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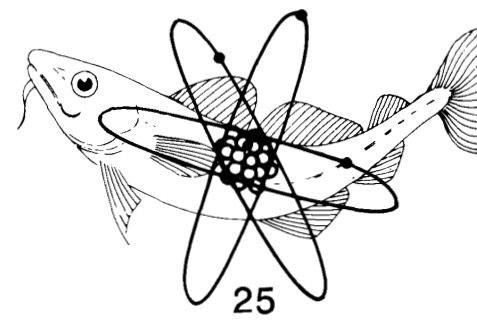
MINISTRY OF AGRICULTURE FISHERIES AND FOOD

DIRECTORATE OF FISHERIES RESEARCH

AQUATIC ENVIRONMENT MONITORING REPORT



Number 21

Radioactivity in surface and coastal waters of the British Isles, 1988

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LOWESTOFT 1989

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Foreword

Aquatic Environment Monitoring Reports are not normally introduced by means of a foreword. However, for this particular report, describing DFR's work on radioactivity, two events merit an exception. First, in 1989 we are celebrating the Ministry of Agriculture, Fisheries and Food's 100th anniversary. Many of our readers will already know this, especially those who have visited the MAFF exhibitions held this year, including the successful open days at this Laboratory which took place in May 1989. Second, this particular report, which covers 1988, marks the 25th year for which the results of the Lowestoft monitoring of Radioactivity in Surface and Coastal Waters of the British Isles have been published. For England, the monitoring is carried out in direct support of the Minister's responsibilities for authorising disposals of radioactive wastes. It is noteworthy that 1988 also saw the 25th anniversary of the coming into force of the Radioactive Substances Act 1960 which gave statutory effect to these responsibilities. The monitoring which we undertake in Wales is carried out on an agency basis in support of similar responsibilities of the Secretary of State. Monitoring is also undertaken in Scotland and Northern Ireland for the territorial Secretaries of State there. We also carry out monitoring in the Isle of Man and Channel Islands and the results for these areas are presented in the annual reports. For 25 years our monitoring has remained unique in its coverage of the whole of the British Isles.

In his foreword to the first report, 'FRL 1', which included results for 1963, my predecessor, Dr H A Cole stated that it was the policy of the DFR 'to publish the results of our surveys, so as to assist in creating an informed climate of public opinion in which the peaceful uses of nuclear energy may be fully exploited'. The need for openness of information remains just as relevant after 25 years. The increasing cost of our monitoring (which now stands at some £1M per annum) has been reflected in progressively greater amounts of data presented, to the standards of the highest quality which we can reasonably achieve. It is without hesitation that I reaffirm our former commitment.

D J Garrod
Director of Fisheries Research
Ministry of Agriculture,
Fisheries and Food

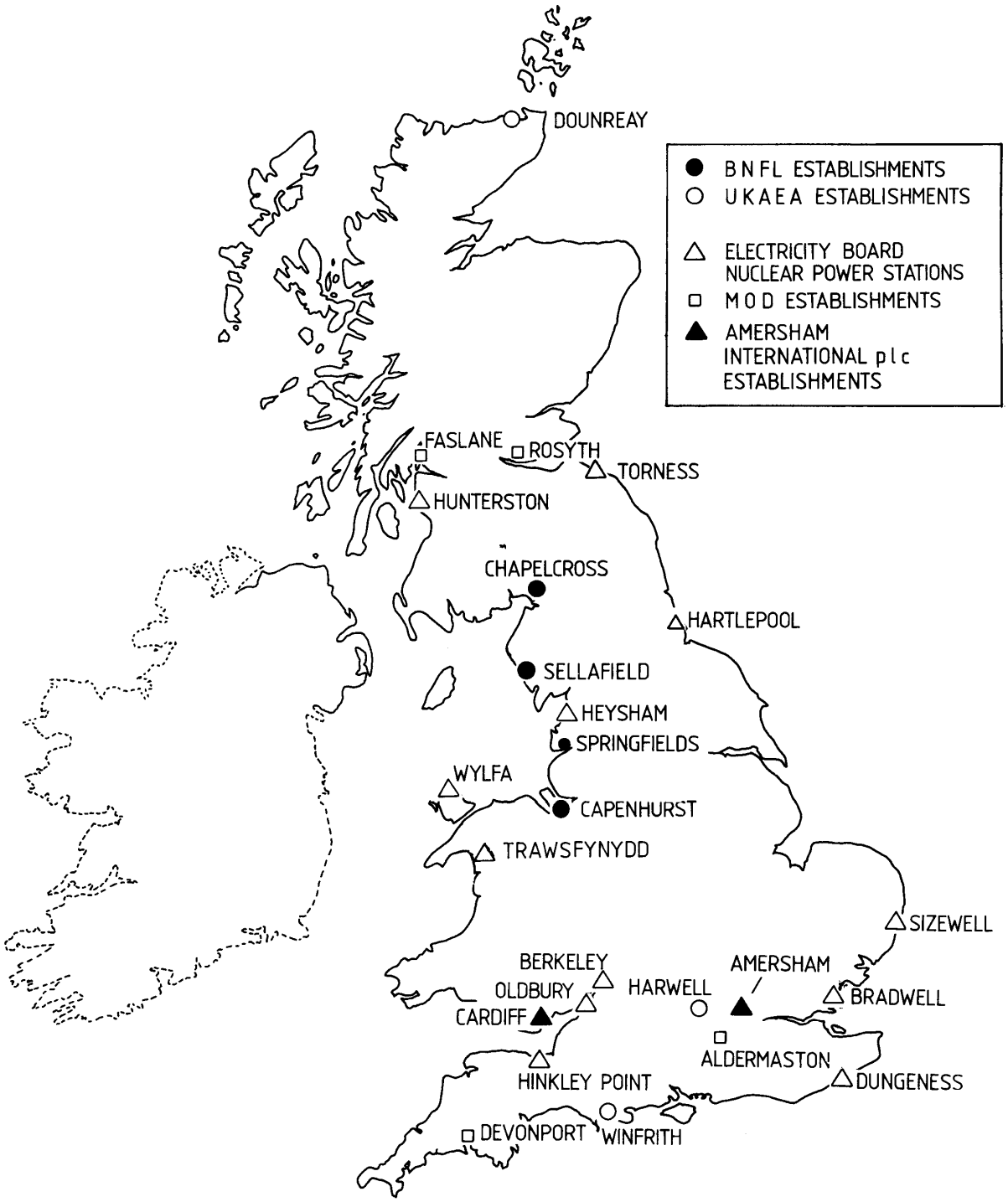

Figure 1 UK nuclear establishments giving rise to principal discharges of liquid radioactive waste.

1. Introduction

This report presents the results of the environmental monitoring programme carried out during 1988 by staff of the Ministry of Agriculture, Fisheries and Food's (MAFF's) Directorate of Fisheries Research (DFR), Lowestoft. The monitoring programme supports MAFF's functions under the Radioactive Substances Act, 1960 (Great Britain – Parliament, 1960). The 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 [DOE (NI)] 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 1988, the special monitoring programme was continued in connection with the accident at Chernobyl, USSR on 26 April 1986. An interim report of this programme for 1988 has already been published (MAFF, 1988). The present report gives summarised data for the whole of 1988, relevant both to regular discharges of radioactive wastes and to fallout from Chernobyl, with the aim of presenting a balanced picture for the complete year. Results are presented within the usual format of monitoring around nuclear sites, except for additional monitoring of radioactivity from Chernobyl in the freshwater environment which is dealt with in a separate section.

To set the monitoring results from our regular programme in context, liquid radioactive discharges from UK nuclear establishments to the aquatic environment in 1988 are first summarised. Before the results are presented, an explanatory section gives details of methods of analysis and presentation and a sub-section explains how results are interpreted in terms of public radiation exposures.

2. Discharges of radioactive waste

Data on radioactive waste discharges are published annually by the Environment Departments (DOE, 1989; SDD, 1988), the latest available data being for the year 1987. Data for 1988 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 1988. 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 1988 are also stated in Table 1.

For completeness, data are included here on the very small discharges into Holy Loch from the US Navy submarine base. Radiological safety for the Holy Loch base is the responsibility of the US Navy in association with the Ministry of Defence who have supplied the following information. For the year 1988, the radioactivity released into the waters of Holy Loch was less than 0.04 GBq of long-lived gamma radioactivity, primarily cobalt-60; less than 0.04 GBq of short-lived radionuclides; less than 0.04 GBq of fission product radionuclides; and less than 0.4 GBq of tritium.

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 1988, 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. However, it is intended to keep open the sea disposal option for large items arising from decommissioning operations.

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

Table 1 Principal discharges of liquid radioactive waste from U.K. nuclear establishments, 1988.

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1988	
			TBq	% of limit
BRITISH NUCLEAR FUELS plc				
Sellafield				
Sea pipelines	Total beta	950	81.26	8.6
	Total alpha	14	2.08	15
	Ruthenium-106	370	23.56	6.4
	Strontium-90	60	10.10	17
	Americium-241	3.3	0.75	23
	Caesium-134	25	0.95	3.8
	Caesium-137	200	13.25	6.6
	Carbon-14	4	3.0	75
	Cerium-144	40	3.18	8.0
	Cobalt-60	9	0.96	11
	Iodine-129	0.4	0.13	33
	Plutonium alpha	10	1.38	14
	Plutonium-241	350	36.15	10
	Technetium-99	10	4.16	42
	Tritium	3500	1724.24	49
	Zirconium-95 plus Niobium-95	250	9.84	3.9
Seaburn sewer	Total activity	0.148	0.0019	1.3
Springfields	Total alpha	13.32	0.42	3.2
	Total beta	444	110	25
Chapelcross	Total alpha	0.1	0.0031	3.1
	Total beta[1]	25	0.17	1
	Tritium	5.5	0.55	10
Capenhurst				
Rivacre Brook	Total activity[2]	0.00148	0.00045	30
Meols outfall	Technetium-99	0.148	Nil	Nil
UNITED KINGDOM ATOMIC ENERGY AUTHORITY				
Winfrith	Total activity	1110	112	10
	Ruthenium-106	333	0.015	1
	Strontium-90	44.4	0.031	1
	Total alpha	44.4	0.0045	1
Harwell	Total activity[1,3]	8.88	0.23	2.6
	Tritium	8.88	1.4	16
Dounreay	Total activity	888	14.2	1.6
	Strontium-90	88.8	1.66	1.9
	Total alpha	8.88	0.16	1.8
CENTRAL ELECTRICITY GENERATING BOARD				
Berkeley	Total activity[1]	7.4	0.33	4.5
	Tritium	55.5	0.27	0.49
Bradwell	Total activity[1]	7.4	0.45	6.1
	Zinc-65	0.185	0.0019	1.0
	Tritium	55.5	0.79	1.4
Dungeness				
"A" Station	Total activity[1]	7.4	0.41	5.5
	Tritium	74	0.34	0.46
"B" Station	Total activity[1,4]	4	0.051	1.3
	Sulphur-35	25	0.19	0.76
	Tritium	650	23	3.5
Hartlepool	Total activity[1,4]	4	0.024	1
	Sulphur-35	7.5	0.21	2.8
	Tritium	1850	34	1.8
Heysham				
Station 1	Total activity[1,4]	4	0.033	1
	Sulphur-35	7.5	0.27	3.6
	Tritium	1850	111	6.0
Station 2	Tritium	1200	0.00974	1
	Sulphur-35	7	0.000011	1
	Cobalt-60	0.036	0.000008	1
	Other radionuclides	0.45	0.00007	1

Table 1 (continued)

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1988	
			TBq	% of limit
Hinkley Point[5]				
"A" Station	Total activity[1,4]	7.4	0.49	6.6
	Sulphur-35	3.7	0.19	5.1
	Tritium	74	2.8	3.8
"B" Station	Total activity[1,4]	3.7	0.026	0.70
	Sulphur-35	22.2	0.97	4.4
	Tritium	666	272	41
Oldbury	Total activity[1]	3.7	0.83	22
	Tritium	74	0.89	1.2
Sizewell	Total activity[1]	7.4	0.46	6.2
	Tritium	111	0.76	1
Trawsfynydd	Total activity[1]	1.48	0.38	26
	Caesium-137	0.259	0.048	19
	Tritium	74	0.55	0.74
Wylfa	Total activity[1]	2.405	0.075	3.1
	Tritium	148	7.3	4.9
SOUTH OF SCOTLAND ELECTRICITY BOARD				
Hunterston				
"A" Station	Total activity[1]	7.5	1.02	14
	Tritium	48	2.2	4.6
"B" Station	Total activity[1,4]	3.7	0.026	1
	Sulphur-35	25.9	1.4	5.4
	Tritium	1480	292	20
Torness	Tritium	1200	26.1	2.2
	Sulphur-35	10	0.09	1
	Cobalt-60	0.05	0.000004	1
	Beta activity[1,4,6]	0.45	0.017	3.8
	Total alpha	0.0045	0.000007	1
MINISTRY OF DEFENCE (PROCUREMENT EXECUTIVE)				
Aldermaston	Total activity[1,3]	5.8	0.079	1.4
	Tritium	5.8	0.0098	1
MINISTRY OF DEFENCE (NAVY DEPARTMENT)				
Devonport[8]	Total activity[1,6]	0.002	0.000197	9.8
	Cobalt-60	0.016	0.0025	16
	Tritium	0.12	0.065	54
Faslane	Total activity[1]	0.037	0.00003	1
Rosyth[9]	Beta activity[1,6]	0.01	0.00028	2.8
	Cobalt-60	0.055	0.0012	2.2
	Tritium	0.01	0.0029	29
	Total alpha	1×10^{-6}	0.84×10^{-6}	84
AMERSHAM INTERNATIONAL plc				
Amersham	Total activity[1,3]	2.7	0.81	30
	Tritium	14.8	4.1	28
Cardiff	Beta/gamma activity[7]	0.096	0.024	25
	Carbon-14	2	1.16	58
	Tritium	1400	661	47

[1]Excluding tritium.
[2]Excluding uranium and its decay products.
[3]Authorisation or agreement specifies a control formula in which the total effective activity is calculated to allow for the relative radiotoxicities of different nuclides. The sums of the actual discharges were lower than the values indicated.
[4]Excluding sulphur-35.
[5]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.
[6]Excluding cobalt-60.
[7]Excluding tritium, carbon-14 and radioisotopes of calcium and strontium.
[8]The operator of this site is Devonport Management Ltd.
[9]The operator of this site is Babcock Thorn Ltd.

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].

3. Methods of analysis and of presentation and interpretation of results

The description of methods in this section refers to our surveillance of nuclear sites, which in 1988 continued to include monitoring of the effects of the accident at Chernobyl. Where there were differences in methodology for the additional monitoring of the freshwater environment described in section 10, these are noted in that section.

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 (Dutton, 1968, 1969), 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(TI) 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. Transuranic nuclides are chemically separated and analysed by alpha spectrometry using silicon surface-barrier detectors 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 (subsection 3.3). Detection limits are usually much lower for radionuclides analysed using these procedures than for gamma-emitting radionuclides. Thus, when samples are analysed for alpha- or beta-emitting radionuclides, positive results are usually reported in the tables.

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

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

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

Table 3 Artificial gamma-emitting radionuclides which are 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.

Table 4 Concentrations of natural radioactivity in various environmental materials and natural background dose rates 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:		μGy h^{-1}
	Sand, shingle	0.03 to 0.05
	Mud	0.05 to 0.1

*Except sediments for which dry concentrations apply.

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 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 accidential 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 2.5 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) has made known its present view 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 limits apply to appropriate critical groups of people 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 individuals within 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, 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. This applies for those organs included in assessment of effective dose; for a few special cases, 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.

Only general guidance has been given by the ICRP (ICRP, 1984a) on the calculation of committed effective dose equivalents following intakes of radionuclides by members of the public. In this report, results are based on committed effective dose equivalents per unit intake 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 ICRP has recently reviewed metabolic factors for actinides (ICRP, 1986). A cautious value of 0.001 is recommended for the gut transfer factor for plutonium, americium and related elements. However, the ICRP states that this cautious value may not be considered as appropriate in all situations where a best estimate of absorption is required, either for a critical group or in estimating population doses. If a different value more suitable to the specific situation can be justified, it should be employed. Recent work at this laboratory, using adult human volunteers, has suggested somewhat lower values in connection with the consumption of shellfish from near Sellafield (Hunt *et al.*, 1986; Hunt *et al.*, in press). When estimating doses to the shellfish consumers near Sellafield, a range of gut transfer factors is used, which includes 0.0005 for plutonium and americium as recommended by the NRPB (NRPB, 1984) and 0.0002 for these elements derived from our recent study (Hunt *et al.*, in press). For dose assessments at sites other than Sellafield, the cautious factor of 0.001, recently recommended by the ICRP (ICRP, 1986), has been used. It is to be noted that, in addition to consideration of gut transfer factors, doses per unit intake for transuranics used in this report include small reductions due to revised body retention times (NRPB, 1987).

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 μGy h^{-1} has been taken as producing an effective dose equivalent rate of 0.87 μSv 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 ICRP-recommended dose limits.

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. These wastes are 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.

Discharges from the Sellafield pipelines during 1988 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 1988. There was a shorter period of plant shutdown for refurbishment than in 1987 and more fuel was reprocessed, thus discharges of some radionuclides to sea were slightly more than in 1987. Discharges of total beta activity were 81 TBq (1987: 89 TBq). Caesium-137 discharges, which prior to SIXEP operation originated mainly from the fuel element storage ponds, in 1988 totalled 13.3 TBq (1987: 11.8 TBq) and were derived predominantly from the reprocessing plant. Discharges of alpha-emitting radionuclides in 1988 totalled 2.1 TBq (1987: 2.2 TBq).

Discharges of carbon-14 increased from 2.1 TBq in 1987 to 3.0 TBq (75% of the authorised limit) in 1988 as a result of greater fuel throughput and of reduced ventilation of an effluent storage and monitoring tank. The reduced ventilation had the effect that some carbon-14 which would have been discharged to the atmosphere was instead discharged in liquid waste to sea. The Authorising Departments were notified, as required by the terms of authorisation, that carbon-14 discharges had exceeded 70% of authorised limits, and of the steps taken to employ BPM to control these discharges. The additional discharges of carbon-14 to sea were of low significance in terms of dose to the public (sub-section 4.1.1).

Our regular monitoring continued during 1988. 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 1988, 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.

The results reflect the progressive dilution of radiocaesium with increasing distance from Sellafield. The reductions in discharges of radiocaesium which have taken place in recent years have resulted in decreased concentrations in fish, especially near Sellafield, and these concentrations do not fall as sharply with distance as in years before the reductions. 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 this ratio was perturbed by the addition of radiocaesium from Chernobyl which was relatively rich in caesium-134; this effect persisted in 1988, but only noticeably in fish from Scottish waters and the North Sea. It is estimated that, in these areas, up to about 40% of the average caesium-137 concentration in 1988 was due to the effect of Chernobyl. Similar effects were not detected in fish from Icelandic waters, and concentrations of artificial radioactivity 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. These observations are consistent with those based on measurements of sea water (Mitchell and Steele, 1988). In the Irish Sea, the ratios of caesium-137 to caesium-134 were generally higher than in Scottish waters and the North Sea. They were also 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, in press).

Table 5(a) Beta/gamma radioactivity in fish from the Irish Sea vicinity and further afield, 1988.

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	7	180	1.1	35
	Plaice	2	170	1.1	35
	Bass	1	270	2.1	88
	Mackerel	1	110	1.0	11
	Grey mullet	1	160	1.2	53
Sellafield offshore area[1]	Cod	4	190	0.9	33
	Plaice	4	130	0.5	21
	Flounder	1	140	1.4	67
	Dab	4	160	0.9	27
	Whiting	2	170	1.3	44
	Spurdog	1	130	ND	7.2
Ravenglass[2]	Cod	18	170	0.9	32
	Plaice	6	120	0.6	19
	Dab	2	110	0.6	19
	Flounder	1	260	2.7	77
	Sea trout	1	200	2.1	47
Whitehaven[2]	Cod	4	160	0.6	23
	Plaice	4	150	0.9	33
	Herring	3	130	0.6	14
	Rays	1	81	ND	4.2
Parton[1]	Cod	1	220	1.1	41
	Plaice	1	140	1.1	43
Maryport[2]	Cod	1	120	0.3	13
	Plaice	1	140	0.5	20
	Rays	1	120	0.8	14
Morecambe Bay[1]	Flounder	4	180	1.4	80
	Plaice	4	120	0.4	20
	Bass	1	220	2.5	130
Cumbrian rivers[4]	Sea trout	3	140	1.3	31
Fleetwood[2]	Cod	4	140	0.5	19
	Plaice	4	120	0.3	16
	Fish meal[5]	1	370	1.0	12
	Fish oil[5]	1	NA	ND	ND
Isle of Man[2]	Cod	4	140	0.4	8.5
	Plaice	5	99	0.3	8.4
	Herring	4	102	0.4	10
	Whiting	1	130	1.5	25
Inner Solway[1]	Salmon	1	120	ND	0.9
	Sea trout	2	130	1.1	18
	Flounder	4	190	1.7	91
Kirkcudbright[2]	Plaice	4	120	0.5	16
North Anglesey	Plaice	2	100	0.2	3.6
	Spurdog	3	100	0.6	16
Northern Ireland[2]	Cod	7	120	0.4	7.1
	Whiting	8	120	0.7	14
	Herring	4	150	0.6	12
	Spurdog	6	120	0.8	18
Ayr[2]	Plaice	4	120	0.5	11
	Cod	4	150	0.6	13
Loch Leven[1]	Salmon	1	130	0.4	2.5
Minch[1]	Plaice	4	110	0.4	6.4
	Cod	5	140	0.4	7.8
	Herring	4	130	0.5	9.5
	Mackerel	7	100	0.06	1.7
Shetland[1]	Fish meal[5]	2	590	0.3	3.5

Table 5(a) (continued)

Sampling area/landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}		
			Total beta	^{134}Cs	^{137}Cs
Northern North Sea[1]	Plaice	6	100	0.1	2.1
	Cod	6	140	0.4	3.2
	Haddock	5	NA	0.04	1.5
	Saithe	3	"	0.3	2.6
	Herring	5	120	0.2	2.0
	Norway pout	1	NA	ND	0.4
	Mackerel	2	240	"	0.6
	Whiting	1	NA	0.3	2.7
Mid-North Sea[1]	Plaice	10	98	0.2	2.3
	Cod	10	150	0.4	4.3
	Haddock	3	NA	0.2	2.5
	Whiting	2	"	0.6	4.9
	Herring	6	100	0.2	2.4
	Mackerel	1	NA	ND	1.2
Southern North Sea[1]	Plaice	4	96	"	1.4
	Cod	5	130	0.1	2.4
	Whiting	1	NA	0.3	2.4
	Herring	2	81	ND	1.6
	Mackerel	1	NA	"	0.5
English Channel[1]	Sole	1	"	"	0.1
Norwegian Sea[1]	Cod	2	130	0.4	2.0
Barents Sea[1]	Cod	1	130	0.1	1.1
Iceland area[1]	Cod	2	110	ND	0.4
	Plaice	2	89	"	0.08
Icelandic processed	Cod	3	110	"	0.2
	Plaice	2	61	"	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 the North West Water Authority; [5]Concentrations refer to weight of sample as supplied.

Table 5(b) Other beta/gamma radioactivity in fish from the Irish Sea vicinity, 1988.

Sampling area/ landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}				
			^{14}C	^{60}Co	^{90}Sr	^{99}Tc	^{147}Pm
Sellafield offshore area[1]	Plaice	1	100	0.1	0.14	0.46	0.020
	Cod	1	87	0.4	0.16	0.17	ND
Whitehaven[2]	Plaice	1	NA	0.1	0.34	NA	NA
	Cod	1	"	ND	0.064	"	"
Fleetwood[2]	Fish meal[4]	1	"	"	0.63	"	"
Shetland[1]	Fish meal[4]	1	"	"	0.068	"	"

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.

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 1988 were generally less than in 1987. There were particular reductions in levels of radiocaesium in fish from the Irish Sea. This is attributed to continuing decreases in concentrations in sea water, following the significant reductions in radiocaesium discharges from Sellafield due to the operation of SIXEP from May 1985.

Specific radionuclides, other than caesium-134 and -137, which were deteced in fish in 1988 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 1988 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.

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 radiocaesium in shellfish in 1988, as for fish, showed general reductions as compared with 1987, reflecting the decreases in discharges over the last few years. Concentrations of short-lived radionuclides, which reflect more closely the recent discharges from Sellafield, were generally similar to concentrations observed in 1987.

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 1988 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.

The non-mobile nature of transuranic nuclides causes a delayed effect in the environment (Hunt, 1985), such that a contribution to present concentrations is provided by discharges in earlier years. Concentrations of transuranics in fish and most species of shellfish from the Irish Sea generally showed continuing reductions in 1988, particularly in areas close to Sellafield, reflecting the decline in discharges over the past decade. However, the reductions were not generally as great as has been the case in previous years, and in some species, including winkles, there was even a slight increase in concentrations as compared with 1987. A gradual slowing down in the rate of decrease of these concentrations is consistent with our model predictions (Hunt, 1986; Pentreath *et al*, 1989 (b)); it is also to be noted that environmental factors are likely to cause fluctuations in measured concentrations.

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 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 1988. Techni-

ques 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

Table 6 Beta/gamma radioactivity in shellfish from the Irish Sea vicinity and further afield, 1988.

Sampling area/ landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}																
			Total beta	^{14}C	^{60}Co	^{65}Zn	^{90}Sr	^{95}Zr + ^{95}Nb	^{99}Tc	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{147}Pm	^{154}Eu	^{155}Eu
Sellafield coastal area[1]	Crabs	3	110	NA	1.9	ND	NA	ND	NA	ND	8.7	5.4	ND	ND	8.4	ND	NA	ND	ND
	Lobsters	2	320	98	2.5	"	0.45	"	380	"	8.0	6.4	"	0.3	11	"	3.0	"	"
	Winkles[4]	12	390	64	12	"	7.8	9.0	76	"	120	12	1.1	0.1	23	3.2	19	"	0.3
	Winkles[5]	4	420	NA	18	"	NA	27	NA	1.4	180	17	4.5	0.5	39	8.4	NA	0.4	0.6
	Winkles[6]	4	350	"	9.2	"	"	24	"	ND	95	10	1.1	0.3	24	7.2	"	ND	0.4
	Winkles[7]	1	350	"	7.1	"	"	8.2	"	"	110	11	2.9	ND	19	4.8	"	"	ND
	Mussels[4]	4	280	"	7.3	"	"	11	"	0.6	130	0.3	0.6	"	12	4.1	"	1.6	1.0
	Limpets[4]	4	390	"	9.3	"	"	2.6	"	ND	74	7.5	3.2	"	26	3.1	"	ND	0.6
Sellafield offshore area[1]	Whelks	2	290	"	9.8	0.4	"	ND	"	"	110	13	0.7	"	6.7	1.9	"	1.0	0.6
St Bees[1]	Winkles	4	360	61	8.8	ND	9.3	11	36	0.5	120	13	3.5	"	24	6.0	19	ND	0.5
	Mussels	4	330	NA	8.3	"	NA	9.9	NA	ND	160	6.5	1.2	"	9.5	6.9	NA	0.9	1.1
	Limpets	4	440	"	6.4	"	"	5.3	"	0.2	90	8.9	5.4	0.1	21	3.0	"	0.4	0.3
Nethertown[1]	Winkles	12	440	69	12	"	16	28	94	0.9	160	15	4.8	0.4	31	11	26	0.4	0.7
Drigg[1]	Winkles	4	590	78	20	"	14	34	120	1.7	250	16	4.5	0.2	26	11	36	0.7	0.5
Ravenglass[1]	Cockles	4	270	NA	20	"	NA	9.2	NA	ND	80	0.8	1.7	ND	18	6.6	NA	3.8	2.2
	Mussels	12	240	"	7.6	"	"	4.7	"	0.1	100	ND	1.6	"	8.4	3.0	"	0.8	1.0
Ravenglass[2]	Crabs	3	120	"	4.4	"	"	ND	"	ND	13	6.2	0.4	0.2	8.8	0.5	"	ND	ND
	Lobsters	3	250	"	2.7	"	"	"	"	"	6.2	7.6	0.3	0.2	12	1.2	"	"	0.1
	Whelks	2	260	"	9.6	0.3	"	0.6	"	"	96	15	1.5	0.1	5.8	1.5	"	0.5	0.3
Tarn Bay[1]	Winkles	4	310	"	7.2	ND	"	11	"	"	95	7.3	1.5	0.7	23	4.6	"	ND	0.3
Whitehaven[2]	*Nephrops*	4	150	"	0.1	"	"	ND	"	"	0.4	0.3	0.1	0.4	20	ND	"	"	ND
	Whelks	4	140	"	1.2	"	"	"	"	"	7.7	3.8	ND	ND	4.0	"	"	"	"
Parton[1]	Winkles	4	230	"	4.5	"	"	0.1	"	0.2	41	6.2	0.8	0.2	23	"	"	"	"
Roosebeck[1]	Oysters	4	62	"	0.3	"	"	ND	"	ND	4.2	4.2	ND	0.03	5.7	"	"	"	"
Morecambe Bay[1]	Shrimps	4	98	"	ND	"	0.11	"	"	"	ND	ND	"	0.5	27	"	"	"	"
	Cockles	4	100	"	2.3	"	1.3	"	"	"	9.5	"	0.7	0.4	15	"	"	"	"
	Mussels	4	64	"	0.7	"	NA	"	"	"	5.6	"	0.4	ND	5.4	"	"	"	"
Isle of Man[2]	Scallops	10	140	"	0.04	"	"	"	"	"	ND	0.4	ND	"	1.7	"	"	"	"
Fleetwood	Squid	1	91	"	ND	"	"	"	"	"	"	ND	"	"	4.0	"	"	"	"
	Whelks	3	97	"	0.3	"	"	"	"	"	2.6	1.1	"	"	3.1	"	"	"	"
Inner Solway[1]	Shrimps	4	89	"	0.03	"	"	"	"	"	ND	0.2	"	0.5	24	"	"	"	"
Southerness[1]	Cockles	2	110	NA	4.0	ND	NA	ND	NA	ND	12	ND	ND	0.2	17	ND	NA	ND	ND
	Winkles	4	170	"	1.7	"	"	"	"	"	12	22	0.3	0.5	21	"	"	"	"
Kirkcudbright[2]	Scallops	4	71	"	ND	"	"	"	"	"	ND	0.04	ND	ND	1.0	"	"	"	"
	Queens	4	63	"	0.3	"	"	"	"	"	"	1.1	"	0.06	2.1	"	"	"	"
North Solway coast[1]	Winkles	4	150	"	1.8	"	"	"	"	"	16	11	"	ND	8.8	"	"	"	"
Powfoot	Cockles	1	100	"	2.9	"	"	"	"	"	7.7	ND	"	"	17	"	"	"	"
Wirral[1]	Shrimps	2	68	"	ND	"	"	"	0.32	"	ND	0.2	"	"	5.7	"	"	"	"
	Cockles	2	65	"	0.6	"	"	"	0.98	"	1.2	ND	"	0.4	9.0	"	"	"	"
Conwy[2]	Mussels	2	46	"	ND	"	"	"	NA	"	0.5	"	"	ND	1.0	"	"	"	"
North Anglesey[1]	Crabs	2	81	"	0.1	0.1	"	"	"	"	ND	5.6	"	0.1	1.9	"	"	"	"
	Winkles	2	74	"	0.3	ND	"	"	"	"	"	3.2	"	ND	3.1	"	"	"	"
Northern Ireland[2]	*Nephrops*	8	110	"	ND	"	"	"	"	"	"	0.2	"	0.1	4.8	"	"	"	"
	Winkles	4	280	"	"	"	"	"	"	"	"	4.2	"	ND	1.6	"	"	"	"
Minch[1]	*Nephrops*	3	100	"	"	"	"	"	"	"	"	0.5	"	"	1.2	"	"	"	"
Northern North Sea[1]	*Nephrops*	4	97	"	"	"	"	"	"	"	"	1.1	"	"	0.6	"	"	"	"
Mid-North Sea[1]	*Nephrops*	1	84	"	"	"	"	"	"	"	"	1.8	"	"	1.2	"	"	"	"
	Mussels[3]	3	29	"	"	"	"	"	"	"	"	ND	"	"	0.1	"	"	"	"
Southern North Sea[1]	Cockles	2	27	"	1.8	0.1	"	"	"	"	0.4	0.6	"	"	0.1	"	"	"	"
	Cockles[9]	2	67	"	0.3	ND	"	"	"	"	ND	0.3	"	"	0.3	"	"	"	"
	Mussels	2	51	"	ND	"	"	"	"	"	"	ND	"	"	0.5	"	"	"	"

NA = not analysed; ND = not detected.
[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 collected by Consumer 471; [8]Landed in Denmark; [9]Landed in Holland.

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 1988, were not significantly different from those in 1987 (Hunt, 1988), 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). 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 1988 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

Table 7 Transuranic radioactivity in fish and shellfish from the Irish Sea vicinity and further afield, 1988.

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	0.022	0.10	NA	0.16	0.00029	0.0034
	Cod	2	"	0.018	0.075	"	0.10	0.00044	0.00020
	Crabs	3	"	0.096	0.4	"	1.6	ND	0.0043
	Lobsters	2	0.041	0.18	0.76	8.8	8.4	0.022	0.031
	Winkles[4]	4	0.18	4.4	19	360	31	0.030	0.083
	Winkles[5]	1	NA	2.8	12	240	19	0.069	0.067
	Winkles[6]	4	"	4.8	22	420	31	0.074	0.090
	Winkles[7]	2	"	5.5	27	440	35	0.21	0.15
	Mussels[4]	1	"	5.6	24	NA	39	0.091	0.099
	Limpets[4]	1	"	4.8	20	"	33	0.12	0.14
Sellafield offshore area[1]	Plaice	1	0.0007	0.0044	0.019	0.39	0.054	ND	ND
	Cod	1	0.0004	0.0023	0.010	NA	0.024	0.00017	0.00009
	Whelks	1	NA	1.4	6.0	"	30	0.062	0.083
St Bees[1]	Winkles	4	0.21	4.4	19	380	30	0.085	0.12
	Mussels	2	NA	6.9	29	580	36	0.12	0.095
	Limpets	1	"	3.7	16	NA	26	0.032	0.14
Nethertown[1]	Winkles	4	0.32	5.9	26	530	39	0.033	0.12
Drigg[1]	Winkles	4	0.34	7.5	33	650	57	0.12	0.19
Ravenglass[1]	Cockles	1	NA	5.8	24	480	55	ND	0.17
	Mussels	4	"	5.0	21	430	33	0.041	0.12
Ravenglass[2]	Cod[8]	1	"	0.0014	0.0065	NA	0.011	ND	ND
	Plaice[8]	1	"	0.0042	0.017	"	0.031	"	"
	Crabs[9]	1	"	0.20	0.87	"	3.3	0.015	0.012
	Lobsters[9]	1	"	0.11	0.45	"	10	ND	0.038
	Whelks[9]	1	"	1.0	4.5	92	12	0.054	0.039
Tarn Bay[1]	Winkles	1	"	4.7	21	390	30	0.064	0.093
Whitehaven[2]	Plaice	1	"	0.0017	0.0081	NA	0.012	ND	0.00004
	Cod	1	"	0.0011	0.0050	"	0.0076	"	ND
	Herring	1	"	0.0057	0.030	"	0.034	"	"
	Rays	1	"	0.00010	0.00042	"	0.00076	"	"
	Nephrops	1	"	0.065	0.30	"	1.8	"	0.0058
	Whelks	1	"	0.28	1.4	24	2.3	"	0.0091
Parton[1]	Winkles	1	"	1.2	5.3	100	8.5	0.018	0.029
Roosebeck	Oysters	1	"	0.27	1.3	NA	1.0	ND	0.0057
Morecambe Bay[1]	Shrimps	1	"	0.0093	0.044	"	0.063	0.00026	0.00026
	Cockles	1	"	0.82	3.7	68	8.4	ND	0.037
	Mussels	1	"	0.20	1.0	NA	1.5	0.0052	0.0050
Fleetwood[2]	Cod	1	"	0.00014	0.00078	"	0.0012	ND	ND
	Plaice	1	"	0.00039	0.0018	"	0.0032	"	0.00001
	Fish meal[10]	1	"	0.018	0.092	"	0.13	"	0.00049
	Whelks	1	"	0.12	0.56	"	0.71	"	0.0017

Table 7 (continued)

Sampling area/ landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}						
			^{237}Np	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Isle of Man[2]	Cod	1	NA	0.00006	0.00028	NA	0.00047	ND	ND
	Plaice	1	"	0.00016	0.00073	"	0.0013	"	0.00001
	Herring	1	"	0.00043	0.0023	"	0.0028	"	0.00001
	Scallops	1	"	0.033	0.15	"	0.042	"	ND
Inner Solway[1]	Sea trout	1	"	0.00028	0.0010	"	0.0015	"	"
Powfoot	Cockles	1	"	1.6	7.7	"	15	0.016	0.063
Southerness[1]	Cockles	1	"	1.2	6.1		11	ND	0.031
	Winkles	1	"	1.0	4.7	"	6.7	0.014	0.031
Kirkcudbright[2]	Plaice	1	"	0.0016	0.0070	"	0.012	ND	0.00006
	Scallops	1	"	0.023	0.12	"	0.035	"	ND
	Queens	1	"	0.035	0.17	"	0.20	0.00058	0.00057
North Solway coast[1]	Winkles	1	"	0.77	3.6	"	5.2	ND	0.017
Ayr[2]	Cod	1	"	0.00022	0.00094	"	0.0011	0.0003	ND
	Plaice	1	"	0.00017	0.00083	"	0.00094	ND	"
Wirral[1]	Cockles	1	"	0.43	2.1	"	4.3	"	0.0070
Conwy[2]	Mussels	1	"	0.055	0.26	"	0.46	0.0040	0.0026
North Anglesey[1]	Spurdog	1	"	0.00004	0.00019	"	0.00033	ND	ND
	Winkles	1	"	0.090	0.47	"	0.68	0.0037	0.0028
Northern Ireland[2]	Whiting	1	"	0.00049	0.0026	"	0.0037	ND	ND
	Nephrops	1	"	0.0056	0.029	"	0.093	"	0.00024
	Winkles	1	"	0.051	0.26	"	0.14	"	0.00045
Minch[1]	Cod	1	"	0.00007	0.00029	"	0.00040	"	ND
	Mackerel	2	"	0.00017	0.00075	"	0.00080	0.00012	0.00001
	Nephrops	1	"	0.00041	0.0030	"	0.0046	ND	ND
Shetland[1]	Fish meal[10]	1	"	0.00098	0.0069	"	0.00098	"	"
Northern North Sea[1]	Cod	1	"	0.00006	0.00026	"	0.00036	0.00001	"
	Nephrops	1	"	0.00023	0.0015	"	0.0020	0.00011	0.00002
Mid-North Sea[1]	Mussels	1	"	0.0073	0.037	"	0.013	ND	0.00008
	Mussels[11]	1	"	0.00038	0.0039	"	0.0022	"	ND
Southern North Sea[1]	Mussels	1	"	0.0058	0.030	"	0.026	"	"
	Cockles	1	"	0.0018	0.0068	"	0.0075	0.00063	0.0015
	Cockles[12]	1	"	0.0017	0.010	"	0.0079	ND	ND
Icelandic processed	Cod	1	"	0.00002	0.00008	"	0.00007	"	"

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 471; [6]Samples collected by Consumer 311; [7]Samples collected by Consumer 460; [8]Samples provided by Fisherman A; [9]Samples provided by Fisherman B; [10]Concentrations refer to weight as supplied; [11]Landed in Denmark; [12]Landed in Holland.

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 1988. 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 effect of applying different gut transfer factors for plutonium and americium is shown in the last two columns. Recent work at this laboratory (Hunt *et al.*, in press) 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. On the basis of this gut transfer factor, the committed effective dose equivalent to the local critical group in 1988 would have been 0.15 mSv. The effect of applying a more cautious gut transfer factor of 0.0005 for plutonium and americium (sub-section 3.4) is shown in the last column of Table 8. On this basis, the committed effective dose equivalent to the critical group of local consumers in 1988 would have been 0.34 mSv. This represents a slight increase from 0.33 mSv reported for 1987 (Hunt, 1988), and is due to the small increase noted above in the concentrations of transuranics in winkles; this increase is probably not significant within the associated variabilities. These committed effective dose equivalents are within the ICRP-recommended principal dose limit for members of the public of 1 mSv year^{-1}.

Table 8 Individual radiation exposures due to consumption of Irish Sea fish and shellfish, 1988.

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 (see text)	
				0.0002	0.0005
Consumers in local fishing community	Fish (plaice and cod):	36.5	^{90}Sr	0.003	0.003
	crustaceans (crabs and lobsters):	6.0	^{106}Ru	0.007	0.007
	molluscs (winkles):	8.3	^{137}Cs	0.015	0.015
			^{238}Pu	0.007	0.018
			^{239}Pu + ^{240}Pu	0.036	0.090
			^{241}Pu	0.013	0.034
			^{241}Am	0.064	0.16
			Total	0.15	0.34
Consumers associated with commercial fisheries: Whitehaven	Fish (plaice and cod):	49	^{137}Cs	0.019	0.019
	crustaceans (*Nephrops*):	11	^{239}Pu + ^{240}Pu	0.002	0.006
	molluscs (whelks):	6	^{241}Am	0.007	0.017
			Total	0.03	0.05
Consumers in Morecambe Bay area	Fish (flounders and plaice):	50	^{137}Cs	0.038	0.038
	crustaceans (shrimps):	18	^{239}Pu + ^{240}Pu	0.007	0.017
	molluscs (cockles and mussels):	15	^{241}Am	0.015	0.037
			Total	0.07	0.11
Consumers associated with commercial fisheries: Fleetwood	Fish (plaice and cod):	82	^{137}Cs	0.025	0.025
	crustaceans (shrimps):	17	^{239}Pu + ^{240}Pu	0.009	0.023
	molluscs (cockles and whelks):	23	^{241}Am	0.020	0.050
			Total	0.07	0.12
Typical member of the fish-eating public consuming fish landed at Whitehaven/Fleetwood	Fish (plaice and cod):	15	^{137}Cs	0.004	0.004
			Total	0.005	0.005

The exposure of the critical group has also been considered in comparison with the ICRP recommendation on lifetime exposure (sub-section 3.4). In 1988, and in recent previous years, realistically-assessed exposures were within the principal dose limit of 1 mSv year^{-1}. For a few years prior to this, exposures were in excess of 1 mSv year^{-1} but within the ICRP-recommended subsidiary dose limit of 5 mSv year^{-1}. Concentrations of radiologically significant nuclides in environmental materials are declining as a result of reduced discharges, and 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). Having demonstrated compliance with the ICRP's lifetime dose objectives, it follows (sub-section 3.4) that non-stochastic effects will also be avoided.

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 1987 on the basis of a gut transfer factor for plutonium and americium of 0.0005 (Hunt, 1988), the committed collective dose equivalents to the groups at Whitehaven and Fleetwood were slightly higher in 1988 (1987: 0.04 mSv year^{-1} and 0.11 mSv year^{-1} respectively) and in the Morecambe Bay area was slightly lower in 1988 (1987: 0.12 mSv year^{-1}). As before, the changes from 1987 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 effective dose in 1988 was 0.005 mSv, which represents a decrease from 0.006 mSv reported for 1987 (Hunt, 1988), 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 2.5 mSv $year^{-1}$ to members of the UK public from all natural sources of radiation (Hughes *et al.*, 1988).

Collective doses received during 1988, 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 were made for the fraction of fish or shellfish consumed. The contribution of weapons-test fallout to the radioactivity concentrations was substracted. 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 and poultry. 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 1988 are preliminary, being based on landings statistics provided by the International Council for the Exploration of the Sea (ICES); where data are not yet available, the previous year's data have been used. The preliminary results will be reviewed in future reports as updated statistics are received. The preliminary results of 30 man-Sv for the UK and 60 man-Sv for other European countries in 1987 respectively given in the previous report (Hunt, 1988), have been adjusted to 40 man-Sv and 70 man-Sv respectively following the receipt of revised landings statistics for shellfish from the Dee estuary; it is likely that much of the catch was exported to the European continent.

Liquid radioactive waste discharges from Sellafield up to the end of 1988 are the main source of collective dose reported here; 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; this contribution for 1988 is estimated as about 4 man-Sv to the UK population and 7 man-Sv to the population of other countries. A lack of measured concentrations of radioactivity in fish from the Baltic Sea has precluded inclusion of collective dose due to the effect on this area of radioactivity from Chernobyl, but the effects of discharges from Sellafield have been included, as in previous years, by the use of modelling techniques. The contribution to the collective dose to the UK population from Baltic Sea fish would have been minimal. 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 result of 40 man-Sv for the UK in 1988 is the same as the final result reported for 1987. The effect of reductions in concentrations of radiocaesium in fish was offset by increased landings of cockles from Morecambe Bay, which replaced those in 1987 from the Dee estuary, which is further from Sellafield. The contribution due to radioactivity from Chernobyl, which was mainly observed in fish from Scottish waters and the North Sea, continued

Table 9 Collective doses from fish and shellfish, 1987 and 1988*

Population	Size of population	Collective committed effective dose equivalent, man-Sv	
		1987	1988*
UK	5.6×10^7	40	40
Other European countries	6.5×10^8	70	50

*Preliminary data.

to decrease. The preliminary result of 50 man-Sv for the collective dose to inhabitants of other countries in 1988 was less than in 1987 (70 man-Sv), reflecting the clearance from Scottish waters and the North Sea of radiocaesium due to both Sellafield and Chernobyl.

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 2.5 mSv due to natural background radiation (see sub-section 3.4). In 1988, the UK collective dose through the fish and shellfish pathway as a result of liquid radioactive waste disposal operations amounted to less than 0.03% of this level.

It is clear from the statements above, which compare the 1987 and 1988 results for both critical group and collective dose rates, than 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 1988 is shown in Figure 2. Comparison with the data for April 1987 (Hunt, 1988) shows that concentrations of caesium-137 in sea water of the eastern Irish Sea have continued to decrease, reflect-

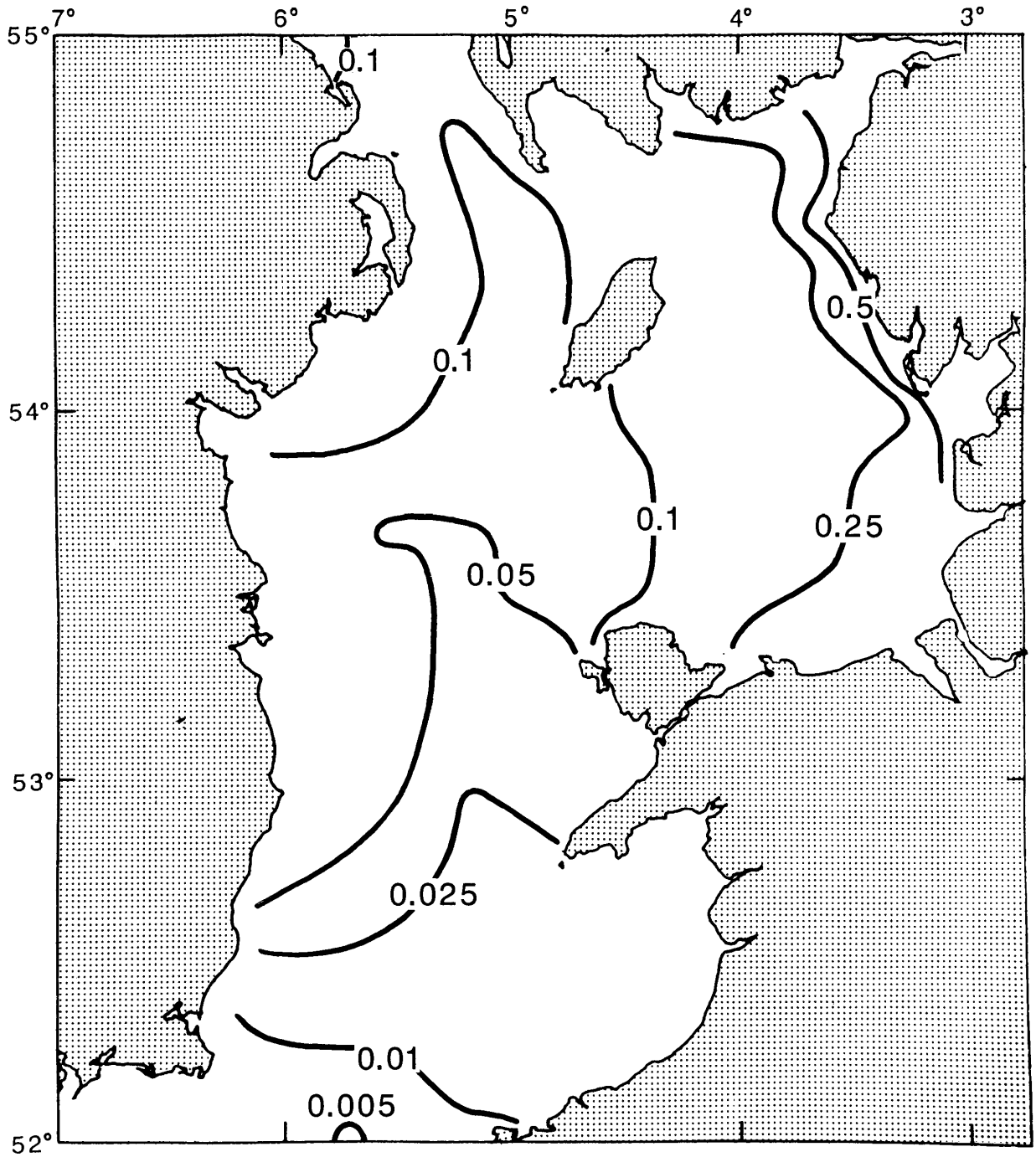

Figure 2 Concentration (Bq kg^{-1}) of caesium-137 in filtered water from the Irish Sea, **March 1988.**

ing the reductions in discharges from Sellafield since 1985, following operation of SIXEP. Our cruise programme in March 1988 included collection of data on the distribution of caesium-137 in sea water west of Scotland; the data are shown in Figure 3 and reflect the pattern expected due to Atlantic water off the continental shelf. Comparison with the data for April 1987 (Hunt, 1988) shows continuing general reductions in concentrations of caesium-137 in Scottish waters. Data for the North Sea during August and September 1988 are shown in Figure 4. Comparison with the distribution observed in August and September 1987 (Hunt, 1988) shows a general reduction in concentrations of caesium-137 in most areas of the North Sea. Some of this caesium-137 is due to the effect of fallout from Chernobyl (Mitchell and Steele, 1988); notable in the distribution for 1988 is the introduction of water from the Baltic Sea which is slightly richer in caesium-137 from Chernobyl than water of the North Sea.

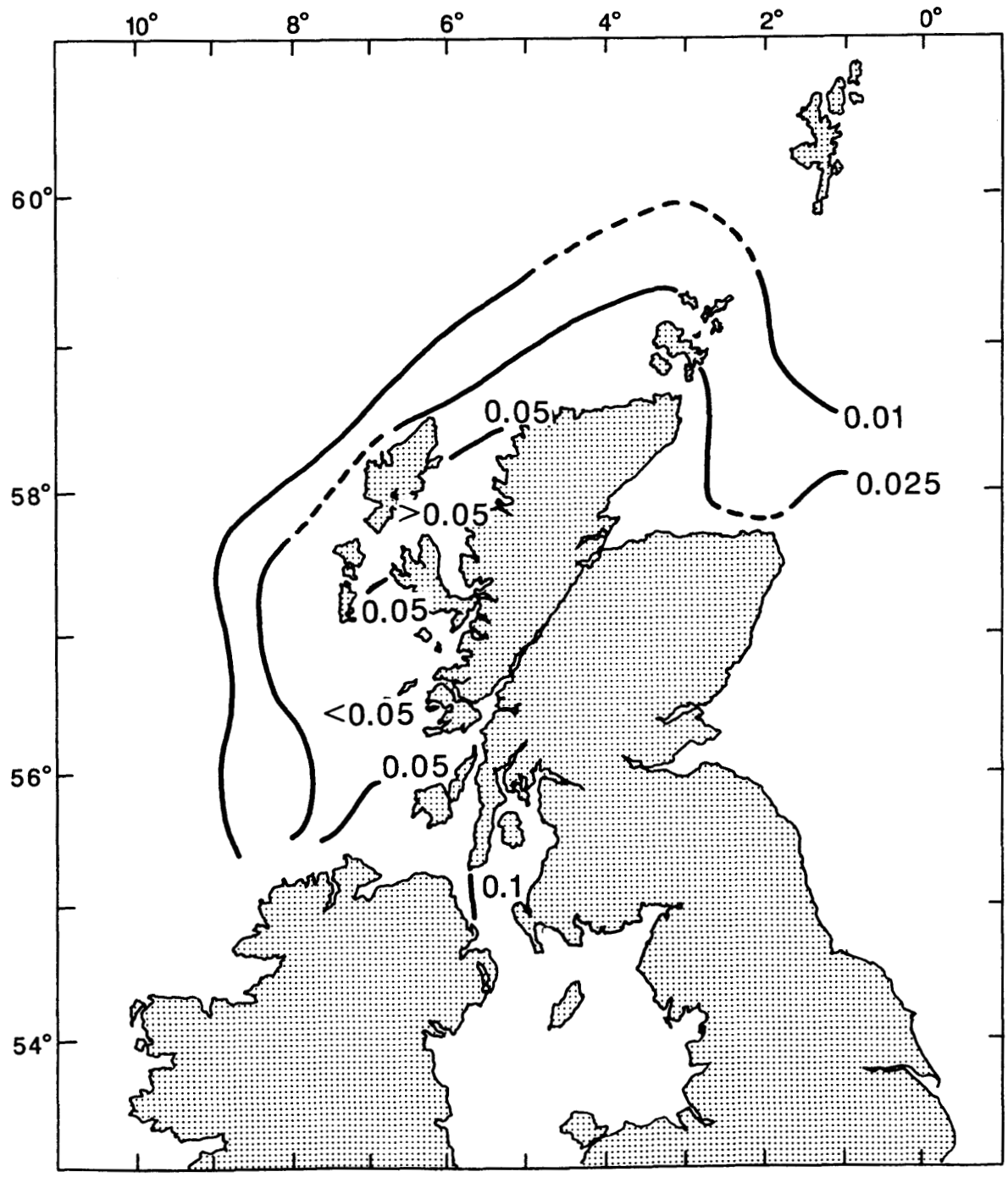

Figure 3 Concentration (Bq kg^{-1}) of caesium-137 in filtered water from the west of Scotland, March 1988. Dotted line indicates data which have not been measured.

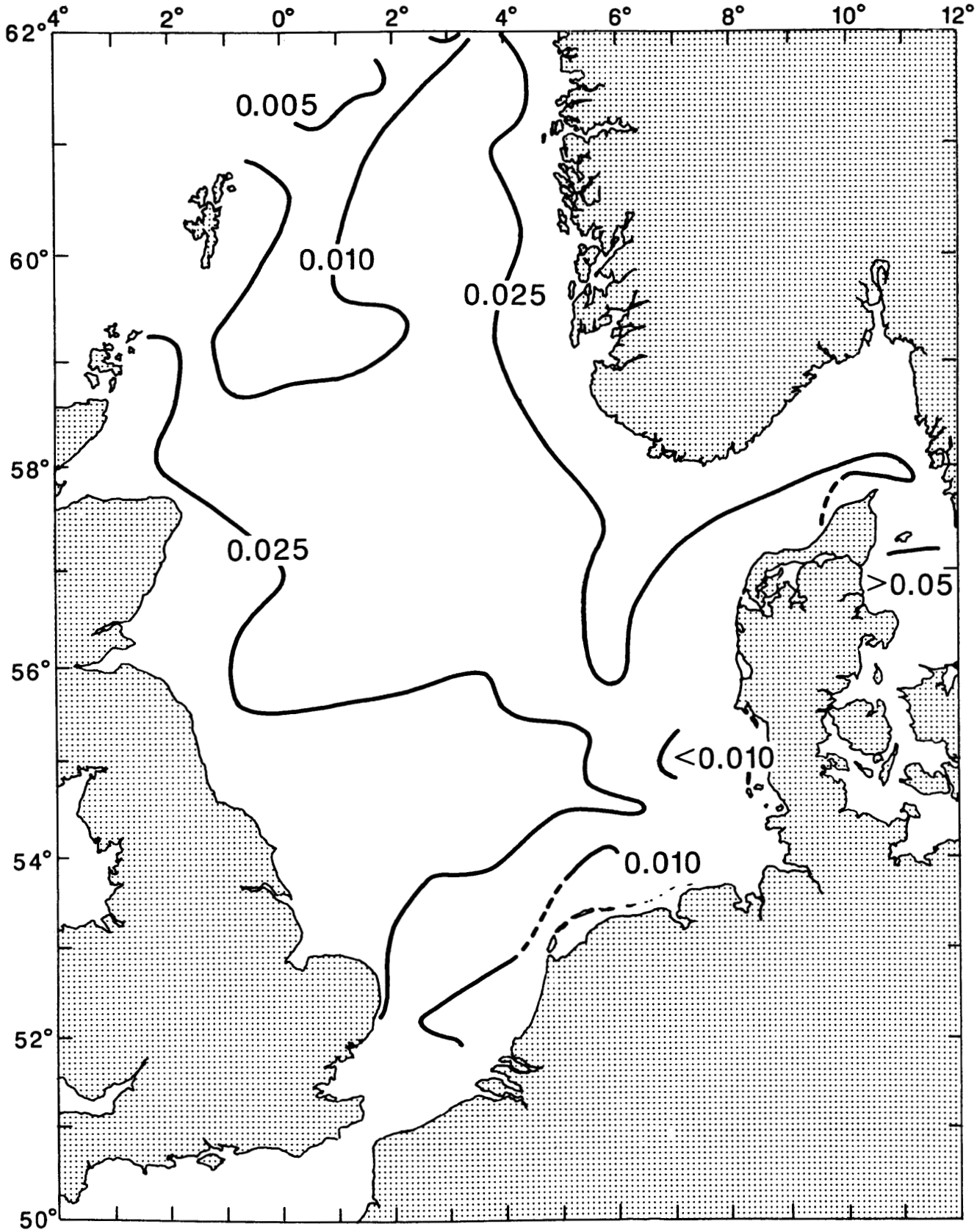

Figure 4 Concentration (Bq kg^{-1}) of caesium-137 in filtered surface water from the North Sea, August-September 1988. Dotted line indicates data which have not been measured.

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 1988 showed general reductions as compared with 1987 (Hunt, 1988).

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

Table 10 Gamma radiation dose rates over intertidal areas of the Cumbrian coast and further afield, 1988.

Location	Ground type	No. of sampling observations†	Mean gamma dose rate in air at 1 m, μGy h^{-1}
Cumbria			
Burgh Marsh	Salt marsh	4	0.11
Greenend	" "	4	0.11
"	Muddy sand	4	0.090
Maryport outer harbour	Mud	4	0.22
" harbour	"	2	0.15
"	Dried mud	1	0.082
Workington harbour	Mud	4	0.23
Harrington harbour	"	4	0.19
Whitehaven outer harbour	Sandy mud	12	0.18
" " "	Coal/sand	12	0.16
" inner "	Mud	12	0.26
" yacht basin	"	12	0.38
St Bees	Sand	4	0.080
Nethertown winkle beds	Rock	4	0.13
Sellafield	Sand	4	0.10
Seascale	"	4	0.10
Drigg pipeline	"	4	0.085
" beach	"	4	0.089
" Barn Scar	Mussel bed	4	0.12
Ravenglass - salmon garth	Sandy mud	12	0.22
" " "	Gravelly silt	12	0.12
" " "	Mussel bed	11	0.14
" - boats area	Sandy mud	12	0.16
" " "	Sand	4	0.082
" - ford area	Mud	4	0.18
" - Ravenvilla	"	12	0.23
" "	Salt marsh	12	0.45
Newbiggin	Mud	12	0.33
" - west of bridge	Sandy mud	4	0.20
" " " "	Salt marsh	12	0.49
Haverigg	Sand	4	0.086
"	Mud	4	0.16
Millom	Sandy mud	4	0.14
Walney Channel	Mud	2	0.14
" Vickers shore	Sandy mud	4	0.10
" west shore	Sand	4	0.067
Low Shaw	Salt marsh	4	0.16
Flookburgh	Muddy sand	4	0.11
Lancashire, Merseyside and North Wales			
Tummer Hill Marsh	Salt marsh	4	0.27
Sunderland Point	Mud	4	0.11
Lytham			
Freckleton	"	4	0.17

Table 10 (continued)

Location	Ground type	No. of sampling observations†	Mean gamma dose rate in air at 1 m, μGy h^{-1}
Lancashire, Merseyside and North Wales (continued)			
Becconsall	Mud	5	0.17
Skipool Creek	"	4	0.18
Fleetwood	Sand	4	0.074
Blackpool	"	4	0.060
Ainsdale	"	4	0.060
New Brighton	"	4	0.068
Mersey (Rock Ferry)	Mud	4	0.14
Llandudno	Gravel	4	0.087
Prestatyn	Sand	4	0.059
South-west Scotland			
Garlieston	Mud	4	0.11
Innerwell	"	4	0.13
Kippford - slipway	"	4	0.12
" - jetty	"	4	0.11
" - merse	Salt marsh	4	0.22
Palnackie harbour	Mud	4	0.17
Carsethorn	Sandy mud	4	0.15

†See sub-section 3.3 for definition.

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 1987 (Hunt, 1988) shows general reductions in line with the behaviour of dose rates. Concentrations of transuranic radionuclides in sediments from areas of south-west Scotland have declined more slowly than has been the general trend elsewhere, some locations even showing slight increases in recent years. This observation supports the view that northward dispersal of transuranics from Sellafield is predominantly due to sediment transport (Mackenzie *et al.*, 1987). Any increases in concentrations have been small but the situation is being kept under review and additional monitoring has been introduced.

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 and the north Solway coast. In west Cumbria, combining dose rates and occupancy times, it is still considered that those who occupy boats are representative of those who receive the highest external exposures, because of the occupancy times involved, which are greater than for other activities, including bait digging. The maximum exposure, allowing for addition of dose due to other pathways such as fish consumption, would have been 0.08 mSv, as compared with 0.11 mSv reported for 1987 (Hunt, 1988). 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 1988 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 3900 h $year^{-1}$ over unshielded mud. Making an allowance for natural background, their external exposure in 1988 was 0.27 mSv. This was slightly higher than in 1987 (0.24 mSv); the effect of reduced dose rates at the boatyards due to declining concentrations of radiocaesium in sediments was offset by greater occupancy times. The exposure remained 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 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 1988 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 of fishing gear in 1988 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.

Table 11 Radioactivity in sediment from the Cumbrian coast and further afield, 1988.

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	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
Cumbria											
Maryport	(mud)	4	3 200	ND	28	52	490	15	20	1 600	48
Harrington	(")	4	4 000	"	27	95	560	18	22	1 000	71
Whitehaven	(")	4	6 000	"	23	72	560	21	28	2 100	53
St Bees	(sand)	4	480	"	3.9	2.6	11	ND	1.0	120	ND
Sellafield	(")	4	770	"	5.0	2.5	21	"	3.6	450	3.9
Seascale	(")	4	600	"	3.7	2.3	15	"	2.2	240	1.5
Newbiggin	(mud)	4	4 200	3.0	63	69	970	35	18	1 300	110
Millom	(")	4	1 300	0.7	15	31	240	10	7.2	470	24
Walney Island	(")	4	1 200	0.6	10	24	150	6.2	4.9	390	15
Flookburgh	(sand)	4	790	ND	1.9	ND	16	ND	2.9	270	ND
Lancashire and Merseyside											
Heysham	(mud)	4	1 200	"	5.0	1.0	55	3.7	5.2	460	"
Sunderland Pt	(")	4	930	0.2	2.8	ND	32	0.6	3.9	300	"
Skipool Creek	(")	4	2 000	ND	7.6	"	120	1.8	19	1 300	"
Fleetwood	(sand)	4	430	"	0.5	"	ND	ND	1.2	61	"
Blackpool	(")	4	250	"	ND	"	"	"	0.2	21	"
New Brighton	(")	4	270	"	"	"	"	"	ND	21	"
Rock Ferry	(mud)	4	2 000	"	5.4	"	51	5.3	13	950	"
South-west Scotland											
Garlieston	(mud)	4	1 500	"	11	3.9	180	4.6	18	520	14
Innerwell	(")	2	1 900	"	22	28	300	12	15	640	21
Kippford slipway	(")	4	2 000	"	14	13	210	4.7	11	660	20
" merse	(marsh)	4	3 300	0.8	25	9.1	340	16	93	1 900	36
Palnackie	(mud)	4	2 400	0.4	23	29	370	11	23	1 100	28
Carsethorn	(")	2	1 300	ND	8.0	12	160	5.4	10	530	11
Northern Ireland											
Strangford Lough*	(mud)	1	600	"	ND	ND	ND	ND	2.8	99	ND
Strangford Lough**	(")	2	520	"	"	"	"	"	1.4	31	"
Groomsport	(sand)	2	310	"	"	"	"	"	ND	18	"
Carlingford Lough	(mud)	2	1 100	"	"	"	16	2.0	10	224	"
Dundrum Bay	(sand)	2	720	"	"	"	ND	ND	ND	25	"
Larne Lough	(mud)	2	980	"	"	"	12	2.1	12	230	"

Table 11 (continued)

Sampling point and sediment type		No. of sampling observations†	Mean radioactivity concentration (dry), Bq kg^{-1}							
			^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Cumbria										
Maryport	(mud)	4	38	27	190	970	NA	1 300	ND	3.6
Harrington	(")	4	29	19	NA	NA	"	720	NA	NA
Whitehaven	(")	4	36	21	190	810	"	1 000	3.2	3.6
St Bees	(sand)	4	4.9	1.9	NA	NA	"	150	NA	NA
Sellafield	(")	4	6.9	3.6	"	"	"	250	"	"
Seascale	(")	4	5.8	4.1	"	"	"	200	"	"
Newbiggin	(mud)	4	58	40	300	1 300	25 000	1 600	ND	7.0
Millom	(")	4	12	8.8	NA	NA	NA	390	NA	NA
Walney Island	(")	4	11	5.8	"	"	"	300	"	"
Flookburgh	(sand)	4	0.7	0.6	"	"	"	59	"	"
Lancashire and Merseyside										
Heysham	(mud)	4	5.9	3.9	22	110	"	150	ND	0.44
Sunderland Pt	(")	4	2.0	3.9	NA	NA	"	88	NA	NA
Skipool Creek	(")	4	13	6.2	"	"	"	310	"	"
Fleetwood	(sand)	4	ND	0.6	"	"	"	20	"	"
Blackpool	(")	4	"	ND	"	"	"	4.6	"	"
New Brighton	(")	4	"	"	"	"	"	2.0	"	"
Rock Ferry	(mud)	4	5.6	4.0	"	"	"	190	"	"
South-west Scotland										
Garlieston	(mud)	4	12	7.6	50	240	"	320	1.1	1.1
Innerwell	(")	2	15	8.3	NA	NA	"	430	NA	NA
Kippford slipway	(")	4	13	9.5	55	250	"	350	0.91	1.1
" merse	(marsh)	4	30	16	120	590	"	750	1.4	2.1
Palnackie	(mud)	4	23	16	95	450	"	590	1.2	1.2
Carsethorn	(")	2	10	6.0	NA	NA	"	180	NA	NA
Northern Ireland										
Strangford Lough*	(mud)	1	ND	ND	1.1	6.1	"	4.5	0.013	0.015
Strangford Lough**	(")	2	"	"	0.27	1.6	"	0.85	ND	0.0042
Groomsport	(sand)	2	"	"	NA	NA	"	0.88	NA	NA
Carlingford Lough	(mud)	2	"	"	2.5	15	"	7.0	ND	ND
Dundrum Bay	(sand)	2	"	"	NA	NA	"	ND	NA	NA
Larne Lough	(mud)	2	"	"	"	"	"	14	"	"

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

4.1.4 Porphyra/laverbread pathway

No harvesting of *Porphyra* in the Sellafield vicinity, for consumption after being made into laverbread, was reported in 1988; 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 1988 are presented in Table 13. Samples of laverbread from the major manufacturers are regularly collected from markets in South Wales and analysed. Results for 1988 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.

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 1988 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

Table 12 Beta radiation dose rates on contact with fishing gear on vessels operating off Sellafield, 1988.

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	0.05
B	Nets	7	0.06
	Ropes	7	0.09
D	Gill nets	4	0.10
	Pots	4	0.11
E	Nets	3	0.07
	Gill nets	3	0.07
I	Nets	4	0.04
K	Gill nets	5	0.19
L	Gill nets	2	0.04
	Pots	2	0.07
M	Nets	4	0.05
	Ropes	4	0.05
N	Nets	1	0.06
	Gill nets	2	0.03
	Pots	2	0.06
P	Nets	4	0.03
Q	Gill nets	2	0.09

†See sub-section 3.3 for definition.

Table 13 Radioactivity in *Porphyra* from UK shorelines of the Irish Sea, 1988.

Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet), $Bq\ kg^{-1}$									
		Total beta	^{54}Mn	^{60}Co	^{90}Sr	$^{95}Zr + {}^{95}Nb$	^{99}Tc	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb
Braystones South	12	350	0.1	3.2	NA	6.4	NA	0.8	160	0.3	2.2
Seascale	52*	NA	0.04	3.4	"	13	"	1.0	190	0.02	8.0
St Bees	4	310	ND	1.4	0.60	6.9	1.7	0.9	120	0.2	4.0
Knock Bay	4	180	"	ND	NA	ND	NA	ND	2.2	ND	ND

Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet), $Bq\ kg^{-1}$									
		^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu	^{238}Pu	$^{239}Pu + {}^{240}Pu$	^{241}Pu	^{241}Am	^{242}Cm	$^{243}Cm + {}^{244}Cm$
Braystones South	12	0.2	12	2.3	0.3	2.2	10	180	14	0.066	0.032
Seascale	52*	0.09	12	3.3	0.1	NA	NA	NA	12	NA	NA
St Bees	4	0.05	8.0	2.4	ND	1.8	7.8	"	13	ND	0.036
Knock Bay	4	0.07	1.0	ND	"	NA	NA	"	0.4	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.

measurements in 1988 on marine plants from shorelines of the Irish Sea and further afield. Although small quantities of samphire and *Rhodymenia* may be eaten, concentrations of radioactivity are of negligible radiological significance. *Fucus* seaweeds are useful indicators particularly of fission product radionuclides other than ruthenium-106; samples of *Fucus vesiculosus* are collected both in the Sellafield vicinity and further afield, and the results are presented here. Monitoring in Scotland is carried out on behalf of departments of the Scottish Office. Analyses of samples collected in Northern Ireland are carried out on behalf of the DOE(NI).

Table 14 Radioactivity in laverbread from South Wales, 1988.

Manufacturer	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}	
		Total beta	^{137}Cs
A	4	77	0.8
C	4	60	0.2
D	4	49	0.2
E	1	100	ND

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, 1988.

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	3	Sellafield: 0.23 Coulderton: 2.3
February	3	
March	2	
April	2	
May	0	
June	2	Sellafield: 0.12
July	0	
August	3	Sellafield: 0.33
September	3	Nethertown: 0.16
October	0	
November	1	
December	0	

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 uranium and thorium 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 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 the discharges from Sellafield (sub-section 4.1.2). We regularly monitor dose rates in relevant areas including muddy creeks where houseboats are moored, and some of these measurements are supported by analyses of sediment. In 1988, we continued to investigate the fish and shellfish consumption pathway by analysing locally-obtained samples, including analyses for isotopes of thorium.

Results for 1988 are shown in Table 17(a) and (b). The only radionuclides detected which were due to Springfields discharges were isotopes of thorium and protactinium-234m and 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 1988, including the Sellafield component, was about 0.27 mSv, slightly higher than for 1987 (0.24 mSv), due to greater occupancy times which offset the declining dose rates following reduced discharges from Sellafield. These occupancy times had become nearly full-time in 1988, and cannot, therefore, increase significantly further. 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 daugher 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. The radiological consequences of these disposals are negligible; moreover, no discharges from Capenhurst took place via Meols in 1988 (Table 1). However, we have established an environmental monitoring programme re-

Table 16 Radioactivity in marine plants from shorelines of the Irish Sea and further afield, 1988.

Type of seaweed and sampling point	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}									
		Total beta	^{54}Mn	^{60}Co	^{90}Sr	^{95}Zr + ^{95}Nb	^{99}Tc	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs
Fucus vesiculosus											
Sellafield	4	1 700	0.5	19	6.8	18	1 900	41	4.2	3.7	0.9
St Bees	4	820	0.1	8.0	4.3	8.4	720	12	1.0	1.9	0.4
Heysham	4	350	ND	0.7	NA	ND	NA	0.2	ND	0.6	0.5
Porthmadog	1	130	"	ND	"	"	"	ND	"	ND	ND
Port William	4	340	"	0.6	"	"	"	"	0.1	0.2	0.4
Garlieston	3	360	"	2.1	"	0.7	"	3.6	ND	1.2	0.6
Auchencairn	4	410	"	1.6	"	0.4	"	1.6	0.1	0.5	0.6
Ardglass	1	320	"	0.3	"	ND	"	ND	ND	ND	ND
Portrush	4	250	"	ND	"	"	"	"	"	"	"
Cape Wrath	1	260	"	"	"	"	"	"	"	"	"
Fucus serratus											
St Bees	1	700	0.4	16	"	2.4	"	30	1.0	2.9	0.6
Fucus spiralis											
Fishguard	1	180	ND	ND	"	ND	"	ND	ND	ND	ND
Garlieston	1	340	"	2.0	"	1.0	"	5.0	0.4	0.7	0.7
Ardglass	2	250	"	0.2	"	ND	"	ND	ND	ND	ND
Samphire											
Ravenglass	1	28	"	0.1	"	"	"	1.2	"	"	"
Heysham	1	120	"	0.2	"	"	"	ND	"	"	0.4
Rhodymenia spp.											
St Bees	2	740	"	2.9	"	28	"	110	1.6	0.4	1.4
Strangford Lough	4	780	"	ND	"	ND	"	ND	ND	ND	0.2
Ascophyllum nodosum											
Ardglass	1	350	"	0.4	"	"	"	"	"	"	ND

Type of seaweed and sampling point	No. of sampling observations†	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	28	3.5	10	ND	0.3	5.4	23	11	0.064	0.029
St Bees	4	18	0.9	NA	0.1	0.1	2.5	11	6.0	0.038	0.018
Heysham	4	27	ND	"	ND	0.1	0.60	2.8	1.5	0.0052	0.0050
Porthmadog	1	1.4	"	"	"	ND	NA	NA	ND	NA	NA
Port William	4	9.3	"	"	"	"	"	"	0.5	"	"
Garlieston	3	18	"	"	"	"	"	"	5.9	"	"
Auchencairn	4	24	"	"	"	0.1	"	"	3.2	"	"
Ardglass	1	4.1	"	"	"	ND	"	"	ND	"	"
Portrush	4	1.1	"	"	"	"	"	"	"	"	"
Cape Wrath	1	1.8	"	"	"	"	"	"	"	"	"
Fucus serratus											
St Bees	4	19	"	"	"	0.4	"	"	7.2	"	"
Fucus spiralis											
Fishguard	1	0.3	"	"	"	ND	"	"	ND	"	"
Garlieston	1	13	"	"	"	"	"	"	6.3	"	"
Ardglass	2	3.3	"	"	"	"	"	"	ND	"	"
Samphire											
Ravenglass	1	4.0	"	"	"	"	"	"	2.3	"	"
Heysham	1	26	"	"	"	"	"	"	6.1	"	"
Rhodymenia spp.											
St Bees	4	43	6.7	"	0.6	0.7	2.6	11	21	0.21	0.074
Strangford Lough	1	6.7	ND	"	ND	ND	0.087	0.42	0.96	ND	0.0018
Ascophyllum nodosum											
Ardglass	1	7.0	"	"	"	"	NA	NA	0.4	NA	NA

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

Table 17(a) Radioactivity in environmental materials near Springfields, 1988.

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			Total beta	^{60}Co	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{154}Eu	^{155}Eu	^{228}Th
Bass	Ribble estuary	1	150	ND	ND	ND	1.5	60	ND	ND	0.0025
Eel	" "	1	75	"	"	"	1.0	40	"	"	0.0020
Grey mullet	" "	1	150	"	"	"	0.78	24	"	"	0.0042
Sea trout	" "	1	130	"	"	"	0.79	18	"	"	0.0019
Shrimps	" "	1	200	"	"	"	0.40	13	"	"	0.024
Cockles	Lytham	1	180	"	"	"	ND	11	"	"	0.56
Mud	Pipeline outlet	4	33 000	6.2	41	"	14	820	4.5	2.5	53
	Becconsall	4	37 000	6.4	71	"	17	1 100	13	4.2	NA
	Skipool Creek	4	2 000	7.6	120	1.8	19	1 300	13	6.2	37
	Rock Ferry	4	2 000	5.4	51	5.3	13	950	5.6	4.0	38
	Penwortham	3	140 000	6.1	55	ND	15	830	ND	ND	NA
Sand	Lytham	1	740	1.3	9.4	"	2.7	150	"	3.0	17

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			^{230}Th	^{232}Th	^{234m}Pa	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Bass	Ribble estuary	1	0.0010	0.00068	ND	NA	NA	ND	NA	NA
Eel	" "	1	0.0011	0.00078	"	"	"	"	"	"
Grey mullet	" "	1	0.0010	0.0010	"	"	"	"	"	"
Sea trout	" "	1	0.00081	0.0011	"	"	"	"	"	"
Shrimps	" "	1	0.022	0.010	"	"	"	"	"	"
Cockles	Lytham	1	1.4	0.37	"	"	"	8.2	"	"
Mud	Pipeline outlet	4	290	67	75 000	36	172	234	0.28	0.66
	Becconsall	4	NA	NA	96 000	NA	NA	320	NA	NA
	Skipool Creek	4	83	39	ND	"	"	310	"	"
	Rock Ferry	4	71	42	"	"	"	190	"	"
	Penwortham	3	NA	NA	340 000	"	"	220	"	"
Sand	Lytham	1	30	18	700	"	"	37	"	"

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, 1988.

Location	No. of sampling observations†	μGy h^{-1}
Pipeline outlet	4	0.14
Freckleton	4	0.17
Becconsall	5	0.17
Lytham	4	0.16
Penwortham	3	0.15

†See sub-section 3.3 for definition.

lated to the pathways which could be of radiological significance; in 1988, this included monitoring the Rivacre Brook. 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 1988 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 consum-

Table 18 Radioactivity in environmental materials in the vicinity of the Wirral, 1988.

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
			Total beta	^{60}Co	^{99}Tc	^{106}Ru	^{110m}Ag	^{155}Eu
Shrimps	Hoylake	2	68	ND	0.32	ND	0.2	ND
Cockles	Dee Estuary	2	65	0.6	0.98	1.2	ND	"
Fucus spiralis	Hoylake	2	220	0.3	16	1.1	"	"
Fucus serratus	Little Orme	2	330	0.3	23	ND	"	"
Water weeds								
Cladophora rupestris	Rivacre Brook	3	190	0.2	12	"	"	"
Elodea canadensis	"	1	130	NA	13	NA	NA	NA
Potamogeton gramineus	"	2	120	ND	11	ND	ND	ND
Mud	"	3	1400	3.6	350	"	"	0.8

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
			^{134}Cs	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{243}Cm + ^{244}Cm
Shrimps	Hoylake	2	ND	5.7	NA	NA	ND	NA
Cockles	Dee Estuary	2	0.4	9.0	0.43	2.1	4.3	0.0070
Fucus spiralis	Hoylake	2	0.4	18	NA	NA	2.1	NA
Fucus serratus	Little Orme	2	0.2	6.0	"	"	ND	"
Water weeds								
Cladophora rupestris	Rivacre Brook	3	0.4	1.3	"	"	"	"
Elodea canadensis	"	1	NA	NA	"	"	NA	"
Potamogeton gramineus	"	2	0.4	1.0	"	"	ND	"
Mud	"	3	12	41	"	"	"	"

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

ers in the vicinity of the Wirral in 1988 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. Small concentrations of technetium-99 from Capenhurst were detected in weeds from the Rivacre Brook, 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; fishermen continue to constitute the critical group in view of their regular occupancy of intertidal areas and consumption of local seafood. 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 1988 are presented in Table 19(a) and (b).

Concentrations of artificial radionuclides in the Chapelcross vicinity are mostly due to Sellafield dis-

Table 19(a) Radioactivity in environmental materials in the vicinity of Chapelcross, 1988.

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	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs
Flounder	Seafield	4	190	ND	ND	ND	ND	ND	ND	1.7	91
Salmon	"	1	120	"	"	"	"	"	"	ND	0.9
Sea trout	"	2	130	"	"	"	"	"	"	1.1	18
Shrimps	"	4	89	"	0.03	"	"	0.2	"	0.5	24
Fucus spiralis	"	1	310	0.2	1.5	"	2.1	ND	0.9	0.5	30
Fucus vesiculosus	"	3	390	ND	0.8	"	1.7	"	ND	0.9	63
Mud	"	4	1700	"	7.1	5.9	130	"	3.1	15	1100
Sand	"	4	620	"	0.2	ND	ND	"	ND	2.0	160

Material	Sampling point	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
Flounder	Seafield	4	ND	ND	ND	NA	NA	ND	NA	NA
Salmon	"	1	"	"	"	"	"	"	"	"
Sea trout	"	2	"	"	"	0.00028	0.0010	0.0015	ND	ND
Shrimps	"	4	"	"	"	NA	NA	ND	NA	NA
Fucus spiralis	"	1	"	"	"	"	"	"	"	"
Fucus vesiculosus	"	3	"	"	"	0.75	3.6	3.8	0.0092	0.010
Mud	"	4	4.9	7.8	2.5	31	160	210	ND	0.31
Sand	"	4	ND	ND	ND	2.4	12	17	"	0.048

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, 1988.

Location	Ground type	No. of sampling observations†	μGy h^{-1}
Seafield	Mud	4	0.12
Seafield	Salt marsh	4	0.12
Battle Hill	Sandy mud	1	0.11
Browhouses	Mud	3	0.12
Dornoch Brow	Sandy mud	4	0.10
Dornoch Brow	Salt marsh	4	0.12

†See sub-section 3.3 for definition.

charges, 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 1988 were generally less than those in 1987, reflecting reductions in Sellafield discharges. Exposure of the critical group in 1988, making the maximising assumption of additivity of the two pathways, amounted to about 0.14 mSv, which is within the ICRP-recommended principal 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, 1989), 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 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 1988, 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

Table 20 Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Harwell, 1988.

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
			Total beta	^{60}Co	^{134}Cs	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Chub	Marlow	1	87	ND	ND	0.5	0.00008	0.00019	0.00032	0.00004	0.00003
	Staines	1	92	"	"	1.1	NA	NA	ND	NA	NA
Pike	Staines	2	110	"	0.1	1.1	"	"	"	"	"
Roach	Marlow	1	120	"	ND	0.7	"	"	"	"	"
Nuphar lutea	Sutton Courtenay	2	64	0.7	"	0.7	"	"	"	"	"
	Marlow	1	49	0.3	"	0.7	"	"	"	"	"
	Staines	2	48	0.2	0.2	0.4	"	"	"	"	"
Sediment	Sutton Courtenay	1	870	26	4.4	560	"	"	"	"	"
	Marlow	1	290	2.5	ND	46	"	"	"	"	"
	Staines	1	90	ND	"	5	"	"	"	"	"

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

Table 21 Radioactivity in environmental materials from the vicinity of Winfrith, 1988.

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
			Total beta	^{54}Mn	^{55}Fe	^{58}Co	^{60}Co	^{65}Zn	^{99}Tc	^{106}Ru	^{125}Sb
Plaice	Weymouth Bay	1	100	ND	1.0	ND	ND	5.9	NA	ND	ND
Crabs	Weymouth Bay	8	73	2.3	27	0.3	16	200	0.1	"	"
	Anvil Point	1	110	1.6	9.2	ND	12	120	NA	"	"
Spider crabs	Weymouth Bay	2	86	0.3	NA	ND	68	82	"	"	"
	Studland	1	96	1.1	"	"	81	100	"	"	"
Lobsters	Weymouth Bay	2	94	1.5	5.4	1.1	11	170	7.6	"	"
Oysters	Poole	2	72	ND	NA	ND	1.0	110	NA	"	"
Cockles	Poole	2	48	"	"	"	15	4.0	"	"	"
Mussels	Lee-on-Solent	1	64	1.0	"	"	12	13	"	"	"
Scallops	Weymouth Bay	4	100	30	65	0.5	9.8	140	"	"	"
Whelks	Weymouth Bay	5	100	0.3	9.5	ND	11	150	"	"	"
	Poole Bay	2	88	0.6	11	"	12	190	"	"	"
Fucus serratus	Arish Mell	2	280	15	12	5.9	84	50	"	"	"
	Kimmeridge	2	280	21	6.4	5.0	73	36	"	"	"
	Swanage	2	240	12	9.4	4.1	72	42	"	"	"
	Hengistbury Head	2	250	2.4	3.0	1.2	26	10	"	"	"
	Bognor Regis	2	220	0.5	1.6	ND	9.9	1.6	"	0.6	"
	Sandgate	2	280	0.4	NA	"	10	1.8	"	3.0	"
	Weymouth	2	220	6.9	18	2.5	37	17	"	ND	"
	Chesil	2	220	ND	NA	ND	4.2	0.4	"	"	"
	Lyme Regis	2	250	"	ND	"	2.3	0.3	"	"	"
Fucus vesiculosus	Bognor Regis	1	NA	0.3	NA	"	5.7	ND	"	"	"
	Lyme Regis	1	"	ND	"	"	0.9	"	"	"	"
Mud	Kimmeridge	1	500	5.9	"	"	37	62	"	"	"
	Poole Harbour	2	160	2.7	"	"	23	3.4	"	"	"
	Hardway	2	620	0.5	"	"	22	0.9	"	2.9	1.0
	Rye Harbour	2	610	3.2	"	"	21	2.6	"	9.0	0.9
Muddy sand	Kimmeridge	1	530	2.2	"	"	42	28	"	ND	ND

Table 21 (continued)

Material	Sampling point	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	^{242}Cm	^{243}Cm + ^{244}Cm
Plaice	Weymouth Bay	1	ND	0.2	ND	NA	NA	ND	NA	NA
Crabs	Weymouth Bay	8	"	0.1	"	0.00069	0.0021	0.0034	0.0013	0.00031
	Anvil Point	1	"	ND	"	NA	NA	ND	NA	NA
Spider crabs	Weymouth Bay	2	"	0.1	"	"	"	"	"	"
	Studland	1	"	ND	"	"	"	"	"	"
Lobsters	Weymouth Bay	2	"	0.3	"	0.00042	0.0012	0.0091	ND	0.00039
Oysters	Poole	2	"	ND	"	NA	NA	ND	NA	NA
Cockles	Poole	2	"	0.8	"	"	"	"	"	"
Mussels	Lee-on-Solent	1	"	ND	"	"	"	"	"	"
Scallops	Weymouth Bay	4	"	0.1	"	0.0036	0.011	0.0045	0.00007	0.00026
Whelks	Weymouth Bay	5	"	ND	"	0.0013	0.0046	0.0041	0.00007	0.00034
	Poole Bay	2	"	"	"	0.0016	0.0055	0.0050	0.00009	0.00033
Fucus serratus	Arish Mell	2	"	"	"	NA	NA	ND	NA	NA
	Kimmeridge	2	"	"	"	"	"	"	"	"
	Swanage	2	"	"	"	"	"	"	"	"
	Hengistbury Head	2	"	"	"	"	"	"	"	"
	Bognor Regis	2	"	0.2	"	"	"	"	"	"
	Sandgate	2	"	0.3	"	"	"	"	"	"
	Weymouth	2	"	0.3	"	"	"	"	"	"
	Chesil	2	"	0.1	"	"	"	"	"	"
	Lyme Regis	2	"	0.2	"	"	"	"	"	"
Fucus vesiculosus	Bognor Regis	1	"	0.2	"	"	"	"	"	"
	Lyme Regis	1	"	0.4	"	"	"	"	"	"
Mud	Kimmeridge	1	"	1.9	"	"	"	"	"	"
	Poole Harbour	2	0.4	2.7	1.4	0.19	0.79	0.57	ND	ND
	Hardway	2	0.4	7.6	ND	NA	NA	ND	NA	NA
	Rye Harbour	2	ND	4.3	1.0	0.17	0.66	0.45	0.0053	0.046
Muddy sand	Kimmeridge	1	"	3.8	ND	NA	NA	ND	NA	NA

Mean gamma dose rate in air at 1 m over intertidal sediments:
Poole Harbour (3 sampling observations†): 0.065 μGy h^{-1}
Kimmeridge (2 sampling observations†): 0.086 μGy h^{-1}
Hardway (2 sampling observations†): 0.080 μGy h^{-1}
Rye Harbour (2 sampling observations†): 0.076 μGy h^{-1}

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

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 1988, 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}.

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 pressure circuit. These wastes are disposed of under authorisation to deep water in Weymouth Bay.

In 1988, the wastes were subjected to additional treatment and storage, mainly to allow the short-lived zinc-65 to decay before release; these procedures were undertaken as a further step towards application of 'best practicable means' (BPM) to reduce discharges as required by Authorising Departments (Smith *et al.*, in press). 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 these radionuclides, particularly zinc-65, declined in 1988 as compared with previous years; this was likely to have been due to the additional treatment procedures noted above. The radiation dose to the critical group of fish and shellfish consumers (Smith and Hunt, 1989) was about 0.05 mSv, or 5% 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.

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 Execu-

Table 22 Radioactivity in environmental materials from the vicinity of Dounreay, 1988.

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	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs
Area of outfall												
Cod	4	130	ND	ND	ND	ND	ND	ND	ND	ND	0.3	3.9
Crabs	4	82	"	"	0.1	"	"	1.4	15	"	ND	0.8
Lobsters	4	110	"	"	0.6	"	"	7.1	88	"	"	1.4
Sandside Bay												
Winkles	4	160	0.3	"	3.3	"	"	55	200	"	0.1	0.3
Limpets	4	160	0.4	"	3.1	1.2	"	52	94	0.3	0.1	1.3
Fucus vesiculosus	4	360	5.0	0.6	3.7	3.0	"	8.3	20	ND	0.3	2.6
Shell sand	4	360	ND	ND	0.5	ND	"	5.2	0.3	"	0.7	9.5
Oigins Geo												
Enteromorpha spp	2	5200	38	0.7	35	220	5.2	3500	210	45	3.9	23
Sludge	3	41000	150	18	180	2600	ND	34000	4200	580	52	280
Brims Ness												
Winkles	4	160	0.4	ND	3.7	ND	"	47	200	ND	ND	0.1
Fucus vesiculosus	3	340	4.2	0.2	3.7	2.8	"	7.5	23	"	0.4	2.3
Fucus spiralis	1	200	1.7	ND	2.4	ND	"	ND	18	"	ND	1.4

Sampling point and 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
Area of outfall									
Cod	4	ND	ND	ND	0.00008	0.0003	0.0005	0.00003	0.00001
Crabs	4	"	"	"	0.0045	0.015	0.017	0.012	0.0008
Lobsters	4	1.2	"	"	0.0097	0.022	0.14	0.057	0.0064
Sandside Bay									
Winkles	4	5.5	"	"	0.17	0.38	0.57	0.31	0.021
Limpets	4	9.8	"	0.4	0.28	0.64	1.1	0.81	0.044
Fucus vesiculosus	4	5.3	"	0.2	NA	NA	ND	NA	NA
Shell sand	4	10	4.1	5.9	5.2	18	24	1.7	0.37
Oigins Geo									
Enteromorpha spp.	2	400	9.6	31	NA	NA	44	NA	NA
Sludge	3	6200	55	180	210	610	430	320	14
Brims Ness									
Winkles	4	6.2	ND	ND	0.16	0.40	0.78	0.29	0.025
Fucus vesiculosus	3	3.6	"	"	NA	NA	ND	NA	NA
Fucus spiralis	1	ND	"	"	"	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediment: Oigins Geo (4 sampling observations†): 0.17 μGy h^{-1}

ND = not detected.
NA = not analysed.
*Except for sediments for which dry concentrations apply.
†See sub-section 3.3 for definition.

tive). In 1988, discharges of total activity and strontium-90 from Dounreay were less than in 1987 but discharges of alpha activity were slightly more, reflecting the campaigns of reprocessing of reactor fuel. All discharges remained well within authorised limits. Our surveys near Dounreay are carried out on behalf of departments of the Scottish Office. Monitoring in 1988 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.

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 1988 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 1988, we carried out monitoring of sludge and seaweed at Oigin's Geo; concentrations of radioactivity were greater than in 1987 but still consistent with the range of levels expected in these materials 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 also 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, limpets and seaweed were sampled as indicator materials. Radiocaesium concentrations are mainly due to discharges from Sellafield. Other radionuclides detected, including transuranics, mainly reflect Dounreay discharges. The radiological significance of fish and shellfish consumption continued to be low: for high-rate consumers the radiation dose was less than 0.02 mSv or 2% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$.

6. Nuclear power stations operated by the electricity boards

All but two of these power stations are in England or Wales and are operated by the Central Electricity Generating Board. The power stations at Hunterston and Torness are operated by the South of Scotland Electricity Board.

6.1 Berkeley, Gloucestershire and Oldbury, Avon

Liquid radioactive wastes from both of these stations are generally similar in composition and 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 silt. In addition, measurements of external exposure are supported by analyses of intertidal mud, and *Fucus vesiculosus* is collected as an indicator material.

Data for 1988 are presented in Table 23. The only artificial radioactivity detected in fish and shellfish was due to 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

Table 23 Radioactivity in environmental materials and gamma dose rates near Berkeley and Oldbury nuclear power stations, 1988.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}									
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{125}Sb	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am
Dab	1	92	ND	ND	ND	ND	ND	0.3	ND	NA	NA	ND
Flounders	3	100	"	"	"	"	"	0.9	"	"	"	"
Grey mullet	1	140	"	"	"	"	"	1.1	"	"	"	"
Plaice	1	93	"	"	"	"	"	1.0	"	"	"	"
Eels	2	82	"	"	"	"	"	1.8	"	"	"	"
Shrimps	3	110	"	"	"	"	0.05	1.1	"	"	"	"
Fucus vesiculosus	3	240	0.6	4.3	1.5	"	3.2	19	"	"	"	"
Mud: area of outfalls	6	810	ND	ND	ND	0.8	5.0	61	1.7	"	"	"
Lydney	2	800	"	"	"	ND	2.2	35	1.8	0.13	0.71	0.50

Mean gamma dose rate in air at 1 m over intertidal mud (12 sampling observations†): 0.086 μGy h^{-1}

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

Table 24 Radioactivity in environmental materials and gamma dose rates near Bradwell nuclear power station, 1988.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{106}Ru	^{110m}Ag	^{125}Sb
Mixed fish	10	120	ND	ND	ND	ND	ND	ND
Oysters	3	66	"	"	17	"	6.4	"
Whelks	2	89	"	0.4	ND	"	4.9	"
Fucus vesiculosus	2	320	"	1.3	0.7	"	0.2	"
Sediment	4	840	0.9	10	ND	16	ND	1.1

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	10	0.2	2.2	ND	NA	NA	ND	NA
Oysters	3	ND	0.3	"	0.0011	0.0038	0.011	0.00043
Whelks	2	"	0.5	"	NA	NA	ND	NA
Fucus vesiculosus	2	0.1	1.9	"	"	"	"	"
Sediment	4	1.6	27	2.2	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediments (7 sampling observations†): 0.075 μGy h^{-1}

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

intertidal sediment, and *Fucus vesiculosus* is analysed as an indicator material.

Measurements for 1988 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.

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 from both 'A' and 'B' stations are made via the same outfall 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 occupany 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 has been analysed as an indicator material. The results for 1988 are given in Table 25.

Table 25 Radioactivity in environmental materials and gamma dose rates near Dungeness nuclear power station, 1988.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs
Cod	1	130	ND	ND	ND	ND	ND	ND	ND
Dab	1	130	"	"	0.5	"	"	"	0.2
Plaice	2	100	"	0.04	0.1	"	"	"	0.1
Shrimps	1	100	"	0.3	3.4	"	"	"	ND
Cockles	1	60	"	7.1	2.2	"	"	"	"
Whelks	2	83	"	1.6	2.9	3.2	0.5	"	"
Fucus serratus	2	280	0.4	10	1.8	3.0	ND	"	"
Sand	2	210	0.3	2.8	ND	ND	"	"	"
Mud	2	610	3.2	21	2.6	9.0	"	0.9	"

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Cod	1	1.0	ND	NA	NA	ND	NA	NA
Dab	1	0.8	"	"	"	"	"	"
Plaice	2	0.6	"	"	"	"	"	"
Shrimps	1	0.7	"	"	"	"	"	"
Cockles	1	0.3	"	"	"	"	"	"
Whelks	2	0.04	"	"	"	"	"	"
Fucus serratus	2	0.3	"	"	"	"	"	"
Sand	2	0.8	"	"	"	"	"	"
Mud	2	4.3	1.0	0.17	0.66	0.45	0.0053	0.046

Mean gamma dose rate in air at 1 m over intertidal sand (6 sampling observations†): 0.060 μGy h^{-1}

Mean gamma dose rate in air at 1 m over intertidal silt in Rye Harbour (2 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.

Concentrations of radiocaesium are attributable to discharges from the station 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, silt 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 less than 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 AGR s. 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 1988 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 1988 would have been less than those of high-rate fish and shellfish consumers, at less than 0.002 mSv.

6.5 Heysham, Lancashire

This establishment comprises two, essentially separate, nuclear power stations both powered by AGR s. The first station came into operation in 1983; the second commenced operation during 1988, and only small discharges were made (Table 1). Discharges of liquid radioactive waste from both stations are made under authorisation to Morecambe Bay via the 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.

Table 26 Radioactivity in environmental materials and gamma dose rates near Hartlepool nuclear power station, 1988.

Material	No. of sampling observations†	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	97	ND	0.1	1.3	ND	NA	NA	ND	NA	NA
Cod	2	140	ND	0.4	4.3	"	0.00003	0.00021	0.00024	ND	ND
Whiting	1	110	"	0.5	6.0	"					
Crabs	2	76	2.0	ND	0.6	"	0.00053	0.0028	0.0018	"	"
Shrimps	1	100	ND	"	1.2	"	0.00016	0.00095	0.00094	ND	ND
Winkles	2	100	"	"	0.9	"	0.0066	0.032	0.023	"	0.00017
Fucus vesiculosus	2	240	"	0.1	1.3	"	NA	NA	ND	NA	NA
Sand/coal	2	260	"	0.2	6.2	0.2	"	"	"	"	"
Mud	2	900	"	2.9	51	2.5	"	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediment (6 sampling observations†): 0.082 μGy h^{-1}

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

The results for 1988 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 1988 of members of the critical group of fish and shellfish consumers in the Morecambe Bay area was about 0.11 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 AGR s. Liquid radioactive waste discharges are made via the same outfall and for the purposes of our environmental monitoring they are considered together. Those mem-

Table 27 Radioactivity in environmental materials and gamma dose rates near Heysham nuclear power station, 1988.

Material	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
Plaice	4	120	ND	ND	ND	ND	ND	0.4	20
Bass	1	220	"	"	"	"	"	2.5	126
Whitebait	1	150	"	"	"	"	"	0.8	25
Cockles	4	110	"	2.7	"	6.0	0.3	0.3	14
Mussels	4	64	"	0.7	"	5.6	0.4	ND	5.4
Fucus vesiculosus	4	350	"	0.7	"	0.3	0.6	0.5	27
Samphire	1	120	"	0.2	"	ND	ND	0.4	26
Sediment:									
Sunderland Point	4	930	0.2	2.8	"	32	0.7	3.9	300
Half Moon Bay	5	1200	ND	4.8	0.8	60	4.3	5.4	470
Turf:									
Tummer Hill Marsh	1	1200	"	ND	ND	ND	ND	15	600

Material	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
Plaice	4	ND	ND	NA	NA	ND	NA	NA
Bass	1	"	"	"	"	"	"	"
Whitebait	1	"	"	0.055	0.25	0.35	ND	0.0009
Cockles	4	"	0.3	0.9	4.3	10	0.017	0.041
Mussels	4	"	ND	0.20	1.0	1.5	ND	0.0049
Fucus vesiculosus	4	"	0.1	0.60	2.8	1.5	0.0050	0.0050
Samphire	1	"	ND	NA	NA	ND	NA	NA
Sediment:								
Sunderland Point	4	2.0	3.9	"	"	88	"	"
Half Moon Bay	5	6.1	3.9	22	110	150	ND	0.44
Turf:								
Tummer Hill Marsh	1	ND	ND	NA	NA	65	NA	NA

Mean gamma dose rate in air at 1 m over intertidal sediment:
Heysham vicinity (24 sampling observations†): 0.10 μGy h^{-1}
Sunderland Point (4 sampling observations†): 0.11 μGy h^{-1}

NA = not analysed.
ND = not detected.
*Except for sediments for which dry concentrations apply.
†See sub-section 3.3 for definition.

bers 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 1988, presented in Table 28, indicate concentrations of radionuclides representing the combined effect of releases from the station, 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}.

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 AGR s. 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 1988 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 1988 following the reductions in Sellafield discharges. In 1988, the exposure of members of the critical group of fish and shellfish consumers near Hunterston was low, at about 0.02 mSv or 2% of the principal ICRP-recommended dose limit of 1 mSv year^{-1}. Radiocaesium concentrations detected in fish from farms

Table 28 Radioactivity in environmental materials and gamma dose rates near Hinkley Point nuclear power station, 1988.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{90}Sr	^{110m}Ag
Flounders	2	140	ND	ND	ND	NA	ND
Eels	1	69	"	"	"	"	"
Shrimps	2	100	"	"	"	0.4	"
Fucus vesiculosus	3	220	0.9	2.0	0.5	NA	0.2
Sediment	3	390	0.9	ND	ND	"	ND

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}				
		^{134}Cs	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am
Flounders	2	ND	1.2	NA	NA	ND
Eels	1	0.3	2.0	"	"	"
Shrimps	2	0.1	1.2	0.00029	0.00074	0.0012
Fucus vesiculosus	3	0.4	4.2	NA	NA	ND
Sediment	3	1.5	16	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediment (8 sampling observations†): 0.082 μGy h^{-1}

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

which are supplied by station cooling water were slightly higher than in previous years, but the increase was of negligible radiological significance. 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 1988 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 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

Table 29 Radioactivity in environmental materials and gamma dose rates near Hunterston nuclear power station, 1988.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{54}Mn	^{58}Co	^{59}Fe	^{60}Co	^{65}Zn	^{106}Ru	^{110m}Ag	^{134}Cs
Cod	1	99	ND	ND	ND	ND	ND	ND	ND	0.5
Grey mullet	1	140	"	"	"	"	"	"	"	0.9
Saithe	2	140	"	"	"	"	"	"	"	0.7
Turbot (fish farm)	4	130	"	"	"	"	"	"	"	3.2
Winkles	4	93	2.8	"	"	2.4	4.8	"	7.0	0.4
Nephrops	2	69	ND	"	"	ND	ND	"	ND	ND
Crabs	1	67	"	"	"	"	0.3	"	2.2	"
Oysters	1	60	"	"	"	"	3.5	"	5.0	"
Fucus spiralis	4	330	11	0.6	0.2	3.6	6.5	0.7	1.0	2.2
Sand	4	270	2.1	ND	ND	1.2	ND	ND	ND	2.6

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
		^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Cod	1	12	NA	NA	ND	NA	NA
Grey mullet	1	12	"	"	"	"	"
Saithe	2	14	"	"	"	"	"
Turbot (fish farm)	4	18	"	"	"	"	"
Winkles	4	5.1	0.042	0.14	0.058	0.011	0.0043
Nephrops	2	4.3	NA	NA	ND	NA	NA
Crabs	1	2.6	"	"	"	"	"
Oysters	1	1.2	"	"	"	"	"
Fucus spiralis	4	13	0.16	0.64	0.13	0.034	0.0064
Sand	4	35	NA	NA	ND	NA	NA

Mean gamma dose rate in air at 1 m over intertidal sediment (8 sampling observations†): 0.086 μGy h^{-1}

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

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 were small in 1988, and well within the limits 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 1988 are shown in Table 31. Any effects of discharges from the station were not discernible above the concentrations of artificial radionuclides due to fallout and the distant effects of Sellafield discharges. Radiation exposure of the critical group of fish and shellfish consumers due to these combined samples was low, at less than 0.005 mSv, or 0.5% 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 1988. 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

Table 30 Radioactivity in environmental materials and gamma dose rates near Sizewell nuclear power station, 1988.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}										
		Total beta	^{60}Co	^{65}Zn	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am
Flounder	1	97	ND	ND	ND	ND	ND	0.18	2.5	NA	NA	ND
Lobsters	2	81	"	"	"	1.4	"	ND	0.87	"	"	"
Shrimps	1	66	"	"	"	ND	"	"	1.2	0.00007	0.00048	0.00026
Crabs	2	86	0.4	"	"	"	0.9	"	ND	NA	NA	ND
Oysters	1	67	ND	1.1	"	3.8	ND	"	0.84	"	"	"
Whelks	1	110	"	ND	"	3.3	"	"	ND	"	"	"
Mud	2	760	4.4	"	13	ND	"	2.1	28	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sand/shingle (10 sampling observations†): 0.057 μGy h^{-1}

Mean gamma dose rate in air at 1 m over intertidal silt in Southwold harbour (2 sampling observations†): 0.074 μGy h^{-1}

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

Trawsfynydd continued during 1988, 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.

Discharges of radiocaesium from the power station increased in 1988 as compared with those in 1987 (Table 1). These increases were within authorised limits. There were consequent increases 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 these changes, however, concentrations of radiocaesium in trout, averaged over the whole year, were lower than those in 1987 (Hunt, 1988). This is thought to be due to the time required for fish to respond to the lower concentrations in lake water in 1987. 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 1988 members of the critical group of fish consumers received about 0.07 mSv, which is within the ICRP-recommended principal dose limit of 1 mSv year^{-1}. This reduced exposure, as compared with 0.25 mSv in 1987 (Hunt, 1988), is mainly due to the decreased concentrations of radiocaesium in trout. However, the increases in concentrations of radiocaesium in lake water for 1988, noted above, may lead to somewhat higher concentrations

Table 31 Radioactivity in environmental materials and gamma dose rates near Torness nuclear power station, 1988.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}				
		Total beta	^{110m}Ag	^{134}Cs	^{137}Cs	^{155}Eu
Cod	2	140	ND	0.6	4.7	ND
Crabs	2	78	3.0	ND	0.7	"
Lobster	1	74	2.0	"	1.5	"
Nephrops	3	100	1.1	0.1	1.8	"
Winkles	3	95	4.9	ND	0.9	"
Fucus vesiculosus	2	270	ND	"	1.2	"
Mud						
Dunbar inner harbour	2	400	"	2.9	27	1.4
Eyemouth harbour	1	500	"	3.6	34	ND
Aberlady Bay	1	330	"	1.2	16	"
Sand						
Thornton Loch beach	2	240	"	ND	4.2	"

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}				
		^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Cod	2	NA	NA	ND	NA	NA
Crabs	2	"	"	"	"	"
Lobster	1	"	"	"	"	"
Nephrops	3	0.0013	0.0068	0.0062	0.00020	0.00009
Winkles	3	NA	NA	ND	NA	NA
Fucus vesiculosus	2	"	"	"	"	"
Mud						
Dunbar inner harbour		"	"	"	"	"
Eyemouth harbour		"	"	"	"	"
Aberlady Bay		"	"	"	"	"
Sand						
Thornton Loch beach	2	"	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediment (10 sampling observations†): 0.069 μGy h^{-1}

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

Table 32 Radioactivity in environmental materials near Trawsfynydd nuclear power station, 1988.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{90}Sr	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
Brown trout	10	240	ND	0.1	ND	5.3	ND	ND	20	130	ND
Brown trout (hatchery)	1	120	"	ND	"	0.4	"	"	ND	0.5	"
Rainbow trout	6	130	"	"	"	5.3	"	"	1.6	8.0	"
Rainbow trout (hatchery)	2	110	"	"	"	2.4	"	"	0.4	2.5	"
Perch	4	780	"	"	"	3.8	"	"	71	630	"
Rudd	2	420	"	"	"	NA	"	"	52	330	"
Fontinalis											
Afon Prysor	2	220	0.4	"	"	"	"	1.0	6.4	23	"
Gwylan Stream	2	690	10	160	1.3	"	29	46	10	72	13
Mud											
Near cooling water outfall	2	3300	3.8	140	ND	"	120	180	290	2300	52
Hot lagoon	2	2000	ND	32	"	"	ND	116	21	2300	16
South end of lake	1	1500	"	7.4	"	"	"	23	76	910	ND
Cae Adda boat mooring	1	3600	2.3	34	"	"	40	40	460	2200	"
Bailey bridge	1	3000	3.1	120	"	"	42	60	290	2700	19
Peat											
Hot lagoon	2	2000	ND	56	"	"	ND	85	64	800	ND
South end of lake	1	1100	"	23	"	"	"	38	44	610	NA
Bailey bridge	1	4200	"	50	"	"	"	66	500	3400	"
Gwylan Stream											
Mud and sand	3	1900	"	25	"	"	"	19	43	990	ND
Peat	1	1300	1.4	29	"	"	23	17	40	550	"
Water											
Hot Lagoon	12	NA	NA	NA	NA	0.16	NA	NA	0.066	0.21	NA
Cold Lagoon	12	"	"	"	"	0.15	"	"	0.053	0.17	"

Material	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
Brown trout	10	ND	ND	0.00071	0.0020	0.0017	0.0010	0.00007
Brown trout (hatchery)	1	"	"	0.00006	0.00033	0.00043	ND	ND
Rainbow trout	6	"	"	0.00009	0.00030	0.00053	0.00007	0.00020
Rainbow trout (hatchery)	2	"	"	0.00010	0.00042	0.00068	0.000065	0.000015
Perch	4	"	"	0.00076	0.0020	0.0030	0.0029	0.00010
Rudd	2	"	"	NA	NA	ND	NA	NA
Fontinalis								
Afon Prysor	2	"	1.7	"	"	"	"	"
Gwylan Stream	3	1.2	4.7	"	"	2.7	"	"
Mud								
Near cooling water outfall	2	15	11	"	"	31	"	"
Hot lagoon	2	12	3.2	6.9	34	46	0.29	0.95
South end of lake	1	ND	ND	NA	NA	ND	NA	NA
Cae Adda boat mooring	1	"	"	"	"	"	"	"
Bailey bridge	1	"	9.2	"	"	10	"	"
Peat								
Hot lagoon	2	"	ND	3.7	14	20	0.61	0.59
South end of lake	1	"	"	NA	NA	ND	NA	NA
Bailey bridge	1	"	"	"	"	"	"	"
Gwylan Stream								
Mud and sand	3	"	"	"	"	"	"	"
Peat	1	"	"	"	"	"	"	"
Water								
Hot Lagoon	12	NA	NA	"	"	"	"	"
Cold Lagoon	12	"	"	"	"	"	"	"

Mean gamma dose rate in air at 1 m over areas near lake shoreline (9 sampling observations†): 0.10 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.

in fish, and hence higher exposures, in 1989. 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, Gwynedd

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 1988 are presented in Table 33.

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 1988, following the reductions in Sellafield discharges in previous years. Data for 1988, including those from a habits survey, confirmed that the critical group consisted of high-rate fish and shellfish consumers, and that their radiation exposure was less than 0.02 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).

Table 33 Radioactivity in environmental materials and gamma dose rates near Wylfa nuclear power station, 1988.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{60}Co	^{65}Zn	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs
Plaice	2	100	ND	ND	ND	ND	ND	0.3	3.6
Spurdog	3	100	"	"	"	"	"	0.6	16
Crabs	2	81	0.1	0.1	"	5.6	"	0.1	1.9
Winkles	2	74	0.32	ND	"	3.2	"	ND	3.1
Mussels	2	46	ND	"	0.5	ND	"	"	1.0
Fucus vesiculosus	4	270	0.05	"	ND	"	"	0.2	5.2
Sediment: Cemlyn Bay	2	1200	2.1	"	20	"	2.2	14	430

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
		^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Plaice	2	ND	NA	NA	ND	NA	NA
Spurdog	3	"	0.00004	0.00019	0.00033	ND	ND
Crabs	2	"	NA	NA	ND	NA	NA
Winkles	2	"	0.090	0.047	0.68	0.0037	0.0028
Mussels	2	"	0.055	0.26	0.46	0.0040	0.0026
Fucus vesiculosus	4	"	NA	NA	0.13	NA	NA
Sediment: Cemlyn Bay	2	1.6	7.8	41	53	ND	ND

Mean gamma dose rate in air at 1 m over intertidal sediment (13 sampling observations†): 0.087 μGy h^{-1}

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

7. Defence establishments

We have continued our regular monitoring of the effects of liquid radioactive waste discharges to sea from naval establishments, and the results are reported in this section. Liquid radioactive wastes are also discharged from the Atomic Weapons Establishment, Aldermaston, to the River Thames; the critical public radiation exposure pathway is likely to be from drinking water, and monitoring is carried out by the DOE (DOE, 1989). In 1988, 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 1988 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 0.001 mSv or less than 0.1% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}.

7.2 Naval establishments

Liquid wastes containing small quantities of radioactivity are discharged from the establishments at Devonport, Faslane and Rosyth under authorisation/agreement with the relevant Authorising Departments (Table 1). 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.

The critical pathway for public radiation exposure near these establishments is via external exposure from sediments, the nuclide of main importance being cobalt-60. We therefore regularly carry out measurements of gamma dose rates; these are supported by analyses of sediments. Indicator shellfish and seaweed are also analysed where appropriate.

Results of monitoring in 1988 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

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, 1988.

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1})								
			Total beta	^{60}Co	^{134}Cs	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Chub	Marlow	1	87	ND	ND	0.5	0.00008	0.00019	0.00032	0.00004	0.00003
	Staines	1	92	"	"	1.1	NA	NA	ND	NA	NA
Roach	Marlow	1	120	"	"	0.7	"	"	"	"	"
Pike	Staines	2	110	"	0.1	1.1	"	"	"	"	"
Nuphar lutea	Pangbourne	1	46	0.2	ND	0.6	"	"	"	"	"
	Marlow	1	49	0.3	"	0.7	"	"	"	"	"
	Staines	2	48	0.2	0.22	0.4	"	"	"	"	"
Sediment	Pangbourne	1	440	1.0	ND	10	"	"	"	"	"
	Marlow	1	290	2.5	"	46	"	"	"	"	"
	Staines	1	92	ND	"	5	"	"	"	"	"

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

has been estimated by calculation based on concentrations of radionuclides in sediments (Hunt, 1984) as well as on occupancy times from habits surveys. In 1988, the exposure of those subject to the highest occupancies 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

Table 35 Radioactivity in environmental materials and gamma dose rates near naval establishments, 1988.

Establishment	Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}				
			Total beta	^{60}Co	^{106}Ru	^{131}I	^{134}Cs
Chatham	Sediment	2	NA	4.8	6.0	ND	2.3
Devonport	Mussels	1	68	1.0	ND	"	ND
	Fucus vesiculosus	2	NA	0.2	"	"	"
	Ascophyllum nodosum	1	200	0.5	"	"	"
	Sediment	6	NA	0.7	"	"	0.2
Faslane	Sediment	2	"	35	7.8	"	11
Rosyth	*Fucus vesiculosus*	2	"	0.09	ND	0.8	ND
	Sediment	9	"	0.6	"	ND	2.4
Holy Loch	Sediment	2	"	2.7	"	"	1.5

Establishment	Material	No. of sampling observations†	Mean radioactivitiy concentration (wet)*, Bq kg^{-1}		Mean gamma dose rate in air at 1 m	
			^{137}Cs	^{155}Eu	No. of sampling observations†	μGy h^{-1}
Chatham	Sediment	2	25	1.5	5	0.068
Devonport	Mussels	1	ND	ND	NP	NP
	Fucus vesiculosus	2	0.3	"	"	"
	Ascophyllum nodosum	1	0.2	ND	"	"
	Sediment	6	4.7	0.6	12	0.083
Faslane	Sediment	2	120	ND	8	0.079
Rosyth	*Fucus vesiculosus*	2	1.3	"	NP	NP
	Sediment	9	27	0.2	7	0.072
Holy Loch	Sediment	2	27	ND	12	0.075

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

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, 1988.

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			Total beta	^{14}C	^{35}S	^{58}Co	^{60}Co	^{134}Cs	^{137}Cs	^{241}Am
Chub	Maple Cross (R. Colne)	1	120	170	ND	ND	ND	ND	ND	ND
	Staines	1	92	NA	NA	"	"	"	1.1	"
Pike	Maple Cross (R. Colne)	1	200	310	ND	"	"	"	1.7	"
	Staines	2	110	NA	NA	"	"	0.1	1.1	
Nuphar lutea	Maple Cross (R. Colne)	1	65	"	"	3.4	"	ND	ND	"
	Staines	2	48	"	"	ND	0.2	0.2	0.4	"
Fontinalis	Maple Cross (R. Colne)	1	84	"	"	"	ND	ND	ND	
Sediment	Maple Cross (R. Colne)	1	540	"	"	"	"	3.4	33	"
	Staines	1	92	"	"	"	"	ND	5	"

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

respect of these discharges is carried out by the DOE (DOE, 1989). However, in 1988 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 1988, 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), the moss *Fontinalis* 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 $year^{-1}$.

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 fish and shellfish 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.

Table 37 Radioactivity in environmental materials and gamma dose rates near the outfall of the sewer serving Amersham International plc, Cardiff, 1988.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta+	^{14}C	^{60}Co	^{131}I	^{134}Cs	^{137}Cs	^{155}Eu
Flounders	5	420	1 400	ND	ND	ND	0.8	ND
Mussels	1	320	1 100	0.4	"	"	2.2	"
Fucus spiralis	4	160	16	ND	0.4	"	0.5	"
Fucus vesiculosus	1	200	NA	"	1.2	"	0.6	"
Mud	5	980	46	"	ND	2.2	47	1.0
Muddy sand	1	420	19	"	"	0.8	9.5	2.8

Mean gamma dose rate in air at 1 m over intertidal sediment (6 sampling observations†): 0.082 μGy h^{-1}

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 marine environmental materials from the Channel Islands, 1988.

Material	Sampling area	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			Total beta	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn	^{90}Sr	^{106}Ru	^{110m}Ag	^{125}Sb
Rays	Guernsey	1	130	ND	ND	ND	ND	NA	ND	ND	ND
Crabs	Guernsey	1	90	"	"	1.8	"	"	"	1.1	"
	Jersey	1	61	"	"	1.5	"	"	6.8	0.8	0.2
	East of Alderney	1	100	"	"	4.8	"	"	22	1.9	0.9
Oysters	Jersey	1	88	"	"	0.9	1.5	"	7.7	1.9	ND
Limpets	Jersey	1	110	"	"	1.2	ND	"	8.5	0.9	"
	Guernsey	1	93	"	"	0.7	"	"	ND	ND	"
	Alderney	1	81	"	"	1.8	"	"	14	"	"
Porphyra	Jersey										
	Greve de Lecq	3	160	"	"	0.6	"	"	11	"	"
	La Rozel	1	170	"	"	0.3	"	"	8.8	"	"
	Guernsey										
	Fermain Bay	4	190	"	"	0.1	"	"	3.6	"	"
	Pembroke Bay	1	160	"	"	ND	"	"	7.5	"	"
	Alderney										
	Quenard Point	2	180	0.08	"	2.1	"	"	57	"	"
Fucus serratus	Jersey										
	La Rozel	4	370	0.03	0.1	5.7	"	0.40	8.1	0.1	0.3
	Guernsey										
	Fermain Bay	4	350	0.04	ND	3.5	"	0.23	5.9	ND	ND
	Pembroke Bay	1	320	0.11	0.1	3.1	"	NA	3.1	"	"
	Alderney										
	Quenard Point	4	410	0.4	0.04	11	0.4	0.55	19	0.3	0.2
Laminaria digitata	Jersey										
	Verclut	3	430	ND	ND	0.5	ND	NA	5.0	0.03	0.1
Sediment	Jersey										
	St Helier Harbour	1	650	1.3	"	16	"	"	53	ND	4.1
	Guernsey										
	Bordeaux Harbour	1	400	ND	"	0.6	"	"	3.6	"	1.2
	Pembroke Bay	1	460	"	"	ND	"	"	ND	"	ND
	Alderney										
	Crabbe Harbour	1	620	1.2	"	7.0	"	"	33	"	6.4

Table 38 (continued)

Material	Sampling area	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
			^{134}Cs	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Rays	Guernsey	1	0.4	3.4	0.00010	0.00043	0.00059	ND	ND
Crabs	Guernsey	1	ND	ND	0.0017	0.0040	0.0093	0.0031	0.0030
	Jersey	1	"	"	0.0028	0.0051	0.0072	0.00018	0.0022
	East of Alderney	1	"		0.0060	0.0083	0.015	0.0011	0.0062
Oysters	Jersey	1	"	"	0.012	0.023	0.019	0.00019	0.0066
Limpets	Jersey	1	"	0.2	0.019	0.038	0.045	0.0014	0.015
	Guernsey	1	"	ND	0.0047	0.010	0.015	0.00019	0.0048
	Alderney	1	"	"	0.010	0.017	0.029	0.0052	0.0093
Porphyra	Jersey								
	Greve de Lecq	3	"	0.04	NA	NA	ND	NA	NA
	La Rozel	1	"	ND	"	"	"	"	"
	Guernsey								
	Fermain Bay	4	"	0.2	"	"	"	"	"
	Pembroke Bay	1	"	ND	"	"	"	"	"
	Alderney								
	Quenard Point	2	"	0.09	"	"	"	"	"
Fucus serratus	Jersey								
	La Rozel	4	"	0.1	0.044	0.079	0.029	0.00079	0.0090
	Guernsey								
	Fermain Bay	4	"	0.2	0.025	0.053	0.023	0.00032	0.0078
	Pembroke Bay	1	"	0.2	NA	NA	ND	NA	NA
	Alderney								
	Quenard Point	4	"	0.3	0.036	0.058	0.049	0.0010	0.018
Laminaria digitata	Jersey								
	Verclut	3	"	0.3	NA	NA	ND	NA	NA
Sediment	Jersey								
	St Helier Harbour	1	"	6.7	1.2	2.6	3.5	0.031	1.0
	Guernsey								
	Bordeaux Harbour	1	"	1.3	0.077	0.30	0.23	0.0043	0.058
	Pembroke Bay	1	"	0.9	NA	NA	ND	NA	NA
	Alderney								
	Crabbe Harbour	1	"	4.9	"	"	"	"	"

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

The results of monitoring in 1988 are presented in Table 37. Of the separate radionuclides listed, only carbon-14 was discharged by this establishment in 1988; 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 1988 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.

10. Monitoring of the freshwater environment for radioactivity from the Chernobyl reactor accident

An extended monitoring programme continued during 1988 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 1988. The results of our additional monitoring, from January to June 1988, have already been published (MAFF, 1988). The results presented in this section are for the whole of 1988. 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.

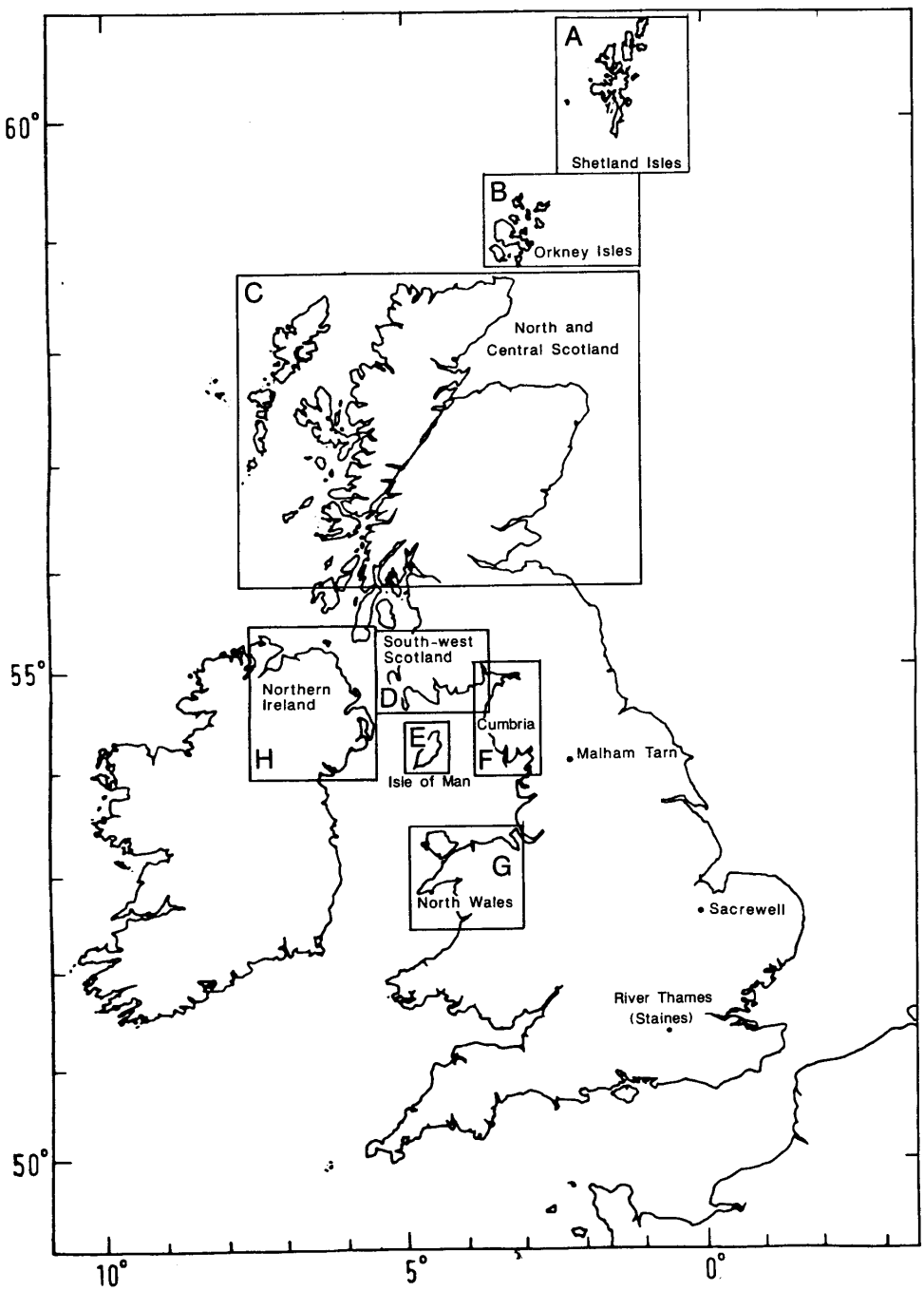

Figure 5 Sampling locations for monitoring of the freshwater environment for radioactivity from Chernobyl.

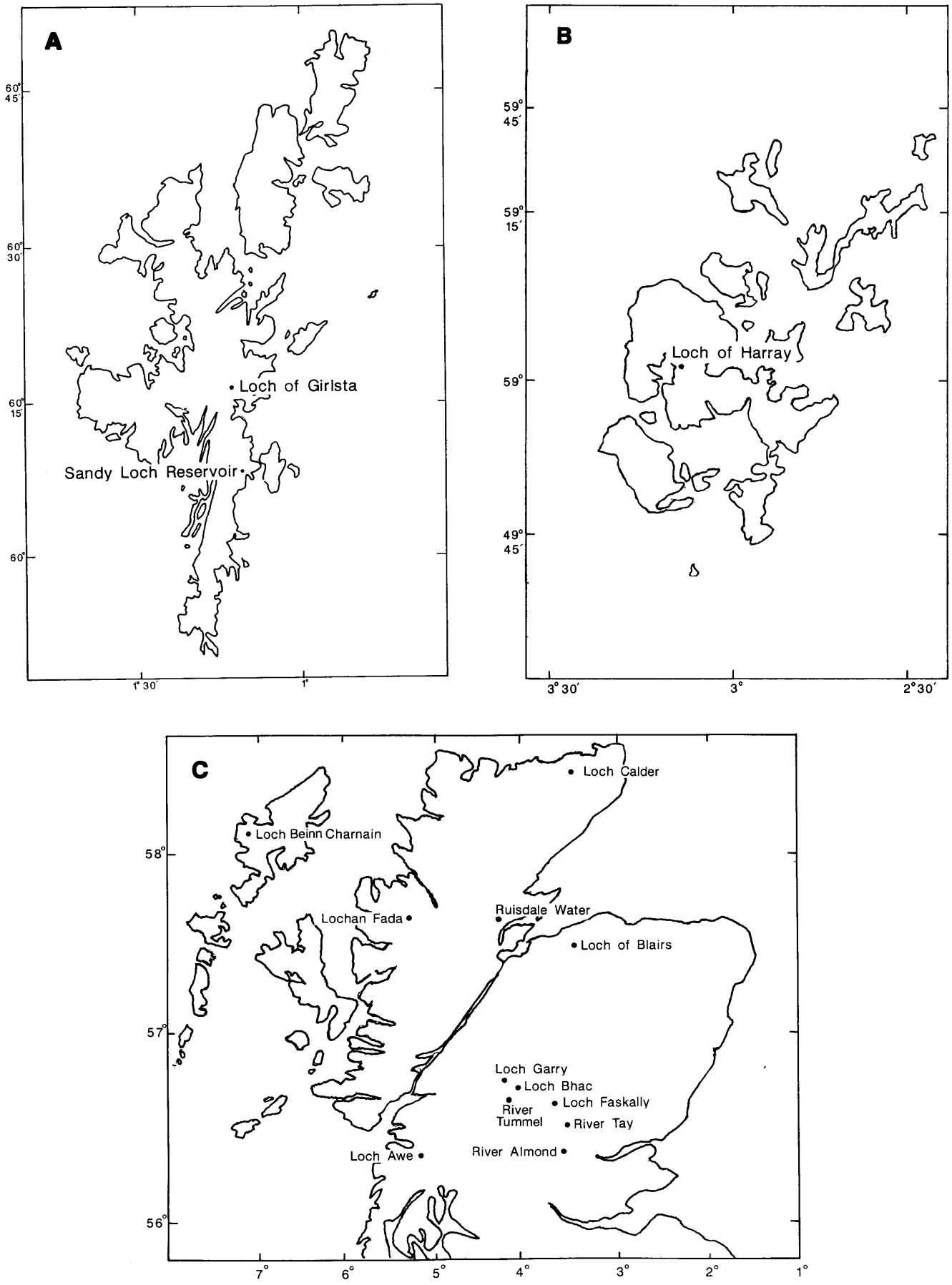

Figure 5: Inset A Sampling locations in the Shetland Isles. **Inset B** Sampling locations in the Orkney Isles. **Inset C** Sampling locations in North and Central Scotland.

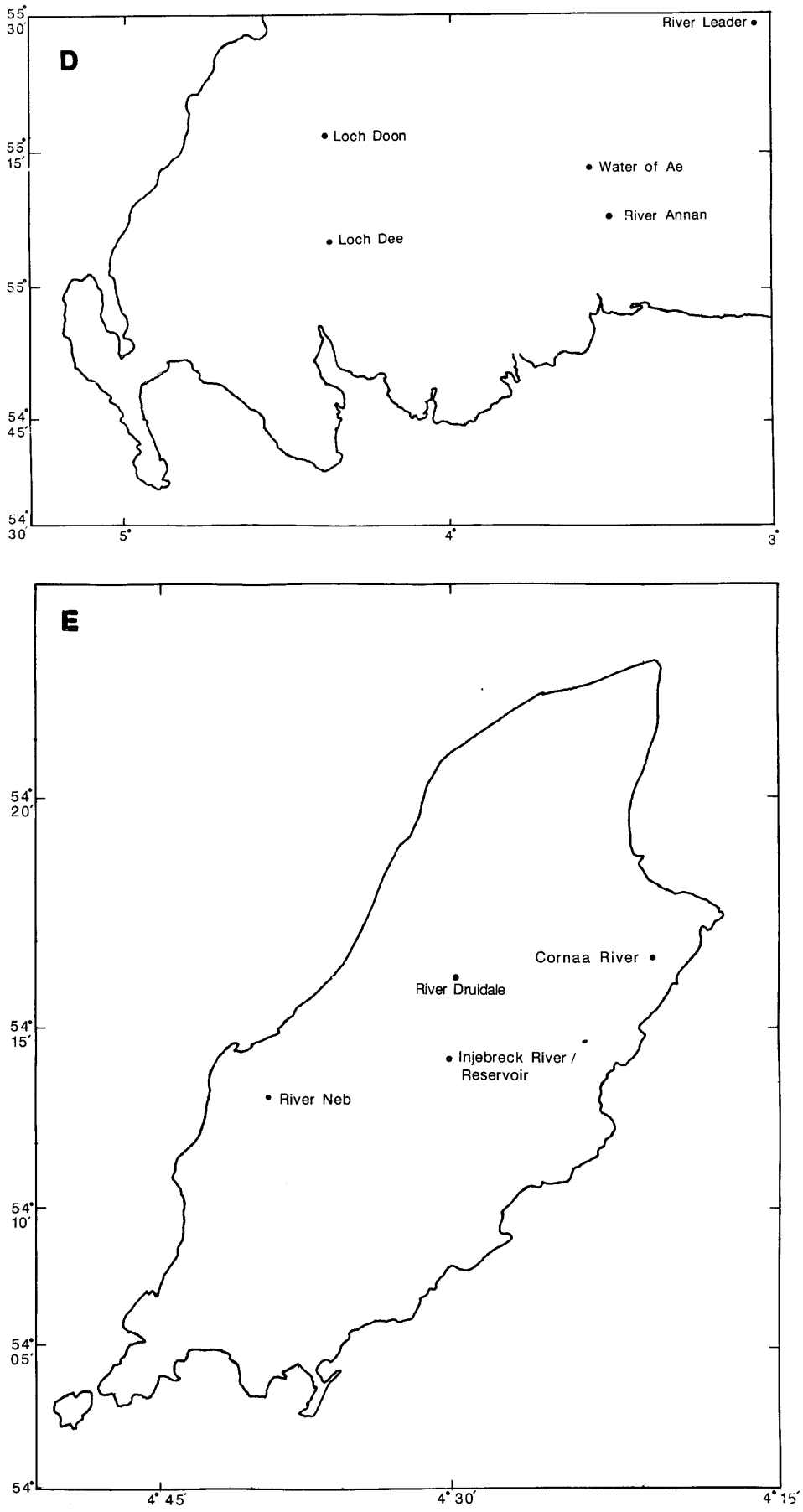

Figure 5: Inset D Sampling locations in South-west Scotland. **Inset E** Sampling locations on the Isle of Man.

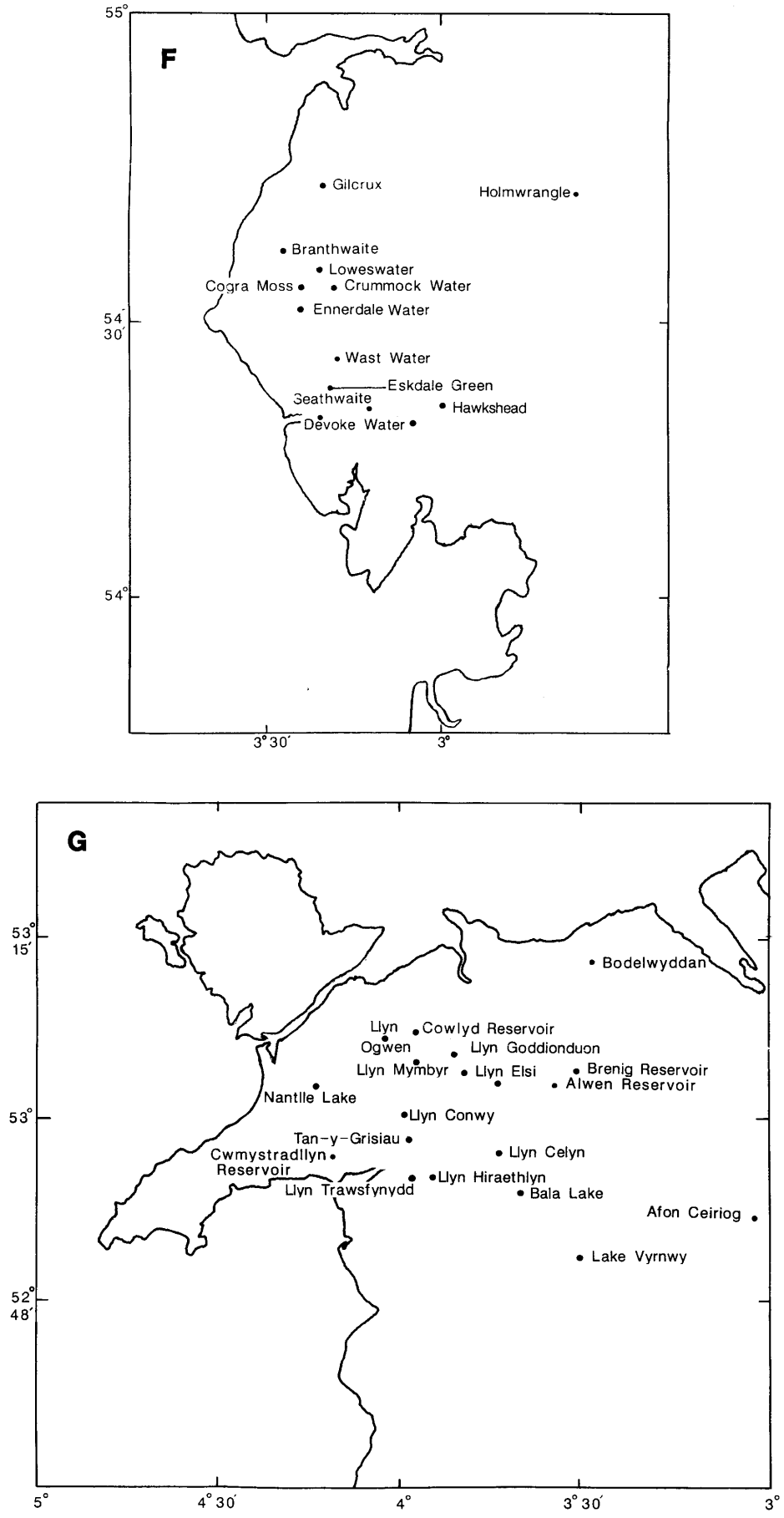

Figure 5: Inset F Sampling locations in Cumbria. **Inset G** Sampling locations in North Wales.

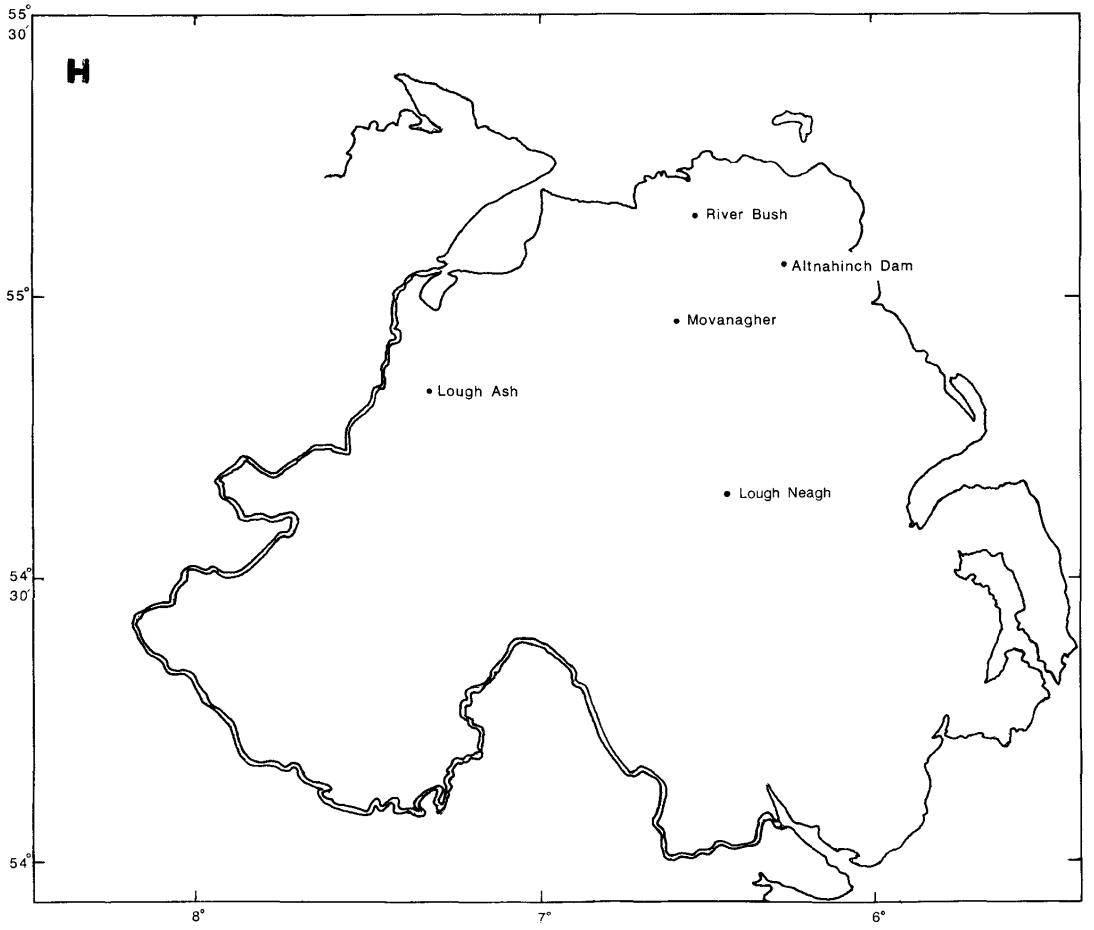

Figure 5: Inset H Sampling locations in Northern Ireland.

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 reporting period. 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 were, in 1988, 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 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. Perch (Table 41), pike (Table 42) and eels (Table 43) had the highest concentrations of any of the freshwater fish species, but as they are not eaten in large quantities their radiological significance is low. Other species (Table 44) had generally lower radiocaesium concentrations, sometimes much lower, than brown trout, perch, pike or eels taken from the same river or lake. Where there are data for the same species and locations to compare with results for 1987 (Hunt, 1988) 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 1988 than in 1987, continuing the reducing trend that began in the latter part of 1987 (Hunt, 1988).

Radiation exposures have been estimated using a procedure based on cautious assumptions, as previously (Hunt, 1988). 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 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 1987. A contribution to dose due to radiostrontium

Table 39 Caesium radioactivity in brown trout, 1988.

Location	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
Cogra Moss	3	38	170
Crummock Water	11	33	110
Devoke Water	94	79	300
Ennerdale Water	68	54	190
Eskdale Green	2	110	460
Loweswater	45	39	130
Wast Water	8	47	210
Malham Tarn	6	3.4	23
WALES			
Cowlyd Reservoir	6	52	200
Cwmystradllyn Reservoir	1	11	28
Bala Lake	6	9.7	36
Llyn Celyn	5	18	52
Llyn Conwy	35	55	230
Llyn Elsi	20	46	170
Llyn Goddionduon	39	170	600
Llyn Mymbyr	10	43	170
Llyn Ogwen	55	91	330
Llyn Trawsfynydd	121	22	150
Nantlle Lake	6	1.7	21
Alwen Reservoir	2	20	69
Lake Vyrnwy	6	ND	1.6
Tan-y-Grisiau	1	16	91
Brenig Reservoir	12	ND	4.4
Afon Ceiriog	15	"	0.6
SCOTLAND			
Loch of Harray	1	7.8	31
Sandy Loch Reservoir	6	12	35
Lochan Fada	3	20	110
Loch Awe	3	8.4	32
Loch Calder	2	9.6	39
Loch Dee	35	150	550
Loch Doon	11	47	180
Loch Garry, Tayside Region	9	76	300
River Leader	2	ND	ND
River Tummel	3	57	210
Ruisdale Water	2	74	320
Loch Beinn Charnain	1	32	150
Water of Ae	1	ND	4.1
Loch of Girlsta	2	54	320
Loch Bhac	1	8.0	46
NORTHERN IRELAND			
Altnahinch Dam	2	14	77
Lough Ash	5	2.3	9.6
Movanagher	1	ND	1.8
River Bush	2	17	84
ISLE OF MAN			
Cornaa River	2	ND	22
River Druidale	2	23	88
Injebreck River/Reservoir	2	32	110
River Neb			

ND = not detected.

Table 40 Caesium radioactivity in rainbow trout, 1988.

Location	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
Cogra Moss	10	ND	5.0
Seathwaite	1	"	5.6
Sacrewell	1	"	ND
Hawkshead	1	"	"
Gilcrux	1	"	"
Branthwaite	1	"	"
WALES			
Llyn Celyn	7	"	2.6
Llyn Elsi	5	47	160
Llyn Trawsfynydd	121	0.51	6.3
Lake Vyrnwy	1	4.0	9.5
Tan-y-Grisiau	5	ND	7.5
Bodelwyddan	1	"	ND
SCOTLAND			
River Almond	3	"	2.7
Water of Ae	3	"	2.3
Loch of Blairs	1	"	6.0
NORTHERN IRELAND			
Movanagher	1	"	4.0
ISLE OF MAN			
River Neb	1	"	7.9

ND = not detected.

Table 41 Caesium radioactivity in perch, 1988.

Location	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
Cogra Moss	5	110	460
Devoke Water	18	250	950
Eskdale Green	2	89	340
Loweswater	9	120	460
Malham Tarn	6	36	140
Crummock Water	5	54	220
WALES			
Llyn Hiraethlyn	5	200	740
Bala Lake	4	10	52
Llyn Celyn	4	6.2	30
Llyn Trawsfynydd	14	86	760
Alwen Reservoir	4	35	120
SCOTLAND			
Loch Faskally	2	51	180
Loch Doon	1	69	280
NORTHERN IRELAND			
Lough Neagh	2	1.5	19

ND = not detected.

Table 42 Caesium radioactivity in pike, 1988.

Location	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
Crummock Water	6	32	120
Loweswater	6	69	230
River Thames (Staines)	2	ND	ND
WALES			
Bala Lake	7	32	110
SCOTLAND			
Loch Faskally	2	97	380
NORTHERN IRELAND			
Lough Neagh	1	8.6	32

ND = not detected.

Table 43 Caesium radioactivity in eels, 1988.

Location	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
Ennerdale Water	1	56	200
Eskdale Green	3	180	630
Loweswater	4	15	56
Devoke Water	1	110	460
WALES			
Llyn Ogwen	1	50	180
SCOTLAND			
Loch Faskally	3	28	100
NORTHERN IRELAND			
Lough Neagh	1	2	10

Table 44 Caesium radioactivity in other species of fish, 1988.

Location		No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
			^{134}Cs	^{137}Cs
ENGLAND				
Crummock Water	Char	1	24	73
Ennerdale Water	"	5	21	79
Holmwrangle	"	1	ND	3.0
WALES				
Bala Lake	Grayling	2	ND	16
" "	Gwyniad	3	5.1	36
" "	Roach	10	13	42
Llyn Trawsfynydd	Rudd	15	36	280
SCOTLAND				
River Annan	Sea trout	2	ND	15
River Leader	Grayling	1	"	ND
River Tay	Salmon	2	"	"
" "	Sea trout	2	"	6.0
River Tummel	Grayling	3	82	300
Loch Garry	Char	6	82	320
Loch Doon	"	1	51	210
NORTHERN IRELAND				
Lough Neagh	Vendace	2	ND	11

ND = not detected.

Table 45 Estimates of maximum dose* to adults due to consumption of freshwater fish from areas of high deposition of fallout from Chernobyl, 1988.

Region	Location	Committed effective dose equivalent, mSv year^{-1}
England	Eskdale Green	0.3
Wales	Llyn Goddionduon	0.4
Scotland	Loch Dee	0.4
Northern Ireland	River Bush	0.05
Isle of Man	Injebreck River/Reservoir	0.07

*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.

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 by the NRPB (NRPB, 1987). 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. 1988 was outside this period but, as was the case in 1987, 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 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 1988, 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 cautious value of 0.001 for the gut transfer factor of plutonium and americium (ICRP, 1986) except where a more appropriate value 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 1988 as compared with 1987, due to a small increase in the concentrations of transuranic nuclides in winkles; this small increase was probably not significant within the associated variabilities, which include environmental factors. Concentrations of transuranic nuclides in fish and most species of shellfish showed continuing decreases in 1988 following the earlier reductions in discharges, but these decreases were not perhaps as rapid as in previous years. A gradual slowing down in the rate of decrease of concentrations of these nuclides 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 1988. 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 exposure 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 increased slightly from 0.24 mSv in 1987 to 0.27 mSv in 1988. This was due to greater amounts of time spent on houseboats rather than to an increase in dose rates, which declined in 1988 following the earlier decreases in discharges of radiocaesium from Sellafield. Dose rates to this group are expected to continue to decline in the future; occupancies are not expected to rise significantly further, as the occupancy in 1988 was near to full-time.

Near Trawsfynydd, exposures were less than in recent years, there being a marked decrease in concentrations of radiocaesium in fish from the lake. This followed the reduction in concentrations of radiocaesium in lake water, and was predicted in our 1987 report (Hunt, 1988). However, these concentrations have risen again in 1988 and are likely to lead to higher concentrations in fish and thus dose rates in 1989, 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 1988. The continuing effect of fallout from Chernobyl on the freshwater environment is described in section 10; concentrations of radiocaesium have diminished in 1988 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 sub-section 4.1.1. In 1988, there was still a contribution to collective dose due to fallout from Chernobyl through the presence of concentrations of radiocaesium from that source in fish, particularly in Scottish waters and the North Sea; this contribution has been included. The preliminary collective committed effective dose equivalent to the UK population in 1988 was 40 man-Sv, the same as in 1987; the effect of reductions in concentrations of radiocaesium in fish and shellfish, following the decreases in discharges from Sellafield and the reduced contribution from Chernobyl, was offset by changes in the area of collection of shellfish which influenced concentrations of radioactivity. For the population of other European countries the preliminary collective committed effective dose equivalent was 50 man-Sv in 1988, less than in 1987 (70 man-Sv), reflecting the reductions in discharges from Sellafield and decreased contribution from Chernobyl.

A contribution to collective dose due to radioactivity (mainly radiocaesium) from Chernobyl is likely to be present for the next few years, particularly as a result of the input to the North Sea which could be supplemented

Table 46 Summarised estimates of public radiation exposure from discharges of liquid radioactive waste in the UK, 1988.

Establishment	Radiation exposure pathway	Critical group	Exposure[+], mSv
BRITISH NUCLEAR FUELS plc			
Sellafield	Fish and shellfish consumption	Local fishing community	0.15 (0.34)*
	External	Houseboat dwellers (River Ribble)	0.27
	Handling of fishing gear	Local fishing community	0.1[‡]
	Porphyra/laverbread consumption	Consumers in South Wales	0.01
Springfields	External	Houseboat dwellers (River Ribble)	0.27[a]
Capenhurst (Meols outfall)	Shellfish consumption	Local fishing community	0.1[a]
Chapelcross	Fish and shellfish consumption External	Local fishermen	0.14[a]
UNITED KINGDOM ATOMIC ENERGY AUTHORITY			
Harwell	Fish consumption External	Anglers**	0.01
Winfrith	Fish and shellfish consumption	Local fishing community	0.05
Dounreay	Handling of fishing gear	Local fishermen	0.1[‡b]
	External	Local community	0.01[b]
	Fish and shellfish consumption	Local fishing community	0.02[b]
NUCLEAR POWER STATIONS OPERATED BY THE ELECTRICITY BOARDS			
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	0.002[a]
Heysham	Fish and shellfish consumption	Local fishing community	0.07 (0.11)*a
	External		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	0.005[a]
Trawsfynydd	Fish consumption External	Local fishing community	0.07
Wylfa	Fish and shellfish consumption External	Local fishing community	0.02[a]

Table 46 (continued)

Establishment	Radiation exposure pathway	Critical group	Exposure[+], mSv
DEFENCE ESTABLISHMENTS			
Aldermaston	Fish consumption External	Anglers**	0.001
Chatham	External	Houseboat dwellers	0.01
Devonport	External	Bait diggers	0.01
Faslane	External	Boatyard workers	0.01[b]
Rosyth	External	Dredgermen	0.01[b]
Holy Loch	External	Local community	0.01[b]
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).
* See sub-section 4.1.1. The first value is based on the gut transfer factor for plutonium and americium of 0.0002; the value using a factor of 0.0005 follows in parentheses.
**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.

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 effluent plant (SIXEP) from May 1985.

12. References

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