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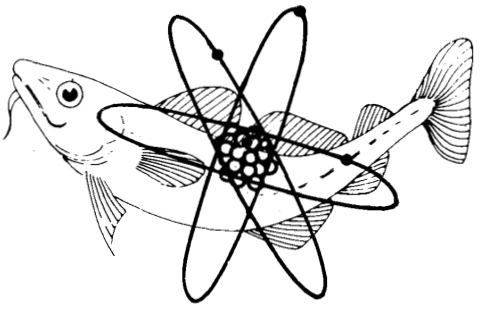
DIRECTORATE OF FISHERIES RESEARCH

AQUATIC ENVIRONMENT MONITORING REPORT



Number 18

Radioactivity in surface and coastal waters of the British Isles, 1986

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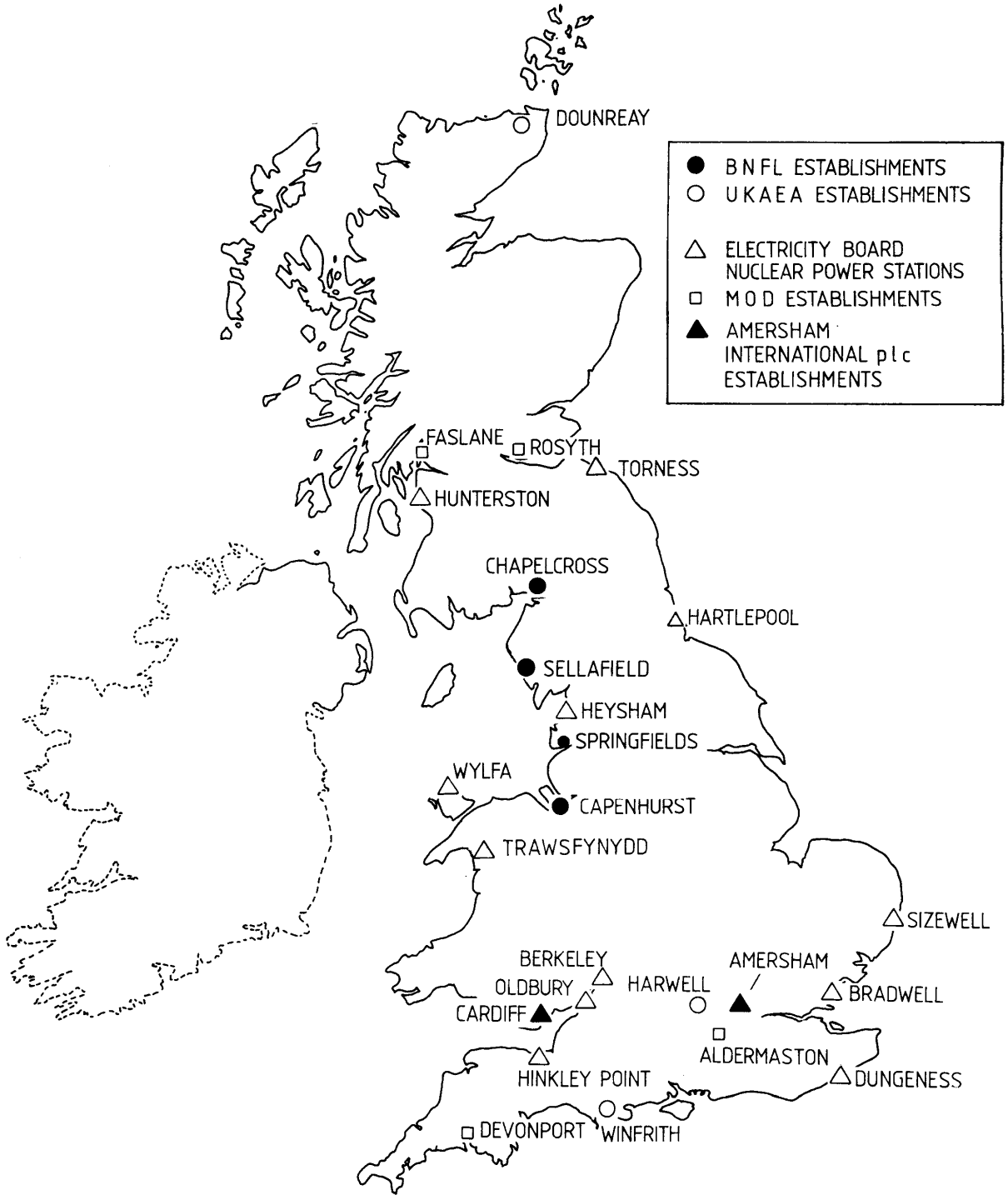

Figure 1 UK nuclear establishments giving rise to principal discharges of liquid radioactive waste.

1. Introduction

This report presents the results of the environmental monitoring programme carried out during 1986 by staff of the Directorate of Fisheries Research, Lowestoft. The monitoring programme supports the Ministry'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.

An important feature of our monitoring during 1986 was the special programme carried out in connection with the accident at Chernobyl, USSR on 26 April 1986. An interim report of this programme has already been published (Camplin *et al.*, 1986). The present report contains summaries of data for the whole of 1986, relevant both to regular discharges of radioactive wastes and to fallout from Chernobyl. 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 1986 are first summarised. Before the results are presented, an explanatory section gives details of methods of analysis and presentation and how results are interpreted in terms of public radiation exposures.

2. Discharges of radioactive waste

Data on radioactive discharges are published annually by the Environment Departments. Data for 1986 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 1986. 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. The limits quoted have been converted where necessary from curies to terabecquerels (sub-section 3.1). 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 recommended by the International Commission on Radiological Protection (ICRP), embodied in national policy (Great Britain — Parliament, 1986). Except for Sellafield, the percentages of the authorised (or agreed) limits taken up in 1986 are also stated in Table 1. At Sellafield, a revised authorisation came into force on 1 July 1986, and two sets of annual limits are included in Table 1, both before and from that date. Direct comparison of the discharges for the whole of 1986 with the new annual limits is not appropriate, but all discharges were well within the appropriate limits applying during 1986.

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 1986, 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 not in coastal waters but mainly in a deep area of the Atlantic Ocean. However, no such disposals have been carried out since 1982.

Routine environmental monitoring does not provide an effective means of assessing radiation exposure from these disposals as their effects are largely undetectable (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 (OECD (NEA)) by means of a Coordinated Research and

Table 1 Principal discharges of liquid radioactive waste from UK nuclear establishments, 1986.

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1986	
			TBq	% of limit
BRITISH NUCLEAR FUELS plc				
Sellafield				
Sea pipeline (see sub-section 2.1)	Total beta	950 (7400)*	118.21	See sub-section 2.1
	Total alpha	14 (22.2)*	4.35	
	Ruthenium-106	370 (1480)*	27.82	
	Strontium-90	60 (740)*	18.25	
	Americium-241	3.3	1.24	
	Caesium-134	25	1.27	
	Caesium-137	200	17.89	
	Carbon-14	4	2.57	
	Cerium-144	40	3.27	
	Cobalt-60	9	1.48	
	Iodine-129	0.4	0.12	
	Plutonium alpha	10	2.65	
	Plutonium-241	350	63.33	
	Technetium-99	10	6.60	
	Tritium	3500	2150.37	
	Zirconium-95 plus Niobium-95	250	14.72	
Seaburn sewer	Total activity	0.148	0.0034	2.3
Springfields	Total alpha	13.32	0.57	4.3
	Total beta	444	115	26
Chapelcross[+]	Total alpha	0.1	0.00078	<1
	Total beta[1]	25	0.086	<1
	Tritium	5.5	0.16	2.9
Capenhurst				
Rivacre Brook	Total activity[2]	0.00148	0.000111	7.5
Meols outfall	Technetium-99	0.148	0.000135	<1
UNITED KINGDOM ATOMIC ENERGY AUTHORITY				
Winfrith	Total activity	1110	52	4.7
	Ruthenium-106	333	0.043	<1
	Strontium-90	44.4	0.055	<1
	Total alpha	44.4	0.0069	<1
Harwell	Total activity[1,3]	8.88	0.53	5.9
	Tritium	8.88	2.1	23.6
Dounreay	Total activity	888	15.7	1.8
	Strontium-90	88.8	2.0	2.2
	Total alpha	88.8	0.46	5.2
CENTRAL ELECTRICITY GENERATING BOARD				
Berkeley	Total activity[1]	7.4	0.31	4.2
	Tritium	55.5	0.10	0.18
Bradwell	Total activity[1]	7.4	0.72	9.7
	Zinc-65	0.185	0.0021	1.1
	Tritium	55.5	6.2	11
Dungeness				
"A" Station	Total activity[1]	7.4	3.1	42
	Tritium	74	2.4	3.2
"B" Station	Total activity[1,4]	4	0.076	1.9
	Sulphur-35	25	0.23	<1
	Tritium	650	30	4.6
Hartlepool	Total activity[1,4]	4	0.064	<1
	Sulphur-35	7.5	0.26	2.4
	Tritium	1850	46	1.2
Heysham[5]	Total activity[1,4]	4	0.015	<1
	Sulphur-35	7.5	0.17	2.3
	Tritium	1850	58	3.1
Hinkley Point[6]				
"A" Station	Total activity[1,4]	7.4	0.45	6.1
	Sulphur-35	3.7	0.19	5.0
	Tritium	74	2.1	2.8
"B" Station	Total activity[1,4]	3.7	0.039	1.0
	Sulphur-35	22.2	1.1	4.9
	Tritium	666	257	39

Table 1 Continued.

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1986	
			TBq	% of limit
Oldbury	Total activity[1]	3.7	0.69	19
	Tritium	74	0.88	1.2
Sizewell	Total activity[1]	7.4	0.76	10
	Tritium	111	3.1	2.8
Trawsfynydd	Total activity[1]	1.48	0.20	14
	Caesium-137	0.259	0.032	12
	Tritium	74	0.63	0.86
Wylfa	Total activity[1]	2.405	0.061	2.5
	Tritium	148	8.7	5.9
SOUTH OF SCOTLAND ELECTRICITY BOARD				
Hunterston "A" Station	Total activity[1]	7.5	1.59	21
	Tritium	45	1.06	2.4
"B" Station	Total activity[1,4]	3.7	0.043	1.2
	Sulphur-35	25.9	2.21	8.5
	Tritium	1480	366	25
MINISTRY OF DEFENCE (PROCUREMENT EXECUTIVE)				
Aldermaston	Total activity[1,3]	5.8	0.139	2.4
	Tritium	5.8	0.088	1.5
MINISTRY OF DEFENCE (NAVY DEPARTMENT)				
Devonport	Total activity[1]	0.148	0.0053	3.5
	Cobalt-60	0.037	0.0049	13
	Tritium	0.37	0.04	11
Faslane	Total activity[1]	0.037	0.000085	<1
Rosyth	Total activity[1]	1.11	0.0061	<1
AMERSHAM INTERNATIONAL plc				
Amersham	Total activity[1,3]	2.7	0.83	31
	Tritium	14.8	1.39	9.4
Cardiff	Beta/gamma activity[7]	0.096	0.0231	24
	Carbon-14	2	1.26	63
	Tritium	1400	826	59

*To 30 June 1986.
+Authorisation was revised with effect from 1 April 1986.
[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]Discharges are from Heysham I.
[6]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; the sulphur-35 allocation for the "A" station was transferred from the "B" station with effect from 1 January 1986.
[7]Excluding tritium, carbon-14 and radioisotopes of calcium and strontium.

Environmental Surveillance Programme (CRESP) (OECD (NEA), 1981). In the absence of readily detectable effects, 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 1986 included monitoring of the effects of the accident at Chernobyl. Differences in methodology for the additional monitoring of the freshwater environment are described in section 10.

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

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, low energy beta-emitters such as carbon-14 and technetium-99 are counted at reduced efficiency and very low beta-emitters, such as tritium and plutonium-241, are excluded. Thus, agreement between the total beta result and 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.

Gamma-emitting nuclides are analysed by gamma spectrometry. This is carried out using both NaI(Tl) and Ge detectors, calibrated using suitable reference sources. The spectra are reduced by computer-aided techniques to give radioactivity concentrations of detected nuclides. For samples of biota and sediments, searches are routinely made for, amongst others, the following artificial gamma emitters: manganese-54, cobalt-60, zinc-65, zirconium-95, plus niobium-95, ruthenium-106, silver-110m, antimony-124 and -125, caesium-134 and -137, and cerium-144. In the tables of results for these materials the absence of a column for any of these nuclides indicates non-detectability in each sample in that table. A feature of some of our results during 1986 was the presence of additional, short-lived gamma-emitters from Chernobyl, particularly iodine-131 and -132, tellurium-129m and -132, caesium-136, barium-140 and lanthanum-140. Results are also included for these nuclides.

Pure beta emitters, such as carbon-14, strontium-90, technetium-99 and promethium-147, are chemically separated from the sampled material 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 (sub-section 3.3).

3.3 Methods of presentation of measurements

The tables of monitoring results generally contain summarised values of observations obtained during the year under review. Observations of a given quantity may vary throughout the year; in general, any variations are larger than the analytical errors inherent in the observations. The variations may, for example, be due to changes in rates of discharge or to different dispersion conditions in the receiving environment. The presentation of the summarised results reflects the purpose of this monitoring which is interpretation in terms of public radiation exposures. The method of interpretation is described more fully in sub-section 3.4. The appropriate integration period for comparison with recommended limits is at least one year; standard practice is to combine annual rates of consumption or occupancy of the more highly exposed members of the public (the critical group) with the arithmetic means of observed radioactivity concentrations or dose rates,

respectively, during the year. The use of, say, the highest observed (but unsustained) radioactivity concentration with an annual consumption rate would not provide a realistic comparison with the recommended limits. Therefore, the tables present the arithmetic means of observations made during the year.

The frequency of sampling reflects the resolution (which affects the accuracy) judged to be necessary in the assessment of dose and is largely governed by the radiological importance. In order to present a balanced picture for the whole of 1986, including the transient effect of radioactivity from Chernobyl, data are included which reflect sampling throughout the year. The results of more frequent monitoring following the accident were reported in our interim report (Camplin *et al.*, 1986). The tables in the present report indicate the number of sampling observations 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 — up to several hundred for fish and molluscs from near Sellafield. For external beta and gamma dose rates, which are measured using portable instruments, 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 in the state in which it is collected. For fish and shellfish the concentrations apply to the edible fractions, because the purpose is assessment of internal exposure of the consumer. Sediments may be analysed in support of measurements of external dose rates; whilst they may readily adsorb many radionuclides, the use of sediments as indicator materials requires caution because adsorption usually varies with particle size. In addition, the water content of sediments is variable, thus dry concentrations are quoted in the tables.

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 remote from nuclear activities or from experience before these activities began. For both types of measurement, however, experience is also useful. Table 3 lists representative values to be expected from natural sources. It is also to 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 100 Bq kg^{-1} (wet) in mussels from a variety of locations (Pentreath *et al.*, 1979; McDonald *et al.*, 1986). Radiation exposures from natural sources are in most cases greater than from artificial radioactivity, although the ICRP dose limits (sub-section 3.4) do not apply to natural and medical irradiation.

Table 3 Natural radioactivity concentrations of 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.

3.4 Methods of interpretation

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 the recommendations of the ICRP. For many years these recommendations have been endorsed for use in the UK by appropriate advisory bodies. Current UK practice relevant to the general public is mainly based on the recommendations of the ICRP as set out in ICRP Publication 26 (ICRP, 1977). The dose limitation

system embodied therein has been accepted as national policy (Great Britain-Parliament, 1986). 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.

The effect of these recommendations on the interpretation of the results will be briefly described. The ICRP prescribes a system of dose limitation which applies to all sources of exposures other than natural radiation and medical procedures. The effects of accidental releases of radioactivity are not formally considered by the ICRP within the scope of this dose limitation system but because the effects of the release from Chernobyl on the UK aquatic environment near nuclear sites were minor (Camplin *et al.*, 1986), and in many cases difficult to distinguish from the effects of site operation, the conservative procedure has been adopted of considering the total exposures due to artificial radionuclides in comparison with ICRP dose limits.

This dose limitation system includes, within appropriate dose limits to individuals, that "all exposures shall be kept as low as reasonably achievable . . ." (ALARA). The requirement for ALARA 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. ICRP Publication 26 does 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. The ICRP concludes that its system of dose limitation is likely to ensure that the annual dose equivalent averaged over the population from all sources, excluding natural and medical irradiation, will not exceed 0.5 mSv. The NRPB considers (NRPB, 1978) that maintenance of the annual dose equivalent below this value, when averaged over the whole UK population, is a reasonable objective; further, that the contribution from all UK waste management practices is unlikely to exceed one tenth of this, that is 0.05 mSv year^{-1}. In this report, an annual average dose equivalent of 0.05 mSv has been used for reference purposes regarding collective doses. By comparison, the average annual effective dose equivalent in the UK from natural radiation is approximately 2 mSv (Hughes and Roberts, 1984).

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 has recently (ICRP, 1985) 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 NRPB has advised (NRPB, 1984a) that procedures leading to exposure of the public should be controlled deliberately to ensure that the lifetime committed effective dose equivalent does not exceed 70 mSv, and that in practice, the simplest way to ensure compliance is to apply the single annual limit on effective dose equivalent of 1 mSv (NRPB, 1986). The ICRP has indicated (ICRP, 1984a) that because of the limitation on lifetime exposure, non-stochastic 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}, and this limit has been taken as appropriate for exposure due to handling of fishing gear.

In this report, committed effective dose equivalents to appropriate critical groups are presented. These are compared with the principal ICRP-recommended dose limit of 1 mSv year^{-1}, or, provided the limitation on lifetime exposure described above is met, with the subsidiary dose limit of 5 mSv year^{-1}. Where appropriate, consideration is given to compliance with the limitation on lifetime exposure.

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 (Greenhalgh *et al.*, 1985; 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 value may not be considered 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 relevant to consumption of shellfish from near Sellafield (Hunt *et al.*, 1986). Further work is being carried out to confirm these observations but in the meantime, when estimating doses to the shellfish consumers near Sellafield, our practice has continued; this uses a range of gut transfer factors which includes 0.0005 for plutonium and americium as recommended by the NRPB (NRPB, 1984b). 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 $\mu Gy\ h^{-1}$ has been taken as producing an effective dose equivalent rate of 0.87 $\mu Sv\ h^{-1}$ (Spiers *et al.*, 1981).

In order to interpret monitoring results in terms of committed effective dose equivalents to critical groups, the remaining data required are, as appropriate, rates of food consumption 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

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. The most significant liquid radioactive waste discharges are from the fuel element storage ponds and the reprocessing plant, through which passes all the irradiated Magnox fuel from the UK nuclear power programme, and some fuel from abroad. Most of the nuclear 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. A revised authorisation to discharge these wastes came into force, with effect from 1 July 1986, specifying lower limits to radioactivity in discharges and laying specific limits on more nuclides (Great Britain - Parliament, 1986), as well as maintaining controls on releases of solvents and particulates. A further condition requires BNFL to use 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 ICRP principles, as described in sub-section 3.4.

Discharges from the Sellafield pipelines during 1986 are summarised in Table 1, and were within the limits set by the authorising Departments. During 1985, the new Site Ion - Exchange Effluent Plant (SIXEP) came into operation as well as a new evaporation plant to concentrate salt-bearing effluent streams prior to decay storage. These plants operated throughout 1986 and discharges to sea, which had reduced in 1985, declined further in 1986. Discharges of total beta activity were 118 TBq (1985: 587 TBq). Caesium-137 discharges, which prior to SIXEP operation originated

predominantly from the fuel element storage ponds, in 1986 totalled 18 TBq (1985: 325 TBq), a greater contribution arising from the reprocessing plant. The introduction and operation of SIXEP was invigilated by the authorising departments to ensure compliance with the conditions of authorisation, including the requirement to use BPM to control discharges. As a result of operation of the salt evaporator, discharges of ruthenium-106 reduced to 28 TBq (1985: 81 TBq). Discharges of plutonium were also reduced by operation of the salt evaporator, such that site releases of alpha-emitting radionuclides in 1986 totalled 4.4 TBq (1985: 5.7 TBq).

Our regular monitoring continued during 1986, and was significantly supplemented to cover the effects of the Chernobyl accident because this area of the country happened to experience relatively high deposition from the plume. Our additional monitoring near Sellafield up to July 1986 has already been described (Camplin *et al.*, 1986); the present report gives summarised data for the whole of 1986. Important radiation exposure pathways were 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 1986, as in previous recent years, there was no harvesting of *Porphyra* in the immediate Sellafield vicinity for manufacture of laverbread, but monitoring was continued because the pathway remains potentially important. An extensive research programme was also continued. The aims of this programme are to improve our knowledge of the distribution and behaviour of radionuclides in the marine environment, especially in relation to the critical exposure pathways, and also to provide a means of assessing other pathways of lower current importance, thereby assisting in keeping all exposure pathways under review. Results from our research programme are included where relevant.

4.1.1 The fish and shellfish consumption pathway

Public radiation exposure from Sellafield discharges by consumption of fish is still predominantly due to radiocaesium. Concentrations of total beta activity and caesium -134 and -137 in fish from the vicinity of the Irish Sea and from further afield are given in Table 4(a). Data are listed by location of sampling or landing point, in approximate order of increasing distance from Sellafield. 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 own sampling of fish is 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 and 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. They also reflect the age of the radioactivity; in previous years, the ratio of caesium -137 to caesium -134 (half-lives 30 years and 2 years respectively) has 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. Fish from Scottish waters and the North Sea, which were affected by deposition from the Chernobyl plume, show this effect particularly; it is estimated that in these areas, about 10-20% of the average caesium -137 concentration in 1986 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, 1987).

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. These variations are likely to be most apparent in the results close to Sellafield because of the relatively rapid variation with distance of the radiocaesium concentration in sea water. To obtain representative results for dose estimation, samples include large numbers of individual fish (sub-section 3.3).

Concentrations of caesium-137 in 1986 were generally less than in 1985 for fish from all sea areas except the northern North Sea, where the effect of deposition from Chernobyl was most noticeable. There were particular reductions in levels of radiocaesium in fish from the Irish Sea. This is attributed to reduced concentrations in sea water, following the significant reductions in radiocaesium discharges from Sellafield due to the operation of SIXEP from May 1985.

Table 4(a) Beta/gamma radioactivity in fish from the Irish Sea vicinity and further afield, 1986.

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	9	220	3.7	79
	Plaice	5	240	4.4	130
	Bass	1	350	9.0	220
	Grey mullet	1	210	5.8	68
Sellafield offshore area[1]	Cod	4	240	3.8	90
	Plaice	4	170	2.6	58
	Flounder	1	190	3.6	160
	Dab	4	210	3.7	82
	Brill	1	210	3.4	71
	Whiting	2	270	5.6	140
	Spurdog	1	91	1.1	16
	Herring	1	150	2.1	26
Ravenglass[2]	Cod[4]	5	180	2.4	65
	Plaice[4]	8	170	2.8	70
	Cod[5]	6	240	3.8	95
Morecambe Bay[1]	Flounder	4	260	4.5	150
Whitehaven[2]	Cod	4	190	2.0	48
	Plaice	4	140	1.7	45
	Herring	3	150	1.9	36
Fleetwood[2]	Cod	4	160	1.7	47
	Plaice	4	150	1.8	50
	Ling	1	NA	0.3	11
	Fish meal[7]	3	300	1.1	27
	Fish oil[7]	3	NA	ND	ND
Cumbrian rivers[6]	Sea trout	5	190	3.2	59
Isle of Man[2]	Cod	3	150	1.0	19
	Plaice	4	110	0.9	23
	Herring	3	140	1.0	21
	Dab	1	87	1.1	12
	Whiting	1	120	1.1	26
Inner Solway[1]	Salmon	1	120	0.2	1.1
	Sea trout	2	140	2.4	33
	Flounder	4	220	4.0	130
Kirkcudbright[2]	Plaice	4	140	1.6	44
North Anglesey	Plaice	1	110	0.7	5.8
	Mackerel	1	120	1.1	6.2
	Pollack	1	160	2.0	36
Northern Ireland[2]	Cod	4	150	1.0	26
	Whiting	4	130	1.6	32
	Herring	4	160	0.9	19
Ayr[2]	Plaice	4	110	0.8	19
	Cod	4	150	1.3	26
Minch[1]	Plaice	4	130	0.5	7.4
	Cod	3	130	0.5	7.5
	Herring	5	140	1.9	22
	Mackerel	3	120	1.2	7.5

Table 4(a) Continued.

Sampling area/landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}		
			Total beta	^{134}Cs	^{137}Cs
Shetland[1]	Fish meal[7]	2	520	4.1	12
Northern North Sea[1]	Plaice	6	110	0.3	3.4
	Cod	6	150	1.0	5.1
	Haddock	4	NA	0.9	3.6
	Saithe	3	"	2.5	7.5
	Herring	2	160	1.2	5.3
	Norway pout	1	NA	1.0	2.2
Mid-North Sea[1]	Plaice	9	110	0.2	3.2
	Cod	9	130	0.5	6.4
	Haddock	3	NA	0.5	4.2
	Whiting	1	"	0.8	8.0
Southern North Sea[1]	Plaice	7	92	0.1	2.5
	Cod	6	120	0.3	4.3
	Whiting	2	NA	0.4	4.1
	Herring	2	110	0.4	4.3
Iceland area[1]	Cod	1	110	ND	0.3
	Plaice	1	78	"	0.2
Icelandic processed	Cod	2	120	"	0.3
	Plaice	2	73	"	0.4

ND = not detected; NA = not analysed; [1]Sampling area; [2]Landing point; [3]See sub-section 3.3 for definition; [4]Samples provided by fisherman A; [5]Samples provided by fisherman B; [6]Samples collected from a number of rivers by the North West Water Authority; [7]Concentrations refer to weight of sample as supplied.

Table 4(b) Other beta/gamma radioactivity in fish from the Irish Sea vicinity, 1986.

Sampling area/ landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}										
			^{14}C	^{90}Sr	^{54}Mn	^{60}Co	^{65}Zn	^{99}Tc	^{103}Ru	^{106}Ru	^{131}I	^{110m}Ag	^{147}Pm
Sellafield offshore area[1]	Plaice	1	75	0.23	ND	ND	ND	1.9	ND	ND	ND	ND	0.11
	Cod	1	88	0.32	"	0.2	"	ND	"	"	"	"	0.13
Ravenglass[2]	Plaice	8	NA	NA	"	0.1	"	NA	"	1.6	"	"	NA
Whitehaven[2]	Plaice	1	"	0.11	"	ND	"	"	"	ND	"	"	"
	Cod	1	"	0.10	"	"	"	"	"	"	"	"	"
Fleetwood[2]	Cod	4	"	NA	"	"	"	"	"	"	1.5	"	"
	Fish meal[4]	3	"	0.59	"	"	"	"	"	"	ND	"	"
Shetland[1]	Fish meal[4]	1	"	0.09	0.6	"	2.8	"	0.9	"	"	10	"
Northern North Sea[1]	Norway pout	1	"	NA	ND	"	0.7	"	ND	"	"	4.4	"

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.

Specific radionuclides other than caesium-134 and -137 which were detected in fish in 1986 are listed in Table 4(b). Trace levels of the short-lived radionuclides, ruthenium-103, silver-110m and iodine-131, in a few species were most probably due to the effects of Chernobyl, and were of negligible radiological significance. Analyses of samples of fish for carbon-14, strontium-90, technetium-99 and promethium-147 were included in our monitoring programme for 1986, 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 exposures. Analyses for these radionuclides are labour-intensive, thus a selection of samples was made based on potential radiological significance. The data for 1986, shown in Table 4(b), confirm that the radiological significance of these radionuclides remained low.

Table 5 Beta/gamma radioactivity in shellfish from the Irish Sea vicinity and further afield, 1986.

Sampling area/ landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}																			
			Total beta	^{14}C	^{60}Co	^{90}Sr	^{95}Zr + ^{95}Nb	^{99}Tc	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{131}I	^{132}I	^{132}Te	^{134}Cs	^{137}Cs	^{140}Ba	^{144}Ce	^{147}Pm	^{154}Eu	^{155}Eu
Sellafield coastal area[1]	Crabs	10	150	58	3.7	6.3	0.9	3.5	2.1	25	11	0.3	ND	ND	ND	0.9	16	ND	0.6	33	ND	ND
	Lobsters	11	300	160	2.8	3.0	ND	340	0.2	12	10	ND	"	"	"	1.5	27	"	0.8	63	"	0.3
	Winkles[4]	12	720	80	16	25	17	35	20	250	34	4.6	"	"	"	1.4	45	"	6.3	120	0.5	0.8
	Winkles[5]	4	510	NA	21	NA	6.1	NA	3.3	290	33	5.4	"	"	"	ND	28	"	1.6	NA	1.0	2.5
	Winkles[6]	4	370	"	7.6	"	2.6	"	68	140	33	4.7	"	"	"	2.0	31	"	1.0	"	ND	ND
	Winkles[7]	2	360	"	11	"	10	"	7.2	150	36	2.2	"	"	"	2.0	29	"	6.1	"	"	"
	Mussels[4]	4	720	"	12	"	19	"	52	390	5.8	3.3	"	"	"	3.7	22	"	10	"	3.0	2.5
	Limpets[4]	4	490	"	11	"	14	"	3.2	150	16	7.9	"	"	"	0.8	30	"	5.6	"	0.7	1.2
Sellafield offshore area[1]	Whelks	2	410	"	6.8	"	ND	"	ND	250	18	ND	"	"	"	ND	22	"	ND	"	ND	ND
St Bees[1]	Winkles	4	450	66	11	19	16	11	4.9	170	20	5.2	"	"	"	"	34	"	3.6	74	"	"
	Mussels	4	550	NA	11	NA	19	NA	3.2	330	16	1.5	"	"	"	0.3	18	"	8.8	NA	3.3	1.9
	Limpets	4	570	"	7.7	"	18	"	18	210	27	8.9	"	"	"	1.2	43	"	9.0	"	ND	1.1
Nethertown[1]	Winkles	12	630	72	17	27	16	32	69	300	38	4.2	14	"	66	4.0	54	"	9.1	120	0.9	1.3
Drigg[1]	Winkles	4	640	77	22	20	13	70	12	340	35	4.0	ND	"	ND	0.4	34	"	4.8	140	0.9	1.0
Ravenglass[1]	Cockles	4	440	NA	28	NA	9.2	NA	73	210	6.2	0.8	"	"	"	4.9	34	"	7.2	NA	3.8	3.5
	Mussels	12	450	"	9.0	"	3.1	"	36	290	2.1	2.1	5.9	38	46	1.5	16	1.7	3.3	"	1.6	2.2
Tarn Bay[1]	Winkles	4	400	"	8.9	"	4.4	"	110	190	29	3.4	ND	ND	ND	2.4	33	ND	ND	"	ND	ND
Ravenglass[2]	Crabs	4	180	"	5.8	"	ND	"	2.2	36	9.9	ND	"	"	"	1.0	21	"	"	"	"	"
	Lobsters	3	410	"	3.9	"	"	"	0.5	5.8	12	"				1.8	35	"	"	"	"	"
	Whelks	4	380	"	11	"	0.3	"	0.6	270	19	0.7	"	"	"	ND	13	"	1.3	"	"	"
Parton[1]	Winkles	4	350	"	7.9	"	ND	"	26	100	15	ND	"	"	"	1.7	39	"	ND	"	"	"
Whitehaven[2]	*Nephrops*	3	150	"	ND	"	"	"	ND	ND	0.2	"	"	"	"	1.2	32	"	"	"	"	"
Roosebeck[1]	Oysters	4	120	"	"	"	"	"	22	33	50	"	"	"	"	1.5	12	"	"	"	"	"
Morecambe Bay[1]	Shrimps	4	110	"	"	1.9	"	"	ND	ND	0.6	"	"	"	"	1.6	34	"	"	"	"	"
	Cockles	4	140	"	2.7	1.0	"	"	33	35	0.6	"	"	"	"	1.8	24	"	"	"	"	"
Isle of Man[2]	Scallops	4	140	"	0.1	NA	"	"	11	4.6	4.6	0.4	"	"	"	2.0	6.4	"	"	"	"	"
Fleetwood	Squid	1	NA	"	ND	"	"	"	ND	ND	ND	ND	"	"	"	ND	ND	"	"	"	"	"
Inner Solway[1]	Shrimps	4	120	"	"	"	"	"	0.6	0.4	3.2	"	"	"	"	2.4	43	"	"	"	"	"
Southerness[1]	Winkles	4	500	NA	1.1	NA	ND	NA	660	300	120	2.9	ND	ND	ND	13	44	ND	ND	NA	ND	1.8
Kirkcudbright[2]	Scallops	4	62	"	ND	"	"	"	ND	ND	2.2	ND	"	"	"	0.2	2.0	"	"	"	"	ND
	Queens	4	67	"	0.2	"	"	"	0.3	2.6	8.0	"	"	"	"	0.1	2.5	"	"	"	"	"
North Solway coast[1]	Winkles	4	220	"	3.3	"	"	"	9.2	45	46	"	"	"	"	1.1	17	"	"	"	"	"
Wirral[1]	Shrimps	2	89	"	ND	"	"	ND	ND	ND	1.3	"	"	"	"	0.9	13	"	"	"	"	"
	Cockles	2	89	"	"	"	"	2.6	"	3.5	ND	"	"	"	"	0.8	13	"	"	"	"	"
Conwy[2]	Mussels	2	73	"	"	"	"	NA	0.9	ND	"	"	"	"	"	0.8	3.1	"	"	"	"	"
Bangor[2]	Mussels	2	48		"	"	"	"	0.8	6.6	1.6	"	"	"	"	0.5	3.6	"	"	"	"	"
North Anglesey[1]	Crabs	2	77	"	"	"	"	"	3.4	2.2	3.8	"	"	"	"	0.4	3.1	"	"	"	"	"
	Winkles	4	110	"	"	"	"	"	1.5	12	14	"	"	"	"	0.4	4.1	"	"	"	"	"
Northern Ireland[2]	*Nephrops*	4	110	"	"	"	"	"	"	ND	0.5	"	"	"	"	0.4	7.1	"	"	"	"	"
	Winkles	5	140	"	0.2	"	"	"	13	11	18	0.3	"	"	"	0.3	5.2	"	"	"	"	"
Minch[1]	*Nephrops*	5	100	"	ND	"	"	"	ND	0.4	1.3	ND	"	"	"	0.3	1.6	"	"	"	"	"
Northern North Sea[1]	*Nephrops*	2	100	"	"	"	"	"	"	ND	2.0	"	"	"	"	0.2	2.6	"	"	"	"	"
Mid-North Sea[1]	Mussels[8]	2	48	"	"	"	"	"	1.3	4.0	0.7	"	"	"	"	0.3	0.7	"	"	"	"	"
Southern North Sea[1]	Cockles	2	16	"	0.8	"	"	"	0.2	1.3	0.3	"	"	"	"	ND	0.4	"	"	"	"	"
	Cockles[10]	1	36	"	1.1	"	"	"	ND	ND	ND	"	"	"	"	"	0.3	"	"	"	"	"
	Mussels	2	37	"	ND	"	"	"	0.3	"	"	"	"	"	"	"	0.5	"	"	"	"	"
	Shrimps	1	NA	"	"	"	"	"	ND	"	2.0	"	"	"	"	"	4.3	"	"	"	"	"

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.

For shellfish, a wide range of radionuclides contributes to radiation exposure of consumers owing to generally greater uptake in these organisms than in fish. Table 5 lists concentrations of total beta activity and beta/gamma-emitting nuclides in shellfish from the Irish Sea and further afield. Results for carbon-14, strontium-90, technetium-99 and promethium-147 are included for 1986. Winkles are of particular radiological importance to the critical group near to Sellafield, as described later in this section. In addition to our own sampling, supplies of winkles. mussels and limpets were obtained from consumers who collected them in the Sellafield coastal area exploited by this critical group.

Short-lived radionuclides, including iodine-131 and -132, tellurium-132 and barium-140, were detected in a few samples taken soon after the Chernobyl accident. A proportion of the ^{103}Ru and ^{134}Cs detected is likely to have been from Chernobyl as well as from Sellafield, but its significance was very low (Camplin *et al.*, 1986). Concentrations of most artificial radionuclides in shellfish, as with fish, diminish with increasing distance from Sellafield; the rate of reduction is least for nuclides which are conservative to sea water, such as isotopes of caesium. There are substantial variations between species: in general, molluscs tend to concentrate the less conservative 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 conservative nuclides.

Concentrations of caesium-137 in shellfish in 1986, as for fish, showed general reductions as compared with 1985, reflecting decreases in discharges. This trend was also observed for most other Sellafield-derived nuclides including ruthenium-106.

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 1986 are presented in Table 6. Transuranics are less conservative to sea water than is radiocaesium; this is reflected in higher concentrations of transuranics in shellfish as compared with fish, and a rapid reduction with distance in concentrations of transuranics, particularly in shellfish.

Concentrations of transuranics in fish and shellfish from the Irish Sea showed general reductions in 1986 as compared with 1985, particularly in areas close to Sellafield. The reductions in concentrations of transuranics continued, as predicted (Hunt, 1986b), to reflect the decline in discharges over the past few years. The non-conservative nature of these nuclides causes a delayed effect in the environment (Hunt, 1985), such that a contribution to present levels is provided by discharges in earlier years. Further reductions in concentrations may be expected in the next few years even though discharges themselves may not reduce until the Enhanced Actinide Removal Plant (EARP) commences operation, scheduled for 1992.

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 in the vicinity of the pipeline. Hence, members of the local community who eat fish and shellfish from these local sources 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 Cumbrian coastal community, the larger population in Cumbria and north Lancashire of 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. This, therefore, represents a second exposed population which is 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 Cumbrian coastal community described above were kept under review in 1986. Techniques used in the collection of data have continued to include the use of consumption logging sheets particularly by members of critical groups (Leonard *et al.*, 1982; Leonard, 1984). Consumption rate data have been interpreted using techniques based upon ICRP recommendations (Hunt *et al.*, 1982) to select appropriate critical groups of higher-rate consumers. We have included consideration of children's consumption rates in this selection process (Leonard and Hunt, 1985).

Radioactivity concentrations in fish and shellfish vary with the species involved, so in estimation of doses to consumers it is not sufficient to determine only the total consumption rates of fish and shellfish together. Our experience (illustrated by Tables 4-6) has shown, however, that for a given area, within each of the classes, fish, crustaceans and molluscs, the concentrations of given nuclides in representative samples are relatively constant. For each of the two exposed populations, therefore, sub-groups of persons were identified who were likely to have received the greatest exposures from eating each class of food-stuff, and mean consumption rates for the sub-groups were determined. For the Cumbrian coastal community these consumption rates of fish and crustaceans in 1986 were 36.5 kg $year^{-1}$ (100 g d^{-1}) and 6.6 kg $year^{-1}$ (18 g d^{-1}) respectively, as for 1985 (Hunt, 1986a). Our surveys revealed, however, a decrease in consumption of molluscs, from 9.5 kg $year^{-1}$ (26 g d^{-1}) in 1985 to 6.6 kg $year^{-1}$ (18 g d^{-1}) in 1986. In this report, exposures of the critical group of fish and shellfish consumers have been assessed on the basis of 1986 consumption rates. For comparison with previous years and because consumption rates may increase again in the future, a summarised assessment is also presented on the basis of the 1981-83 consumption rate of 16.4 kg $year^{-1}$ (45 g d^{-1}).

Table 6 Transuranic radioactivity in fish and shellfish from the Irish Sea vicinity and further afield, 1986.

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	2	NA	0.019	0.08	NA	0.088	0.00078	0.00034
	Cod	2	"	0.0066	0.028	"	0.036	ND	ND
	Crabs	3	0.16	0.53	2.0	63	4.0	0.032	0.016
	Lobsters	3	0.12	0.26	1.0	25	12	0.028	0.050
	Winkles[4]	4	0.28	7.4	31	700	43	0.11	0.13
	Winkles[5]	2	NA	4.2	19	410	26	0.092	0.10
	Winkles[6]	4	"	3.3	15	330	18	0.036	0.069
	Winkles[7]	2	"	4.7	20	450	45	0.14	0.14
	Mussels[4]	1	"	10	42	NA	58	0.18	0.21
	Limpets[4]	1	"	5.2	22	"	34	0.15	0.10
Sellafield offshore area[1]	Plaice	1	0.00050	0.0032	0.013	0.28	0.021	0.00021	0.000050
	Cod	1	0.00030	0.0028	0.012	0.23	0.022	ND	0.00010
	Whelks	1	NA	0.93	4.0	NA	10	"	0.046
St Bees[1]	Winkles	4	0.18	5.2	22	500	31	0.11	0.13
	Mussels	2	NA	9.5	39	900	50	0.13	0.19
	Limpets	1	"	6.4	27	NA	37	0.23	0.16
Nethertown[1]	Winkles	4	0.35	8.5	35	790	49	0.15	0.21
Drigg[1]	Winkles	4	0.21	7.5	32	710	58	0.10	0.22
Ravenglass[1]	Cockles	1	NA	6.4	28	460	58	0.15	0.28
	Mussels	6	"	7.6	31	480	45	0.044	0.19
Tarn Bay[1]	Winkles	1	"	4.3	19	400	28	0.079	0.10
Ravenglass[2]	Cod[8]	1	"	0.0026	0.010	NA	0.014	ND	ND
	Plaice[8]	1	"	0.0040	0.016	"	0.024	"	0.00007
	Crabs[9]	1	"	0.43	1.7	"	6.5	0.022	0.037
	Lobsters[9]	1	"	0.26	0.99	"	9.8	0.011	0.038
	Whelks[9]	1	"	1.5	5.7	130	12	0.060	0.066
Parton[1]	Winkles	1	"	2.6	12	240	15	0.11	0.079
Whitehaven[2]	Plaice	1	"	0.00082	0.0039	NA	0.0069	ND	ND
	Cod	1	"	0.00091	0.0044	"	0.0064	"	0.00004
	Herring	1	"	0.0097	0.046	"	0.054	"	0.00016
	Nephrops	1	"	0.037	0.16	"	0.69	0.0026	0.0026
Roosebeck	Oysters	1	"	0.44	1.9	"	1.2	ND	0.0055
Morecambe Bay[1]	Shrimps	1	"	0.0095	0.046	"	0.066	"	0.00031
	Cockles	1	"	0.77	3.6	"	8.6	"	0.029
Fleetwood[2]	Cod	1	"	0.00020	0.00089	"	0.00141	"	0.00001
	Plaice	1	"	0.00049	0.0022	"	0.0026	"	0.00002
	Fish meal[10]	3	"	0.014	0.061	"	0.063	"	0.000097
Isle of Man[2]	Cod	1	NA	0.00020	0.00087	NA	0.0010	0.00005	ND
	Plaice	1	"	0.00033	0.0014	"	0.0015	0.00009	"
	Herring	1	"	0.00090	0.0046	"	0.0056	ND	0.00002
	Scallops	1	"	0.048	0.24	"	0.080	"	0.00023
Inner Solway[1]	Sea trout	1	"	0.00010	0.00051	"	0.00053	"	ND
Southerness[1]	Winkles	1	"	0.34	1.5	"	2.5	0.0049	0.0075
Kirkcudbright[2]	Plaice	1	"	0.0015	0.0075	"	0.013	ND	0.00004
	Scallops	1	"	0.063	0.29	"	0.11	"	ND
	Queens	1	"	0.029	0.13	"	0.13	0.00045	0.00044
North Solway coast[1]	Winkles	1	"	0.99	4.5	"	6.8	0.0076	0.030
Ayr[2]	Cod	1	"	0.00012	0.00059	"	0.00073	ND	ND
	Plaice	1	"	0.00069	0.0030	"	0.0026	"	"
Wirral[1]	Cockles	1	"	0.41	1.9	"	3.9	"	0.014
Conwy[2]	Mussels	1	"	0.070	0.33	"	0.53	"	0.0020
North Anglesey[1]	Winkles	1	"	0.080	0.39	"	0.48	0.0034	0.0017
Northern Ireland[2]	Cod	1	"	0.00009	0.00043	"	0.00060	ND	ND
	Whiting	1	"	0.00031	0.0018	"	0.0021	"	0.00001
	Nephrops	1	"	0.0033	0.018	"	0.035	"	0.00009
	Winkles	1	"	0.045	0.21	"	0.095	"	ND

Table 6 Continued.

Sampling area/ landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}						
			^{237}Np	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Minch[1]	Cod	1	"	0.00028	0.0011	"	0.00081	"	"
	Mackerel	1	"	0.00010	0.00048	"	0.00044	"	"
	Nephrops	1	"	0.00057	0.0038	"	0.0055	"	"
Shetland[1]	Fish meal[10]	1	"	0.0012	0.0083	"	0.0014	0.00021	0.00001
Northern North Sea[1]	Cod	1	"	0.00016	0.00063	"	0.00045	ND	ND
	Nephrops	1	"	0.0011	0.0052	"	0.0064	0.00056	0.00019
Mid-North Sea[1]	Mussels[11]	1	"	0.00048	0.0041	"	0.0014	0.00011	ND
Southern North Sea[1]	Cod	1	"	0.00010	0.00033	"	0.00028	ND	"
	Plaice	1	"	0.00009	0.00054	"	0.00030	"	"
	Mussels	1	"	0.00049	0.0048	"	0.0021	"	"
	Cockles	1	"	0.0018	0.010	"	0.0054	0.00023	0.00039
	Cockles[12]	1	"	0.0015	0.0066	"	0.0053	0.00036	0.00057
Icelandic processed	Cod	1	"	0.00004	0.00019	"	0.00011	ND	ND

ND = not detected.
NA = not analysed.

[1]Sampling area; [2]Landing point; [3]See sub-section 3.3 for definition; [4]Samples collected by Consumer 116; [5]Samples collected by Consumer 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.

The habits survey data obtained show that above-average consumers in each of the component sub-groups are not generally members of another component sub-group. However, there are people who are members of more than one sub-group so that 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 is 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 is based on an equal mix of crabs and lobsters from the "Coastal Area", whilst the exposure from consumption of molluscs is based upon averaged radionuclide concentrations in winkles from the "Coastal Area", including data from both our own sampling at specific locations within this Area and from samples collected by local consumers.

Table 7 summarises exposures in 1986. 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.*, 1986) has suggested that a gut transfer factor of 0.0001 may be used for these elements in realistic assessments of dose from eating winkles from near Sellafield, and further work is being carried out to confirm these observations. On the basis of this gut transfer factor the committed effective dose equivalent to the local critical group in 1986 would have been 0.12 mSv. This result is significantly less than the dose of 0.49 mSv reported for 1985. Reductions in concentrations of radionuclides (particularly radiocaesium and ruthenium-106) in fish and shellfish and the decrease in mollusc consumption have contributed to this reduction; it should also be noted that the 1985 result of 0.49 mSv included contributions due to americium-241 based on a gut transfer factor of 0.0005, and doses per unit intake for transuranics based on currently-recommended body retention times (sub-section 3.4). The effect of applying a gut transfer factor of 0.0005 for plutonium and americium (sub-section 3.4) is shown in the last column of Table 7. On this basis, the committed effective dose equivalent to the critical group of local consumers in 1986 would have been 0.34 mSv, a decrease from 0.73 mSv reported in 1985. All these results are within the ICRP-recommended principal dose limit for members of the public of 1 mSv year^{-1}.

For comparison with the doses reported in previous years and because consumption rates of molluscs could possibly increase again in the future, an assessment has also been carried out using the local critical group consumption rates which obtained in 1981-83 (i.e. 36.5 kg year^{-1} (100g d^{-1}) fish, 6.6 kg year^{-1} (18 g d^{-1})

Table 7 Individual radiation exposures due to consumption of Irish Sea fish and shellfish, 1986.

Exposed population	Consumption rate used in assessment (see text)			Nuclide	Committed effective dose equivalent, mSv $year^{-1}$, on basis of following gut transfer factors for Pu, Am (see text)	
		kg $year^{-1}$	(g d^{-1})		0.0001	0.0005
Consumers in local fishing community	fish:	36.5	(100)	^{90}Sr	0.006	0.006
	crustaceans:	6.6	(18)	^{106}Ru	0.009	0.009
	molluscs:	6.6	(18)	^{134}Cs	0.002	0.002
				^{137}Cs	0.038	0.038
				^{238}Pu	0.003	0.017
				$^{239}Pu + ^{240}Pu$	0.016	0.080
				^{241}Pu	0.007	0.036
				^{241}Am	0.029	0.15
				Total	0.12	0.34
Consumers associated with commercial fisheries (Whitehaven, Fleetwood, Morecambe Bay)	fish:	82	(225)	^{90}Sr	0.002	0.002
	crustaceans:	18	(50)	^{106}Ru	0.003	0.003
	molluscs:	15	(40)	^{134}Cs	0.003	0.003
				^{137}Cs	0.06	0.06
				^{238}Pu	0.001	0.005
				$^{239}Pu + ^{240}Pu$	0.005	0.03
				^{241}Pu	0.003	0.01
				^{241}Am	0.01	0.06
				Total	0.10	0.18
Typical member of the fish-eating public consuming fish landed at Whitehaven/Fleetwood	fish:	15	(40)	^{137}Cs	0.008	0.008
				Total	0.009	0.009

crustaceans and 16.4 kg $year^{-1}$(45 g d^{-1}) molluscs). If these consumption rates had applied in 1986, the dose to the critical group would have been 0.23 mSv on the basis of a gut transfer factor of 0.0001 for plutonium and americium. Using a gut transfer factor of 0.0005, the dose would have been 0.74 mSv. These results show significant decreases as compared with previous years, due to lower concentrations in fish and shellfish of transuranics, ruthenium-106 and radiocaesium. They include a small decrease (equivalent to 0.13 mSv in the latter case) due to revised body retention times for transuranics (sub-section 3.4). They are also in general agreement with our earlier predictions of dose to the critical group on the basis of likely future discharges from Sellafield (Hunt, 1986b).

The exposure of the critical group has been considered in comparison with the ICRP-recommended dose limits including the recommendation on lifetime exposure (sub-section 3.4). In 1986, and for the two 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 in the next few years for exposures, calculated using realistic parameters, 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, 1986b). Having demonstrated compliance with the ICRP's lifetime dose objectives, it follows (sub-section 3.4) that non-stochastic effects will also be avoided.

In 1986, further information became available in relation to the consumers associated with commercial fisheries based mainly on Whitehaven, Fleetwood and the Morecambe Bay area. This indicated reduced critical sub-group consumption rates for fish at 82 kg $year^{-1}$ (225 g d^{-1}) compared with 131 kg $year^{-1}$ (360 g d^{-1}) in 1985. However, there was no need to revise these rates for crustaceans and molluscs; these are 18 kg $year^{-1}$ (50 g d^{-1}) and 15 kg $year^{-1}$ (40 g d^{-1}) respectively. Because high-rate consumers are members of more than one sub-group, the overall

critical group has been defined by the maximising procedure of summing exposures due to these component consumption rates. The dose rate due to intake of fish has been assessed using activity concentrations of an equal mix of plaice and cod landed at Whitehaven and Fleetwood. Consumption of crustaceans has been based on shrimps from Morecambe Bay, and consumption of molluscs has been based on Morecambe Bay cockles. The committed effective dose equivalent to members of this critical group in 1986 is given in Table 7. The total of 0.18 mSv, on the basis of the gut transfer factor for plutonium and americium of 0.0005, represents a decrease from 0.30 mSv reported for 1985 (Hunt, 1986a). The decrease was mainly due to the lower consumption rates of fish with reduced radiocaesium concentrations.

The effective dose appropriate to a consumption rate of 15 kg $year^{-1}$ (40 g d^{-1}) of fish from landings at Whitehaven and Fleetwood is also given in Table 7. This consumption rate represents an average for typical fish-eating members of the public. The effective dose in 1986 was 0.009 mSv, which represents a decrease from 0.02 mSv reported for 1985 (Hunt, 1986a), due to the reduced concentrations of radiocaesium in Irish Sea fish.

Collective doses from consumption of fish and shellfish during 1986 have been estimated for the UK and other European countries. In general, the method used has been to combine data on fish and shellfish landings from relevant sea areas with average radioactivity concentrations in fish and shellfish caught in these areas. Sea areas considered 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 for weapons-test fallout to the radioactivity concentrations was subtracted. Consideration has been given to the pathway due to fish offal and industrial fisheries, the product of both of which is fish meal which is fed to pigs 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 8. The results for 1985 and 1986 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 opportunity has been taken for interim revision of our results for 1985 to take account of improved data on radioactivity concentrations in some fish landings. The preliminary results will be reviewed in future reports as updated statistics are received.

Table 8 Collective doses from fish and shellfish, 1985 and 1986.

Population	Size of population	Collective committed effective dose equivalent*, man-Sv	
		1985	1986
UK	5.6×10^7	50	50
Other European countries	6.5×10^8	80	90

*preliminary data. The word 'committed' has been included to accurately reflect the basis of calculation, to which there has been no change as compared with previous years.

Liquid radioactive discharges from Sellafield 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 is estimated at about 15 man-Sv to the UK population and 20 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 Sellafield discharges 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 from all sea areas is due to radiocaesium in edible fish; the contribution due to shellfish is 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 50 man-Sv for the UK in 1986 is the same as the revised result for 1985. The effect of radioactivity from Chernobyl, mainly on fish from Scottish waters and the North Sea, has essentially offset the effect of reductions in discharges from Sellafield, manifested in all areas, and particularly in the Irish Sea. The preliminary result of 90 man-Sv for the collective dose to inhabitants of other countries in 1986 was slightly more than in 1985 (80 man-Sv), reflecting the contribution due to radioactivity from Chernobyl in Scottish waters and the North Sea.

The collective dose for the UK, given in Table 8, may be compared with the annual dose equivalent averaged over the population of 0.05 mSv considered unlikely to be exceeded (NRPB, 1978) (sub-section 3.4) as a result of all waste management practices. In 1986, the UK

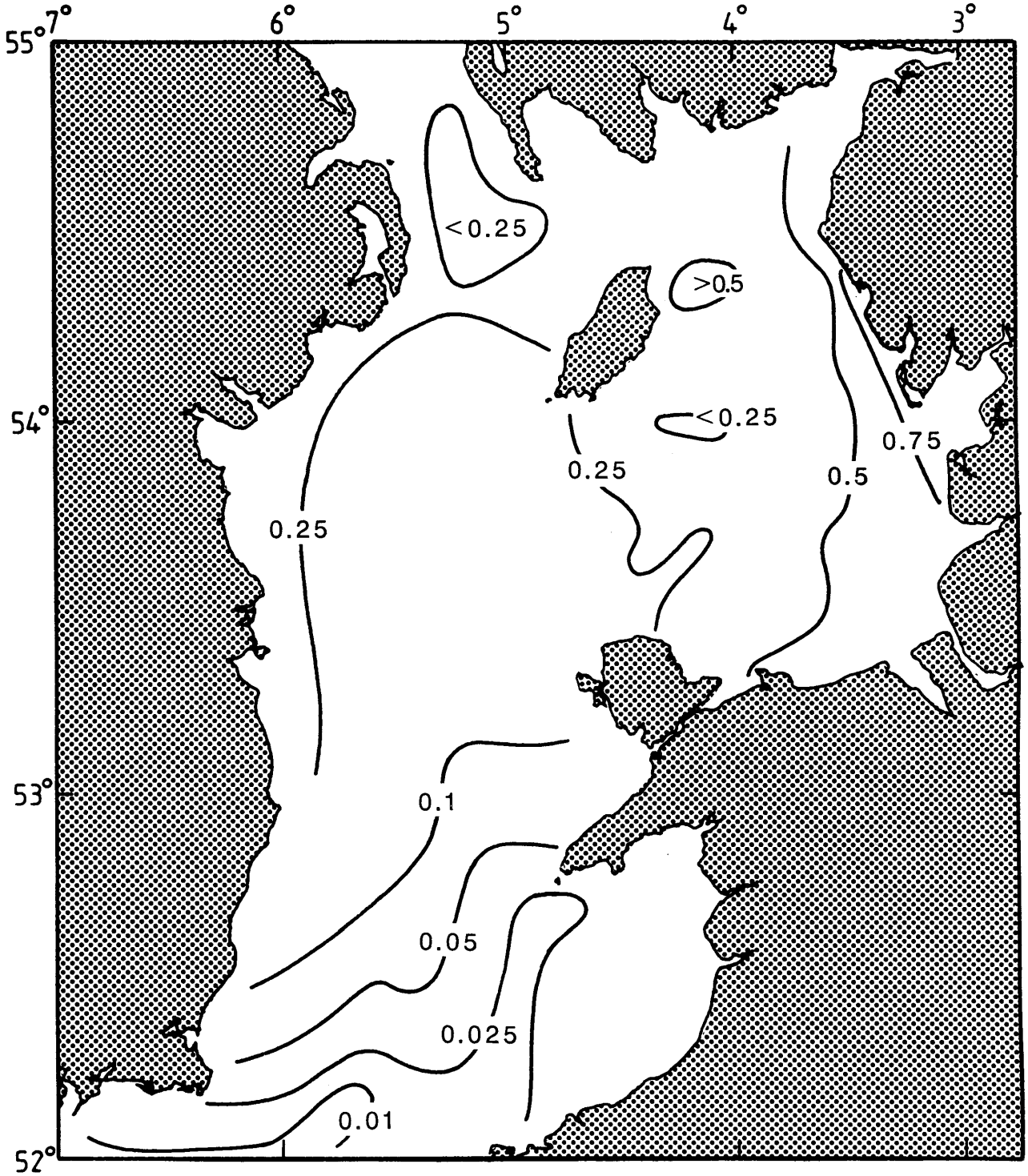

Figure 2 Concentration (Bq kg^{-1}) of caesium – 137 in filtered water from the Irish Sea, April 1986.

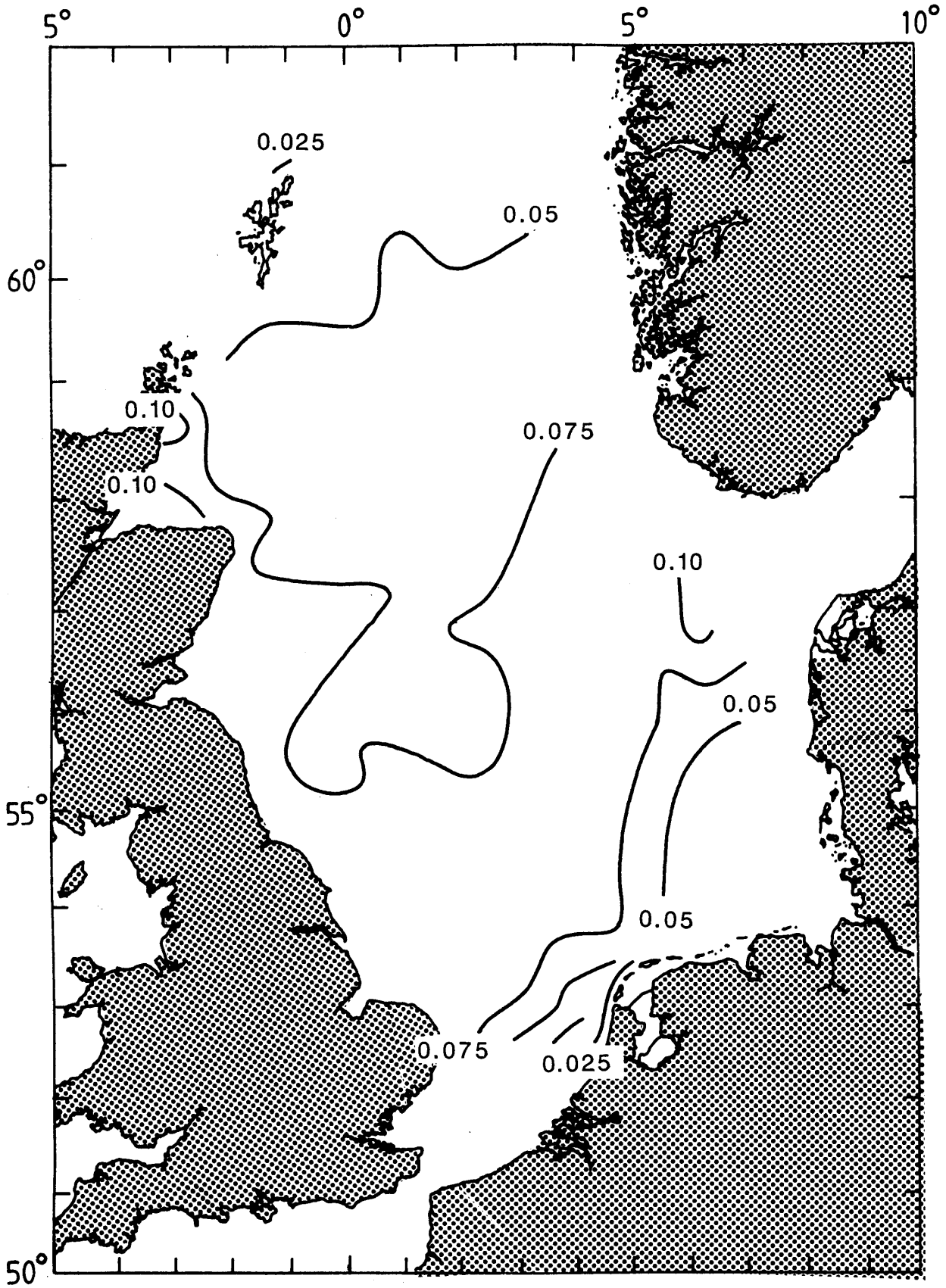

Figure 3 Concentration (Bq kg^{-1}) of caesium – 137 in filtered water from the North Sea, August–September 1986.

collective dose through the fish and shellfish pathway as a result of liquid radioactive waste disposal operations amounted to less than 2% of this value.

It is clear from the statements above, which compare the 1985 and 1986 results for both critical group and collective dose rates, that an important factor determining exposures is the distribution of radioactivity in the marine environment. We maintain a continuing programme of research on marine behaviour and distribution (including budget assessments) of significant radionuclides. Data on the distribution of caesium-137 in sea water are regularly collected by research vessel cruises; the distribution observed in the Irish Sea in April 1986 is shown in Figure 2. Comparison with the data for March-April 1985 (Hunt, 1986a) shows that concentrations of caesium-137 in sea water of the eastern Irish Sea reduced significantly, reflecting the decreased discharges from Sellafield during 1985, following operation of SIXEP. Continuing reductions in radiocaesium concentrations in water and fish are expected in 1987. The distribution of caesium-137 in sea water of the North Sea during August and September 1986 is shown in Figure 3. Comparison with the distribution observed in August and September 1985 (Hunt, 1986a) shows a general reduction in concentrations off eastern Scotland and north-east England. The pattern elsewhere is complicated by the effect of fallout from Chernobyl, which has increased concentrations of radiocaesium, particularly in northern and eastern areas of the North Sea (Mitchell and Steele, 1987).

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 9 lists the locations monitored together with the dose rates in air at 1 m above ground level. Monitoring in Scotland is carried out on behalf of the departments of the Scottish Office. Dose rates on Irish Sea shorelines near other nuclear establishments which reflect Sellafield discharges are given later in this report (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 1986 showed general reductions as compared with 1985 (Hunt, 1986a), except for locations in Scotland where small increases were due to fallout from Chernobyl, as explained below.

We also regularly monitor radioactivity concentrations in sediments. This is both because of their relevance to dose rates and in order to keep under review distributions of adsorbed radioactivity. Concentrations of beta/gamma radioactivity and transuranics, in most cases at the same locations as the dose rate measurements, are given in Table 10. Variations similar in cause to those of the dose rates are observed, and comparison with results for 1985 (Hunt, 1986a) shows general reductions in concentrations of radionuclides of predominantly Sellafield origin, namely zirconium-95 plus niobium-95, ruthenium-106, radiocaesium, cerium-144, radioeuropium and transuranic nuclides. Short-lived radionuclides due to fallout from Chernobyl (sub-section 3.2) were also detected; concentrations at locations in England were insignificant in terms of dose rates (Table 9) which declined in line with reductions in Sellafield discharges as described earlier in this section. At coastal locations in south-west Scotland, where there was greater rainout from the Chernobyl plume, concentrations of these short-lived radionuclides were higher than at coastal locations in north-west England, leading to small increases in average dose rates compared with those in 1985. However, these increases were of minor radiological significance. It is also to be noted that the levels of radionuclide concentrations in Table 10 give rise to negligible exposure following inhalation of resuspended sediment (Pattenden *et al.*, 1981).

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

Table 9 Gamma radiation dose rates over intertidal areas of the Cumbrian coast and further afield, 1986.

Location	Ground type	No. of sampling observations†	Mean gamma dose rate in air at 1 m, μGy h^{-1}
Burgh Marsh	Salt marsh	4	0.12
Greenend	" "	4	0.12
"	Sand	4	0.099
Maryport harbour	Silt	4	0.20
" "	Dried silt	4	0.17
Workington harbour	Silt	4	0.25
Harrington harbour	"	4	0.28
Whitehaven outer harbour	"	12	0.27
" " "	Coal/sand	12	0.21
" inner "	Silt	12	0.36
Whitehaven yacht basin	Silt	12	0.49
St Bees	Sand	4	0.086
Nethertown winkle beds	Rock	1	0.12
Sellafield	Sand	4	0.12
Seascale	"	4	0.11
Drigg	"	4	0.094
Ravenglass - Salmon Garth	Sand	12	0.14
" "	Silt	12	0.23
" "	Mussel bed	12	0.21
Ravenglass - boats area	Sand	4	0.10
" " "	Silt	12	0.19
Ravenglass - ford area	"	4	0.26
Ravenglass - Ravenvilla	"	12	0.33
" "	Salt marsh	12	0.58
Newbiggin	Silt	12	0.41
Newbiggin - west of bridge	Sand/silt	4	0.30
" " " "	Salt marsh	4	0.67
Haverigg	Sand	4	0.12
"	Silt	4	0.23
Millom	"	4	0.21
Walney Channel	Sand	4	0.12
" "	Silt	4	0.18
" west shore	Sand	4	0.079
Low Shaw	Salt marsh	4	0.19
Flookburgh	Sand	4	0.12
Skipool Creek	Silt	4	0.21
Fleetwood	Sand	4	0.083
Blackpool	"	4	0.065
Ainsdale	"	5	0.067
New Brighton	"	4	0.072
Mersey (Rock Ferry)	Silt	4	0.14
Llandudno	Sand	4	0.078
Prestatyn	"	4	0.058
Garlieston	Silt	4	0.14
Kippford - slipway	"	4	0.18
" - jetty	"	4	0.18
" - merse	Salt marsh	4	0.32

†See sub-section 3.3 for definition.

including Cumbria, Lancashire and the north Solway coast. In west Cumbria, combining dose rates and occupancy times, it is still considered that those who live on board boats in Whitehaven harbour are representative of those who receive the highest external exposures. Occupancy of these boats declined during 1986; the maximum exposure was equivalent to that from spending 300 h $year^{-1}$ over unshielded mud. Allowing for addition of dose due to other pathways such as fish consumption the maximum exposure would have been 0.12 mSv, as compared with 0.35 mSv reported for the critical group in 1985 (Hunt, 1986a). 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

Table 10 Radioactivity in sediment from the Cumbrian coast and further afield, 1986.

Sampling point and sediment type		No. of sampling observations†	Mean radioactivity concentration (dry), Bq kg^{-1}										
			Total beta	^{54}Mn	^{60}Co	^{95}Zr + ^{95}Nb	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{131}I	^{134}Cs	^{137}Cs
Maryport	(silt)	4	5 100	0.6	37	76	45	1 300	5.7	34	ND	81	1 600
Harrington	(")	4	5 300	1.2	40	79	48	1 400	4.4	36	"	67	1 500
Whitehaven	(")	4	7 700	2.6	30	97	200	1 300	4.4	33	"	120	3 000
Newbiggin	(silt)	4	6 300	ND	65	55	84	2 400	ND	58	"	77	2 500
Walney Island	(")	4	1 600	"	8.0	12	62	270	1.8	7.7	"	29	620
Flookburgh	(sand)	4	1 000	"	4.4	9.1	9.1	150	0.4	3.2	"	11	390
Heysham	(silt)	4	940	"	2.7	ND	4.2	96	ND	2.8	"	11	360
Sunderland Pt	(")	4	1 400	"	4.5	2.2	31	160	0.8	1.5	"	27	680
Skipool Creek	(")	4	3 100	"	9.0	ND	82	440	2.0	4.4	"	70	1 900
Fleetwood	(sand)	4	360	"	0.2	"	3.5	7.6	ND	ND	"	2.7	56
Blackpool	(")	4	300	"	ND	"	0.2	ND	"	"	"	0.9	37
New Brighton	(")	4	290	"	"	"	ND	"	"	"	"	1.0	32
Rock Ferry	(silt)	4	2 000	0.4	3.9	"	38	110	"	0.9	"	25	830
Garlieston	(sand)	4	570	ND	0.6	"	4.1	9.8	"	ND	"	5.1	96
"	(silt)	4	2 200	"	11	"	66	430	6.3	7.2	"	67	850
Kippford slipway	(")	4	2 300	1.5	13	27	550	500	15	22	230	160	950
" merse	(")	2	5 000	ND	14	ND	1 200	820	3.5	40	ND	810	2 700
" "	(marsh)	2	3 200	"	16	12	100	560	7.7	12	"	160	1 500
Palnackie	(")	4	3 200	0.4	17	2.1	380	630	16	20	"	250	1 400

Sampling point and sediment type		No. of sampling observations†	Mean radioactivity concentration (dry), Bq kg^{-1}								
			^{140}Ba	^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Maryport	(silt)	4	ND	77	36	29	170	760	NA	930	1.3	3.8
Harrington	(")	4	"	105	45	32	NA	NA	"	910	NA	NA
Whitehaven	(")	4	"	80	52	34	190	830	"	1 000	1.7	2.7
Newbiggin	(silt)	4	"	130	110	82	420	1 700	37 000	2 000	4.2	4.5
Walney Island	(")	4	"	14	15	10	NA	NA	NA	440	NA	NA
Flookburgh	(sand)	4	"	5.5	4.4	4.0	"	"	"	120	"	"
Heysham	(silt)	4	"	ND	ND	3.6	16	77	"	99	0.095	0.34
Sunderland Pt	(")	4	"	"	5.6	4.9	NA	NA	"	120	NA	NA
Skipool Creek	(")	4	"	8.2	17	11	"	"	"	370	"	"
Fleetwood	(sand)	4	"	ND	ND	ND	"	"	"	12	"	"
Blackpool	(")	4	"	"	"	"	"	"	"	4.6	"	"
New Brighton	(")	4	"	"	"	"	"	"	"	1.0	"	"
Rock Ferry	(silt)	4	"	"	0.7	3.2	"	"	"	130	"	"
Garlieston	(sand)	4	"	"	ND	0.6	"	"	"	29	"	"
"	(silt)	4	"	14	13	12	50	230	"	290	ND	0.70
Kippford slipway	(")	4	150	26	8.0	7.2	48	230	"	300	0.4	1.2
" merse	(")	2	ND	33	20	6.6	91	420	"	550	1.2	1.8
" "	(marsh)	2	"	28	19	11	NA	NA	"	400	NA	NA
Palnackie	(")	4	"	28	17	12	66	310	"	420	0.8	1.3

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

of those who receive the highest external exposures from the effects of discharges from Sellafield. Taking account of the time the boats are shielded from the mud by tidal effects and the shielding afforded by the boats themselves, their exposure in 1986 was equivalent to that from spending 3500 h year^{-1} over unshielded mud. From Table 9, making an allowance for natural background, their external exposure in 1986 was about 0.34 mSv.

These people do not engage in fishing and their consumption of fish and shellfish is negligible. Their exposure is within the ICRP-recommended principal dose limit of 1 mSv year^{-1} for members of the public.

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.

Table 11 Beta radiation dose rates on contact with fishing gear on vessels operating off Sellafield, 1986.

Vessel	Type of gear	No. of sampling observations†	Mean beta dose rate in tissue, $\mu Gy\ h^{-1}$
A	Nets	4	0.16
	Ropes	4	0.12
B	Nets	14	0.12
	Ropes	8	0.13
D	Nets	4	0.08
	Pots	3	0.11
E	Nets	8	0.33
F	Nets	4	0.05
	Ropes	1	0.02
G	Nets	2	0.07
	Ropes	2	0.04
I	Nets	2	0.02
J	Nets	1	0.06
	Pots	3	0.07
K	Nets	4	0.20
	Pots	1	0.04
L	Nets	3	0.07
	Pots	3	0.06
M	Nets	2	0.04
	Ropes	2	0.07
N	Nets	3	0.01
	Pots	1	0.14

†See sub-section 3.3 for definition.

4.1.3 *Fishing gear*

During immersion in sea water, fishing gear may entrain particles of sediment on which radioactivity is adsorbed. Fishermen handling this gear may be exposed to external radiation, mainly to skin from beta particles. We regularly monitor fishing gear using portable beta dose-meters. Results for 1986 are presented in Table 11. 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 1986 would have been 0.1 mSv, less than 1% of the ICRP-recommended dose limit appropriate for exposures to skin of members of the public, based on non-stochastic effects (sub-section 3.4). Handling of fishing gear, therefore, continues to be a minor radiation exposure pathway.

4.1.4 *Porphyra/laverbread pathway*

No harvesting of *Porphyra* in the Sellafield vicinity for consumption after being made into laverbread was reported in 1986; 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. Samples of *Porphyra* are regularly collected from selected locations along UK shores of the Irish Sea. Results of analyses for 1986 are presented in Table 12, and for radionuclides of Sellafield origin showed similar reductions to those observed in other materials as compared with results for 1985. Short-lived radionuclides from Chernobyl were also detected following the accident. Samples of

Table 12 Radioactivity in *Porphyra* from UK shorelines of the Irish Sea, 1986.

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	^{131}I	^{132}Te
Braystones South	12	430	0.1	1.8	NA	1.6	NA	84	240	2.1	1.8	ND	ND
Seascale	52*	NA	ND	2.5	"	7.5	"	77	220	1.3	3.9	37	25
St Bees	4	290	"	1.2	0.74	3.4	1.2	57	130	0.7	5.4	ND	ND
Knock Bay	4	210	"	ND	NA	ND	NA	37	20	2.9	ND	"	"

Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet), $Bq\ kg^{-1}$										
		^{134}Cs	^{137}Cs	^{140}Ba	^{144}Ce	^{154}Eu	^{238}Pu	$^{239}Pu + {}^{240}Pu$	^{241}Pu	^{241}Am	^{242}Cm	$^{243}Cm + {}^{244}Cm$
Braystones South	12	2.2	14	ND	1.0	0.1	1.5	6.3	130	10	0.053	0.040
Seascale	52*	2.2	18	0.7	1.7	0.1	NA	NA	NA	17	NA	NA
St Bees	4	1.3	11	ND	0.7	ND	1.6	7.0	"	12	0.074	0.071
Knock Bay	4	0.5	3.2	"	ND	"	NA	NA	"	ND	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.

Table 13 Radioactivity in laverbread from South Wales, 1986.

Manufacturer	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}								
		Total beta	^{103}Ru	^{106}Ru	^{110m}Ag	^{129m}Te	^{131}I	^{134}Cs	^{137}Cs	^{140}Ba
A	4	68	7.5	4.7	1.0	1.3	0.5	0.1	0.5	ND
C	4	71	9.4	6.6	1.2	ND	0.9	0.1	0.5	"
D	4	81	13	7.9	1.1	"	1.3	ND	1.1	0.1
E	1	79	ND	ND	ND	"	ND	"	1.3	ND

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

laverbread from the major manufacturers are regularly collected from markets in South Wales and analysed. Results for 1986 are presented in Table 13. These also show the presence of short-lived radioactivity from Chernobyl, but this was of negligible radiological significance. The exposure of critical laverbread consumers was less than 0.01 mSv, confirming the virtual abeyance of this exposure pathway.

Table 14 Summary of contact beta dose rate monitoring of intertidal areas of Cumbria, 1986.

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	1	Sellafield:	0.14
February	5		
March	4		
April	14	Drigg:	0.12
May	1		
June	1	Sellafield:	0.38
		Nethertown:	2.20
July	0		
August	1	Sellafield:	0.10
September	0		
October	0		
November	0		
December	2		

4.1.5 Contact beta dose-rate monitoring of intertidal areas

We regularly monitor contact beta dose rates in intertidal areas to locate and remove any material with unusual levels of contamination. A summary of items detected during 1986 is presented in Table 14. 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. 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.

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 concentrate certain radionuclides so they greatly facilitate measurement and assist in the tracing of these radionuclides in the environment. Table 15 presents the results of measurements in 1986 on marine plants from shorelines of the Irish Sea. In addition to radioactivity from Sellafield, a number of mainly short half-life radionuclides were detected from the Chernobyl reactor accident. Although small quantities of samphire and *Rhodymenia* may be eaten, radioactivity concentrations are of negligible radiological significance. *Fucus* seaweeds are useful indicators particularly of fission product radioactivity other than from ruthenium-106; samples of *Fucus vesiculosus* are collected both in the Sellafield vicinity and further afield, and the results are presented here. Monitoring in Scotland is carried out on behalf of departments of the Scottish Office. Analyses of samples collected in Northern Ireland are carried out on behalf of the DOE (NI).

Table 15 Radioactivity in marine plants from shorelines of the Irish Sea, 1986.

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	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs
Fucus vesiculosus												
Sellafield	4	1 100	0.5	18	3.6	12	1 200	1.4	31	7.9	2.7	2.9
St Bees	4	900	0.6	11	6.3	8.8	760	27	29	8.1	2.7	11
Heysham	4	330	ND	0.8	NA	0.2	NA	5.0	4.5	1.2	0.1	3.0
Port William	4	320	0.1	0.7	"	ND	"	1.1	3.1	4.4	ND	1.9
Garlieston	4	390	ND	1.8	"	"	"	2.2	7.8	6.1	0.3	2.6
Auchencairn	4	630	0.1	1.9	"	2.8	"	150	46	8.7	2.2	37
Ardglass	1	270	ND	ND	"	ND	"	ND	ND	ND	ND	ND
Portrush	4	260	"	"	"	"	"	12	5.6	3.8	"	1.0
Fucus spiralis												
St Bees	4	630	0.4	7.6	5.9	5.2	310	65	40	8.2	1.7	29
Ardlgass	1	280	ND	ND	NA	ND	NA	38	13	5.1	ND	4.5
Fucus serratus												
St Bees	4	730	0.4	20	4.9	4.8	520	9.8	48	5.3	2.3	4.2
Laminaria												
St Bees	4	600	ND	0.9	4.8	6.7	280	4.7	39	4.0	1.2	2.1
Samphire												
Newbiggin	1	80	"	1.4	NA	8.2	NA	ND	21	ND	ND	1.4
Heysham	1	60	"	ND	"	ND	"	"	1.6	"	"	0.6
Rhodymenia spp.												
St Bees	3	710	0.1	3.7	1.0	13	1.1	0.8	97	0.5	1.3	4.3
Millisle	5	620	ND	ND	NA	ND	NA	ND	4.1	2.4	ND	1.6
Ascophyllum nodosum												
St Bees	4	850	"	5.0	4.1	5.7	1 000	29	29	6.7	3.1	8.5
Ardglass	2	350	"	ND	NA	ND	NA	ND	ND	1.5	ND	1.2
Chondrus crispus												
St Bees	2	470	0.6	6.0	8.0	6.4	1.6	13	110	4.4	3.6	1.8
Enteromorpha spp.												
St Bees	4	290	ND	2.0	7.1	14	2.9	36	74	0.9	1.8	5.0
Dilsea carnosa												
St Bees	1	720	"	1.5	NA	6.1	NA	50	47	6.9	ND	5.3

Type of seaweed and sampling point	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}										
		^{137}Cs	^{140}Ba	^{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	49	ND	1.6	24	ND	ND	4.5	20	8.9	0.028	0.024
St Bees	4	57	"	0.8	NA	0.6	"	3.7	16	8.7	0.041	0.039
Heysham	4	41	"	ND	"	ND	"	0.62	3.0	1.2	ND	0.0057
Port William	4	18	"	"	"	"	"	NA	NA	0.5	NA	NA
Garlieston	4	31	"	"	"	"	"	"	"	2.7	"	"
Auchencairn	4	100	150	1.2	"	"	"	"	"	3.4	"	"
Ardglass	1	13	ND	ND	"	"	"	"	"	ND	"	"
Portrush	4	4.6	"	"	"	"	"	"	"	"	"	"
Fucus spiralis												
St Bees	4	77	"	0.2	"	0.3	0.2	2.6	11	7.2	0.042	0.028
Ardglass	1	14	"	ND	"	ND	ND	NA	NA	ND	NA	NA
Fucus serratus												
St Bees	4	43	"	1.3	"	0.7	0.4	6.1	25	11	0.061	0.026
Laminaria												
St Bees	4	33	"	0.6	"	ND	ND	2.7	11	3.9	0.029	0.015
Samphire												
Newbiggin	1	16	"	ND	"	"	"	NA	NA	14	NA	NA
Heysham	1	10	"	"	"	"	"	"	"	1.5	"	"
Rhodymenia spp.												
St Bees	3	82	"	4.4	"	"	"	2.6	11	21	0.16	0.10
Millisle	5	18	"	ND	"	"	"	NA	NA	0.2	NA	NA
Ascophyllum nodosum												
St Bees	4	42	"	0.5	"	"	"	2.6	11	5.0	0.044	0.021
Ardglass	2	8.8	"	ND	"	"	"	NA	NA	ND	NA	NA
Chondrus crispus												
St Bees	2	41	"	6.9	"	"	"	3.6	15	30	0.14	0.13
Enteromorpha spp.												
St Bees	4	79	"	6.7	"	1.1	1.1	5.5	24	39	0.28	0.16
Dilsea carnosa												
St Bees	1	35	"	ND	"	ND	ND	NA	NA	11	NA	NA

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

Table 16(a) Radioactivity in environmental materials near Springfields, 1986.

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (dry), Bq kg^{-1}											
			Total beta	^{54}Mn	^{60}Co	^{95}Zr + ^{95}Nb	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{140}Ba	^{144}Ce
Bass	Ribble estuary	1	270	ND	ND	ND	ND	ND	ND	ND	4.5	120	ND	ND
Grey mullet	" "	1	160	"	"	"	"	"	"	"	2.1	44	"	"
Cockles	Lytham	1	170	"	"	"	37	24	"	"	2.0	21	"	"
Silt	Pipeline outlet	4	5 400	"	5.8	9.4	60	190	"	4.4	44	950	"	12
	Becconsall	4	17 000	"	9.2	ND	94	330	2.3	4.5	68	1 500	6.6	46
	Skipool Creek	4	3 100	"	9.0	"	82	440	2.0	4.4	70	1 900	ND	8.2
	Rock Ferry	4	2 000	0.4	3.9	"	38	110	ND	0.9	25	830	"	ND
Sand	Lytham	1	420	ND	0.6	"	20	23	"	ND	4.7	100	"	"

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (dry), Bq kg^{-1}										
			^{154}Eu	^{155}Eu	^{228}Th	^{230}Th	^{232}Th	^{234m}Pa	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Bass	Ribble estuary	1	ND	ND	0.0012	ND	ND	ND	NA	NA	ND	NA	NA
Grey mullet	" "	1	"	"	0.0045	0.0002	"	"	"	"	"	"	"
Cockles	Lytham	1	"	"	0.66	1.3	0.41	"	"	"	7.1	"	"
Silt	Pipeline outlet	4	5.4	2.7	45	250	56	20 000	33	160	200	ND	0.85
	Becconsall	4	13	4.1	NA	NA	NA	38 000	NA	NA	470	NA	NA
	Skipool Creek	4	17	11	36	86	41	ND	"	"	370	"	"
	Rock Ferry	4	0.7	3.2	42	67	44	"	"	"	130	"	"
Sand	Lytham	1	ND	ND	10	17	11	"	"	"	19	"	"

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

4.2 Springfields, Lancashire

This establishment is mainly concerned with manufacture of fuel elements for nuclear reactors and production of uranium hexafluoride. Radioactive waste arisings are small and consist 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 as 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 1986, we continued to investigate the fish and shellfish consumption pathway by analysing locally-obtained samples, including analyses for isotopes of thorium.

Table 16(b) Gamma dose rates in air at 1m over intertidal areas near Springfields, 1986.

Location	No. of sampling observations†	μGy h^{-1}
Pipeline outlet	4	0.18
Freckleton	4	0.21
Becconsall	4	0.19
Lytham	4	0.20

†See sub-section 3.3 for definition.

Results for 1986 are shown in Table 16(a) and (b). The only radionuclides detected which were due to Springfields discharges were isotopes of thorium and protactinium-234m; other radionuclides present were mainly from Sellafield, with a very small effect due to fallout from Chernobyl. Exposure of the critical group of houseboat dwellers in 1986, including the Sellafield component, was about 0.34 mSv, slightly more than in 1985 (0.30 mSv) due to increased times spent on houseboats. Dose rates themselves decreased, following reduced discharges from Sellafield; the

contribution due to Springfields 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 in fish from the Ribble Estuary were not significantly different from those to be 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 in silt in areas outside the Ribble Estuary were consistent with natural sources, as were concentrations of thorium in sand from Lytham.

4.3 Capenhurst, Cheshire

The main function of the Capenhurst Works is isotopic enrichment of uranium. Radioactive waste arisings, mainly of uranium and its daughter products and technetium-99 from recycled uranium, are very small; the Works has authorisations to dispose of liquid wastes to the Rivacre Brook and to the North Wirral sewage outfall at Meols. It is not expected that the environmental consequences of these small disposals would be detectable above background levels due both to natural sources of radioactivity and to Sellafield discharges. However, we have established an environmental monitoring programme related to the potentially critical pathway due to consumption of shellfish caught in the vicinity of the Wirral. *Fucus* seaweed is also sampled, being a good indicator for technetium-99. 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 1986 are presented in Table 17. The concentrations of artificial radioactivity are mainly due to Sellafield discharges and are consistent with values to be expected at this distance from Sellafield; there is also a small contribution of short-lived radionuclides due to the Chernobyl accident. Technetium-99 concentrations continued to be low, reflecting the much reduced discharges of technetium-99 from Sellafield because decay-stored liquors were not being released.

Table 17 Radioactivity in environmental materials in the vicinity of the Wirral, 1986.

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
			Total beta	^{60}Co	^{99}Tc	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb
Shrimps	Hoylake	2	89	ND	ND	ND	ND	1.3	ND
Cockles	Dee Estuary	2	89	"	2.6	"	3.5	ND	"
Fucus spiralis	Hoylake	2	260	0.2	34	12	5.6	1.0	"
Fucus spiralis	Little Orme	1	200	ND	25	18	9.4	14	"
Silt	Hoylake	2	1100	2.9	5.4	67	120	4.8	6.5

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	^{243}Cm + ^{244}Cm
Shrimps	Hoylake	2	0.9	13	ND	NA	NA	ND	NA
Cockles	Dee Estuary	2	0.8	13	"	0.41	1.9	3.9	0.014
Fucus spiralis	Hoylake	2	5.8	36	"	NA	NA	1.3	NA
Fucus spiralis	Little Orme	1	4.6	14	"	"	"	ND	"
Silt	Hoylake	2	41	550	2.6	14	71	91	0.22

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

Discharges of technetium-99 from Capenhurst increased during 1986 (Table 1) but were still at a low percentage of the authorised limits; any effect on concentrations in the environment would have been negligible. Exposure of critical shellfish consumers in the vicinity of the Wirral in 1986 amounted at most to about 0.1 mSv, 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.

4.4 Chapelcross, Dumfriesshire

At this establishment BNFL operates a magnox-type nuclear power station. Liquid waste arisings are discharged to the Solway Firth under authorisation of the Scottish Development Department. The authorisation was revised with effect from 1 April 1986 at the same time as the authorisation for airborne discharges. The revised liquid authorisation includes a specific limit on alpha-emitters (Table 1). The radioactivity in liquid discharges in 1986 was less than in 1985 mainly because the pond was not discharged for cleaning operations as in previous years, but these operations may be resumed in the future. 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 vesiculosus,* as a useful indicator, are also analysed. The results of monitoring in 1986 are presented in Table 18(a) and (b).

Concentrations of artificial radionuclides in the Chapelcross vicinity are mostly due to Sellafield discharges, and the general levels of relevant nuclides given in Table 18(a) are consistent with values to be expected at this distance from Sellafield; transient levels of short-lived radionuclides due to the Chernobyl accident were also detected, but were of negligible radiological significance. Radiocaesium concentrations in 1986 were generally less than those in 1985, reflecting reductions in Sellafield discharges. Exposure of the critical group in 1986, making the maximising assumption of additivity of the two pathways,

Table 18(a) Radioactivity in environmental materials in the vicinity of Chapelcross, 1986.

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}										
			Total beta	^{54}Mn	^{60}Co	^{95}Zr + ^{95}Nb	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{140}Ba
Flounder	Seafield	4	220	ND	ND	ND	ND	ND	ND	ND	4.0	130	ND
Salmon	"	1	120	"	"	"	"	"	"	"	0.2	1.1	"
Sea trout	"	2	140	"	"	"	"	"	"	"	2.4	33	"
Shrimps	"	4	120	"	"	"	0.6	0.4	3.2	"	2.4	43	"
Fucus spiralis	"	2	310	"	1.4	"	ND	4.6	0.4	0.2	1.4	51	"
Fucus vesiculosus	"	3	310	0.1	1.6	"	22	9.8	1.4	0.3	6.6	69	24
Silt	"	4	1800	0.3	7.3	11	30	230	ND	ND	31	980	ND
Sand	"	4	1100	ND	1.4	ND	240	110	3.5	5.3	77	480	"

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	"	"	"	0.00010	0.00051	0.00053	ND	ND
Shrimps	"	4	"	"	"	NA	NA	ND	NA	NA
Fucus spiralis	"	2	"	"	0.3	"	"	3.2	"	"
Fucus vesiculosus	"	3	"	"	ND	0.69	3.2	3.0	0.01	0.0085
Silt	"	4	14	9.1	"	30	140	180	0.2	0.59
Sand	"	4	4.4	0.5	1.0	9.4	42	57	ND	0.15

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

Table 18(b) Gamma dose rates in air at 1m over intertidal areas in the vicinity of Chapelcross, 1986.

Location and sediment type	No. of sampling observations†	μGy h^{-1}
Seafield (silt)	4	0.11
Seafield (merse)	4	0.13
Torduff Point (silt)	4	0.14
Dornoch Brow (silt)	4	0.11
Dornoch Brow (merse)	4	0.14

†See sub-section 3.3 for definition.

amounted to less than 0.2 mSv, 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 is due to Sellafield discharges.

5. United Kingdom Atomic Energy Authority

We regularly monitor the environmental impact of liquid radioactive discharges from two UKAEA sites. These are the Atomic Energy Establishment, Winfrith and the Dounreay Nuclear Power Development Establishment. Liquid radioactive wastes also arise at the Atomic Energy Research Establishment, Harwell. In common with such wastes from other nuclear establishments in the Thames Valley area, these are discharged into the River Thames, and the critical exposure pathway is from drinking water. Monitoring in respect of these discharges is therefore carried out by the DOE rather than by this Ministry.

5.1 Atomic Energy Establishment, Winfrith, Dorset

The principal source of liquid radioactive wastes at this establishment is the Steam Generating Heavy Water Reactor. Most of the activity 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. It is the activation products rather than tritium which are of greater, but still small, environmental significance. 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 in Poole Harbour where the fine silt has the potential to adsorb radioactivity. Monitoring of the indicator material *Fucus serratus* and of sediments from a number of locations along the south coast provides additional information on the distribution of activation products. Data are presented in Table 19.

The impact of Winfrith discharges was, as in previous years, mainly observed in the concentrations of activation products. The greater concentration of zinc-65 in crabs as compared with 1985 is likely to have been contributed by a small increase, well within authorised limits, in discharges of this nuclide. Greater concentrations of activation products in scallops were likely to have been due to sampling closer to the pipeline outfall rather than to any systematic increase in discharges. Trace concentrations of silver-110m and caesium-134 detected in environmental materials are likely to have been due to the Chernobyl reactor accident, but were of negligible radiological significance. Further information on the consumption rates of fish and shellfish eaters became available in 1986, but this information was of a provisional nature and further studies are being carried out. Using these provisionally - revised consumption rates, the radiation dose to the critical group of fish and shellfish consumers near this establishment was about 0.1 mSv, within the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$. External gamma radiation dose rates continued to be indistinguishable from natural background.

5.2 Dounreay Nuclear Power Development Establishment (DNPDE), 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) operated by the Ministry of Defence (Procurement Executive). In 1986, discharges from DNPDE were less than in 1985 reflecting a period of reprocessing of Prototype Fast Reactor (PFR) fuel following plant refurbishment. Discharges from the Vulcan site were also less than in 1985 due to completion of a refurbishment programme. Our surveys near Dounreay are carried out on behalf of departments of the Scottish Office. Monitoring in 1986 continued to increase, including samples of shellfish from the area of the Dounreay outfall.

Recent habits surveys have confirmed the existence of three potentially critical exposure pathways, two of which involve external radiation. 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

Table 19 Radioactivity in environmental materials from the vicinity of Winfrith, 1986.

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			Total beta	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn	^{110m}Ag	^{106}Ru	^{134}Cs
Plaice	Weymouth Bay	1	97	ND	ND	ND	1.4	ND	ND	ND
Crabs	Weymouth Bay	2	100	1.9	2.9	38	240	"	"	"
Oysters	Poole	2	45	ND	ND	2.3	110	0.6	"	"
Cockles	Poole	1	87	"	2.8	36	12	ND	"	"
Scallops	Weymouth Bay	2	160	170	16	100	570	0.6	3.7	"
Fucus serratus	Arish Mell	1	350	39	65	240	138	ND	ND	"
	Kimmeridge	2	250	23	20	110	35	"	"	"
	Swanage	2	300	9.6	12	105	35	"	"	"
	Hengistbury Head	2	220	3.9	4.5	53	10	"	"	"
	Bognor Regis	2	250	1.6	ND	22	3.6	"	"	"
	Sandgate	2	260	0.2	"	15	0.7	"	0.8	"
	Weymouth	2	220	5.7	8.9	48	16	"	ND	"
	Chesil	2	210	ND	ND	4.2	1.0	"	"	"
	Lyme Regis	2	200	"	"	2.5	ND	"	"	"
Silt	Kimmeridge	2	570	6.5	25	134	180	"	"	"
	Poole Harbour	2	320	6.9	ND	40	3.0	"	"	1.3
	Calshot	2	860	2.3	"	44	2.2	"	4.4	1.3
	Hardway	2	655	1.3	"	19	1.3	"	ND	ND
	Littlehampton	2	390	0.5	"	11	0.6	"	5.1	0.6
	Rye Harbour	2	530	1.1	"	14	ND	"	7.0	1.8

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			^{137}Cs	^{144}Ce	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Plaice	Weymouth Bay	1	0.3	ND	ND	NA	NA	ND	NA	NA
Crabs	Weymouth Bay	2	ND	"	"	"	"	"	"	"
Oysters	Poole	2	"	"	"	"	"	"	"	"
Cockles	Poole	1	"	"	"	"	"	"	"	"
Scallops	Weymouth Bay	2	"	"	"	0.019	0.033	0.012	0.0018	0.0016
Fucus serratus	Arish Mell	1	"	"	"	NA	NA	ND	NA	NA
	Kimmeridge	2	"	"	"	"	"	"	"	"
	Swanage	2	0.2	"	"	"	"	"	"	"
	Hengistbury Head	2	0.2	"	"	"	"	"	"	"
	Bognor Regis	2	0.3	"	"	"	"	"	"	"
	Sandgate	2	0.5	"	"	"	"	"	"	"
	Weymouth	2	0.3	"	"	"	"	"	"	"
	Chesil	2	0.1	"	"	"	"	"	"	"
	Lyme Regis	2	0.1	"	"	"	"	"	"	"
Silt	Kimmeridge	2	6.9	4.9	"	"	"	"	"	"
	Poole Harbour	2	5.9	ND	"	0.29	0.98	0.63	0.012	0.017
	Calshot	2	11	"	"	NA	NA	ND	NA	NA
	Hardway	2	4.0	"	"	"	"	"	"	"
	Littlehampton	2	3.1	"	"	"	"	"	"	"
	Rye Harbour	2	8.4	"	0.7	"	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediments:
Poole Harbour (2 sampling observations†): 0.072 μGy h^{-1}
Kimmeridge (2 sampling observations†): 0.090 μGy h^{-1}

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

Table 20 Radioactivity in environmental materials from the vicinity of Dounreay, 1986.

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												
Crabs	3	74	ND	ND	0.5	ND	ND	ND	4.2	ND	0.2	1.8
Lobsters	3	120	"	"	3.6	"	"	8.4	29	"	0.4	3.9
Sandside Bay												
Winkles	4	180	0.4	"	15	0.6	31	37	76	0.3	1.3	3.7
Limpets	4	450	ND	"	9.0	ND	320	160	47	1.9	5.9	13
Fucus vesiculosus	4	440	2.6	0.1	35	1.5	15	13	12	0.2	2.3	8.2
Fucus serratus	4	390	2.7	0.1	43	1.4	15	11	12	ND	1.8	7.2
Shell sand	4	410	ND	ND	2.2	ND	6.3	8.0	ND	"	0.9	15
Brims Ness												
Limpets	4	470	0.2	"	12	"	400	190	56	3.5	11	21
Fucus vesiculosus	2	400	3.3	0.4	28	2.3	ND	4.9	11	ND	0.7	4.8
Fucus spiralis	3	340	2.8	0.2	33	0.6	35	16	13	"	3.6	10

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}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Area of outfall										
Crabs	3	ND	ND	ND	0.0076	0.026	NA	0.099	0.029	0.009
Lobsters	3	1.1	"	0.3	0.030	0.094	1.5	0.46	0.12	0.032
Sandside Bay										
Winkles	4	4.7	"	0.8	0.23	0.7	13	1.8	1.6	0.082
Limpets	4	11	"	2.2	0.30	0.9	16	3.5	4.8	0.16
Fucus vesiculosus	4	3.1	"	1.1	NA	NA	NA	0.2	NA	NA
Fucus serratus	4	3.7	"	0.9	"	"	"	1.3	"	"
Shell sand	4	11	4.1	5.7	4.4	16	180	18	1.2	0.32
Brims Ness										
Limpets	4	7.7	ND	1.5	0.30	0.90	15	3.2	3.9	0.21
Fucus vesiculosus	2	11	"	3.7	NA	NA	NA	2.2	NA	NA
Fucus spiralis	3	6.1	"	1.2	"	"	"	0.6	"	"

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

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 will be low. Monitoring by the UKAEA in 1986 has confirmed that the exposure of these fishermen remained low, at less than 0.02 mSv or less than 1% of the ICRP-recommended dose limit of 50 mSv year^{-1} for skin exposures (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. Monitoring of the foreshore dose rates is also carried out by the UKAEA. 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 crabs and lobsters from the outfall area and winkles from Sandside Bay to enable this pathway to be kept under review. Additionally, as in previous years, limpets and seaweed were sampled as indicator materials. Results are presented in Table 20. Radiocaesium concentrations are mostly due to discharges from Sellafield. Other radionuclides detected, including transuranics, mainly reflect Dounreay discharges; there was also a small

contribution due to the Chernobyl accident. 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 station at Hunterston is operated by the South of Scotland Electricity Board. Results are also presented for measurements made near the second Scottish nuclear power station which is presently nearing completion at Torness.

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 and sand. In addition, measurements of external exposure are supported by analyses of intertidal mud, and *Fucus vesiculosus* is collected as an indicator material.

Data for 1986 are presented in Table 21. The only artificial radioactivity detected in fish and shellfish was due to radiocaesium. Concentrations of radiocaesium represent the combined effect of discharges from the stations and fallout, and possibly include a small Sellafield-derived component, but apportionment is difficult at the low levels detected. Radiation exposure of the critical group of fish and shellfish consumers was very low, at less than 0.001 mSv or 0.1% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$. Very small concentrations of other artificial radionuclides, in addition to radiocaesium, were detected in mud and seaweed but taken together were of negligible radiological significance. No radioactivity was detected from the Chernobyl accident. Directly-measured gamma dose rates over intertidal mud continued to be indistinguishable from the natural background.

6.2 Bradwell, Essex

Radioactive liquid effluent from this power station is discharged to the estuary of the River Blackwater. There are two potentially critical pathways, via consumption of locally-caught fish and shellfish, and external exposure of people who live in houseboats moored in muddy areas of the estuary. Our environmental monitoring reflects these pathways.

Table 21 Radioactivity in environmental materials and gamma dose rates near Berkeley and Oldbury nuclear power stations, 1986.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}									
		Total beta	^{54}Mn	^{60}Co	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{243}Cm + ^{244}Cm
Flounders	2	100	ND	ND	ND	2.0	ND	NA	NA	ND	NA
Grey mullet	2	110	"	"	"	1.9	"	"	"	"	"
Eels	1	61	"	"	"	ND	"	"	"	"	"
Shrimps	1	150	"	"	"	1.5	"	"	"	"	"
Fucus vesiculosus	2	210	0.1	0.8	0.5	6.5	"	"	"	"	"
Mud: area of outfalls	4	780	ND	ND	2.5	48	2.0	"	"	"	"
Lydney	2	720	"	"	2.1	40	1.5	0.13	0.72	0.50	0.23

Mean gamma dose rate in air at 1 m over intertidal mud (10 sampling observations†): 0.089 μGy h^{-1}

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

Table 22 Radioactivity in environmental materials and gamma dose rates near Bradwell nuclear power station, 1986.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs
Mixed fish	7	120	ND	ND	ND	0.1	ND	ND	ND	0.6
Oysters	1	140	"	0.8	31	ND	9.9	42	"	ND
Whelks	1	150	"	1.3	ND	5.0	ND	14	"	0.6
Fucus vesiculosus	2	200	"	1.0	0.2	0.3	"	1.5	0.4	1.5
Sediment	4	980	0.8	7.8	ND	13	31	29	0.9	10

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
Mixed fish	7	4.2	ND	NA	NA	ND	NA	NA
Oysters	1	ND	"	0.00049	0.0020	0.0049	0.00042	0.00023
Whelks	1	1.6	"	NA	NA	ND	NA	NA
Fucus vesiculosus	2	6.0	"	"	"	"	"	"
Sediment	4	62	0.7	"	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediments (7 sampling observations†): 0.077 μGy h^{-1}

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

Table 23 Radioactivity in environmental materials and gamma dose rates near Dungeness nuclear power station, 1986.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{106}Ru	^{110m}Ag	^{134}Cs	^{137}Cs	^{155}Eu
Cod	1	130	ND	0.2	ND	ND	ND	ND	1.5	ND
Eel	1	94	"	ND	"	"	"	"	1.7	"
Flounder	1	130	"	"	"	"	"	0.3	1.6	"
Plaice	2	110	"	"	"	"	"	ND	0.6	"
Shrimps	3	100	"	1.7	0.2	1.4	2.1	"	0.6	"
Whelks	2	35	"	0.3	0.2	ND	ND	"	ND	"
Fucus serratus	2	260	0.2	15	0.7	0.8	"	"	0.5	"
Sand	2	210	ND	3.6	ND	ND	"	0.5	2.0	"
Silt	2	530	1.1	14	"	7.0	"	1.8	8.4	0.7

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†): 0.075 μGy h^{-1}

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

Gamma dose rate measurements are supported by analyses of intertidal sediment, and *Fucus vesiculosus* is analysed as an indicator material.

Measurements for 1986 are summarised in Table 22. In fish and shellfish, artificial radioactivity was detected due to the combined effects of discharges from the station, Sellafield discharges, radioactivity from the Chernobyl accident, and weapons-test fallout. During May 1986, the Water Research Centre carried out an offshore tracer test to investigate dispersion of sewage sludge (Whitelaw and Andrews, 1987); this test used silver-110m and may have contributed to the measured concentrations of this nuclide, but silver-110m was also present in the fallout from Chernobyl. Apportionment of the effects of all these sources is difficult because of the low levels detected, but the short-lived ruthenium-103 is likely to have derived from Chernobyl. The overall dose to members of the critical group of fish and shellfish consumers was low, totalling less than 0.02 mSv or 2% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}. Concentrations of artificial radionuclides detected in mud and seaweed were also low and of negligible radiological significance. Gamma dose rates, as directly measured, were indistinguishable from the natural background.

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 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 occupancy of the foreshore. Our monitoring programme therefore includes analyses of fish and shellfish and gamma dose rate surveys of the intertidal areas. More fish and shellfish samples were taken than in 1985 in the course of a review of exposure pathways. Samples of sediment are also collected and analysed. Seaweed has been analysed as an indicator material. The results for 1986 are given in Table 23.

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 cobalt-60 and zinc-65 in some materials are likely to be due mainly to discharges from AEE Winfrith rather than Dungeness, as demonstrated by the indicator sampling programme described in sub-section 5.1. Trace amounts of ruthenium-106 were also detected in shrimps, 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 nuclide. The small concentration of silver-110m in shrimps may be due to the Chernobyl accident. Our review of exposure pathways confirmed that the critical group are local fish and shellfish consumers, and their exposure during 1986 was very low, at less than 0.002 mSv or 0.2% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}. Gamma dose rates over sand were indistinguishable from natural background.

6.4 Hartlepool, Cleveland

This twin-AGR station came into operation in 1983 and discharges of liquid radioactive wastes in 1986 came closer to levels typical of normal operation, but were still well within authorised limits (Table 1). Potentially critical pathways for radiation exposure of the public near this station are internal irradiation following consumption of local fish and shellfish and external exposure from occupancy of intertidal areas. Collectors of small coal, which is washed ashore along this stretch of coast, account for the highest beach occupancies, but the highest external exposures are likely to be to fishermen who operate in muddy areas near the mouth of the Tees.

Results of our monitoring programme carried out in 1986 are shown in Table 24. Concentrations of radiocaesium and transuranics were mainly due to discharges from Sellafield and to weapons-test fallout; small increases in levels of caesium-134 as compared with 1985 are likely to have been due to the Chernobyl accident but were of negligible radiological significance. Any effects of station operation were not detectable above the background due to these sources. 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 continued to be indistinguishable from natural background.

Table 24 Radioactivity in environmental materials and gamma dose rates near Hartlepool nuclear power station, 1986.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Cod	2	140	0.3	7.0	ND	0.00003	0.00015	0.00026	ND	ND
Plaice	4	100	ND	3.4	"	0.00048	0.0024	0.0014	"	"
Crabs	5	70	"	1.3	"	0.00052	0.0024	0.0017	0.00006	0.00001
Winkles	3	80	0.5	1.7	"	NA	NA	ND	NA	NA
Fucus spp.	2	190	0.2	3.6	"	"	"	"	"	"
Sand/coal	2	190	ND	5.4	"	"	"	"	"	"
Silt	2	710	1.8	65	1.9	0.39	2.0	0.41	0.0050	ND

Mean gamma dose rate in air at 1 m over intertidal sediment (6 sampling observations†): 0.096 μGy h^{-1}

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

Table 25 Radioactivity in environmental materials and gamma dose rates near Heysham nuclear power station, 1986.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{60}Co	^{95}Zr + ^{95}Nb	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs
Plaice	4	110	ND	ND	ND	ND	ND	ND	1.4	37
Whitebait	1	160	"	"	"	"	"	"	1.6	42
Sprats	1	160	"	"	"	"	"	"	2.1	66
Cockles	4	180	3.3	"	26	36	"	"	1.8	25
Mussels	4	110	ND	"	17	34	2.0	"	1.1	12
Fucus vesiculosus	4	330	0.8	0.2	5.0	4.5	1.2	0.1	3.0	41
Samphire	1	60	ND	ND	ND	1.6	ND	ND	0.6	9.8
Sediment:										
Sunderland Point	4	1400	4.5	2.2	31	160	0.8	1.5	27	680
Half Moon Bay	4	940	2.7	ND	4.2	96	ND	2.8	11	360

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
Whitebait	1	"	"	0.057	0.26	0.30	ND	0.0012
Sprats	1	"	"	0.046	0.21	0.25	"	0.00098
Cockles	4	"	"	1.2	5.6	12	0.03	0.054
Mussels	4	"	"	0.43	2.0	2.8	0.0064	0.0086
Fucus vesiculosus	4	"	"	0.62	3.0	1.2	ND	0.0057
Samphire	1	"	"	NA	NA	1.5	NA	NA
Sediment:								
Sunderland Point	4	5.6	4.9	"	"	120	"	"
Half Moon Bay	4	ND	3.6	16	77	99	0.095	0.34

Mean gamma dose rate in air at 1 m over intertidal sediment:
Heysham vicinity (26 sampling observations†): 0.11 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.

6.5 Heysham, Lancashire

This establishment will comprise two, essentially separate, nuclear power stations both powered by AGRs. The first station came into operation in 1983; the second is still under construction. Discharges of liquid radioactive waste in 1986 came closer to levels typical of normal operation, but were still well within authorised limits (Table 1). 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 potential use as a foodstuff.

The results for 1986 are given in Table 25. These mainly reflect discharges from Sellafield; some short-lived radioactivity from Chernobyl was also detected, but was of negligible radiological significance. The effect of discharges from Heysham was not detectable above the background due to these sources. Estimates of the radiation exposure in 1986 of members of the critical group of fish and shellfish consumers associated with commercial fisheries (which include the Morecambe Bay area) are given in sub-section 4.1.1. External exposure of members of the public was at most about 0.1 mSv, within the ICRP-recommended principal dose limit of 1 mSv year^{-1}. Concentrations of radioactivity in samphire were of negligible radiological significance.

Table 26 Radioactivity in environmental materials and gamma dose rates near Hinkley Point nuclear power station, 1986.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn	^{90}Sr	^{103}Ru	^{110m}Ag
Flounders	3	120	ND	ND	ND	ND	NA	ND	ND
Eels	2	94	"	"	"	"	"	"	"
Shrimps	3	77	"	"	"	"	0.1	"	"
Winkles	1	73	"	"	"	"	NA	"	"
Fucus serratus	1	310	2.6	"	1.8	0.7	"	"	"
Fucus vesiculosus	4	240	2.5	0.1	0.8	0.3	"	0.8	0.8
Sediment	2	640	1.2	ND	ND	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	^{243}Cm + ^{244}Cm
Flounders	3	ND	2.9	NA	NA	ND	NA
Eels	2	0.3	2.3	"	"	"	"
Shrimps	3	ND	1.0	0.00025	0.0011	0.0011	0.00004
Winkles	1	"	1.6	NA	NA	ND	NA
Fucus serratus	1	0.9	3.2	"	"	"	"
Fucus vesiculosus	4	1.0	2.7	"	"	"	"
Sediment	2	0.9	33	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediment (8 sampling observations†): 0.11 μGy h^{-1}

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

6.6 Hinkley Point, Somerset

At this establishment there are two essentially separate "A" and "B" nuclear power stations; the "A" station is powered by magnox-type reactors and the "B" station by AGRs. Liquid radioactive waste discharges are made via the same outfall and for the purposes of our environmental monitoring they are considered together. There are two potentially critical radiation exposure pathways associated with these discharges: consumption of locally-caught fish and shrimps gives rise to internal irradiation, while external exposure results from occupancy of intertidal areas. Our monitoring programme includes analyses of locally-caught fish and shellfish. 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.

The results for 1986, presented in Table 26, indicate concentrations of radionuclides representing the combined effect of discharges from the station and from Sellafield, in addition to some short-lived radioactivity (of negligible radiological significance) from Chernobyl. The radiation exposure of high-rate fish and shellfish consumers was low, at less than 0.002 mSv or 0.2% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}. The concentrations in shrimps of transuranic nuclides were of negligible radiological significance. Gamma radiation dose rates over intertidal sediment close to the station were indistinguishable from the natural background.

6.7 Hunterston, Ayrshire

This establishment also comprises "A" and "B" stations and the latter is powered by AGRs. Liquid radioactive waste discharges are made to the Firth of Clyde under authorisation of the Scottish Development Department. There are two potentially critical radiation exposure pathways: 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 together with *Fucus* seaweed as indicators. The results of monitoring in 1986 are shown in Table 27.

The concentrations of artificial radioactivity in this area are predominantly due to Sellafield discharges, the general values being consistent with those to be expected at this distance from Sellafield. Small amounts of short-lived radionuclides from Chernobyl were also detected in 1986, but were of negligible radiological significance. The exposure of members of the critical group of fish and shellfish consumers near Hunterston in 1986 was low, at about 0.03 mSv or 3% of the principal ICRP-recommended dose limit of 1 mSv year $^{-1}$. Radiocaesium concentrations detected in fish from farms which are supplied by station cooling water were lower than in fish caught in the open sea; this is because the farmed fish are fed on manufactured food which has a lower radioactivity concentration. The concentrations 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.

6.8 Sizewell, Suffolk

Radioactive liquid effluent from this station is discharged 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 1986 are shown in Table 28.

The concentrations of radioactivity in fish and shellfish represent the combined effect of discharges from the station and from Sellafield, as well as of the Chernobyl accident and weapons-test fallout. Apportionment is difficult at the low levels detected. Trace levels of cobalt-60 and ruthenium-106 in some shellfish and silt are likely to have been due to discharges from the station, but their radiological significance was negligible. Ruthenium-103, silver-110m and some of the caesium-134 are likely to have derived from Chernobyl. The total radiation exposure 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 dose rates, as in previous years, were indistinguishable from the natural background.

6.9 Torness, East Lothian

This station, which will be powered by two AGRs, is not yet in operation. Our investigations have shown that potential critical pathways for radiation exposure of the public, likely to be associated with future liquid discharges, 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, which has commenced prior to station operation in order to establish background levels and reliable sources of supply of environmental materials. In 1986, samples of fish and shellfish were collected and analysed, and

Table 27 Radioactivity in environmental materials and gamma dose rates near Hunterston nuclear power station, 1986.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{103}Ru	^{106}Ru	^{110m}Ag	^{134}Cs
Saithe	4	170	ND	ND	ND	ND	ND	ND	2.3
Grey mullet	1	150	"	"	"	"	"	"	2.9
Turbot (fish farm)	4	91	"	"	"	"	"	"	0.8
Cockles	2	61	"	3.3	3.5	"	"	"	ND
Winkles	4	110	5.8	4.9	6.0	2.9	2.7	14	0.7
Fucus spiralis	4	310	14	5.3	8.3	2.5	7.8	2.3	3.3
Sand	4	300	3.8	1.9	0.6	1.2	1.6	ND	4.9

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
Saithe	4	37	ND	NA	NA	ND	NA	NA
Grey mullet	1	30	"	"	"	"	"	"
Turbot (fish farm)	4	9.6	"	"	"	"	"	"
Cockles	2	4.1	"	"	"	"	"	"
Winkles	4	7.4	"	0.067	0.21	0.10	0.0093	0.012
Fucus spiralis	4	23	"	0.17	0.61	0.12	0.011	0.0097
Sand	4	74	0.5	NA	NA	0.7	NA	NA

Mean gamma dose rate in air at 1 m over intertidal sediment (12 sampling observations†): 0.10 μGy h^{-1}

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

Table 28 Radioactivity in environmental materials and gamma dose rates near Sizewell nuclear power station, 1986.

	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta	^{60}Co	^{103}Ru	^{106}Ru	^{110m}Ag	^{134}Cs	^{137}Cs
Plaice	2	93	ND	ND	ND	ND	0.2	1.5
Shrimps	1	100	"	"	"	1.4	ND	5.0
Crabs	2	83	0.2	0.3	"	18	0.1	1.0
Mussels	2	46	0.3	0.7	1.5	0.3	0.1	0.9
Oysters	2	43	0.1	ND	ND	7.6	ND	0.6
Silt	2	85	2.7	14	16	ND	4.4	57

Mean gamma dose rate in air at 1 m over intertidal sand/shingle (10 sampling observations†): 0.053 μGy h^{-1}

Mean gamma dose rate in air at 1 m over intertidal silt in Southwold harbour (2 sampling observations†): 0.072 μGy h^{-1}

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

Table 29 Radioactivity in environmental materials and gamma dose rates near Torness nuclear power station, 1986.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta	^{60}Co	^{103}Ru	^{106}Ru	^{110m}Ag	^{134}Cs	^{137}Cs
Cod	2	140	ND	ND	ND	ND	0.2	7.4
Crabs	2	77	"	"	"	1.4	0.2	1.6
Lobster	1	83	"	"	"	2.2	ND	2.1
Nephrops	4	100	"	"	"	0.3	0.2	3.5
Winkles	2	81	0.3	1.1	8.5	6.4	ND	1.1
Fucus vesiculosus	2	230	ND	0.7	2.6	1.0	0.5	2.9
Silt	3	530	"	0.5	1.5	ND	2.2	6.4
Fine sand	2	180	"	ND	ND	"	0.4	45

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}				
		^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{244}Cm	^{243}Cm + ^{244}Cm
Cod	2	NA	NA	ND	NA	NA
Crabs	2	"	"	"	"	"
Lobster	1	"	"	"	"	"
Nephrops	4	0.00073	0.0036	0.0053	0.00003	0.00004
Winkles	2	NA	NA	ND	NA	NA
Fucus vesiculosus	2	"	"	"	"	"
Silt	3	"	"	"	"	"
Fine sand	2	"	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediment (8 sampling observations†): 0.061 μGy h^{-1}

*Except for sediment where dry concentrations apply.
†See sub-section 3.3 for definition.

samples of seaweed and sediment were monitored as indicator materials. Measurements were also made of gamma dose rates over intertidal areas.

Results of this monitoring are shown in Table 29. The very low concentrations of artificial radionuclides are due to fallout and the distant effects of Sellafield discharges, with a contribution from the Chernobyl accident mainly indicated by the presence of short-lived radionuclides. The measured gamma dose rate is consistent with that to be expected from 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, leading to internal irradiation; the important radionuclides are those of caesium and, to a lesser extent, strontium-90. Species of fish consumed are brown trout, rainbow trout and, in very small amounts, perch. Perch and some brown trout are indigenous to the lake but rainbow trout and a smaller number of brown trout are regularly introduced from a hatchery. Because of the limited period which they spend in the lake, introduced fish generally exhibit lower radiocaesium concentrations than do indigenous fish.

Our monitoring programme reflects the exposure pathways. Samples of rainbow trout, brown trout and perch are regularly obtained from local anglers as well as from our own surveys. As part of our research programme, mud and peat from the lake bed are also

Table 30 Radioactivity in environmental materials near Trawsfynydd nuclear power station, 1986.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{35}S	^{54}Mn	^{60}Co	^{90}Sr	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs
Brown trout	6	380	38	ND	ND	9.4	ND	ND	ND	ND	36
Rainbow trout	6	140	28	"	"	5.7	"	"	"	"	1.4
Rainbow trout (hatchery)	1	120	NA	"	0.4	3.5	"	"	"	"	1.0
Perch	2	1200	"	"	ND	9.4	"	"	"	"	180
Eels	1	330	"	"	0.5	19	"	"	"	"	25
Fontinalis											
Afon Prysor	2	330	"	1.5	ND	NA	14	31	0.6	1.0	6.6
Gwylan Stream	2	530	"	21	140	"	10	33	2.0	41	14
Mud	2	3000	"	ND	7.1	"	ND	ND	ND	68	10
Peat	2	3600	"	"	28	"	"	"	"	340	32
Water											
Hot Lagoon	4	NA	"	NA	NA	0.17	NA	NA	NA	NA	0.094
Cold Lagoon	4	"	"	"	"	0.17	"	"	"	"	0.10

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Brown trout	6	230	ND	ND	ND	0.00013	0.00050	0.00063	0.00007	0.00001
Rainbow trout	6	6.6	"	"	"	0.00013	0.00057	0.00081	0.00007	0.00002
Rainbow trout (hatchery)	1	7.4	"	"	"	0.00013	0.00043	0.00063	ND	ND
Perch	2	1200	"	"	"	0.00014	0.00051	0.00062	"	"
Eels	1	220	"	"	"	0.00011	0.00043	0.0012	0.00018	0.00005
Fontinalis										
Afon Prysor	2	16	0.8	"	1.9	NA	NA	ND	NA	NA
Gwylan Stream	2	76	21	1.8	2.0	"	"	2.7	"	"
Mud	2	2000	ND	ND	9.1	3.9	20	26	0.25	0.58
Peat	2	2000	"	28	13	13	55	90	0.86	1.7
Water										
Hot Lagoon	4	0.35	NA	NA	NA	NA	NA	NA	"	"
Cold Lagoon	4	0.36	"	"	"	"	"	"	"	"

Mean gamma dose rate in air at 1 m over areas near lake shoreline (6 sampling observations†): 0.096 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.

sampled and 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. Gamma dose rates over lake shoreline areas are also kept under review. Our monitoring, particularly of fish, was increased in 1986 following the Chernobyl accident. The results of our additional monitoring are reported in section 10. Our regular programme of monitoring at Trawsfynydd continued during 1986 and is reported here to present a balanced picture of public radiation exposures for the whole year. The results of this monitoring are shown in Table 30.

Radiocaesium discharges from the power station decreased in 1986 as compared with 1985 (Table 1). However, there were increases in concentrations of radiocaesium in lake water, likely to be due to the input from Chernobyl. Radiocaesium concentrations in brown trout, averaged over the whole year, were generally similar to those in 1985 (Hunt, 1986a). There was a significant reduction in average radiocaesium concentrations in rainbow trout; this is thought to be due to shorter residence times in the lake after stocking. Radiocaesium concentrations in the indigenous perch increased in 1986 following the behaviour of the concentrations in water, but the

amounts of perch eaten are so small that they are of much lower radiological significance. The contribution to radiocaesium concentrations as a result of the input from Chernobyl may be estimated from the behaviour of the ratio of caesium-137 to caesium-134. It is estimated that up to half of the caesium-137 in lake water, averaged over the year, was from Chernobyl; because of the time required for uptake by fish, only about a quarter of the caesium-137 in rainbow trout and less than 10% in brown trout originated from Chernobyl. In 1986, trout were analysed for sulphur-35 which arises from station operation, but the concentrations were of negligible radiological significance. Increased concentrations of cobalt-60 as compared with 1985 were observed in *Fontinalis* from the Gwylan stream; this is consistent with increased discharges of this nuclide from the station, but was of negligible radiological significance. The trace levels of the short-lived radionuclides ruthenium-103 and silver-110m observed in *Fontinalis* are likely to have been from Chernobyl. As in previous years, low concentrations of transuranic nuclides from station operations were observed in fish; these continued to be of negligible radiological significance. Concentrations of transuranic nuclides in mud and peat were generally similar to those in 1985; there is a transcription error in our previous report (Hunt, 1986a) such that the stated concentrations of transuranics in mud and peat should be treated as Bq g^{-1}, not Bq kg^{-1}.

It is estimated that in 1986 members of the critical group of fish consumers received about 0.17 mSv, which is within the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$. This reduced exposure as compared with 1985 (Hunt, 1986a) reflects the behaviour of radiocaesium concentrations in trout noted above; the effect of radioactivity from Chernobyl was not sufficient to offset the effect of reduced discharges from the power station. Gamma dose rates were consistent with those to be expected from natural background.

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

Table 31 Radioactivity in environmental materials and gamma dose rates near Wylfa nuclear power station, 1986.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{60}Co	^{95}Zr + ^{95}Nb	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs
Mackerel	1	120	ND	ND	ND	ND	ND	ND	1.1
Plaice	1	100	"	"	"	"	"	"	0.7
Pollack	1	160	"	"	"	"	"	"	2.0
Crabs	2	77	"	"	3.4	2.2	3.8	"	0.4
Winkles	4	110	"	"	1.5	12	14	"	0.4
Mussels	2	73	"	"	0.9	ND	ND	"	0.8
Fucus vesiculosus	4	250	"	"	11	4.6	8.4	"	3.3
Sediment: Cemlyn Bay	2	2000	0.4	50	400	180	14	14	130

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		^{137}Cs	^{144}Ce	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Mackerel	1	6.2	ND	ND	NA	NA	ND	NA	NA
Plaice	1	5.8	"	"	"	"	"	"	"
Pollack	1	36	"	"	"	"	"	"	"
Crabs	2	3.1	"	"	"	"	"	"	"
Winkles	4	4.1	"	"	0.080	0.39	0.48	0.0034	0.0017
Mussels	2	3.1	"	"	0.070	0.33	0.53	ND	0.0020
Fucus vesiculosus	4	12	"	"	NA	NA	ND	NA	NA
Sediment: Cemlyn Bay	2	670	29	2.8	9.5	47	58	0.19	0.12

Mean gamma dose rate in air at 1 m over intertidal sediment (11 sampling observations†): 0.083 μGy h^{-1}

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

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 1986 are presented in Table 31.

Any effects of discharges from this station are masked by Sellafield-derived radioactivity. Concentrations of artificial radionuclides in environmental materials were consistent with those to be expected at this distance from Sellafield, and generally decreased in 1986, particularly for radiocaesium, in line with the reducing trend in Sellafield discharges. The total radiation exposure of members of the critical group in 1986 was less than 0.1 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 continued to be indistinguishable from the natural background.

7. Naval establishments

Liquid wastes containing small quantities of radioactivity are discharged from the establishments at Devonport, Faslane and Rosyth, all of which are operated by the Ministry of Defence (Navy Department). The US naval base at Holy Loch discharges small quantities of radioactive waste. We carry out monitoring programmes near all 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.

Table 32 Radioactivity in environmental materials and gamma dose rates near naval establishments, 1986.

Establishment	Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
			^{54}Mn	^{60}Co	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs
Chatham	Sediment	4	ND	4.3	2.4	2.6	ND	ND	5.8
Devonport	Mussels	2	"	ND	ND	ND	"	"	ND
	Fucus vesiculosus	2	"	0.3	"	"	"	"	"
	Sediment	6	0.1	1.3	"	"	"	"	0.3
Faslane	Sediment	4	ND	15	13	19	"	3.1	11
Rosyth	Sediment	2	"	1.5	ND	ND	"	ND	1.5
Holy Loch	Sediment	2	"	51	9.9	8.4	0.9	ND	6.3

Establishment	Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}			Mean gamma dose rate in air at 1 m	
			^{137}Cs	^{155}Eu	^{241}Am	No. of sampling observations†	μGy h^{-1}
Chatham	Sediment	4	34	0.9	ND	10	0.069
Devonport	Mussels	2	ND	ND	"	NP	NP
	Fucus vesiculosus	2	0.2	"	"	"	"
	Sediment	6	6.2	0.6	"	12	0.087
Faslane	Sediment	4	120	ND	"	10	0.083
Rosyth	Sediment	2	33	1.6	"	4	0.078
Holy Loch	Sediment	2	130	ND	1.3	12	0.083

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

The critical pathway for public radiation exposure near these establishments is via external exposure from occupancy of intertidal areas, 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 1986 are presented in Table 32. The small concentrations of cobalt-60 mainly reflect discharges from the establishments; levels of caesium-137 and americium-241 are due to discharges from Sellafield. The other radionuclides, most of which are short-lived, are likely to be from Chernobyl; the trace concentrations are of negligible radiological significance. Gamma dose rates over intertidal sediments remained indistinguishable from the natural background, such that public radiation exposure was very low, 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

Amersham International plc is engaged in the manufacture of radioactive materials for use in medicine, research and industry. The company's parent establishment is located in Amersham, Buckinghamshire, from which radioactive discharges are made into the catchment of the River Thames. As explained in section 5, environmental monitoring in respect of these discharges is carried out by the DOE. A further laboratory, situated near Cardiff, is engaged in the production of labelled compounds mainly used in biomedical 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 nuclear facilities which discharge small amounts of radioactive wastes to the Severn Estuary and the Bristol Channel, and possibly to Sellafield. Any effects due to Chernobyl were negligible.

The results of monitoring in 1986 are presented in Table 33. Of the separate nuclides listed, only carbon-14 was discharged by this establishment in 1986: the presence of the other nuclides 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. Further data on fish and shellfish consumption were obtained in 1986. The exposure of the critical group was less than 0.1 mSv, which is within the ICRP-recommended principal dose limit of 1 mSv year^{-1}. Gamma dose rates over sediment were indistinguishable from those to be expected from natural background.

Table 33 Radioactivity in environmental materials and gamma dose rates near the outfall of the sewer serving Amersham International plc, Cardiff, 1986.

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	2	640	2 500	ND	ND	ND	0.8	ND
Fucus spiralis	4	210	52	"	5.4	"	0.7	0.1
Sediment	4	1 100	510	0.2	ND	1.6	53	0.6

Mean gamma dose rate in air at 1 m over intertidal sediment (4 sampling observations†): 0.084 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 34 Radioactivity in marine environmental materials from the Channel Islands, 1986.

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	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb
Ray	Guernsey	1	140	ND	ND	ND	ND	NA	ND	ND	ND	ND
Crabs	Guernsey	1	110	"	"	0.4	"	"	"	"	"	"
	Jersey	1	87	"	"	2.5	1.2	"	"	7.0	1.4	"
Oysters	Jersey	1	95	"	"	1.2	3.4	"	"	8.9	2.0	"
Limpets	Jersey	1	97	"	"	1.8	0.7	"	"	8.3	0.7	0.6
	Guernsey	1	85	"	"	1.1	ND	"	"	6.1	ND	ND
	Alderney	1	75	"	"	3.0	"	"	2.8	25	0.9	"
Porphyra	Jersey											
	Greve de Lecq	4	230	"	"	1.3	"	"	ND	17	ND	"
	La Rozel	3	270	"	"	0.7	"	"	"	18	"	"
	Guernsey											
	Fermain Bay	5	180	"	"	0.5	"	"	"	11	"	"
	Alderney											
	Quenard Point	3	250	"	"	2.2	"	"	"	71	"	"
Fucus serratus	Jersey											
	La Rozel	4	400	"	"	8.0	0.2	0.39	"	9.9	"	"
	Guernsey											
	Fermain Bay	4	350	"	"	4.1	ND	0.24	"	4.2	"	"
	Alderney											
	Quenard Point	4	490	0.3	0.2	15	0.5	0.69	"	32	"	"
Sediment	Jersey											
	St Helier Harbour	1	540	ND	ND	3.3	ND	NA	"	16	"	2.4
	Guernsey											
	Bordeaux Harbour	1	430	"	"	0.8	"	"	"	5.2	"	ND

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
Ray	Guernsey	1	0.5	4.8	0.0012	0.0046	0.0019	ND	0.00002
Crabs	Guernsey	1	ND	0.5	0.00047	0.00083	0.0055	0.00014	0.0027
	Jersey	1	"	0.2	0.0012	0.0020	0.011	0.00059	0.0058
Oysters	Jersey	1	"	ND	0.0092	0.018	0.015	0.0005	0.0061
Limpets	Jersey	1	"	"	0.0094	0.018	0.027	0.00068	0.0082
	Guernsey	1	"	0.6	0.0077	0.016	0.022	0.00084	0.0085
	Alderney	1	"	ND	0.010	0.017	0.034	0.0016	0.015
Porphyra	Jersey								
	Greve de Lecq	4	"	0.1	NA	NA	ND	NA	NA
	La Rozel	3	"	ND	"	"	"	"	"
	Guernsey								
	Fermain Bay	5	"	0.1	"	"	"	"	"
	Alderney								
	Quenard Point	3	"	0.3	"	"	"	"	"
Fucus serratus	Jersey								
	La Rozel	4	0.1	0.3	0.050	0.084	0.033	0.00077	0.012
	Guernsey								
	Fermain Bay	4	ND	0.1	0.022	0.043	0.019	0.00042	0.0076
	Alderney								
	Quenard Point	4	"	0.3	0.079	0.10	0.070	0.0018	0.033
Sediment	Jersey								
	St Helier Harbour	1	0.7	8.2	NA	NA	ND	NA	NA
	Guernsey								
	Bordeaux Harbour	1	ND	3.1	0.11	0.36	0.30	0.0066	0.087

NA = not analysed.
ND = not detected.

*Except for sediment where dry concentrations apply.
†See sub-section 3.3 for definition.

9. Channel Islands monitoring

We have continued to analyse marine environmental samples provided by the Channel Islands States 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.

The results for 1986 are given in Table 34. Concentrations of caesium-137 in fish and shellfish were not significantly in excess of those to be expected from other sources, including fallout. 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. No effects of radioactivity from Chernobyl were detected.

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

Our regular monitoring programme was extended during 1986 in surveillance of the effects of fallout from the Chernobyl reactor accident. Most of the deposition of radioactivity in the UK from this accident occurred during May 1986 and the extended programme was introduced at the beginning of that month. An earlier report (Camplin *et al.*, 1986) presented the results of this monitoring, up to the end of July 1986 for marine materials and to the end of August 1986 for monitoring of the freshwater environment. The results showed that whilst the effect of fallout from Chernobyl in the marine environment could be easily detected during May 1986, it soon declined and by the end of the reporting period levels were in most cases difficult to distinguish from those before the accident. Using pessimistic assumptions about consumption patterns, estimates of individual radiation exposure of the UK public due to the Chernobyl accident from marine pathways were made, and shown to be very low. Our additional monitoring in the marine environment was therefore integrated with the normal programme. Results for the marine environment covering the whole of 1986, including the effects of Chernobyl, have already been presented in this report.

Because of more limited dispersion rates, parts of the freshwater environment continued to show the effect of Chernobyl fallout throughout 1986 and some additional monitoring has continued during 1987. The results of our additional monitoring of the freshwater environment from May to December 1986 are presented in this section. The sampling locations are shown in Figure 4. They are mostly in areas of relatively high deposition, namely Cumbria, North Wales and parts of Scotland, but samples from Northern Ireland and the Isle of Man and areas of low deposition were also obtained for completeness and comparison.

Tables 35-43 present concentrations of caesium-134 and -137 in fish and other fauna, giving the means 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 mean value. Table 44 shows the concentrations of radionuclides other than of radiocaesium, where detected, and/or when specific radiochemical analyses were performed. In these cases, the dates of sample collection are given.

Concentrations of radioactivity in freshwater fish varied widely between locations, reflecting the areas of deposition of radioactivity from Chernobyl. Most samples analysed were of brown trout, in recognition of the potential radiological significance of this species; although rainbow trout are more commonly eaten, their radiocaesium concentrations were very low compared with wild brown trout because rainbow trout are mostly hatchery-reared and fed on relatively uncontaminated food. Perch (Table 37) had the highest concentrations of any of the freshwater fish species; this is in accord with our experience at Trawsfynydd in North Wales. However, as perch are seldom eaten their radiological significance is low. Other species (Tables 37-43) had generally lower radiocaesium concentrations, sometimes much lower, than brown trout or perch taken from the same river or lake.

Very few radionuclides other than of caesium were detected in freshwater fish (Table 44). Sulphur-35 and cobalt-60 in samples from Llyn Trawsfynydd can be attributed to discharges from the power station (sub-section 6·10). The concentrations of all nuclides other than caesium-137 and caesium-134 were very low and of negligible radiological importance.

Radiation exposures from Chernobyl fallout have been estimated using a procedure based on conservative

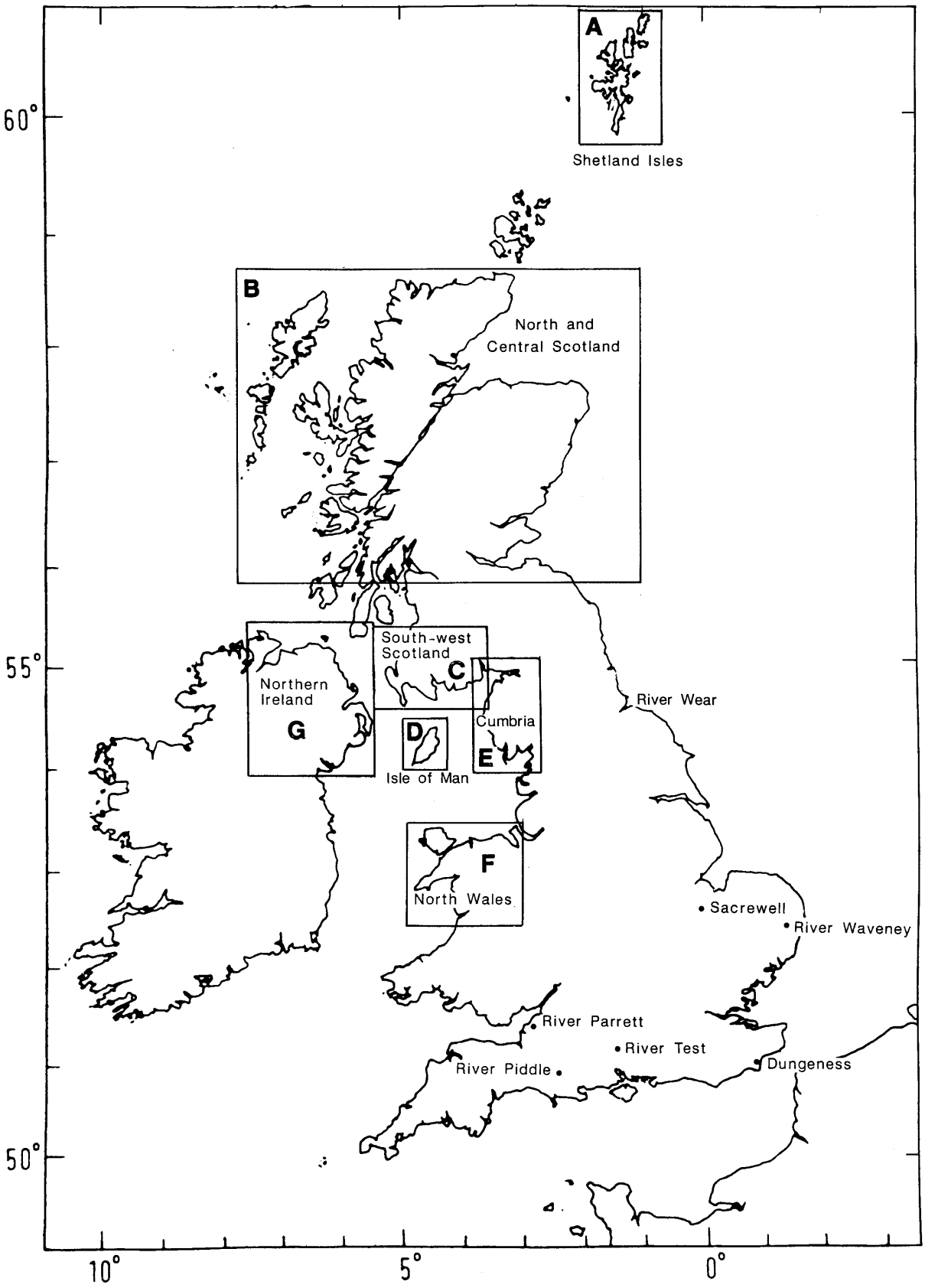

Figure 4 Sampling locations for monitoring of the freshwater environment for radioactivity from Chernobyl.

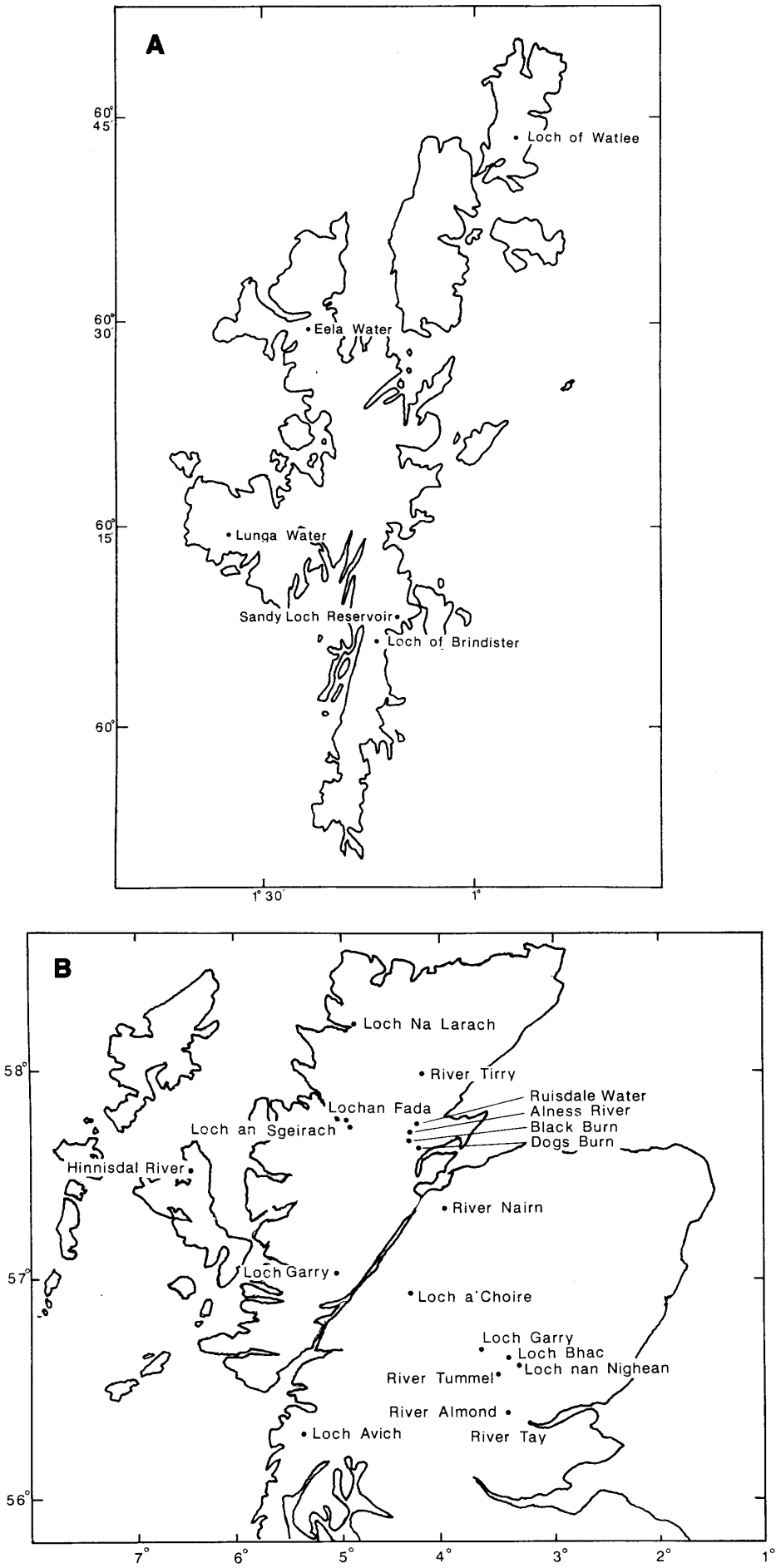

Figure 4: Inset (A) Sampling locations in the Shetlands. **Inset (B)** Sampling locations in North and Central Scotland.

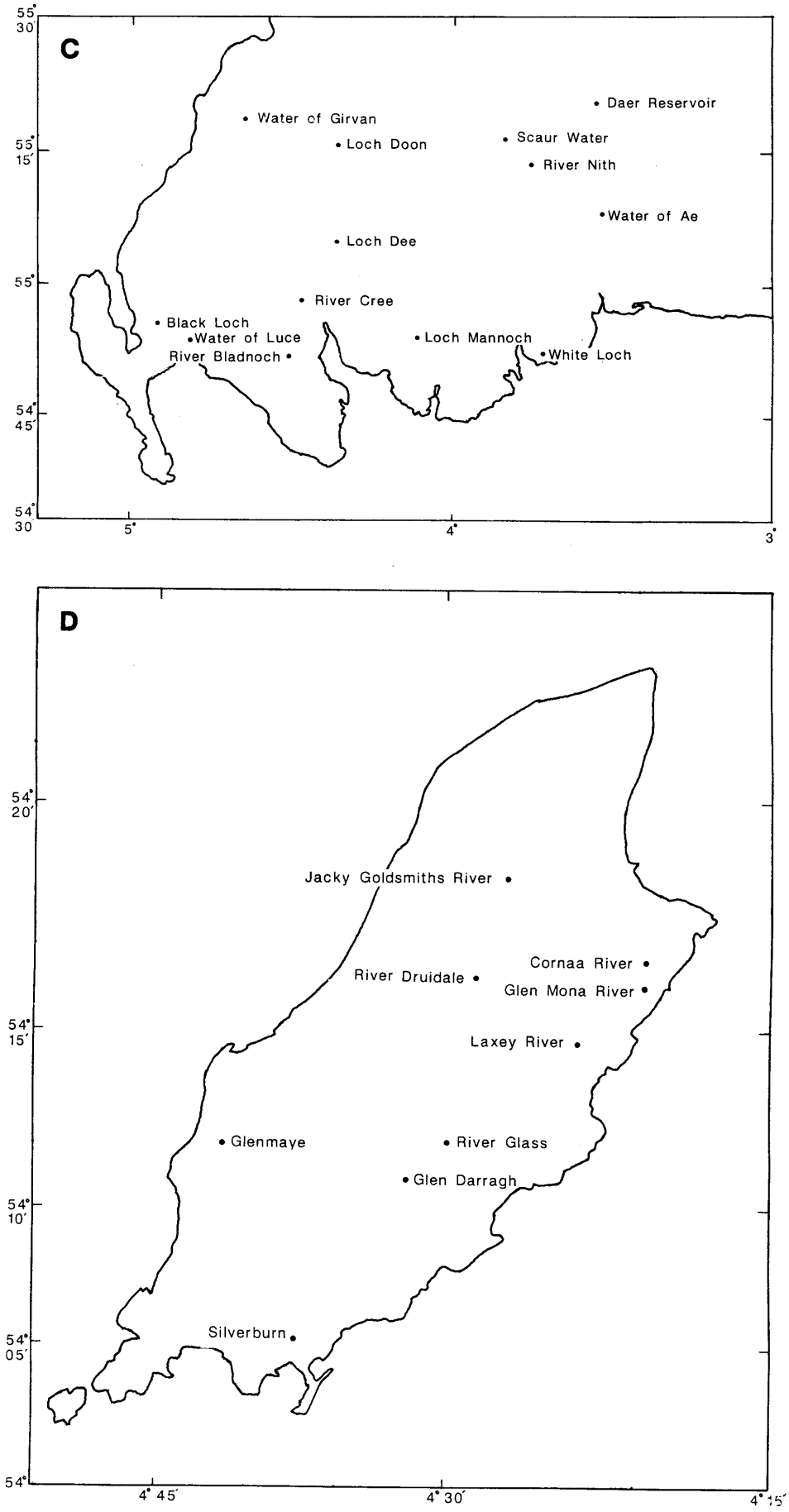

Figure 4: Inset (C) Sampling locations in South-west Scotland. **Inset (D)** Sampling locations on the Isle of Man.

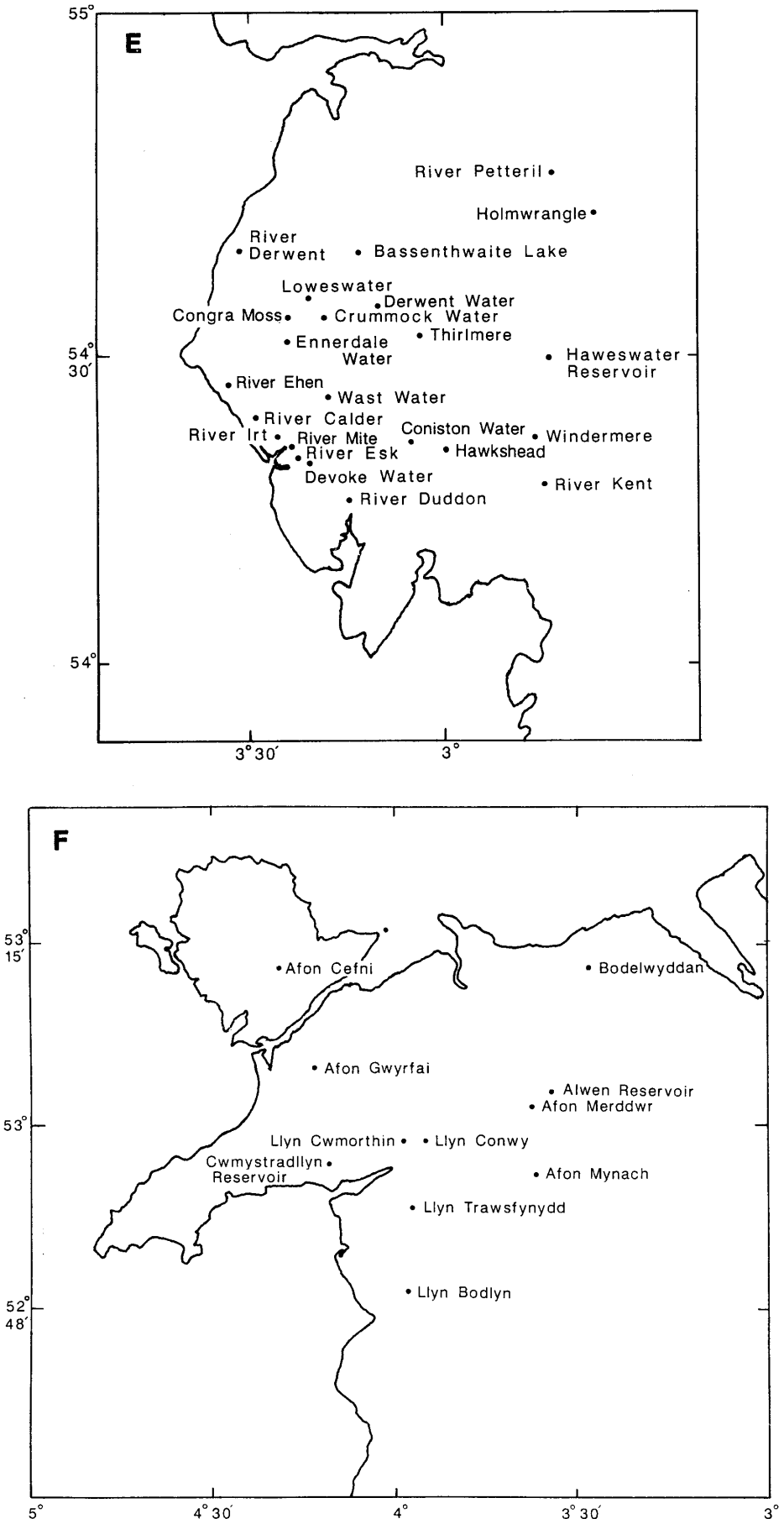

Figure 4: Inset (E) Sampling locations in Cumbria. **Inset (F)** Sampling locations in North Wales.

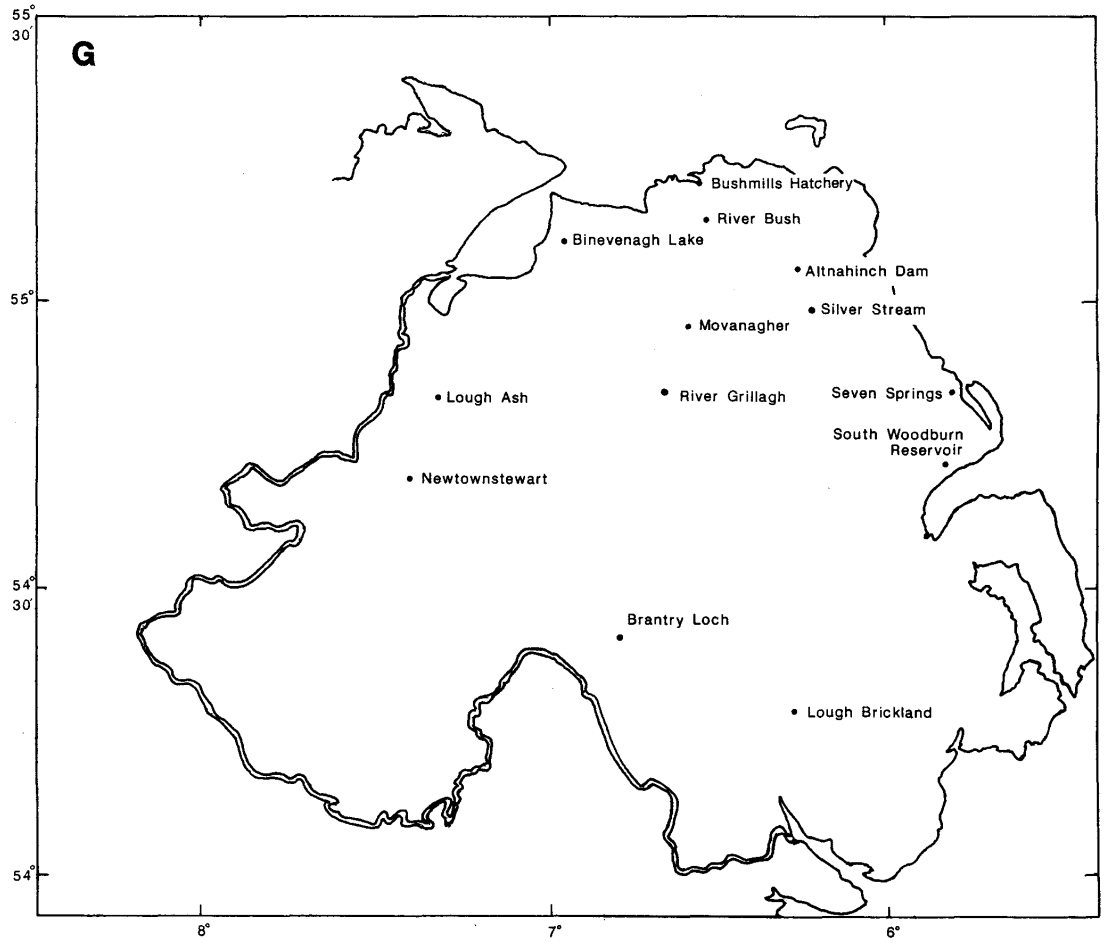

Figure 4: Inset (G) Sampling locations in Northern Ireland.

assumptions. 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 of the high consumption rate assumed but also because in practice hatchery-reared or farmed fish of much lower radiocaesium concentration may contribute to the diet. It can be shown that exposures of children and infants would be likely to be lower than for adults. Concentrations of radiocaesium in brown trout representative of the highest in each region were chosen. In some cases, locations with the highest concentrations were excluded on grounds of low availability of samples and/or the unlikelihood of sustained high consumption rates, these two factors often being linked. A contribution to dose due to radiostrontium was included but this was very small in comparison to that from radiocaesium. Effective dose and organ doses were estimated using committed dose equivalents per unit intake provided by the NRPB (NRPB, 1987). Estimates of dose are presented in Table 45.

The ICRP (ICRP, 1984 b) provides guidance in the context of emergencies which includes suggested levels of dose below which particular counter-measures would not be warranted. The suggested level of effective dose equivalent in relation to the situation reported here is 5 mSv in the first year. All of the estimated doses presented in Table 45 are 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. 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 minor importance, was from consumption of marine fish, as considered in sub-section 4.1.1.

Table 35 Caesium radioactivity in brown trout, 1986.

Location	No. of samples†	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
Windermere	14	14	33
Holmwrangle	5	ND	2.6
River Derwent	1	38	71
River Petteril	1	5.5	8.1
Crummock Water	5	110	240
River Ehen	4	49	96
Bassenthwaite Lake	6	18	52
Wast Water	1	110	250
Ennerdale Water	28	230	500
Devoke Water	15	390	860
Loweswater	20	360	770
Congra Moss	2	190	360
Haweswater Reservoir	2	33	72
River Test	1	ND	ND
River Calder	4	78	530
River Wear	4	0.5	1.2
WALES			
Llyn Trawsfynydd	68	44	220
Afon Merddwr	1	53	100
Afon Gwyrfai	1	56	120
Afon Cefni	5	16	21
Cwmystradllyn Reservoir	11	39	86
Llyn Cwmorthin	3	55	140
Llyn Bodlyn	7	29	67
Llyn Conwy	22	210	490
Alwen Reservoir	18	69	150
Afon Mynach	2	27	57
SCOTLAND			
Loch A'Choire	9	27	63
Loch Garry, Tayside Region	9	160	350
Loch Bhac	6	87	180
Hinnisdal River	1	35	130
Water of Ae	2	72	160
River Tirry	1	94	190
Dogs Burn	1	51	110
Lochan an Nighean	6	54	120
Loch Garry, Highland Region	2	32	78
Alness River	2	84	190
Ruisdale Water	1	190	490
Loch Na Larach	2	27	62
Loch an Sgeirach	1	110	280
Lochan Fada	1	140	340
Black Burn	1	120	250
Eela Water	2	310	730
Loch of Brindister	1	160	300
Lunga Water	2	330	710
Sandy Loch Reservoir	1	230	520
Loch of Watlee	2	190	440
Loch Doon	14	180	400
Loch Avich	1	5.4	23
Daer Reservoir	7	99	210
River Cree	1	100	220
Water of Girvan	1	11	29
Scaur Water	1	31	66
Water of Luce	2	25	68
River Bladnoch	2	140	310
Loch Mannoch	9	55	120
Black Loch	1	16	40
Loch Dee	7	590	1300
NORTHERN IRELAND			
Seven Springs	1	ND	2.1
Movanagher	1	ND	3.0
Newtownstewart	1	1.4	3.3
River Grillagh	7	23	46
Altnahinch Dam	12	80	220
River Bush	2	93	250
Binevenagh Lake	2	22	38
Bushmills Hatchery	7	ND	2.3
Lough Ash	10	120	270
Lough Brickland	5	15	40
South Woodburn Reservoir	4	30	63
Brantry Lough	4	31	64
ISLE OF MAN			
River Druidale	5	160	360
Cornaa River	4	110	220
Laxey River	3	25	59
Silverburn	3	56	120
Glen Mona River	3	44	100
Jacky Goldsmiths River	3	64	120
Glen Darragh	3	93	190
River Glass	4	77	160

ND = not detected.
†see section 10 for definition.

Table 36 Caesium radioactivity in rainbow trout, 1986.

Location	No. of samples†	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
Hawkshead	13	ND	2.3
Sacrewell	3	"	2.2
Congra Moss	14	0.4	3.0
River Piddle	1	ND	ND
WALES			
Llyn Trawsfynydd	58	2.3	11
Bodelwyddan	12	0.1	3.7
SCOTLAND			
River Nairn	2	0.9	4.1
River Almond	2	0.4	3.1
Loch Avich	1	ND	6.8
Water of Ae	2	0.8	3.8
NORTHERN IRELAND			
Seven Springs	1	ND	2.5
Movanagher	1	"	ND
Newtownstewart	1	0.8	3.3
Silver Stream	1	ND	3.0
Binevenagh Lake	2	12	21
ISLE OF MAN			
Cornaa River	1	0.9	4.1
Glenmaye	1	2.8	7.0

ND = not detected.
†see section 10 for definition.

Table 37 Caesium radioactivity in perch, 1986.

Location	No. of samples†	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
Windermere	7	23	51
Haweswater Reservoir	2	31	79
Loweswater	13	540	1200
Crummock Water	11	160	360
Devoke Water	11	480	1200
Coniston Water	1	55	110
Derwent Water	5	130	280
WALES			
Llyn Trawsfynydd	61	240	1500
Alwen Reservoir	1	71	150
SCOTLAND			
Loch Doon	6	290	660
White Loch	1	240	590

†see section 10 for definition.

Table 38 Caesium radioactivity in char, 1986.

Location	No. of samples†	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
Windermere	13	29	60
Ennerdale Water	17	99	220
Wast Water	2	30	65
Thirlmere	4	15	27
SCOTLAND			
Loch Doon	1	240	540

†see section 10 for definition.

Table 39 Caesium radioactivity in pike, 1986.

Location	No. of samples†	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
Windermere	13	24	52
Crummock Water	9	94	220
Loweswater	3	210	460
SCOTLAND			
White Loch	3	410	970
River Cree	1	110	210

†see section 10 for definition.

Table 40 Caesium radioactivity in salmon, 1986.

Location	No. of samples†	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
River Wear	1	ND	2.8
Crummock Water	1	4.7	ND
SCOTLAND			
River Nith	1	39	68
Scaur Water	1	40	81
River Tay	4	1.2	3.1

ND = not detected
†see section 10 for definition.

Table 41 Caesium radioactivity in eels, 1986.

Location	No. of samples†	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
Dungeness	1	ND	1.7
River Parrett	1	0.3	5.0
River Calder	3	10	140
River Waveney	1	ND	4.5
Windermere	2	9.9	25
River Derwent	1	5.3	12
River Mite	1	8.0	30
River Esk	1	23	180
River Irt	1	33	71
River Ehen	1	6.9	19
Ennerdale Water	2	8.2	21
Devoke Water	1	160	420
Loweswater	1	63	140
SCOTLAND			
River Cree	1	74	180
Loch Avich	1	ND	28
Black Loch	1	23	38
Scaur Water	1	11	28
Water of Luce	1	6.1	25

ND = not detected.
†see section 10 for definition.

Table 42 Caesium radioactivity in sea trout, 1986.

Location	No. of samples†	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
River Ehen	6	1.4	69
River Calder	7	4.0	59
River Derwent	1	5.3	80
River Kent	1	3.8	67
River Duddon	2	0.6	26
SCOTLAND			
Water of Ae	1	19	140
River Tay	3	1.2	11
River Bladnoch	1	39	100
Water of Luce	3	3.7	41
Hinnisdal River	1	12	26

†see section 10 for definition.

Table 43 Caesium radioactivity in various freshwater fauna, 1986.

Species	Location	No. of samples†	Mean radioactivity concentration (wet), Bq kg^{-1}	
			^{134}Cs	^{137}Cs
Grayling	River Tummel	6	190	440
Minnow	River Cree	1	66	130
Mussels	Windermere	1	ND	4.9
Crayfish	"	1	10	22
Brook trout	Holmwrangle	1	ND	ND
Rudd	Llyn Trawsfynydd	10	110	560

ND = not detected.
†see section 10 for definition.

Table 44 Radioactivity in freshwater fish, 1986.

Species	Location	Date collected	Mean radioactivity concentration (wet), Bq kg^{-1}											
			^{35}S	^{60}Co	^{89}Sr	^{90}Sr	^{99}Tc	^{103}Ru	^{131}I	^{134}Cs	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am
BROWN TROUT	ENGLAND													
	Ennerdale Water	19 Aug	NA	ND	6.0	2.1	NA	ND	ND	320	660	NA	NA	NA
	"	23 Sep	"	"	3.7	2.2	"	"	"	530	1100	"	"	"
	"	10 Dec	"	"	ND	2.4	"	"	"	320	700	"	"	"
	Loweswater	11 May	"	"	NA	NA	"	0.58	6.7	2.7	12	0.000072	0.00042	0.00046
	Devoke Water	22 Sep	"	"	3.7	3.6	"	ND	ND	550	1200	NA	NA	NA
	"	7 Dec	"	"	ND	16	"	"	"	290	750	"	"	"
	"	8 "	"	"	"	3.2	"	"	"	740	1700	"	"	"
	River Wear	12 May	"	"	NA	NA	"	"	6.6	ND	1.8	"	"	"
	Windermere	15 "	"	"	"	"	"	"	2.2	0.89	5.5	"	"	"
	WALES													
	Llyn Trawsfynydd	8 May	"	"	2.8	4.4	ND	1.1	4.8	3.2	17	NA	NA	NA
	"	4 Jun	"	"	37	11	NA	ND	ND	190	1000	"	"	"
	"	6 "	65	"	NA	NA	"	"	"	76	460	"	"	"
	"	6 "	NA	2.0	"	"	"	"	"	142	884	"	"	"
	"	31 Aug	26	"	"	"	"	"	"	16	61	"	"	"
	"	16 Sep	NA	"	25	9.2	"	"	"	160	970	"	"	"
	"	17 "	"	"	13	7.7	"	"	"	200	960	"	"	"
	"	16 Oct	11	"	NA	NA	"	"	"	10	43	"	"	"
	"	31 "	NA	ND	ND	17	"	"	"	230	860	"	"	"
	SCOTLAND													
	Loch Doon	18 Sep	"	"	7.0	3.8	"	"	ND	320	730	"	"	"
	"	16 Dec	"	"	ND	6.3	"	"	"	250	540	"	"	"
	Loch Dee	27 Oct	"	"	"	7.8	"	"	"	1000	2300	"	"	"
	Loch A'Choire	15 Jun	"	"	NA	NA	"	"	"	19	40	0.000073	0.00042	0.00042
RAINBOW TROUT	ENGLAND													
	Hawkshead	13 May	"	"	NA	NA	"	"	3.2	ND	0.95	"	"	"
	WALES													
	Llyn Trawsfynydd	8 "	"	"	1.9	4.7	ND	"	ND	0.84	3.4	"	"	"
	"	24 "	29	"	NA	NA	NA	"	"	1.1	4.1	"	"	"
	"	31 Aug	26	"	"	"	"	"	"	1.4	5.2	"	"	"
	"	22 Oct	11	"	"	"	"	"	"	2.5	10	"	"	"
PERCH	ENGLAND													
	Devoke Water	5 Sep	NA	"	5.4	ND	"	"	"	340	830	"	"	"
	"	11 Sep	"	"	6.3	"	"	"	"	560	1300	"	"	"
	"	1 Nov	"	"	ND	2.8	"	"	"	810	2000	"	"	"
	WALES													
	Llyn Trawsfynydd	4 Aug	"	"	25	5.8	"	"	"	310	2000	"	"	"
	"	17 Sep	"	"	9.8	5.7	"	"	"	380	2900	"	"	"
	"	14 Nov	"	"	ND	11	"	"	"	420	2100	"	"	"
	"	29 Nov	"	"	"	16	"	"	"	490	2600	"	"	"

NA = not analysed.
ND = not detected.

Table 45 Estimates of maximum dose* to adults due to consumption of freshwater fish from areas of high deposition of Chernobyl fallout, 1986.

Region	Location	Committed effective dose equivalent, mSv year^{-1}
England	Loweswater	0.6
Wales	Llyn Conwy	0.3
Scotland	Loch Dee	0.9
Northern Ireland	Lough Ash	0.2
Isle of Man	River Druidale	0.3

*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 for routine discharges.

11. Summary and conclusions

A summary of estimated public radiation exposures in 1986 relating to liquid radioactive waste discharges from nuclear establishments which we monitor 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} to members of the public.

Discharges from Sellafield have, as in previous years, given rise to the highest exposures. The most important contributions to these exposures were due to radiocaesium and transuranic radionuclides. Details are given in sub-section 4.1.1. Exposures near Sellafield decreased in 1986 as compared with 1985, mainly because of the reducing trend in discharges, but there was also a reduction in consumption of locally-caught molluscan shellfish. Consumption rates could increase again in the future, but it is considered unlikely that exposures, calculated using realistic parameters, will exceed the 1 mSv year^{-1} level. Even though further significant reductions in discharges are not likely until the Enhanced Actinide Removal Plant

Table 46 Summarised estimates of public radiation exposure from discharges of liquid radioactive waste in the UK, 1986.

Establishment	Radiation exposure pathway	Critical group	Exposure[+], mSv
BRITISH NUCLEAR FUELS LIMITED			
Sellafield	Fish and shellfish consumption	Local fishing community	0.12 (0.34)*
		Commercial fishing community	0.10 (0.18)*
	External	Houseboat dwellers (river Ribble)	0.34
	Handling of fishing gear	Local fishing community	<0.1[‡]
	Porphyra/laverbread consumption	Consumers in South Wales	<0.01
Springfields	External	Houseboat dwellers	0.34[a]
Capenhurst (Meols outfall)	Shellfish consumption	Local fishing community	<0.1[a]
Chapelcross	Fish and shellfish consumption External	Local fishermen	0.2[a]
UNITED KINGDOM ATOMIC ENERGY AUTHORITY			
Winfrith	Fish and shellfish consumption	Local fishing community	0.1**
Dounreay	Handling of fishing gear	Local fishermen	<0.02[‡b]
	External	Local community	<0.01[b]
	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	<0.001[b]
Bradwell	Fish and shellfish consumption	Local fishing community	<0.02[b]
	External	Houseboat dwellers	
Dungeness	Fish and shellfish consumption External	Local fishing community	<0.002
Hartlepool	Fish and shellfish consumption	Local fishing community	<0.01[a]
	External	Coal collectors	<0.01[a]
Heysham	Fish and shellfish consumption	Local fishing community	0.10 (0.18)*[a]
	External		0.1[a]
Hinkley Point	Fish and shellfish consumption External	Local fishing community	<0.002[b]
Hunterston	Fish and shellfish consumption External	Local fishing community	0.03[a]
Sizewell	Fish and shellfish consumption External	Local fishing community	<0.01[b]
Trawsfynydd	Fish consumption	Local fishing community	0.17
Wylfa	Fish and shellfish consumption External	Local community	<0.1[a]
NAVAL ESTABLISHMENTS			
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			
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 0.0001; the value using a factor of 0.0005 follows in parentheses.

**Provisional value.

‡ 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.

(EARP) commences operation, scheduled for 1992, it is expected that exposures will continue to decline in line with our predictions (Hunt, 1986b) because of the dispersion time in the environment. Dose rates which were above the 1 mSv $year^{-1}$ level some years ago have not occured for long enough for lifetime exposure to have exceeded 1 mSv $year^{-1}$ on average, and thus the dose limitation objectives of ICRP will be met.

Radioactivity from Sellafield also 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 fallout from the Chernobyl reactor accident and the small contribution due to weapons-test fallout) are quoted in Table 46, with appropriate footnotes. Fallout from Chernobyl was detected in environmental materials near many nuclear establishments, mainly by the presence of short-lived radionuclides, but the effect at coastal establishments was transient and of negligible radiological significance. The effect of fallout from Chernobyl on the freshwater environment is described in section 10; concentrations of radiocaesium have been slower to diminish than in the marine environment, but estimates of exposures remained well within ICRP reference levels for consideration of countermeasures.

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 1986 there was a contribution to collective dose due to fallout from Chernobyl, which enhanced radiocaesium concentrations in fish particularly in Scottish waters and the North Sea; this contribution has been included. The preliminary collective effective dose equivalent to the UK population in 1986 was 50 man-Sv, the same as in 1985; the effect of radioactivity from Chernobyl has offset that of the reductions in Sellafield discharges. For the population of other European countries the preliminary collective effective dose equivalent was 90 man-Sv in 1986, slightly more than in 1985 (80 man-Sv), reflecting the effect of radioactivity from Chernobyl. A contribution to collective dose from this source is likely to be present for the next few years, and could be affected by radioactivity in the Baltic Sea, from Chernobyl. The contribution due to Sellafield is expected to continue to decline, reflecting the reducing trend in discharges over the past few years, particularly following operation of the Site Ion-Exchange Effluent Plant (SIXEP) from May 1985.

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