39	0.1	"	0.3	"	"	"
Sediment	Pangbourne	1	310	1.3	"	7.2	"	"	"
	Hardwick Island	1	470	4.5	0.6	64	1.9	"	"
	Maple Durham	1	310	1.5	ND	21	ND	"	"

NA = not analysed.
ND = not detected.
* Except for sediment where dry concentrations apply.
# See sub-section 3.3 for definition.

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). The US naval base at Holy Loch discharges small quantities of radioactive waste (sub-section 2.1). We carry out monitoring programmes near all of these establishments, in the case of Faslane and Rosyth on behalf of departments of the Scottish Office. Monitoring near Chatham also continues in surveillance of the effects of past discharges.

Public radiation exposures due to the effects of 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

Table 35. Radioactivity in environmental materials and gamma dose rates near naval establishments, 1989.

Establishment	Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							Mean gamma dose rate in air at 1m	
			Total beta	^{60}Co	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{155}Eu	No. of sampling observations#	µGy h^{-1}
Chatham	Sediment	1	NA	3.6	ND	ND	1.2	20	ND	4	0.078
Devonport	Mussels	2	60	0.1	"	"	ND	ND	"	NP	NP
	Fucus vesiculosus	2	NA	0.5	"	"	"	0.2	"	"	"
	Sediment	6	"	1.3	"	"	"	5.7	"	12	0.083
Faslane	Sediment	2	"	16	"	2.7	4.2	100	"	22	0.069
Rosyth	Crab	2	75	ND	0.2	ND	ND	0.5	"	NP	NP
	Fucus vesiculosus	2	NA	0.1	ND	"	"	1.2	"	"	"
	Sediment	10	610	0.6	"	"	2.1	35	1.0	10	0.070
Holy Loch	Sediment	2	370	3.6	"	"	1.2	25	ND	19	0.069

NA = not analysed
ND = not detected
NP = not applicable
* Except for sediment where dry concentrations apply.
# See sub-section 3.3 for definition.

(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 1989 are presented in Table 35. 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 1989, the exposure of critical groups, taking account of consumption of marine foods and occupancy times, continued to remain very low near all of these naval establishments, at less than 0.01 mSv year $^{-1}$. This represents less than 1% of the ICRP-recommended principal dose limit of 1 mSv year $^{-1}$.

8. AMERSHAM INTERNATIONAL PLC

This company is engaged in the manufacture of radioactive materials for use in medicine, research and industry. The company's parent 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 DOE (DOE, 1990). However, in 1989 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. In 1989, we continued our small programme of monitoring of fish and other aquatic materials in surveillance of the effects of these discharges, including monitoring at locations remote from nuclear establishments. Analyses were carried out of available fish species with *Nuphar lutea* (yellow water lily) and sediments as indicator materials.

The results of this monitoring are presented in Table 36. 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. If any fish were eaten, even at rates typical of enthusiastic trout consumers, 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 less than 0.01 mSv or less than 1% of the ICRP-recommended principal dose limit of 1 mSv year $^{-1}$.

Table 36. Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Amersham International plc, Amersham, 1989.

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			Total beta	^{14}C	^{35}S	^{58}Co	^{60}Co	^{65}Zn	^{134}Cs	^{137}Cs
Rainbow trout	Huntsmoor	1	110	NA	NA	ND	ND	ND	ND	0.3
Chub	Grand Union Canal	1	140	160	18	"	"	"	"	0.5
	Staines	1	110	NA	ND	"	"	"	"	ND
Nuphar lutea	Grand Union Canal	1	57	"	NA	"	"	"	"	"
	Staines	1	39	"	"	"	0.1	"	"	0.3
Mud	Grand Union Canal		440	"	"	9.7	ND	11	2.6	20

NA = not analysed.
ND = not detected.
* Except for sediment where dry concentrations apply.
\# See sub-section 3.3 for definition.

8.2 Cardiff Laboratory

A second laboratory, situated near Cardiff, is engaged in the production of labelled compounds used in research and of 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 1989 are presented in Table 37. Of the separate radionuclides listed, only carbon-14 and sulphur-35 were discharged by this establishment in 1989; the presence of the other radionuclides was therefore due to the combined background effects noted above. Small amounts of iodine-131 detected in seaweed are likely to have been due to discharges from a local hospital. The exposure of the critical group of fish and shellfish consumers was less than 0.1 mSv, which is within the ICRP-recommended principal dose limit of 1 mSv year $^{-1}$. This exposure includes a small contribution due to external irradiation of the critical group, 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.

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 1989 are given in Table 38. 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. However, the concentrations of artificial radionuclides in each of these materials were of negligible radiological significance.

Table 37. Radioactivity in environmental materials and gamma dose rates near the outfall of the sewer serving Amersham International plc, Cardiff, 1989.

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta§	^{14}C	^{35}S	^{131}I	^{134}Cs	^{137}Cs	^{155}Eu
Flounder	3	290	940	ND	ND	ND	0.8	ND
Fucus spiralis	4	190	18	22	1.0	0.02	0.5	0.03
Fucus vesiculosus	2	270	NA	NA	ND	ND	0.6	ND
Mud	3	920	12	"	"	2.2	35	1.7
Muddy sand	1	450	24	"	"	ND	12	2.4

Mean gamma dose rate in air at 1m over intertidal sediment (4 sampling observations): 0.077 μGy h^{-1}

NA = not analysed.

ND = not detected.

* Except for sediment where dry concentrations apply.

\# See sub-section 3.3 for definition.

§ Includes contribution from carbon-14 at low counting efficiency due to the low energy of beta particles emitted by this radionuclide.

Table 38. Radioactivity in environmental materials and gamma dose rates from the Channel Islands, 1989.

Material	Sampling area/ landing point	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}									
			Total beta	^{14}C	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn	^{90}Sr	^{106}Ru	^{110m}Ag	^{125}Sb
Rays	Guernsey[2]	1	120	19	ND	ND	ND	ND	NA	ND	ND	ND
Crabs	Guernsey[2]	1	69	NA	"	"	0.4	"	"	"	0.5	"
	Jersey[2]	1	120	"	"	"	1.7	"	"	3.7	1.4	"
	Alderney[2]	1	110	20	"	"	1.2	0.9	"	1.5	0.3	0.4
Oysters	Jersey[2]	1	72	NA	"	"	1.1	1.6	"	4.9	2.5	ND
Limpets	Jersey[1]											
	La Rozel	1	81	"	"	"	0.9	ND	"	2.5	0.6	0.5
	Verclut	1	110	"	"	"	2.4	"	"	3.9	0.5	ND
	Guernsey[1]											
	Bordeaux Harbour	1	96	"	"	"	1.1	"	"	4.8	ND	"
	Alderney[1]											
	Quenard Point	1	100	"	"	"	1.9	0.4	"	19	0.9	0.4
Winkles	Jersey[1]											
	La Rocque	1	140	19	"	"	3.5	ND	"	28	ND	1.4
	Alderney[1]											
	Quenard Point	1	150	30	"	"	7.1	"	"	45	1.9	ND
Scallops	Guernsey[2]	1	86	NA	0.3	"	1.3	"	"	10	0.8	"
Porphyra	Jersey[1]											
	Greve de Lecq	4	180	"	ND	"	0.6	0.05	"	12	ND	"
	Guernsey[1]											
	Fermain Bay	4	170	"	"	"	0.5	ND	"	6.3	"	"
	Alderney[1]											
	Quenard Point	4	140	"	"	"	1.4	"	"	26	"	0.03
Fucus serratus	Jersey[1]											
	La Rozel	4	380	"	0.04	0.05	6.0	"	0.36	5.5	0.2	0.3
	Verclut	1	490	"	0.1	ND	5.3	0.2	NA	4.3	0.1	0.2
	Guernsey[1]											
	Fermain Bay	4	290	"	0.07	0.04	3.2	ND	0.20	3.0	ND	0.04
	Alderney[1]											
	Quenard Point	4	270	"	0.2	ND	7.8	0.1	0.41	7.8	0.2	0.3
Laminaria digitata	Jersey[1]											
	Verclut	4	420	"	ND	"	0.6	ND	NA	4.2	0.08	0.1
Sediment	Jersey[1]											
	St Helier Harbour	2	690	"	2.0	"	25	"	"	51	ND	5.6
	Guernsey[1]											
	Bordeaux Harbour	1	510	"	ND	"	1.6	"	"	4.7	"	1.1
	Pembroke Bay	1	420	"	"	"	ND	"	"	ND	"	ND
	St Sampsons Harbour	1	450	"	0.8	"	7.6	"	"	19	"	2.1
	Alderney[1]											
	Douglas Harbour	1	320	"	ND	"	0.7	"	"	5.0	"	ND

Table 38. Continued.

Material	Sampling area/ landing point	No. of sampling observa-tions#	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
Rays	Guernsey[2]	1	ND	0.7	ND	ND	0.00017	0.00024	0.00036	ND	ND
Crabs	Guernsey[2]	1	"	ND	"	"	0.0016	0.0033	0.0047	0.00007	0.0017
	Jersey[2]	1	"	0.2	"	"	0.0016	0.0031	0.0065	0.00007	0.0023
	Alderney[2]	1	"	0.2	"	"	NA	NA	ND	NA	NA
Oysters	Jersey[2]	1	"	ND	"	"	0.0093	0.014	0.014	0.00023	0.0049
Limpets	Jersey[1]										
	La Rozel	1	"	"	"	"	0.0077	0.012	0.017	0.00056	0.0052
	Verclut	1	"	"	"	"					
	Guernsey[1]	1	"	0.4	"	"	0.010	0.016	0.026	0.0014	0.0076
	Alderney[1]	1	"	ND	"	"	0.023	0.020	0.068	0.0010	0.032
Winkles	Jersey[1]	1	"	"	"	"	NA	NA	ND	NA	NA
	Alderney[1]	1	"	0.9	"	"	0.097	0.13	0.21	0.0021	0.084
Scallops	Guernsey[1]	1	"	0.3	"	"	NA	NA	ND	NA	NA
Porphyra	Jersey[1]	4	"	0.07	"	"	"	"	"	"	"
	Guernsey[1]	4	"	0.06	"	"	"	"	"	"	"
	Alderney[1]	4	0.01	0.3	"	"	"	"	"	"	"
Fucus serratus	Jersey[1]										
	La Rozel	4	ND	0.3	"	0.05	0.064	0.096	0.037	0.00046	0.013
	Verclut	1	"	0.3	"	ND	NA	NA	ND	NA	NA
	Guernsey[1]										
	Fermain Bay	4	"	0.2	"	"	0.023	0.040	0.023	0.0013	0.0097
	Alderney[1]										
	Quenard Point	4	"	0.2	0.09	0.04	0.052	0.060	0.047	0.0024	0.025
Laminaria digitata	Jersey[1]										
	Verclut	4	"	0.3	ND	ND	NA	NA	ND	NA	NA
Sediment	Jersey[1]										
	St Helier Harbour	2	0.3	10	3.1	3.2	1.4	3.3	4.5	0.058	1.3
	Guernsey[1]										
	Bordeaux Harbour	1	ND	2.4	ND	ND	0.10	0.37	0.30	ND	0.050
	Pembroke Bay	1	"	0.8	"	"	NA	NA	ND	NA	NA
	St Sampsons Harbour	1	"	6.2	"	1.0	"	"	"	"	"
	Alderney[1]										
	Douglas Harbour	1	"	3.8	"	0.7	"	"	0.70	"	"

Mean gamma dose rate in air at 1m over intertidal sediments:

Jersey (7 sampling observations):	0.090	$\mu Gy\ h^{-1}$
Guernsey (1 sampling observation):	0.068	$\mu Gy\ h^{-1}$
Alderney (4 sampling observations):	0.072	$\mu Gy\ h^{-1}$

1 = Sampling area
2 = Landing point
NA = not analysed.
ND = not detected.
* Except for sediment where dry concentrations apply.
\# See sub-section 3.3 for definition.

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

An extended monitoring programme continued during 1989 in surveillance of the effects of fallout from this accident. Because of more limited dispersion rates than in marine situations, parts of the freshwater environment continued to show the effect of fallout from Chernobyl during 1989. The results of our additional monitoring for 1989 are presented in this section. The sampling locations are shown in Figure 5. They are mostly in areas of relatively high deposition of fallout from Chernobyl, namely Cumbria, North Wales and parts of Scotland, but samples from Northern Ireland, the Isle of Man and areas of low deposition were also obtained for completeness and comparison.

Tables 39-44 present 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. The number of samples analysed is specified. The sample size in terms of the number of individual fish varied from one to about ten, depending on availability and radiological importance. The maximum concentrations in samples from a given location varied up to a factor of two or three times the average value. Artificial radionuclides other than those of radiocaesium, in 1989, 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. Most samples analysed were of brown trout (Table 39), in

Table 39. Caesium radioactivity in brown trout, 1989.

Location	No. of samples	Mean radioactivity concentration (wet) Bq kg^{-1}	
		^{134}Cs	^{137}Cs
England			
Cogra Moss	1	ND	110
Devoke Water	41	35	190
Ennerdale Water	36	24	130
Loweswater	25	6.3	41
River Calder	2	ND	38
Wales			
Bala Lake	6	ND	18
Llyn Conwy	16	15	87
Llyn Elsi	14	27	140
Llyn Goddionduon	15	42	180
Llyn Mymbyr	5	34	180
Llyn Ogwen	12	59	280
Llyn Trawsfynydd	105	51	260
Scotland			
Loch of Harray	2	2.5	21
Lochan Fada	2	10	84
Loch Awe	2	ND	17
Loch Calder	2	2.9	22
Loch Dee	15	69	380
Loch Doon	2	20	120
Loch Garry, Tayside Region	2	27	130
River Leader	2	ND	ND
River Tummel	2	23	120
Ruisdale Water	2	40	230
Loch Beinn Charnain	2	43	250
Water of Ae	1	ND	ND
Loch of Girlsta	3	45	240
Loch Ness	2	35	190
Northern Ireland			
Altnahinch Dam	1	14	130
Movanagher	1	ND	ND
Isle of Man			
Cornaa River	1	4.4	26
River Druidale	1	32	150
Injebreck River/Reservoir	1	8.4	53
River Neb	1	ND	21

ND=not detected

Table 40. Caesium radioactivity in rainbow trout, 1989.

Location	No. of samples	Mean radioactivity concentration (wet) Bq kg^{-1}	
		^{134}Cs	^{137}Cs
England			
Cogra Moss	1	ND	5.4
Sacrewell	1	ND	ND
Branthwaite	1	ND	ND
Thrushbank	3	ND	4.7
Wales			
Llyn Elsi	1	12	53
Llyn Trawsfynydd	14	2.7	13
Bodelwyddan	1	ND	2.4
Bala Lake	2	ND	6.7
Scotland			
River Almond	1	ND	ND
Water of Ae	1	ND	ND
Loch of the Blairs	1	ND	4.9
Northern Ireland			
Movanagher	1	ND	ND
Isle of Man			
Cornaa River	1	ND	ND
River Neb	1	ND	3.1

ND = not detected

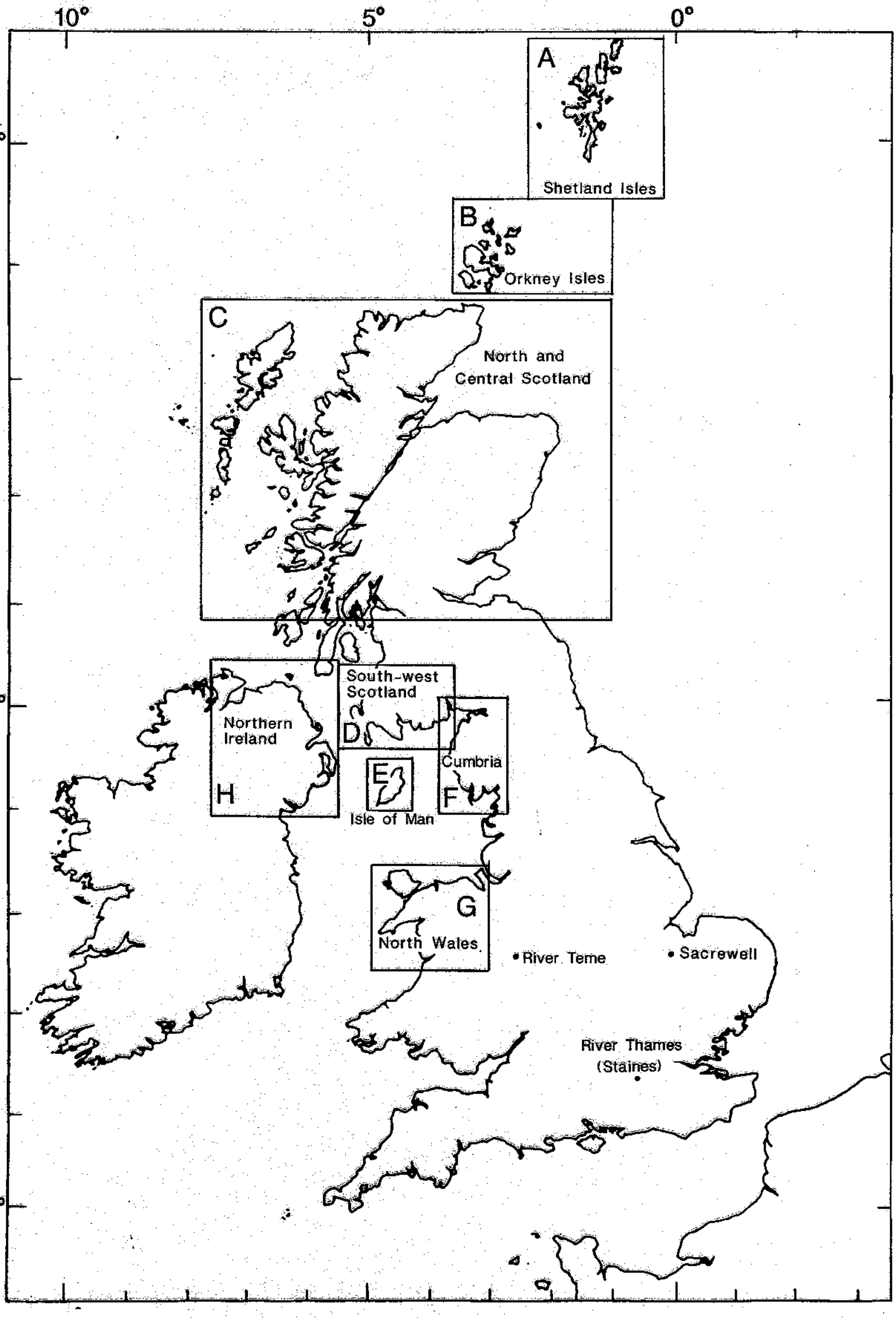


Figure 5. Sampling locations for monitoring of the freshwater environment for radioactivity from Chernobyl.

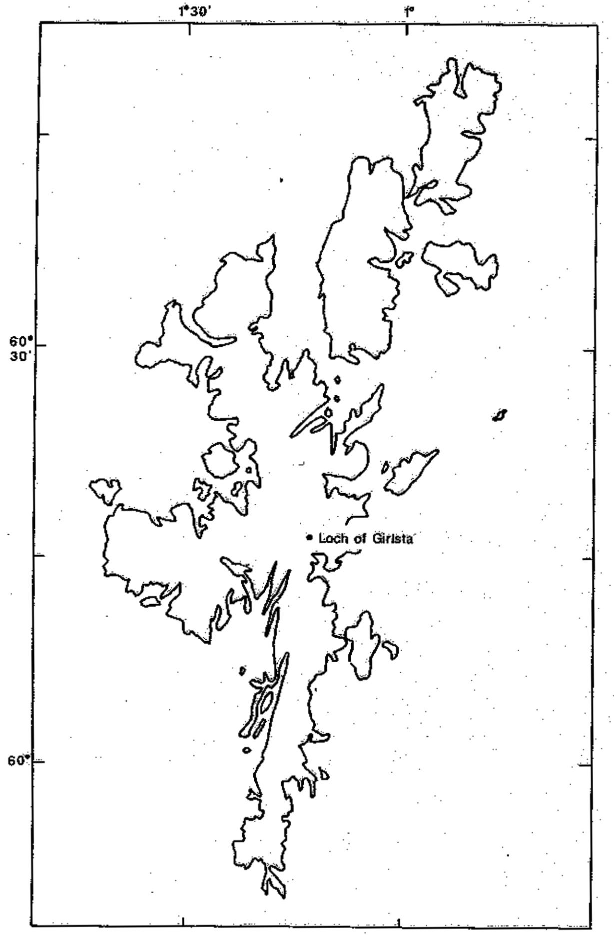


Figure 5. Inset A. Sampling locations in the Shetland Isles.

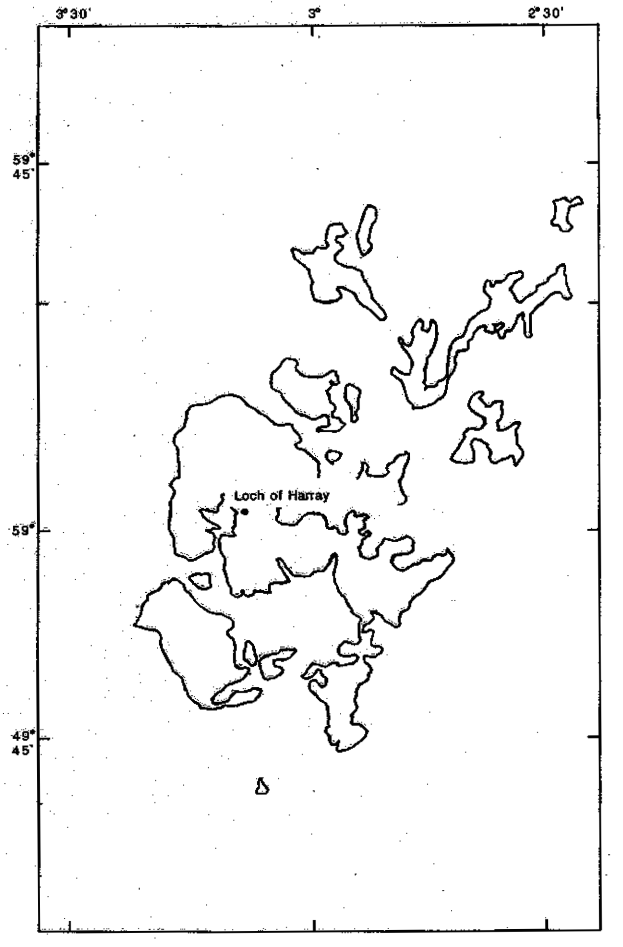


Figure 5. Inset B. Sampling locations in the Orkney Isles.

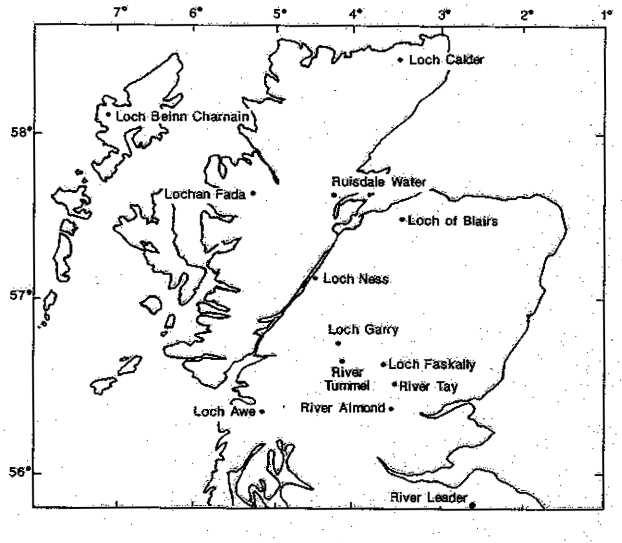


Figure 5. Inset C. Sampling locations in north and central Scotland.

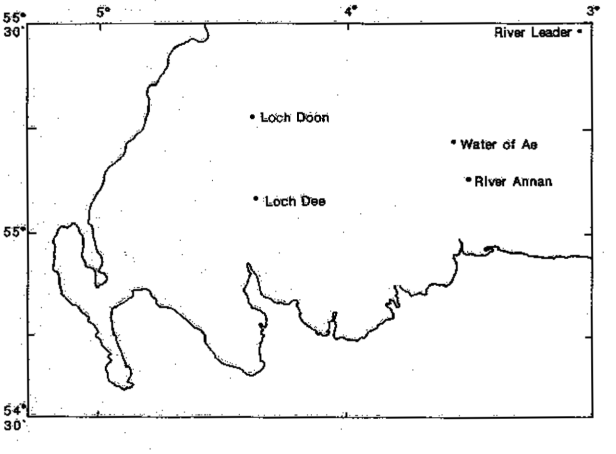


Figure 5. Inset D. Sampling locations in south-west Scotland.

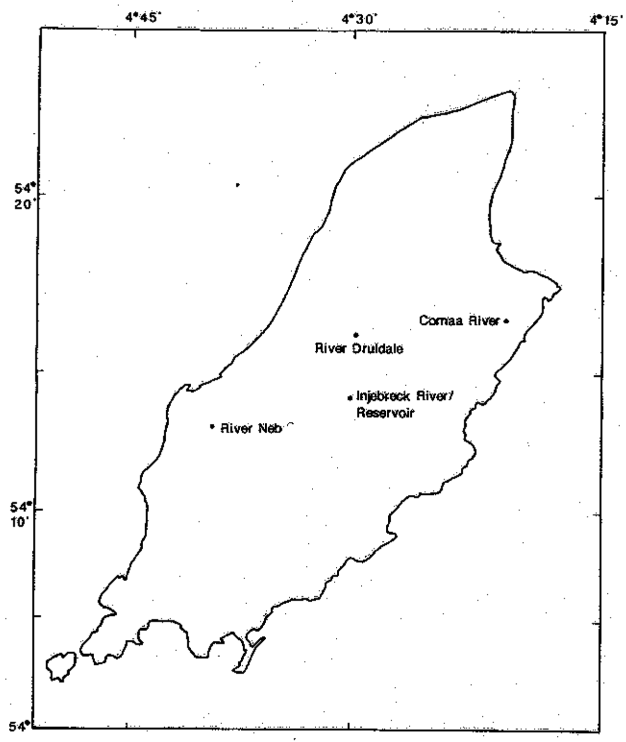


Figure 5. Inset E. Sampling locations in the Isle of Man.

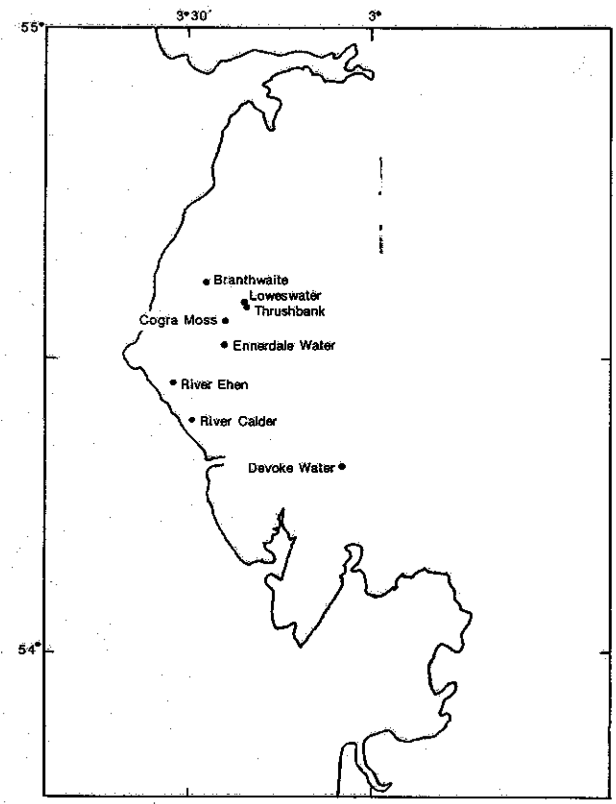


Figure 5 . Inset F. Sampling locations in Cumbria.

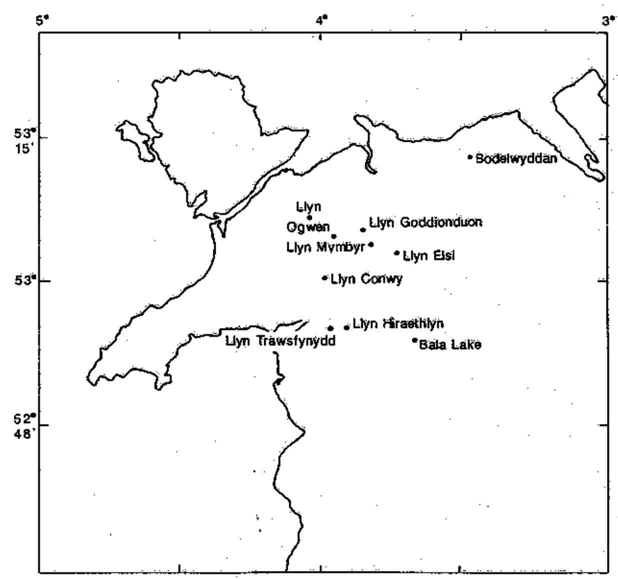


Figure 5. Inset G. Sampling location in north Wales.

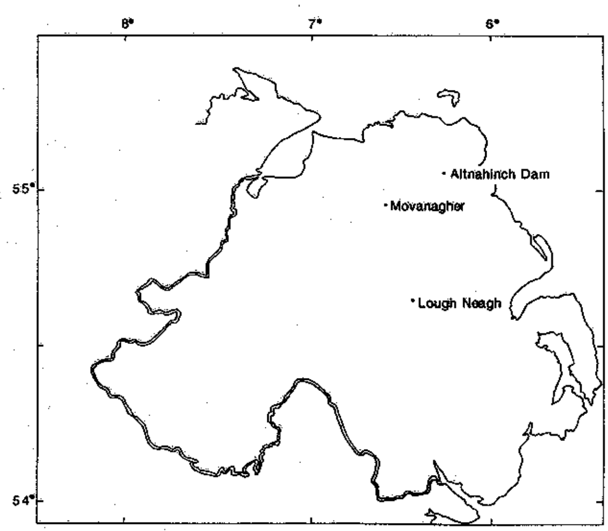


Figure 5. Inset H. Sampling locations in Northern Ireland.

Table 41. Caesium radioactivity in pike, 1989.

Location	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
England			
Loweswater	3	23	79
Scotland			
Loch Faskally	3	51	250
Wales			
Bala Lake	6	20	100

ND = not detected

Table 42. Caesium radioactivity in perch, 1989.

Location	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
England			
Cogra Moss	1	65	380
Devoke Water	4	120	720
Loweswater	23	55	290
Wales			
Llyn Hiraethlyn	3	120	670
Bala Lake	2	8	26
Llyn Trawsfynydd	8*	110	600
Scotland			
Loch Faskally	2	28	160
Loch Doon	1	47	270
Northern Ireland			
Lough Neagh	1	ND	15

ND = not detected
* = Bulk sample

Table 43. Caesium radioactivity in eels, 1989.

Location	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	
England			
Ennerdale Water	1	ND	58
Loweswater	5	30	140
River Calder	1	ND	22
River Ehen	1	ND	6.4
Scotland			
Loch Faskally	1	26	110
Northern Ireland			
Lough Neagh	1	ND	8.2

ND = not detected

recognition of the potential radiological significance of this species; although rainbow trout are more commonly eaten, their radiocaesium concentrations were low (Table 40) compared with wild brown trout because rainbow trout are mostly hatchery-reared and fed on relatively uncontaminated food prior to release. Pike (Table 41) and perch (Table 42) had the highest concentrations of any of the freshwater species, but as they are not eaten in large quantities their radiological significance is low. Other species (Tables 43 and 44) had generally lower radiocaesium concentrations, sometimes much lower, than brown trout, perch or pike taken from the same river or lake. Where there are data for the same species and locations to compare with results for 1988 (Hunt, 1989) 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 significantly lower in 1989 than in 1988, continuing the reducing trend that began in the latter part of 1987 (Hunt, 1988). The exception to this trend in radiocaesium concentrations at Trawsfynydd has been discussed in sub-section 6.10.

Radiation exposures have been estimated using a procedure based on cautious assumptions, as previously (Hunt, 1989). A consumption rate of brown trout of 100 g d^{-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. Concentrations of radiocaesium in brown trout representative of the highest in each region were chosen; thus, some of the locations were different from those used for 1988. A contribution to dose due to radiostrontium was included but this was very small in comparison to that from radiocaesium. Effective dose and organ doses were estimated using committed dose equivalents per unit intake provided as described in sub-section 3.4. Estimates of dose are presented in Table 45. The major contribution to dose was due to radiocaesium.

The ICRP (ICRP, 1984b) provides guidance in the context of emergencies which includes suggested levels of dose below which particular countermeasures would not be warranted. The suggested level of effective dose equivalent is 5 mSv in the first year. 1989 was outside this period but, as was the case in 1988, the estimated doses for all areas of the UK were less than 1 mSv year^{-1}. It can be shown that organ doses (in this case the lower large intestine is the critical organ) are not more limiting. Given that these dose estimates are cautious, it is clear that contamination of freshwater fish from fallout from Chernobyl was only of minor

Table 44. Caesium radioactivity in other species of fish, 1989.

Location	Species	No. of samples	Mean radioactivity concentration (wet) Bq kg^{-1}	
			^{134}Cs	^{137}Cs
England				
Ennerdale Water	Char	15	7	43
River Teme	Chub	1	0.12	0.87
Wales				
Bala Lake	Grayling	2	2.2	16
Bala Lake	Gwyniad	6	1.1	13
Bala Lake	Roach	6	ND	24
Llyn Trawsfynydd	Rudd	3	72	380
Scotland				
River Tay	Salmon	2	ND	ND
River Tay	Sea trout	2	ND	4.8
River Annan	Salmon	1	ND	1
River Annan	Sea trout	1	ND	11
Loch Doon	Char	1	34	130
River Tummel	Grayling	2	34	190
Northern Ireland				
Lough Neagh	Vendace	1	ND	6.9
Isle of Man				
River Neb	Sea trout	1	ND	12

ND = not detected

Table 45. Estimates of maximum dose* from Chernobyl to adults due to consumption of freshwater fish from areas of high deposition of fallout, 1989.

Region	Location	Committed effective dose equivalent, mSv year^{-1}
England	Devoke Water	0.12
Wales	Llyn Ogwen	0.18
Scotland	Loch Dee	0.24
Northern Ireland	Altnahinch Dam	0.08
Isle of Man	River Druidale	0.10

*See text for a description of the bases of these estimates, and the levels with which they should be compared, which are different from those used for routine discharges.

radiological importance. The collective dose from consumption of freshwater fish is likely to have been very small, as estimates have shown (Camplin *et al.*, 1986). The more significant contribution to collective dose, but still of low importance, was from consumption of marine fish, as considered in sub-section 4.1.1.

11. SUMMARY AND CONCLUSIONS

A summary of estimated public radiation exposures in 1989, relating to liquid radioactive waste discharges from nuclear establishments, is presented in Table 46. The exposures are expressed in terms of the committed effective dose equivalents to, or as doses to skin of, members of the critical groups. Results for internal exposures incorporate the best-estimate value of 0.0005 for the gut transfer factor of plutonium and americium (NRPB, 1990) except for consumers of winkles from the north-east Irish Sea, where a more realistic value of 0.0002 is justified (sub-section 3.4). Committed effective dose equivalents were all within the ICRP-recommended principal dose limit of 1 mSv year^{-1} for members of the public.

The more important contributions to exposures from the effects of discharges from Sellafield were due to radiocaesium and transuranic radionuclides. Details are given in sub-section 4.1. Exposures of high-rate fish and shellfish consumers near Sellafield increased slightly in 1989 as compared with 1988, due to small differences in the revised values for dose per unit intake (sub-section 3.4) and to small increases in the concentrations of transuranic nuclides in shellfish;

Table 46. Summarised estimates of public radiation exposure from discharges of liquid radioactive waste in the UK, 1989.

Establishment	Radiation exposure pathway	Critical group	Exposure+, mSv
British Nuclear Fuels plc			
Sellafield	Fish and shellfish consumption	Local fishing community	0.19
	External	Houseboat dwellers (River Ribble)	0.17
	Handling of fishing gear	Local fishing community	< 0.1#
	Porphyra/laverbread consumption	Consumers in South Wales	< 0.01
Springfields	External	Houseboat dwellers (River Ribble)	0.17[a]
Capenhurst	Shellfish consumption	Local fishing community	< 0.1[a]
Chapelcross	Fish and shellfish consumption External }	Local fishermen	< 0.1[a]
United Kingdom Atomic Energy Authority			
Harwell	Fish consumption External }	Anglers*	< 0.01
Winfrith	Fish and shellfish consumption	Local fishing community	0.03
Dounreay	Handling of fishing gear	Local fishermen	< 0.1#b
	External	Local community	< 0.01[b]
	Fish and shellfish consumption	Local fishing community	< 0.01[b]
Nuclear Power Stations Operated by the Electricity Companies			
Berkeley and Oldbury	Fish and shellfish consumption External }	Local fishing community	< 0.01[b]
Bradwell	External	Houseboat dwellers	< 0.02[b]
Dungeness	External Fish and shellfish consumption }	Bait diggers	0.01
Hartlepool	Fish and shellfish consumption	Local fishing community	< 0.01[a]
	External	Coal collectors	< 0.001[a]
Heysham	Fish and shellfish consumption External }	Local fishing community	0.15[a] < 0.1[a]
Hinkley Point	Fish and shellfish consumption External }	Local fishing community	< 0.01[b]
Hunterston	Fish and shellfish consumption External }	Local fishing community	< 0.02[a]
Sizewell	Fish and shellfish consumption External }	Local fishing community	< 0.003[b]
Torness	Fish and shellfish consumption External }	Local fishing community	< 0.003[a]
Trawsfynydd	Fish consumption External }	Local fishing community	0.09
Wylfa	Fish and shellfish consumption External }	Local fishing community	0.01[a]
Defence Establishments			
Aldermaston	Fish consumption External }	Anglers*	< 0.002
Chatham	External	Houseboat dwellers	< 0.01
Devonport	External	Bait diggers	< 0.01
Faslane	Fish and shellfish consumption External }	Anglers	< 0.01[a]
Rosyth	External	Dredgermen	< 0.01[a]
Holy Loch	External	Local community	< 0.01[a]
Amersham International plc			
Amersham	Fish consumption External }	Anglers*	< 0.01
Cardiff	Fish and shellfish consumption External }	Local fishing community	< 0.1

+ Unless otherwise stated represents the committed effective dose equivalent, to be compared with the ICRP-recommended principal dose limit of 1 mSv year^{-1} or with the subsidiary limit of 5 mSv year^{-1} provided the lifetime average does not exceed 1 mSv year^{-1} (see sub-section 3.4).

* A notional group with maximising consumption and occupancy rates has been assumed (see text).

\# Exposure to skin, to be compared with the ICRP-recommended dose limit of 50 mSv year^{-1} (see sub-section 3.4).

[a] Mainly due to discharges from Sellafield.

[b] Partly due to discharges from Sellafield.

these small increases were due to environmental factors. A gradual slowing down in the rate of decrease of concentrations of these nuclides following the earlier reductions in discharges is consistent with model predictions (Hunt, 1986; Pentreath *et al.*, 1989(b)). There was no significant change in fish and shellfish consumption rates by the group of high-rate fish and shellfish consumers near Sellafield in 1989. Consumption rates could increase again in the future, but it is considered unlikely that exposures, calculated using realistic parameters, will again exceed the 1 mSv year $^{-1}$ level. Further reductions in discharges of radiologically significant nuclides are planned when the enhanced actinide removal plant (EARP) commences operation, scheduled for 1992. Dose rates which were above the 1 mSv year $^{-1}$ level in the past did not occur for long enough for lifetime exposures to have exceeded 1 mSv year $^{-1}$ on average, and thus the dose limitation objectives of the ICRP will be met.

Exposures of the externally-exposed group of houseboat dwellers in the area of the Ribble estuary decreased from 0.27 mSv in 1988 to 0.17 mSv in 1989. This was due to a decline in occupancy times corrected for shielding by the boats themselves, and to declining dose rates over sediments following the earlier decreases in discharges of radiocaesium from Sellafield.

Near Trawsfynydd, exposures were slightly greater than in 1988, following a return to more typical levels of concentrations of radiocaesium in fish from the lake. This followed an increase in concentrations of radiocaesium in lake water, and was predicted in our report for 1988 (Hunt, 1989). These concentrations have remained at similar levels in 1989, and the lag effect may lead to marginally higher concentrations in fish and thus dose rates in 1990, but these dose rates are likely to be well within recommended dose limits.

Radioactivity from Sellafield contributed to exposures near many other nuclear establishments. Since apportionment of exposure to radioactivity of local origin is often difficult, the exposures from all artificial sources (including the small contribution due to weapons-test fallout) are quoted in Table 46, with appropriate footnotes. The effects of fallout from the Chernobyl accident are also included, but these were small in 1989. The continuing effect of fallout from Chernobyl on the freshwater environment is described in section 10; concentrations of radiocaesium have generally diminished in 1989 and conservative estimates of exposures were, as before, within 1 mSv year $^{-1}$.

As in previous years, collective doses have also been considered. The most significant radioactive waste discharges giving rise to collective dose, compared with which all other discharges may be disregarded, were those from Sellafield, radiocaesium being the most significant component. Details are given in subsection 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. The preliminary collective committed effective dose equivalent to the UK population in 1989 was 20 man-Sv, less than in 1988 (30 man-Sv). 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 30 man-Sv in 1989, also less than in 1988 (50 man-Sv). These decreases reflect 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 30 man-Sv to the collective dose to other European countries in both 1988 and 1989.

A declining contribution to collective dose due to radioactivity (mainly radiocaesium) from Chernobyl is likely to be present for the next few years. Concentrations of radiocaesium from Chernobyl in the North Sea could be supplemented by outflow from the Baltic Sea. The contribution to collective dose due to Sellafield is expected to continue to decline, reflecting the reduced discharges over the past decade, particularly following operation of the site ion-exchange plant (SIXEP) from May 1985.

12. REFERENCES

BRITISH COMMITTEE ON RADIATION UNITS AND MEASUREMENTS, 1978. Recommendations on the introduction of the new SI Units for use with radioactivity and ionising radiations. National Physical Laboratory, Teddington, 12pp.

CAMPLIN, W.C., MITCHELL, N.T.,LEONARD, D.R.P., AND JEFFERIES, D.F., 1986. Radioactivity in surface and coastal waters of the British Isles. Monitoring of fallout from the Chernobyl reactor accident. Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft, *(15)*: 1-49.

COMMISSION OF THE EUROPEAN COMMUNITIES, 1980. Council directive of 15 July 1980 amending the directives laying down the revised basic safety standards for the health protection of the general public and workers against the dangers of ionising radiation. Off. J. Eur. Commun., *23 (L246)*: 1-2.

DEPARTMENT OF THE ENVIRONMENT, 1990. Radioactivity. DOE, London, Statist. Bull., *(90-3)*: 1-26.

DODDINGTON, T.C., JONES, P.G.W. AND LEONARD, D.R.P. , 1988. Investigation of radiation exposure pathways from liquid effluents at Hinkley Point power station: local habits survey, 1986. Fish. Res. Data Rep., MAFF Direct. Fish. Res., Lowestoft, *(13)*: 1-23.

DODDINGTON, T.C., CAMPLIN, W.C. AND THURSTON, L.M.., 1989. External exposure in the eastern Irish Sea. pp.367-370. In: E. P. Goldfinch (Ed.), 'Radiation Protection - Theory and Practice, Proc. 4th Int. Symp. Soc. Radiol. Prot., Malvern, 4-9 June 1989'. Institute of Physics, Bristol and New York.

DODDINGTON, T.C., CAMPLIN, W.C. AND CALDWELL, P., 1990. Investigation of external radiation exposure pathways in the eastern Irish Sea, 1989. Fish. Res. Data Rep., MAFF Direct. Fish. Res., Lowestoft *(19)*: 1-29.

DUTTON, J.W.R., 1968. Gross beta counting of environmental materials. Tech. Rep. Fish. Radiobiol. Lab., MAFF Direct. Fish. Res., Lowestoft, (FRL) *(3)*: 1-13.

FULLER, D. AND CASEY, E., 1990. Marine environmental radioactivity surveys at nuclear submarine berths in the UK, 1989. Defence Radiological Protection Service. HMSO, London, 111 pp.

GREAT BRITAIN - PARLIAMENT., 1960. Radioactive Substances Act, 1960. HMSO, London, 28pp.

GREAT BRITAIN - PARLIAMENT, 1986. Radioactive Waste. The Government's Response to the Environment Committee's Report. HMSO, London, 28pp. (Cmnd 9852).

GREAT BRITAIN - PARLIAMENT, 1988. Radioactive Waste (Disposal). Official Record (Hansard), 26 May 1988, Col. 233. HMSO, London.

HARVEY, B.R. AND THURSTON, L.M., 1988. Analytical procedures for the determination of neptunium radionuclides in marine waters, sediments and biota. Aquat. Environ. Prot.: Analyt. Meth., MAFF Direct. Fish. Res., Lowestoft, *(1)*, 1-37.

HARVEY, B.R. , IBBETT, R.D., LOVETT, M.B. AND WILLIAMS, K.J., 1989. Analytical procedures for the determination of strontium radionuclides in environmental materials. Aquat. Environ. Prot.: Analyt. Meth., MAFF Direct. Fish. Res., Lowestoft, *(5)*: 1-33.

HUGHES, J.S., SHAW, K.B. AND O'RIORDAN, M.C., 1988. Radiation exposure of the UK population - 1988 review. NRPB Report R-227. HMSO, London, 96pp.

HUNT, G.J., 1984. Simple models for prediction of external radiation exposure from aquatic pathways. Radiat. Prot. Dosim., *8 (4)*: 215-224.

HUNT, G.J., 1985. Timescales for dilution and dispersion of transuranics in the Irish Sea near Sellafield. Sci. Total Environ., *46*: 261-278.

HUNT, G.J., 1986. Time-dependent estimates of dose to the critical group of fish and shellfish consumers near Sellafield. J. Soc. Radiol. Prot., *6*: 125-130.

HUNT, G. J., 1988. Radioactivity in surface and coastal waters of the British Isles, 1987. Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft, *(19)*: 1-67.

HUNT, G.J, 1989. Radioactivity in surface and coastal waters of the British Isles, 1988. Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft, *(21)*: 1-69.

HUNT, G.J. AND JEFFERIES, D.F., 1981. Collective and individual radiation exposure from discharges of radioactive waste to the Irish Sea. pp.535-570. In: 'Proc. Int. Symp. IAEA on the Impacts of Radionuclide Releases into the Marine Environment'. IAEA. Vienna, IAEA-SM-248/101.

HUNT, G. J. and KERSHAW, P. J., 1990. Remobilisation of artificial radionuclides in the sediment of the Irish Sea. J. Radiol. Prot., *10(2)*: 147-151.

HUNT, G. J., HEWITT, C. J. and SHEPHERD, J. G., 1982. The identification of critical groups and its application to fish and shellfish consumers in the coastal area of the North-East Irish Sea. Hlth Phys., *43*: 875-889.

HUNT, G. J., LEONARD, D. R. P. and LOVETT, M. B., 1986. Transfer of environmental plutonium and americium across the human gut. Sci. Total Environ., *53*: 89-109.

HUNT, G. J., LEONARD, D. R. P. and LOVETT, M. B., 1990. Transfer of environmental plutonium and americium across the human gut: a second study. Sci. Total Environ., *90*: 273-282.

INTERNATIONAL ATOMIC ENERGY AGENCY, 1982. Basic safety standards for radiation protection. Saf. Ser. Int. Atom. En. Ag., Vienna, *(9)*: 1-172.

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1977. Recommendations of the International Commission on Radiological Protection. Annal. ICRP *1(3)*. Pergamon Press, Oxford, 53pp. (ICRP Publ. *(26)*).

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1984(a). Statement from the 1983 Meeting of the International Commission on Radiological Protection. Annal ICRP *14(1)*. Pergamon Press, Oxford, 8pp. (ICRP Publ. *(39)*).

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1984(b). Protection of the public in the event of major radiation accidents: principles for planning. Annal. ICRP *14(2)*. Pergamon Press, Oxford, 22pp. (ICRP Publ. *40)*).

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1985. Statement from the 1985 Paris Meeting of the International Commission on Radiological Protection. J. Soc. Radiol. Prot., *5*: 87-88.

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1987. Statement from the 1987 Como Meeting of the International Commission on Radiological Protection. Annal. ICRP *17(4)*i-v. Pergamon Press, Oxford, (ICRP Publ. *(52)*).

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1989. Age-dependent doses to members of the public from intake of radionuclides: Part 1. Annal. ICRP *20(2)*. Pergamon Press, Oxford, 122 pp. (ICRP Publ. *(56)*).

LEONARD, D. R. P., 1984. Investigation of individual radiation exposures: comparative use of interview and logging techniques in habits surveys of the Cumbrian coastal fishing community. pp.763-766. In: A. Kaul, R. Neider, J. Pensko, F.-E. Stieve and H. Brunner (Eds.), 'Radiation-Risk-Protection, Vol. II. Proc. 6th Int. Congr. Int. Radiat. Prot. Assoc., Berlin'. Fachverband für Strahlenschutz e.V., Julich.

LEONARD, D. R. P. and HALL, I. R., 1989. The design and implementation of an environmental monitoring programme around the Torness nuclear power station. pp.375-378. In: E. P. Goldfinch (Ed.), 'Radiation Protection - Theory and Practice, Proc. 4th Int. Symp. Soc. Radiol. Prot., Malvern, 4-9 June 1989'. Institute of Physics, Bristol and New York.

LEONARD, D. R. P. and HUNT, G. J., 1985. A study of fish and shellfish consumers near Sellafield: assessment of the critical groups including consideration of children. J. Soc. Radiol. Prot., *5*: 129-139.

LEONARD, D. R. P. and SMITH, B. D., 1982. Sizewell Nuclear Power Station: investigation of radiation exposure pathways from liquid effluents: local habits survey 1981. Sizewell Inquiry Series, MAFF Direct. Fish. Res., Lowestoft, *(1)*: 1-19.

LEONARD, D. R. P., CAMPLIN, W. C. and TIPPLE, J. R., 1990. The variability of radiocaesium concentrations in freshwater fish caught in the UK following the Chernobyl nuclear reactor accident: an assessment of potential doses to critical group consumers. 'Proc. Int. Symp. on Environmental Contamination Following a Major Nuclear Accident'. IAEA, Vienna, IAEA-SM-306/15: 247-256.

LEONARD, D. R. P., HUNT, G. J. and JONES, P. G. W., 1982. Investigation of individual radiation exposures from discharges to the aquatic environment: techniques used in habits surveys. pp.512-517. In: 'Proc. 3rd Int. Symp. Soc. Radiol. Prot., Inverness, 2.' Society of Radiological Protection.

LOVETT, M. B., BOGGIS, S. J. and BLOWERS, P., 1990. The determination of alpha-emitting nuclides of plutonium, americium and curium in environmental materials: Part 1. Sea water. Aquat. Environ. Prot.: Analyt. Meth., MAFF Direct. Fish. Res., Lowestoft *(7)*: 1-36.

McDONALD, P., FOWLER, S. W., HEYRAUD, M. and BAXTER, M. S., 1986. Polonium-210 in mussels and its implications for environmental autoradiography. J. Environ. Radioact., *3*: 293-303.

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD, 1989. Research into Fisheries and the Marine Environment, 1987-88. Report of the Director of Fisheries Research, MAFF, Lowestoft, 76 pp.

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD, 1990. Terrestrial radioactivity monitoring programme, 1989. MAFF, London, TRAMP/4, 95 pp.

MITCHELL, N. T. and STEELE, A. K., 1988. The marine impact of caesium-134 and -137 from the Chernobyl reactor accident. J. Environ. Radioact., *6*: 163-175.

NATIONAL RADIOLOGICAL PROTECTION BOARD, 1984. Metabolic and dosimetric models for application to members of the public. HMSO, London, 6pp. (NRPB-GS3).

NATIONAL RADIOLOGICAL PROTECTION BOARD, 1987. Revised generalised derived limits for radioisotopes of strontium, iodine, caesium, plutonium, americium and curium. HMSO, London, 45pp. (NRPB-GS8).

NATIONAL RADIOLOGICAL PROTECTION BOARD, 1990. Gut transfer factors. Docs. NRPB *1(2)*. NRPB, Chilton, 26 pp.

ORGANISATION FOR ECONOMIC COOPERATION AND DEVELOPMENT, NUCLEAR ENERGY AGENCY, 1981. Research and environmental surveillance programme related to sea disposal of radioactive waste. OECD, Paris, 38pp.

ORGANISATION FOR ECONOMIC COOPERATION AND DEVELOPMENT, NUCLEAR ENERGY AGENCY, 1985. Review of the continued suitability of the dumping site for radioactive waste in the North-East Atlantic. OECD, Paris, 448pp.

PATTENDEN, N. J., CAMBRAY, R. S., PLAYFORD, K. S., EAKINS, J. D. and FISHER, E. M. R., 1981. Atmospheric measurements on radionuclides previously discharged to sea. pp.201-221. In: 'Proc. Int. Symp. IAEA on the Impacts of Radionuclide Releases into the Marine Environment'. IAEA, Vienna, IAEA-SM-248/138.

PENTREATH, R. J. and ALLINGTON, D. J., 1988. Dose to man from the consumption of marine seafoods: a comparison of the naturally-occurring ^{210}Po with artificially-produced radionuclides. pp.1582-1585. In: 'Radiation Protection Practice, Vol. III. Proc. 7th Int. Congr. Int. Radiat. Prot. Assoc., Sydney, Australia, 10-17 April 1988'. Pergamon Press, Sydney, Oxford and New York, etc.

PENTREATH, R. J., LOVETT, M. B., HARVEY, B. R. and IBBETT, R. D., 1979. Alpha-emitting nuclides in commercial fish species caught in the vicinity of Windscale, United Kingdom, and their radiological significance to man. pp.227-245. In: 'Proc. Int. Symp. IAEA on Biological Implications of Radionuclides Released from Nuclear Industries'. IAEA, Vienna, IAEA-SM-237/1.

PENTREATH, R. J., CAMPLIN, W. C. AND ALLINGTON, D. J., 1989(a). Individual and collective dose rates from naturally-occurring radionuclides in seafood. pp.297-300. In: E. P. Goldfinch (Ed.), 'Radiation Protection - Theory and Practice, Proc. 4th Int. Symp. Soc. Radiol. Prot., Malvern, 4-9 June 1989'. Institute of Physics, Bristol and New York.

PENTREATH, R. J., GURBUTT, P. A., KERSHAW, P. J., WOODHEAD, D. S., AUSTIN, L. S. and HUNT, G. J., 1989(b). Modelling the behaviour of long-lived radionuclides in the Irish Sea, and estimating future doses. pp.333-336. In: E. P. Goldfinch (Ed.), 'Radiation Protection - Theory and Practice, Proc. 4th Int. Symp. Soc. Radiol. Prot., Malvern, 4-9 June 1989'. Institute of Physics, Bristol and New York.

SAXEN, R., IKAHEIMONEN, T. K. and ILUS, E., 1989. Monitoring of radionuclides in the Baltic Sea in 1988, Supplement 1 to Annual Report 1988. Finnish Centre for Radiation and Nuclear Safety, Helsinki, STUK-A90, 24 pp.

SCOTTISH DEVELOPMENT DEPARTMENT, 1988. Radioactive waste disposals from nuclear sites in Scotland: 1982-1987. SDD, Scottish Office, Edinburgh, Statist. Bull., *2(E)*: 1-19.

SMITH, B. D. and HUNT, G. J., 1989. A technique for reducing diverse habits survey data and its application to seafood consumption near Winfrith. pp.401-404. In: E. P. Goldfinch (Ed.), 'Radiation Protection - Theory and Practice, Proc. 4th Int. Symp. Soc. Radiol. Prot., Malvern, 4-9 June 1989'. Institute of Physics, Bristol and New York.

SPIERS, F. W., GIBSON, J. A. B. and THOMPSON, I. M. G., 1981. A guide to the measurement of environmental gamma-ray dose rate. National Physical Laboratory, Teddington, 107pp.

WOODHEAD, D. S., 1984(a). Contamination due to radioactive materials. Mar. Ecol., *5(3)*: 1111-1287.

WOODHEAD, D. S., 1984(b). The radiation exposure of black-headed gulls (*Larus ridibundus*) in the Ravenglass estuary, Cumbria, UK: a preliminary assessment. Sci. Total Environ., *58*: 273-281.

13. RECENT PUBLICATIONS ON RADIOACTIVITY IN THE AQUATIC ENVIRONMENT BY STAFF OF THE DIRECTORATE OF FISHERIES RESEARCH

**Note: Where all authors are not from MAFF, MAFF authors are indicated by italics.*

1989

BAKER, C. W. and YOUNG, A. K. The determination of thorium-234 and uranium-238 disequilibrium in sediments contaminated by man-made radionuclides. Internal Rep., MAFF Direct. Fish. Res., Lowestoft, *(17)*: 1-31.

CAMPLIN, W. C. and AARKROG, A. Radioactivity in north European waters. Report of Working Group II of CEC Project MARINA. Fish. Res. Data. Rep., MAFF, Direct. Fish. Res., Lowestoft, *(20)*: 1-20.

CAMPLIN, W. C., AUSTIN, L. S. and EATON, T. E. An assessment of radiation exposure due to liquid effluents from the Hinkley Point Power Station. Fish. Res. Data Report, MAFF, Direct. Fish. Res., Lowestoft, *(15)*: 1-48.

CAMPLIN, W. C., LEONARD, D. R. P., TIPPLE, J. R. and DUCKETT, L. Radioactivity in freshwater systems in Cumbria (UK) following the Chernobyl accident. Fish. Res. Data Rep., MAFF, Direct. Fish. Res., Lowestoft, *(18)*: 1-90.

DODDINGTON, T. C., CAMPLIN, W. C. and THURSTON, L. M. External exposure in the eastern Irish Sea. pp.367-370. In: E. P. Goldfinch (Ed.), 'Radiation Protection - Theory and Practice, Proc. 4th Int. Symp. Soc. Radiol. Prot., Malvern, 4-9 June 1989'. Institute of Physics, Bristol and New York.

GURBUTT, P. A., KERSHAW, P. J. and WOODHEAD, D. S. Modelling the behaviour of plutonium and americium in the Irish Sea. pp.685-694. In: R. A. Falconer, P. Goodwin and R. G. S. Matthew (Eds.), 'Hydraulic and Environmental Modelling of Coastal Estuarine and River Waters'. Gower Technical Press, Aldershot.

HARVEY, B. R. and THURSTON, L. M. Analytical procedures for the determination of neptunium radionuclides in marine waters, sediments and biota. Aquat. Environ. Prot.: Analyt. Meth., MAFF Direct. Fish. Res., Lowestoft, *(1)*: 1-37.

HARVEY, B. R., IBBETT, R. D., LOVETT, M. B. and WILLIAMS, K. J. Analytical procedures for the determination of strontium radionuclides in environmental materials. Aquat. Environ. Prot.: Analyt. Meth., MAFF Direct. Fish. Res., Lowestoft, *(5)*: 1-35.

HUGGINS, I. A., ANDREWS, D. J. and BEACH, M. H. Large area beta/gamma probes for the detection of particulate radioactivity in the environment. pp.405-408. In: E. P. Goldfinch (Ed.), 'Radiation Protection, Theory and Practice, Proc. 4th Int. Symp. Soc. Radiol. Prot., Malvern, 4-9 June 1989'. Institute of Physics, Bristol and New York.

HUNT, G. J. Radioactivity in surface and coastal waters of the British Isles, 1988. Aquat. Environ. Monit. Rep., MAFF, Direct. Fish. Res., Lowestoft, *(21)*: 1-69.

HUNT, G. J., LEONARD, D. R. P.** and FRY, F. A. High rate seafood consumers near Sellafield: comparison of conventional assessment of ^{137}Cs intakes with the results of whole-body monitoring. Radiat. Prot. Dosim., *27(1)*: 35-41.

JEFFERIES, D. F. and STEELE, A. K. Observed and predicted concentrations of caesium-137 in sea water of the Irish Sea, 1970-1985. J. Environ. Radioact., *10*: 173-189.

KERSHAW, P. J., PENTREATH, R. J., DICKSON, R. R. and LOVETT, M. B. Caesium and transuranium radionuclides in seawater, sediments and biota on and around the NEA dumpsite. pp.88-94. In: F. Nyffeler and W. Simmons (Eds.), 'Interim Oceanographic Description of the North-East Atlantic Site for the Disposal of Low-Level Radioactive Waste, Vol. 3'. OECD, Paris.

LEONARD, D. R. P. Monitoring for radionuclides at fish farms and from 'put-and-take' fisheries. Trout News, MAFF, Direct. Fish. Res., Lowestoft, *(9)*: 18-22.

*LEONARD, D. R. P.** and HALL, I. R. The design and implementation of an environmental monitoring programme around the Torness nuclear power station. pp.375-378. In: E. P. Goldfinch (Ed.), 'Radiation Protection - Theory and Practice, Proc. 4th Int. Symp. Soc. Radiol. Prot., Malvern, 4-9 June 1989'. Institute of Physics, Bristol and New York.

PENTREATH, R. J. Radionuclides in the aquatic environment. pp.99-119. In: J. H. Harley, G. D. Schmidt and G. Silini (Eds.), 'Radionuclides in the Food Chain'. Springer-Verlag, Berlin.

PENTREATH, R. J., CAMPLIN, W. C. and ALLINGTON, D. J. Individual and collective dose rates from naturally-occurring radionuclides in seafood. pp.297-300. In: E. P. Goldfinch (Ed.), 'Radiation Protection - Theory and Practice, Proc. 4th Int. Symp. Soc. Radiol. Prot., Malvern, 4-9 June 1989'. Institute of Physics, Bristol and New York.

PENTREATH, R. J., GURBUTT, P. A., KERSHAW, P. J., WOODHEAD, D. S., AUSTIN, L. S. and HUNT, G. J. Modelling the behaviour of long-lived radionuclides in the Irish Sea and estimating future doses. pp.333-336. In: E. P. Goldfinch (Ed.), 'Radiation Protection - Theory and Practice, Proc. 4th Int. Symp. Soc. Radiol. Prot., Malvern, 4-9 June 1989'. Institute of Physics, Bristol and New York.

SMITH, B. D. and HUNT, G. J. A technique for reducing diverse habits survey data and its application to seafood consumption near Winfrith. pp.401-404. In: E. P. Goldfinch (Ed.), 'Radiation Protection - Theory and Practice, Proc. 4th Int. Symp. Soc. Radiol. Prot., Malvern, 4-9 June 1989'. Institute of Physics, Bristol and New York.

SWIFT, D. J. The accumulation and retention of ^{95m}Tc by the edible winkle (*Littorina littorea* L.). J. Environ. Radioact., *9*: 31-52.

1990

DODDINGTON, T. C., CAMPLIN, W. C. and CALDWELL, P. Investigation of external radiation exposure pathways in the eastern Irish Sea, 1989. Fish. Res. Data Rep., MAFF, Direct. Fish. Res., Lowestoft, *(22)*: 1-29.

HUNT, G. J. and KERSHAW, P. J. Remobilisation of artificial radionuclides from the sediment of the Irish Sea. J. Radiol. Prot., *10(2)*: 147-151.

HUNT, G. J., LEONARD, D. R. P. and LOVETT, M. B. *Transfer of environmental plutonium* and americium across the human gut: a second study. Sci. Total Environ., *90*: 273-282.

LEONARD, D. R. P., CAMPLIN, W. C. and TIPPLE, J. R. The variability of radiocaesium concentrations in freshwater fish caught in the UK following the Chernobyl nuclear reactor accident: an assessment of potential doses to critical group consumers. 'Proc. Int. Symp. on Environmental Contamination Following a Major Nuclear Accident'. IAEA, Vienna, IAEA-SM-306/15: 247-256.

LOVETT, M. B., BOGGIS, S. J. and BLOWERS, P. The determination of alpha-emitting nuclides of plutonium, americium and curium in environmental materials. Part 1: Sea water. Aquat. Environ. Prot.: Analyt. Meth., MAFF Direct. Fish. Res., Lowestoft, *(7)*: 1-36.

MALCOLM, S. J., KERSHAW, P. J., LOVETT, M. B. and HARVEY, B. R. The interstitial water chemistry of ^{239,240}Pu and ^{241}Am in the sediment of the Irish Sea. Geochim. Cosmochim. Acta, *(54)*: 29-35.

ORLANDINI, K. A., PENROSE, W. R., *HARVEY, B. R.**, *LOVETT, M. B.** and FINDLAY, M. W. Colloidal behavior of actinides in an oligotrophic lake. Environ. Sci. Technol., *24(5)*: 706-712.

Ministry of Agriculture, Fisheries and Food
Directorate of Fisheries Research
Fisheries Laboratory
Lowestoft
Suffolk
NR33 OHT
England