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DIRECTORATE OF FISHERIES RESEARCH

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Number 19

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G.J. Hunt

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The author:

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

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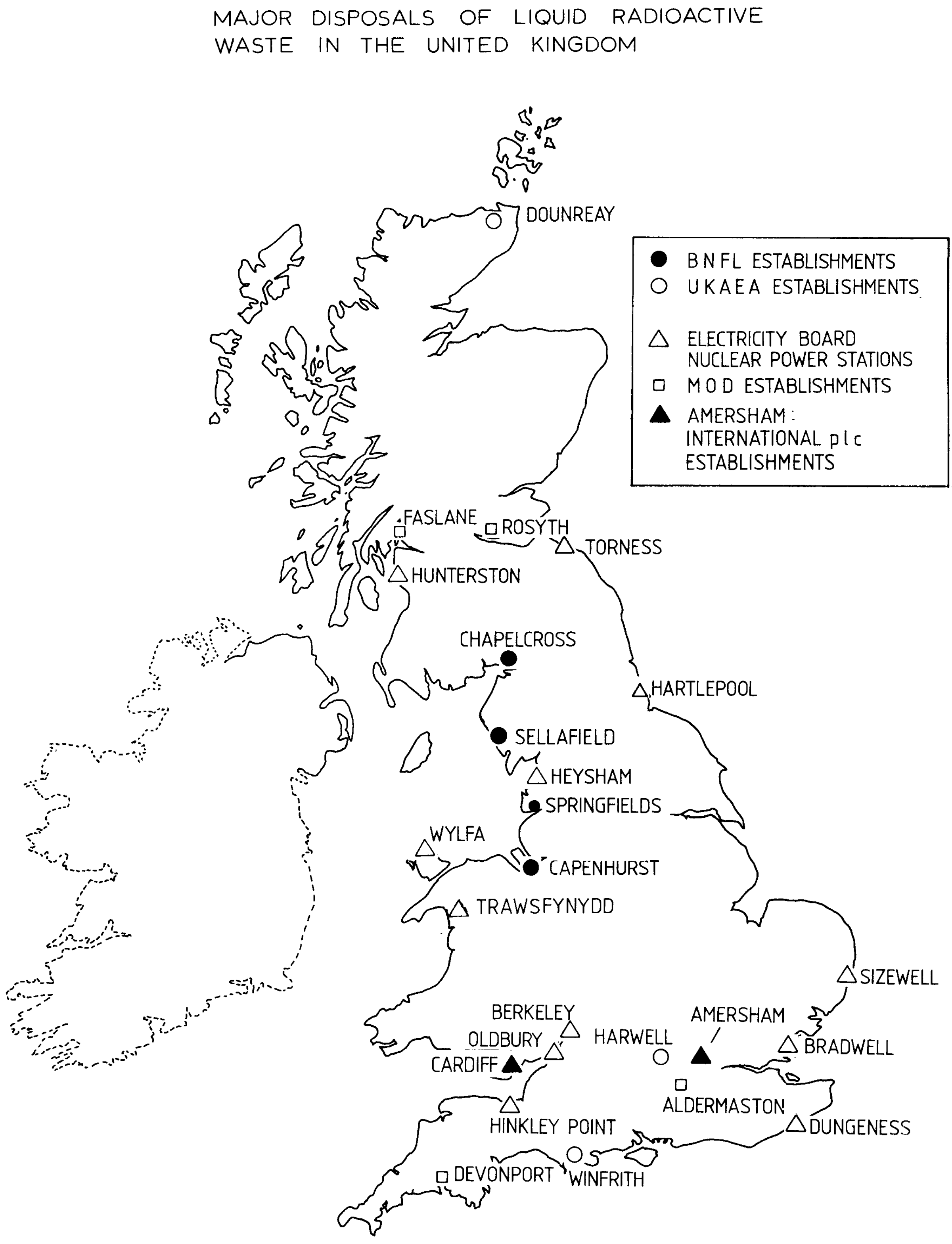


Figure 1 UK nuclear establishments giving rise to principal discharges of liquid radioactive waste.

1. Introduction

This report presents the results of the environmental monitoring programme carried out during 1987 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.

During 1987, the special programme was continued in connection with the accident at Chernobyl, USSR on 26 April 1986. An interim report of this programme for 1987 has already been published (MAFF, 1987). The present report gives summarised data for the whole of 1987, relevant both to regular discharges of radioactive wastes and to fallout from Chernobyl, with the aim of presenting a balanced picture for the complete year. Results are presented within the usual format of monitoring around nuclear sites, except for additional monitoring of radioactivity from Chernobyl in the freshwater environment which is dealt with in a separate section.

To set the monitoring results from our regular programme in context, liquid radioactive discharges from UK nuclear establishments to the aquatic environment in 1987 are first summarised. Before the results are presented, an explanatory sub-section gives details of methods of analysis and presentation and a further sub-section explains 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 1987 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 1987. The locations of these establishments are shown in Figure 1. Table 1 also lists the discharge limits which are authorised or, in the case of Crown operators, administratively agreed. In some cases, the authorisations specify limits in greater detail than can be summarised in a single table: in particular, where periods shorter than one year are specified the annual equivalent has been used. The limits are usually very much lower than the activities which could be released without exceeding the dose limits recommended by the International Commission on Radiological Protection (ICRP), embodied in national policy (Great Britain — Parliament, 1986). The percentages of the authorised (or agreed) limits taken up in 1987 are also stated in Table 1.

For completeness, data are included here on the very small discharges into Holy Loch from the US Navy submarine base. Radiological safety for the Holy Loch base is the responsibility of the US Navy in association with the Ministry of Defence who have supplied the following information. For the year 1987 the radioactivity released into the waters of Holy Loch was less than 0.04 GBq of long-lived gamma radioactivity, primarily cobalt-60; less than 0.04 GBq of short-lived radionuclides; less than 0.04 GBq of fission product radionuclides; and less than 0.4 GBq of tritium.

2.2 Solid radioactive waste

In addition to receiving most of the above liquid discharges, the marine environment has also received low specific activity packaged solid waste, disposed of mainly in an area of the deep Atlantic Ocean. The most recent such disposal was in 1982; none was carried out in 1987, and it was announced recently by the Secretary of State for Energy (Great Britain — Parliament, 1988) that sea dumping of drummed radioactive wastes will not be resumed. Instead, such wastes will be prepared for eventual disposal in a deep facility to be developed for both low- and intermediate-level radioactive wastes. However, it is intended to keep open the sea disposal option for large items arising from decommissioning operations.

Routine environmental monitoring does not provide an effective means of assessing radiation exposure from sea dumping as radionuclides from this practice are largely undetectable in deep-sea samples [OECD (NEA), 1985]. International surveillance of the effects of these disposals is coordinated by the Nuclear Energy Agency of the Organisation for Economic Cooperation and Development [OECD (NEA)] by means of a

Table 1 Principal discharges of liquid radioactive waste from UK nuclear establishments, 1987.

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1987 TBq	Discharges during 1987 % of limit
BRITISH NUCLEAR FUELS plc				
Sellafield				
Sea pipelines	Total beta	950	89.31	9.4
	Total alpha	14	2.16	15
	Ruthenium-106	370	22.10	6.0
	Strontium-90	60	15.02	25
	Americium-241	3.3	0.65	19
	Caesium-134	25	1.17	4.7
	Caesium-137	200	11.80	5.9
	Carbon-14	4	2.11	53
	Cerium-144	40	3.92	9.8
	Cobalt-60	9	1.44	16
	Iodine-129	0.4	0.10	25
	Plutonium alpha	10	1.33	13
	Plutonium-241	350	31.93	9.1
	Technetium-99	10	3.65	36
	Tritium	3500	1375.22	39
	Zirconium-95 plus Niobium-95	250	13.36	5.3
Seaburn sewer	Total activity	0.148	0.0036	2.4
Springfields	Total alpha	13.32	0.53	4.0
	Total beta	444	77	17
Chapelcross	Total alpha	0.1	0.0042	4.2
	Total beta[1]	25	0.498	2.0
	Tritium	5.5	0.713	13
Capenhurst				
Rivacre Brook	Total activity[2]	0.00148	0.000034	2.3
Meols outfall	Technetium-99	0.148	Nil	Nil
UNITED KINGDOM ATOMIC ENERGY AUTHORITY				
Winfrith	Total activity	1110	97	8.8
	Ruthenium-106	333	0.043	<1
	Strontium-90	44.4	0.036	<1
	Total alpha	44.4	0.0067	<1
Harwell	Total activity[1,3]	8.88	0.41	4.6
	Tritium	8.88	2.8	32
Dounreay	Total activity	888	24	2.7
	Strontium-90	88.8	2.4	2.7
	Total alpha	8.88	0.15	1.7
CENTRAL ELECTRICITY GENERATING BOARD				
Berkeley	Total activity[1]	7.4	0.24	3.2
	Tritium	55.5	1.1	2.0
Bradwell	Total activity[1]	7.4	0.71	9.6
	Zinc-65	0.185	0.0027	1.6
	Tritium	55.5	1.6	2.9
Dungeness				
"A" Station	Total activity[1]	7.4	0.57	7.7
	Tritium	74	0.20	0.27
"B" Station	Total activity[1,4]	4	0.018	<1
	Sulphur-35	25	0.32	1.3
	Tritium	650	6.8	1.0
Hartlepool	Total activity[1,4]	4	0.033	<1
	Sulphur-35	7.5	0.28	3.7
	Tritium	1850	32	1.7
Heysham				
Station 1	Total activity[1,4]	4	0.024	<1
	Sulphur-35	7.5	0.19	2.5
	Tritium	1850	83	4.5
Station 2[5]	Tritium	1200	Nil	Nil
	Sulphur-35	7	"	"
	Cobalt-60	0.036	"	"
	Other radionuclides	0.45	"	"
Hinkley Point[6]				
"A" Station	Total activity[1,4]	7.4	0.96	13
	Sulphur-35	3.7	0.29	7.8
	Tritium	74	5.4	7.3
"B" Station	Total activity[1,4]	3.7	0.019	0.51
	Sulphur-35	22.2	0.48	2.2
	Tritium	666	169	25

Table 1 Continued.

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1987 TBq	Discharges during 1987 % of limit
Oldbury	Total activity[1]	3.7	0.56	15
	Tritium	74	0.87	1.2
Sizewell	Total activity[1]	7.4	0.71	9.6
	Tritium	111	2.3	2.1
Trawsfynydd	Total activity[1]	1.48	0.18	12
	Caesium-137	0.259	0.029	11
	Tritium	74	3.8	5.1
Wylfa	Total activity[1]	2.405	0.058	2.4
	Tritium	148	6.2	4.2
SOUTH OF SCOTLAND ELECTRICITY BOARD				
Hunterston "A" Station	Total activity[1]	7.5	1.1	15
	Tritium	45	1.3	2.9
"B" Station	Total activity[1,4]	3.7	0.026	<1
	Sulphur-35	25.9	1.61	6.2
	Tritium	1480	269	18
Torness[7]	Tritium	1200	Nil	Nil
	Sulphur-35	10	"	"
	Cobalt-60	0.05	"	"
	Beta activity[1,4,8]	0.45	"	"
	Total alpha	0.0045	"	"
MINISTRY OF DEFENCE (PROCUREMENT EXECUTIVE)				
Aldermaston	Total activity[1,3]	5.8	0.088	1.5
	Tritium	5.8	0.059	1.0
MINISTRY OF DEFENCE (NAVY DEPARTMENT)				
Devonport[9]	Total activity[1,8]	0.002 (0.148)[9]	0.000049	2.0
	Cobalt-60	0.016 (0.037)	0.0038	17
	Tritium	0.12 (0.37)	0.047	23
Faslane	Total activity[1]	0.037	0.000046	<1
Rosyth[10]	Beta activity[1,8]	0.01 (1.11)[10]	0.00025	2.5
	Cobalt-60	0.055	0.0013	2.4
	Tritium	0.01	0.0059	59
	Total alpha	1×10^{-6}	0.72×10^{-6}	72
AMERSHAM INTERNATIONAL plc				
Amersham	Total activity[1,3]	2.7	1.02	38
	Tritium	14.8	5.7	38
Cardiff	Beta/gamma activity[11]	0.096	0.016	16
	Carbon-14	2	1.22	61
	Tritium	1400	817	58

[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] Authorisation came into effect on 2 November 1987: no discharges took place during 1987.
[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.
[7] Authorisation came into effect on 10 June 1987: no discharges took place during 1987.
[8] Excluding cobalt-60.
[9] With effect from 1 June 1987, Devonport Management Ltd, the operators of the privatised Dockyard, were authorised to discharge liquid radioactive wastes. The new authorised limits are shown with the former limits, agreed with MOD, in parentheses. The former limit on total activity included cobalt-60. Discharges are totals for the year. "% of limit" applies to discharges made since 1 June 1987.
[10] With effect from 6 April 1987, Babcock Thorn Ltd, the operators of the privatised Dockyard, were authorised to discharge liquid radioactive wastes. The new authorised limits are shown with the former limit on total activity, agreed with MOD, in parentheses. Discharges are totals for the year. "% of limit" applies to discharges made since 6 April 1987.
[11] Excluding tritium, carbon-14 and radioisotopes of calcium and strontium.

Coordinated Research and Environmental Surveillance Programme (CRESP) [OECD (NEA), 1981]. This Programme is continuing. In the absence of ready detectability of the dumping practice, radiation exposure is assessed mainly by the use of mathematical modelling. The emphasis of surveillance within CRESP has been to improve, by means of appropriate research, the data for modelling assessments. These assessments indicate that the environmental impact of these disposals is negligible [OECD (NEA), 1985].

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

The description of methods in this section refers to our surveillance of nuclear sites which in 1987 continued to include monitoring of the effects of the accident at Chernobyl. Where there were differences in methodology for the additional monitoring of the freshwater environment described in section 10, these are noted in that section.

3.1 SI units

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

3.2 Summary of analytical methods

Although some of the analytical methods which we have used are detailed elsewhere (Dutton, 1968, 1969), a very brief summary is given here in support of the measurements and the method of their presentation. The tables of results mostly include measurements of total beta radioactivity and of specific gamma-emitting nuclides. Pure beta emitters and alpha emitters (including transuranics) are also measured in appropriate cases.

Total beta radioactivity is measured using thin sources with a potassium-40 standard (Dutton, 1968). The efficiency of the method is nearly constant over a wide range of beta energies and the result gives a measure of the total radioactivity of the beta emitters present, including natural radioactivity. However, agreement with the total as derived from isotopic analysis is not expected to be exact. The main advantage of total beta measurements is that they can be carried out quickly to give an early warning of any change in radioactivity concentrations which might require further investigation.

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.

Pure beta emitters, such as carbon-14, strontium-90, technetium-99 and promethium-147, are chemically separated from samples before beta counting. Transuranic nuclides are chemically separated and analysed by alpha spectrometry using silicon surface-barrier detectors or, in the case of plutonium-241, by liquid scintillation counting. Radiochemical procedures are generally labour-intensive and are carried out on samples in which these nuclides are of particular relevance, often on an annual bulk (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

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

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 basis for comparison with the recommended limits. Therefore, the tables present the arithmetic means of observations made during the year. This procedure takes account of corrections for radioactive decay which are made to the time of sampling.

The frequency of sampling reflects the resolution (which affects the accuracy) judged to be necessary in the assessment of dose and is largely governed by the radiological importance. The tables indicate the number of sampling observations 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 calibrated against reference standards, each observation consists of the mean of a number of individual readings at a given location. This number again depends upon the radiological importance of the observation; the locations or materials chosen are generally those where there is likely to be occupancy or handling by persons as determined by habits surveys (see sub-section 3.4).

Analyses requiring radiochemical separation may be carried out on individual samples directly or on bulks made up of a number of individual samples collected over an extended period; in tables combining the results of gamma spectrometry and radiochemical analysis the extended period is one year unless otherwise stated.

Measurements on biota are given in terms of concentrations in wet material. For fish and shellfish the concentrations apply to the edible parts, because the purpose is assessment of internal exposure of the consumer. For sediments, whose water content is more variable, dry concentrations are given.

The results for certain measurements, particularly total beta radioactivity concentrations and gamma dose rates, include a contribution due to natural radioactivity. Further analysis of samples (usually by gamma spectrometry) indicates the component of total beta radioactivity which is due to artificial sources and the component due to natural radionuclides (mainly potassium-40 and the decay products of uranium and thorium). In the case of gamma dose rates, an indication of the natural background component can be gained from measurements at similar locations 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 shellfish from a variety of locations (Pentreath *et al.*, 1979; McDonald *et al.*, 1986; Pentreath and Allington, 1988). Radiation exposures from natural sources are in most cases greater than from artificial radioactivity. For example, natural polonium-210 alone can result in dose rates of up to 0.5 mSv $year^{-1}$ to high-rate consumers of fish and shellfish (Pentreath and Allington, 1988). However, the ICRP dose limits (sub-section 3.4) do not apply to natural and medical irradiation.

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:		$\mu Gy\ h^{-1}$
	Sand, shingle	0.03 to 0.05
	Mud	0.05 to 0.1

*Except sediments for which dry concentrations apply.

3.4 Method 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. These recommendations are endorsed for use in the UK by the National Radiological Protection Board (NRPB). 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 (ICRP, 1987) and advice from the NRPB (NRPB, 1987).

The ICRP system of dose limitation applies to all sources of exposures other than natural radiation and medical procedures. The effects of accidental releases of radioactivity strictly do not fall 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 separate from the effects of site operation, the total exposures due to artificial radionuclides have conservatively been considered 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. The ICRP and the NRPB do not recommend a dose limit for populations; such a limit might be regarded as suggesting the acceptability of a higher population exposure than is either necessary or probable. For reference purposes in this report, collective doses averaged over the UK population are compared with the average natural background level of approximately 2.2 mSv (Hughes, 1988).

ICRP Publication 26 recommends that doses should meet the ALARA objective, subject to compliance with appropriate individual dose limits. Control of individual exposures is intended to limit stochastic effects (i.e. those whose probability depends on the dose) to an acceptable level and to prevent non-stochastic (threshold) effects. For stochastic effects, it is recommended that the risk should be equal whether the whole body is irradiated uniformly or non-uniformly; weighting factors proportional to the risk are defined for different organs. The weighted sum of organ doses is called the effective dose equivalent. Exposures from intakes of radioactivity can continue for a number of years, depending upon body retention time. The committed effective dose equivalent represents the integrated exposure over 50 years following an intake. The ICRP (ICRP, 1985) has made known its present view that the principal limit for the committed effective dose equivalent received by a member of the public is 1 mSv in a year. However, it is permissible to use a subsidiary dose limit of 5 mSv in a year for some years provided that the average annual committed effective dose equivalent over a lifetime does not exceed 1 mSv $year^{-1}$. The ICRP-recommended dose limits apply to the sum of the effective dose equivalent resulting from external exposure during 1 year and the committed effective dose equivalent incurred from that year's intake of radionuclides. For members of the public, the dose limits apply to appropriate critical groups of people likely to be the most exposed.

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

Only general guidance has been given by the ICRP (ICRP, 1984a) on the calculation of committed effective dose equivalents following intakes of radionuclides by members of the public. In this report, results are based on committed effective dose equivalents per unit intake derived by the NRPB using ICRP principles (NRPB, 1987). Our dose assessments include consideration of children, where they are known to be members of critical groups, and the use of appropriate gut transfer factors. The ICRP has recently reviewed metabolic factors for actinides (ICRP, 1986). A cautious value of 0.001 is recommended for the gut transfer factor for plutonium, americium and related elements. However, the ICRP states that this cautious value may not be considered as appropriate in all situations where a best estimate of absorption is required, either for a critical group or in estimating population doses. If a different value more suitable to the specific situation can be justified, it should be employed. Recent work at this laboratory using adult human volunteers has suggested somewhat lower values 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 pre-existing 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, 1984). 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 pass 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. These wastes are discharged under an authorisation which took effect from 1 July 1986, specifying lower limits to radioactivity in discharges than previously and limiting more nuclides specifically, maintaining controls on releases of solvents and particulates (Great Britain — Parliament, 1986). A further condition requires BNFL to use best practicable means (BPM) to control discharges. This condition reflects, *inter alia,* the objective of keeping radiation exposures as low as reasonably achievable (ALARA), to comply with the ICRP principles, as described in sub-section 3.4.

Discharges from the Sellafield pipelines during 1987 are summarised in Table 1, and were within the limits set by the Authorising Departments. The new site ion-exchange effluent plant (SIXEP) and the salt evaporator operated throughout 1987. There was a longer period of plant shutdown for refurbishment than in previous years, thus discharges to sea, which had reduced in 1986 mainly because of the introduction of the new treatment plants, declined further in 1987. Discharges of total beta activity were 89 TBq (1986: 118 TBq). Caesium-137 discharges, which prior to SIXEP operation originated mainly from the fuel element storage ponds, in 1987 totalled 11.8 TBq (1986: 17.9 TBq) and were derived predominantly from the reprocessing plant. Discharges of alpha-emitting radionuclides in 1987 also declined, totalling 2.2 TBq (1986: 4.4 TBq).

Our regular monitoring continued during 1987. Important radiation exposure pathways were still from consumption of fish and shellfish and from external exposure to gamma rays from occupancy over sediments, with other pathways being kept under review. Following established practice, the largest monitoring effort was expended on these more important pathways. In 1987, 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 specific surveys are carried out in the smaller "Sellafield Offshore Area" where experience has shown that good catch rates may be obtained. This Area consists of a rectangle, one nautical mile wide by two nautical miles long, situated south of the pipeline with the long side parallel to the shoreline; it averages about 5 km from the pipeline outlet.

The results reflect the progressive dilution of radiocaesium with increasing distance from Sellafield. They also reflect the age of the radioactivity; up to 1985, the ratio of caesium-137 to caesium-134 (half-lives 30 years and 2 years respectively) increased with distance from Sellafield, but in 1986 this ratio was perturbed by the addition of radiocaesium from Chernobyl which was relatively rich in caesium-134; this effect persisted in 1987. Fish from Scottish waters and the North Sea, which were affected by rain-out from the Chernobyl plume, show this effect particularly; it is estimated that in these areas, up to about 50% of the average caesium-137 concentration in 1987 was due to the effect of Chernobyl. Similar effects were not detected in fish from Icelandic waters, and concentrations of artificial radioactivity remained typical of those from weapons-test fallout, at a value of about 0.1–0.4 Bq kg^{-1} for caesium-137 in fish. These observations are consistent with those based on measurements of sea water (Mitchell and Steele, 1988).

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 steep concentration gradient of radiocaesium 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 1987 were generally less than in 1986 for fish from all sea areas. 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.

Specific radionuclides other than caesium-134 and -137 which were detected in fish in 1987 are listed in Table 4(b). Trace levels of the short-lived radionuclides which characterised some of the results in 1986 and which were most probably due to the effects of Chernobyl, were, as expected, no longer detectable in 1987. Analyses of samples of fish for carbon-14, strontium-90, technetium-99 and promethium-147 continued to be included in our monitoring programme to enable the effects of discharges of these nuclides from Sellafield to be assessed, and for results based on measurements to be included later in consideration of critical group and collective dose. Analyses for these radionuclides are labour-intensive, thus a selection of samples was made based on potential radiological significance. The data for 1987, shown in Table 4(b), confirm that the radiological significance of these radionuclides remained low.

For shellfish, a wide range of radionuclides contributes to radiation exposure of consumers owing to generally greater uptake in these organisms than in fish. Table 5 lists concentrations of total beta activity and beta/gamma-emitting nuclides in shellfish from the Irish Sea and further afield. Results for carbon-14, strontium-90, technetium-99 and promethium-147 are included. Winkles are of particular radiological

Table 4(a) Beta/gamma radioactivity in fish from the Irish Sea vicinity and further afield, 1987.

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	5	200	1.8	45
	Plaice	3	240	2.4	88
	Bass	1	290	6.0	180
Sellafield offshore area[1]	Cod	4	190	1.7	39
	Plaice	4	160	1.3	35
	Flounder	1	180	5.8	99
	Dab	3	160	1.7	39
	Whiting	2	210	3.3	74
	Spurdog	1	110	2.1	18
	Rays	1	130	1.5	26
Ravenglass[2]	Cod	19	180	1.9	43
	Plaice	11	170	1.7	50
	Flounder	2	240	4.4	76
	Saithe	1	200	3.8	67
	Whitebait	1	150	1.2	32
Morecambe Bay[1]	Flounder	4	210	2.8	98
	Plaice	4	120	0.8	23
Whitehaven[2]	Cod	4	160	1.4	28
	Plaice	4	150	1.5	41
	Herring	4	130	1.3	22
Fleetwood[2]	Cod	4	150	1.3	24
	Plaice	4	133	1.0	18
	Fish meal[5]	3	310	0.9	19
	Fish oil[5]	3	NA	ND	ND
Cumbrian rivers[4]	Sea trout	7	160	2.3	36
Isle of Man[2]	Cod	4	140	1.1	18
	Plaice	4	110	0.7	13
	Herring	4	110	0.9	12
	Dab	1	110	0.5	8.7
Inner Solway[1]	Salmon	1	120	ND	1.1
	Sea trout	2	180	0.9	23
	Flounder	4	210	3.6	99
Kirkcudbright[2]	Plaice	4	130	1.3	29
North Anglesey	Plaice	2	110	0.6	5.2
	Spurdog	4	110	0.7	14
Northern Ireland[2]	Cod	4	150	1.2	14
	Whiting	8	150	1.5	24
	Herring	4	140	1.4	16
	Spurdog	4	100	0.8	12
Ayr[2]	Plaice	4	120	0.8	14
	Cod	4	160	1.4	26
Minch[1]	Plaice	4	110	0.5	4.7
	Cod	5	130	0.6	5.1
	Herring	5	110	0.4	6.8
	Mackerel	4	110	0.2	2.7
Shetland[1]	Fish meal[5]	3	640	0.7	3.5

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
Northern North Sea[1]	Plaice	4	110	0.4	2.1
	Cod	7	130	0.8	3.9
	Haddock	4	NA	0.4	3.0
	Saithe	3	"	0.8	4.0
	Herring	4	110	0.4	3.4
	Norway pout	1	NA	0.3	0.8
	Mackerel	3	"	0.2	1.8
Mid-North Sea[1]	Plaice	9	100	0.3	3.2
	Cod	10	140	0.8	6.5
	Haddock	4	NA	0.5	3.5
	Whiting	3	"	0.8	7.4
	Herring	6	120	0.8	3.9
	Mackerel	1	NA	0.4	2.7
Southern North Sea[1]	Plaice	4	100	0.3	2.0
	Cod	4	120	0.4	4.1
	Whiting	1	NA	0.5	5.2
	Herring	1	120	0.4	4.3
Iceland area[1]	Cod	1	130	ND	0.3
Icelandic processed	Cod	2	120	"	0.3
	Plaice	2	84	0.07	1.0

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

Table 4(b) Other beta/gamma radioactivity in fish from the Irish Sea vicinity, 1987.

Sampling area/ landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}				
			^{14}C	^{90}Sr	^{60}Co	^{99}Tc	^{147}Pm
Sellafield offshore area[1]	Plaice	1	110	0.19	ND	0.68	ND
	Cod	1	83	0.17	0.1	0.39	"
Ravenglass[2]	Whitebait	1	NA	1.1	ND	NA	NA
Whitehaven[2]	Plaice	1	"	0.22	0.1	"	"
	Cod	1	"	0.056	ND	"	"
Fleetwood[2]	Cod	4	"	NA	"	"	"
	Fish meal[4]	3	"	1.4	"	"	"
Shetland[1]	Fish meal[4]	1	"	0.052	"	"	"
Northern North Sea[1]	Norway pout	1	"	NA	"	"	"

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

Table 5 Beta/gamma radioactivity in shellfish from the Irish Sea vicinity and further afield, 1987.

Sampling area/ landing point	Sample	No. of sampling observa-tions[3]	Mean radioactivity concentration (wet), Bq kg^{-1}																
			Total beta	^{14}C	^{60}Co	^{65}Zn	^{90}Sr	^{95}Zr + ^{95}Nb	^{99}Tc	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{147}Pm	^{154}Eu	^{155}Eu
Sellafield coastal area[1]	Crabs	5	120	60	3.4	ND	0.83	ND	2.6	ND	11	14	ND	0.5	9.4	ND	3.2	ND	ND
	Lobsters	4	440	120	3.7	"	1.9	"	500	"	12	11	"	0.9	16	2.9	25	"	"
	Winkles[4]	12	440	87	15	"	15	22	58	"	140	30	2.6	0.3	27	5.2	26	0.4	0.8
	Winkles[5]	4	360	NA	13	"	NA	36	NA	0.4	120	26	3.1	0.5	21	7.3	NA	0.2	0.5
	Winkles[6]	4	200	"	4.5	"	"	2.2	"	ND	50	20	1.3	0.4	18	2.7	"	ND	ND
	Winkles[7]	2	290	"	10	"	"	7.6	"	"	100	27	1.9	ND	23	11	"	"	"
	Mussels[4]	4	280	"	7.1	"	"	16	"	0.3	120	ND	0.8	0.1	9.5	4.0	"	2.0	1.4
	Limpets[4]	4	460	"	9.2	"	"	16	"	ND	94	16	7.7	0.08	27	5.9	"	0.5	1.1
Sellafield offshore area[1]	Whelks	2	410	"	9.9	0.6	"	3.4	"	0.4	160	16	1.1	0.2	8.8	3.5	"	1.1	0.9
St Bees[1]	Winkles	4	350	52	10	ND	12	16	30	ND	110	27	5.2	0.4	28	7.4	21	0.5	0.4
	Mussels	4	470	NA	11	"	NA	65	NA	0.5	240	13	2.5	ND	18	12	NA	ND	1.7
	Limpets	4	490	"	8.7	"	"	12	"	0.4	82	20	2.8	0.7	34	4.3	"	0.4	0.6
Nethertown[1]	Winkles	12	440	64	13	"	17	38	60	0.5	150	30	4.7	1.0	31	10	32	ND	0.4
Seascale	Shrimps	1	140	NA	1.0	"	NA	ND	NA	ND	ND	3.4	ND	1.4	23	ND	NA	"	ND
Drigg[1]	Winkles	4	600	100	21	"	15	46	130	"	230	31	3.1	0.8	31	12	38	0.7	0.5
Ravenglass[1]	Cockles	4	410	NA	28	"	NA	67	NA	0.8	130	2.0	ND	0.3	26	17	NA	3.8	3.2
	Mussels	12	340	"	8.8	"	"	19	"	0.2	160	ND	1.4	ND	10	5.5	"	0.8	1.9
Ravenglass[2]	Crabs	2	150	"	3.3	"	"	ND	"	ND	28	17	0.8	0.5	11	ND	"	ND	ND
	Lobsters	3	380	"	4.4	"	"	"	"	"	9.8	14	ND	0.7	15	1.7	"	"	0.6
	Whelks	3	310	"	11	0.4	"	2.5	"	"	130	21	1.1	0.2	7.0	1.7	"	"	ND
Tarn Bay[1]	Winkles	4	380	"	15	ND	"	97	"	2.3	230	24	1.4	1.5	61	17	"	1.3	0.4
Whitehaven[2]	*Nephrops*	4	130	"	ND	"	"	ND	"	ND	ND	0.8	ND	0.7	19	ND	"	ND	ND
	Whelks	2	110	"	1.1	"	"	"	"	"	7.7	9.5	"	0.2	3.8	"	"	"	"
Parton[1]	Winkles	4	290	"	6.5	"	"	8.6	"	"	85	16	"	0.8	31	3.8	"	"	0.4
Roosebeck[1]	Oysters	4	64	"	0.4	"	"	ND	"	"	5.7	25	"	ND	5.0	ND	"	"	ND
Morecambe Bay[1]	Shrimps	4	100	"	ND	"	0.10	"	"	"	ND	ND	"	0.6	31	"	"	"	"
	Cockles	4	120	"	2.2	"	1.5	"	"	"	5.7	"	"	0.3	17	"	"	"	"
	Mussels	4	87	"	ND	"	NA	"	"	"	9.2	"	"	ND	8.7	"	"	"	"
Isle of Man[2]	Scallops	6	120	"	0.03	"	"	"	"	"	0.4	1.9	"	0.2	2.7	"	"	"	"
Fleetwood	Squid	2	76	"	ND	"	"	"	"	"	ND	0.1	"	0.1	2.6	"	"	"	"
	Whelks	2	120	"	0.4	"	"	"	"	"	4.0	2.8	"	0.2	3.5	"	"	"	"
Inner Solway[1]	Shrimps	4	100	"	ND	"	"	"	"	"	ND	2.4	"	0.7	30	"	"	"	"
Southerness[1]	Winkles	4	200	"	0.7	"	"	"	"	"	19	72	"	1.5	26	"	"	"	"
Kirkcudbright[2]	Scallops	4	55	"	ND	"	"	"	"	"	ND	2.1	"	0.08	1.4	"	"	"	"
	Queens	4	78	"	"	"	"	"	"	"	"	4.1	"	0.07	2.0	"	"	"	"
North Solway coast[1]	Winkles	4	150	"	2.1	"	"	"	"	"	15	30	"	0.4	8.6	"	"	"	"
Wirral[1]	Shrimps	2	55	"	ND	"	"	"	ND	"	ND	ND	"	0.3	8.3	"	"	"	"
	Cockles	2	84	"	"	"	"	"	1.9	"	"	"	"	ND	6.5	"	"	"	"
Conwy[2]	Mussels	2	53	"	"	"	"	"	NA	"	2.9	"	"	0.1	2.1	"	"	"	"
North Anglesey[1]	Crabs	2	85	"	0.2	"	"	"	"	"	2.0	13	"	0.1	2.5	"	"	"	"
	Winkles	2	90	"	ND	"	"	"	"	"	ND	9.0	"	ND	2.0	"	"	"	"
Northern Ireland[2]	*Nephrops*	8	110	"	"	"	"	"	"	"	"	0.5	"	0.6	6.8	"	"	"	"
	Winkles	4	95	"	"	"	"	"	"	"	"	16	"	0.3	2.6	"	"	"	"
Minch[1]	*Nephrops*	3	95	"	"	"	"	"	"	"	"	1.4	"	0.1	3.1	"	"	"	"
Northern North Sea[1]	*Nephrops*	3	110	"	"		"	"	"	"	"	1.9	"	0.2	2.5	"	"	"	"
Mid-North Sea[1]	Mussels	1	86	"	"	"	"	"	"	"	"	ND	"	ND	0.4	"	"	"	"
	Mussels[8]	2	54	"	"	"	"	"	"	"	"	"	"	"	0.3	"	"	"	"
Southern North Sea[1]	Cockles	2	31	"	2.0	"	"	"	"	"	ND	5.5	"	"	0.4	"	"	"	"
	Cockles[9]	1	61	"	3.2	"	"	"	"	"	3.3	5.2	"	"	0.8	"	"	"	"
	Mussels	2	60	"	ND	"	"	"	"	"	ND	ND	ND	0.1	1.0	"	"	"	"

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.

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.

As for fish, the short-lived radioactivity from Chernobyl which was detected in a few samples of shellfish in 1986 was no longer detectable in 1987. 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 relatively mobile in sea water, such as isotopes of caesium. There are substantial variations between species: in general, molluscs tend to concentrate the less mobile nuclides to a greater extent than do crustaceans, which in turn tend to concentrate them more than fish; the reverse behaviour is generally observed for mobile nuclides.

Concentrations of caesium-137 in shellfish in 1987, as for fish, showed general reductions as compared with 1986, 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 1987 are presented in Table 6. Transuranics are less mobile than radiocaesium in sea water; this is reflected in higher concentrations of transuranics in shellfish as compared with fish, and a rapid reduction with distance in concentrations of transuranics, particularly in shellfish.

Concentrations of transuranics in fish and shellfish from the Irish Sea generally showed continuing reductions in 1987 as compared with previous years, particularly in areas close to Sellafield. These reductions, as predicted (Hunt, 1986), continued to reflect the decline in discharges over the past few years. The non-mobile 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 further until operation of the Enhanced Actinide Removal Plant (EARP), 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, eaters of fish and shellfish within the local community represent one exposed population whose consumption rates we have studied and kept under review. As regards the other main variable, consumption rates, surveys have shown that, in addition to the local fishing community, the larger population in Cumbria and north Lancashire including those associated with commercial fisheries based primarily at Whitehaven, Fleetwood and in the Morecambe Bay area contains consumers of large quantities of fish and shellfish. These additional populations are kept under review, even though, in general, the relevant fishing grounds are further afield than the Cumbrian Coastal Area and concentrations of radioactivity in fish landed are lower.

The consumption rates of the local fishing community described above were kept under review in 1987. 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 exposed populations, therefore, sub-groups of persons were identified who were likely to have received the greatest exposures from eating each class of foodstuff, and mean consumption rates for the sub-groups were determined. For the local fishing community, the consumption rate of fish in 1987 was 36.5 kg year^{-1}, as for 1986 (Hunt, 1987). Our surveys revealed a decrease in consumption of crustaceans, from 6.6 kg year^{-1} in 1986 to 6.0 kg year^{-1} in 1987. However, an increase in consumption of molluscs from 6.6 kg year^{-1} in 1986 to 8.3 kg year^{-1} was also observed. In this report, exposures of the critical group of fish and shellfish consumers have been assessed on the basis of 1987 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 rates of 36.5 kg year^{-1} fish, 6.6 kg year^{-1} crustaceans and 16.4 kg year^{-1} molluscs.

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, members of more than one sub-group do exist, so to avoid underestimating the exposure of the overall critical group, this exposure is derived by adding together the exposures of each sub-group. Comparison based on individual critical group members' exposures shows that this procedure is not excessively conservative (Leonard and Hunt, 1985). Plaice and cod are overwhelmingly the most popular fish eaten by the high-

Table 6 Transuranic radioactivity in fish and shellfish from the Irish Sea vicinity and further afield, 1987.

Sampling area/ landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}						
			^{237}Np	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Sellafield coastal area[1]	Plaice	1	NA	0.050	0.23	NA	0.34	0.0010	0.0010
	Cod	1	"	0.015	0.060	"	0.082	ND	ND
	Crabs	2	0.015	0.23	1.0	19	3.6	0.032	0.015
	Lobsters	3	0.12	0.48	2.1	73	14	0.031	0.051
	Winkles[4]	4	0.25	5.1	22	460	33	0.12	0.12
	Winkles[5]	2	NA	3.3	14	290	21	0.42	0.11
	Winkles[6]	4	"	2.0	9.1	180	15	0.10	0.056
	Winkles[7]	2	"	3.4	14	290	23	0.14	0.078
	Mussels[4]	1	"	6.1	26	NA	42	0.14	0.13
	Limpets[4]	1	"	5.4	22	"	34	0.15	0.14
Sellafield offshore area[1]	Plaice	1	0.0016	0.0037	0.016	0.25	0.026	ND	0.00035
	Cod	1	0.0008	0.0037	0.016	NA	0.027	0.00060	0.00011
	Rays	1	NA	0.020	0.086	"	0.11	ND	ND
	Whelks	1	"	1.5	6.2	"	22	0.081	0.074
St Bees[1]	Winkles	4	0.14	4.6	19	390	28	0.11	0.12
	Mussels	2	NA	8.6	36	750	48	0.33	0.24
	Limpets	1	"	4.2	18	NA	28	0.064	0.081
Nethertown[1]	Winkles	4	0.21	5.8	25	510	38	0.33	0.15
Drigg[1]	Winkles	4	0.27	8.3	35	690	55	0.21	0.18
Ravenglass[1]	Cockles	1	NA	9.2	39	740	75	0.41	0.35
	Mussels	4	"	7.4	31	630	46	0.12	0.18
Ravenglass[2]	Cod[8]	1	"	0.0020	0.0088	NA	0.016	ND	ND
	Plaice[8]	1	"	0.0034	0.015	"	0.026	0.00008	0.0001
	Whitebait	1	"	0.80	0.34	6.4	0.44	0.0039	0.0012
	Crabs[9]	1	"	0.35	1.5	NA	4.6	0.027	0.021
	Lobsters[9]	1	"	0.29	1.2	"	20	0.078	0.059
	Whelks[9]	1	"	1.2	4.8	97	10	0.062	0.034
Tarn Bay[1]	Winkles	1	"	5.1	23	440	33	0.21	0.14
Whitehaven[2]	Plaice	1	"	0.0032	0.013	NA	0.022	0.00032	0.00008
	Cod	1	"	0.0012	0.0058	"	0.0082	ND	ND
	Herring	1	"	0.0087	0.042	"	0.054	"	0.00011
	Nephrops	1	"	0.041	0.19	"	0.62	0.0019	0.0023
	Whelks		"	0.16	0.72	15	0.98	0.0017	0.0026
Parton[1]	Winkles	1	"	3.0	12	220	17	0.055	0.057
Roosebeck	Oysters	1	"	0.41	1.8	"	1.3	0.0029	0.0028
Morecambe Bay[1]	Shrimps	1	"	0.0095	0.046	1.3	0.065	ND	0.00016
	Cockles	1	"	0.70	3.5	40	8.0	"	0.020
	Mussels	1	"	0.45	2.1	NA	3.1	"	0.0088
Fleetwood[2]	Cod	1	"	0.00024	0.0012	"	0.0021	"	0.00001
	Plaice	1	"	0.00065	0.0032	"	0.0053	"	ND
	Fish meal[10]	3	"	0.011	0.054	"	0.072	"	0.00033
	Whelks	1	"	0.10	0.49	9.0	0.70	"	0.0015
Isle of Man[2]	Cod	1	"	0.00018	0.00086	NA	0.00088	"	ND
	Plaice	1	"	0.00037	0.0017	"	0.0031	"	0.00002
	Herring	1	"	0.00073	0.0040	"	0.0045	"	ND
	Scallops	1	"	0.041	0.19	"	0.55	"	"
Inner Solway[1]	Sea trout	1	"	0.0015	0.0069	"	0.010	"	"
Southerness[1]	Winkles	1	"	0.82	3.6	"	5.4	0.024	0.027
Kirkcudbright[2]	Plaice	1	"	0.0016	0.0080	"	0.012	ND	0.00004
	Scallops	1	"	0.020	0.10	"	0.039	"	ND
	Queens	1	"	0.023	0.11	"	0.064	"	"
North Solway coast[1]	Winkles	1	"	0.58	2.6	"	4.1	0.014	0.0098
Ayr[2]	Cod	1	"	0.00057	0.0028	"	0.0040	ND	ND
	Plaice	1	"	0.0016	0.0080	"	0.012	"	"
Wirral[1]	Cockles	1	"	0.22	1.1	"	2.3	"	0.0098
Conwy[2]	Mussels	1	"	0.054	0.26	"	0.46	"	0.0020
North Anglesey[1]	Spurdog	1	"	0.00008	0.00027	"	0.00031	"	ND
	Winkles	1	"	0.036	0.18	"	0.23	"	"

Table 6 Continued.

Sampling area/ landing point	Sample	No. of sampling observa- tions[3]	Mean radioactivity concentration (wet), Bq kg^{-1}						
			^{237}Np	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Northern Ireland[2]	Cod	1	NA	0.00014	0.00069	NA	0.0011	ND	ND
	Whiting	2	"	0.00068	0.0030	"	0.0042	"	"
	Spurdog	1	"	0.0012	0.0054	"	0.0052	"	0.00002
	Nephrops	2	"	0.0050	0.027	"	0.062	"	0.00014
	Winkles	1	"	0.050	0.23	"	0.11	"	ND
Minch[1]	Cod	1	"	0.00007	0.00032	"	0.00046	"	"
	Mackerel	1	"	0.00003	0.00019	"	0.00014	"	"
	Nephrops	1	"	0.0015	0.0084	"	0.0085	"	"
Shetland[1]	Fish meal[10]	1	"	0.00033	0.0036	"	0.00083	"	"
Northern North Sea[1]	Cod	1	"	0.00004	0.00015	"	0.00019	"	"
	Nephrops	1	"	0.0011	0.0050	"	0.0094	0.00092	0.00015
Mid-North Sea[1]	Mussels	1	"	0.0035	0.017	"	0.0029	ND	ND
	Mussels[11]	1	"	0.0013	0.0093	"	0.0037	"	"
Southern North Sea[1]	Mussels	1	"	0.0095	0.047	"	0.019	0.00022	0.00003
	Cockles	1	"	0.0022	0.0096	"	0.0092	0.00015	0.00095
	Cockles[12]	1	"	NA	NA	"	0.026	0.00028	0.0014
Icelandic processed	Cod	1	"	0.00002	0.00014	"	0.00016	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.

rate consumers, and the assessment of exposure of the critical group of local consumers 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, following the recent review of consumption rates, is calculated on the basis of a mix of two-thirds crabs and one-third lobsters from the Coastal Area and landings at Ravenglass, combined equally. The exposure from consumption of molluscs is calculated on the basis of averaged radionuclide concentrations in winkles from the Coastal Area, including data from both our own sampling at specific locations within this Area and from samples collected by local consumers.

Table 7 summarises exposures in 1987. 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 1987 would have been 0.10 mSv. This result is slightly lower than the dose of 0.12 mSv reported for 1986. Reductions in concentrations of radionuclides (particularly radiocaesium) in fish and shellfish have caused this decrease; the reductions in concentrations outweighed the effect of the higher consumption rate of molluscs. 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 1987 would have been 0.33 mSv, a slight decrease from 0.34 mSv reported in 1986. All of 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} fish, 6.6 kg year^{-1} crustaceans and 16.4 kg year^{-1} molluscs). If these consumption rates had applied in 1987, the dose to the critical group would have been 0.18 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 0.61 mSv. These results show decreases as compared with previous years, due to lower concentrations in fish and shellfish of transuranics, ruthenium-106 and radiocaesium. 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, 1986).

Table 7 Individual radiation exposures due to consumption of Irish Sea fish and shellfish, 1987.

Exposed population	Consumption rate used in assessment (see text), kg year^{-1}		Nuclide	Committed effective dose equivalent, mSv year^{-1}, on basis of following gut transfer factors for Pu, Am (see text)	
				0.0001	0.0005
Consumers in local fishing community	fish (plaice and cod):	36.5	^{90}Sr	0.004	0.004
	crustaceans (crabs and lobsters):	6.0	^{106}Ru	0.007	0.007
	molluscs (winkles):	8.3	^{134}Cs	0.001	0.001
			^{137}Cs	0.022	0.022
			^{238}Pu	0.004	0.018
			$^{239}Pu + ^{240}Pu$	0.017	0.083
			^{241}Pu	0.007	0.034
			^{241}Am	0.030	0.15
			Total	0.10	0.33
Consumers associated with commercial fisheries: Whitehaven	fish (plaice and cod):	49	^{134}Cs	0.001	0.001
	crustaceans (*Nephrops*):	11	^{137}Cs	0.023	0.023
	molluscs (whelks):	6	$^{239}Pu + ^{240}Pu$	0.001	0.003
			^{241}Am	0.001	0.006
			Total	0.03	0.04
Consumers in Morecambe Bay area	fish (flounders and plaice):	50	^{134}Cs	0.002	0.002
	crustaceans (shrimps):	18	^{137}Cs	0.045	0.045
	molluscs (cockles and mussels):	15	$^{239}Pu + ^{240}Pu$	0.004	0.020
			^{241}Am	0.008	0.041
			Total	0.06	0.12
Consumers associated with commercial fisheries: Fleetwood	fish (plaice and cod):	82	^{134}Cs	0.002	0.002
	crustaceans (shrimps):	17	^{137}Cs	0.030	0.030
	molluscs (cockles and whelks):	23	$^{239}Pu + ^{240}Pu$	0.004	0.022
			^{241}Am	0.010	0.049
			Total	0.05	0.11
Typical member of the fish-eating public consuming fish landed at Whitehaven/Fleetwood	fish (plaice and cod):	15	^{137}Cs	0.005	0.005
			Total	0.006	0.006

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 1987, and in recent previous years, realistically-assessed exposures were within the principal dose limit of 1 mSv year^{-1}. For a few years prior to this, exposures were in excess of 1 mSv year^{-1} but within the ICRP-recommended subsidiary dose limit of 5 mSv year^{-1}. Concentrations of radiologically significant nuclides in environmental materials are declining as a result of reduced discharges, and consumption rates of shellfish would need to increase substantially 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, 1986). Having demonstrated compliance with the ICRP's lifetime dose objectives, it follows (sub-section 3.4) that non-stochastic effects will also be avoided.

Consumption rates in the wider fishing communities of Cumbria and north Lancashire have been kept under review and in 1987 further information became available which allowed specific assessments to be made for each of the areas Whitehaven, Fleetwood and Morecambe Bay. Previously, a composite assessment had been made (Hunt, 1987). The specific consumption rates are given in Table 7, together with the species whose radioactivity concentrations, following the information from habits surveys, formed the basis of the assessments. Because high-rate consumers in all areas may eat both fish and shellfish, the critical groups have been defined by the maximising procedure of summing exposures due to the component consumption rates. The committed effective dose equivalents received by the groups are given in Table 7. The results for Whitehaven were less than those for Morecambe Bay or Fleetwood, mainly because of lower consumption rates and radioactivity concentrations in molluscs. In order to compare the results with those for 1986 an assessment has also been carried out using the former, composite, method (Hunt, 1987). On the basis of a gut transfer factor for plutonium and americium of 0.0005, a result of 0.14 mSv was obtained, this represents a decrease from 0.18 mSv reported for 1986, due to reductions in radioactivity concentrations. The result also shows that the composite method of assessment was a maximising one.

The effective dose appropriate to a consumption rate of 15 kg year^{-1} of fish from landings at Whitehaven and Fleetwood is also given in Table 7. This consumption rate represents an average for typical fish-eating members of the public. The effective dose in 1987 was 0.006 mSv, which represents a decrease from 0.009 mSv reported for 1986 (Hunt, 1987), due to the reduced concentrations of radiocaesium in Irish Sea fish.

Comparison of the exposures reported in Table 7 with those due to ingestion of natural polonium-210 in fish and shellfish is of interest although this source of exposure is not subject to the ICRP-recommended dose limits. For the high consumption rate groups, dose rates up to 0.5 mSv year^{-1} could be received (Pentreath and Allington, 1988). The exposures reported may also be compared with the average dose of approximately 2.2 mSv year^{-1} to members of the UK public from all natural sources of radiation (Hughes, 1988).

Collective doses received during 1987 from consumption of fish and shellfish have been estimated for the UK and other European countries. In general, the method used has been to combine data on 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 of 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 1987 are preliminary, being based on landings statistics provided by the International Council for the Exploration of the Sea (ICES); where data are not yet available, the previous year's data have been used. The preliminary results will be reviewed in future reports as updated statistics are received. The results for 1985 and 1986, reported as preliminary in the previous report (Hunt, 1987), are now confirmed.

Liquid radioactive discharges from Sellafield up to the end of 1987 are the main source of collective dose reported here; by comparison, the effect of liquid discharges from other establishments is very small. The contribution due to fallout from the Chernobyl reactor accident in the Irish Sea, Scottish waters and the North Sea, has been included; this contribution for 1987 is estimated as about 10 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 30 man-Sv for the UK in 1987 represents a significant reduction as compared with 50 man-Sv reported for 1986. This reduction was mainly due to decreases in discharges from Sellafield; the contribution due to radioactivity from Chernobyl, which was mainly observed in fish from Scottish waters

Table 8 Collective doses from fish and shellfish, 1985 to 1987.

Population	Size of population	Collective committed effective dose equivalent, man-Sv		
		1985	1986	1987*
UK	5.6×10^7	50	50	30
Other European countries	6.5×10^8	80	90	60

*Preliminary data.

and the North Sea, also decreased. The preliminary result of 60 man-Sv for the collective dose to inhabitants of other countries in 1987 was also less than in 1986 (90 man-Sv), reflecting the reductions in discharges from Sellafield.

The collective dose for the UK, given in Table 8, may be compared on a *per caput* basis with the annual dose equivalent averaged over the population of 2.2 mSv due to natural background radiation (see sub-section 3.4) as a result of all waste management practices. In 1987, the UK collective dose through the fish and shellfish pathway as a result of liquid radioactive waste disposal operations amounted to less than 0.03% of this level.

It is clear from the statements above, which compare the 1986 and 1987 results for both critical group and collective dose rates, that an important factor determining exposures is the distribution of

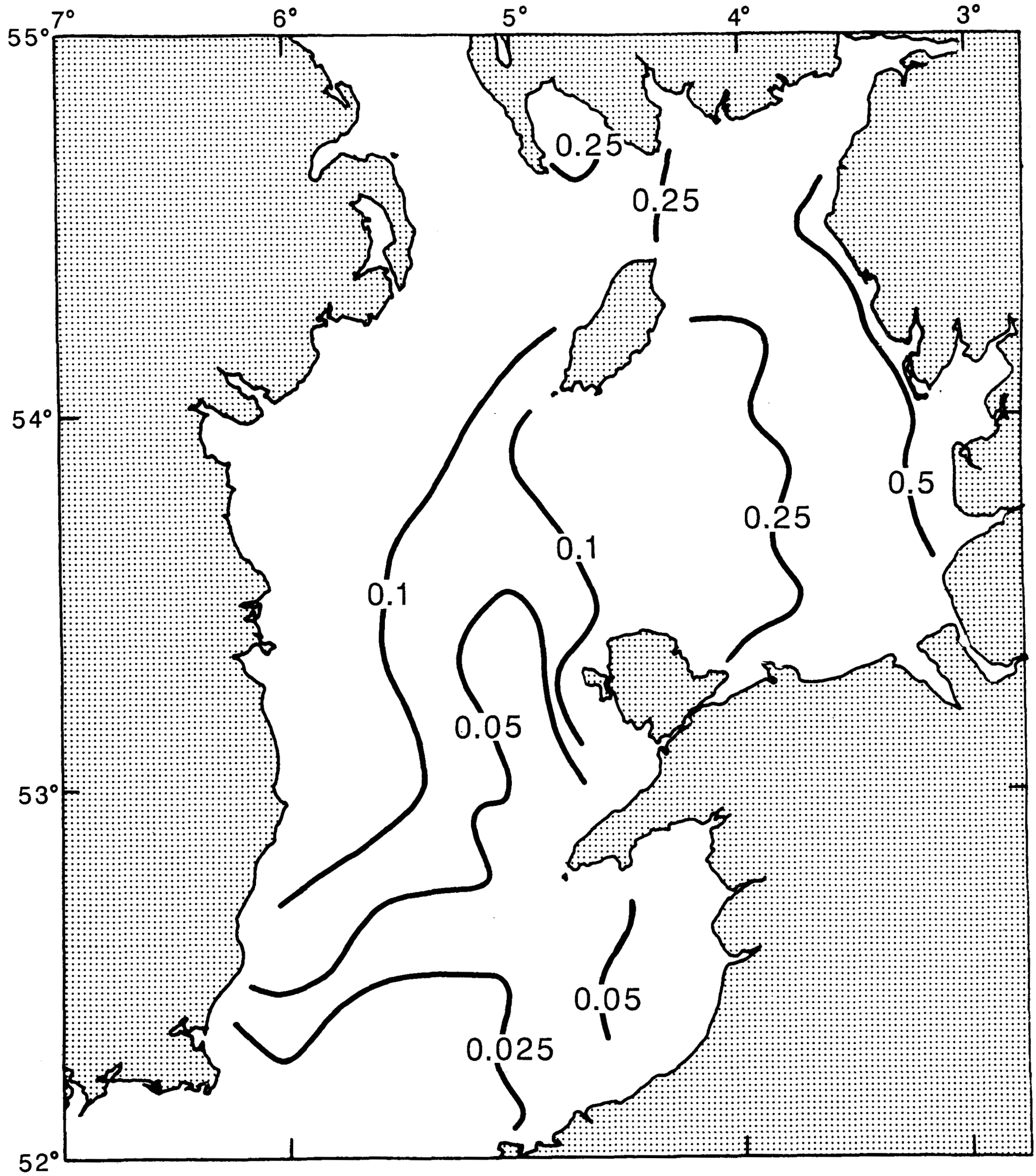


Figure 2 Concentration (Bq kg^{-1}) of caesium – 137 in filtered water from the Irish Sea, April 1987.

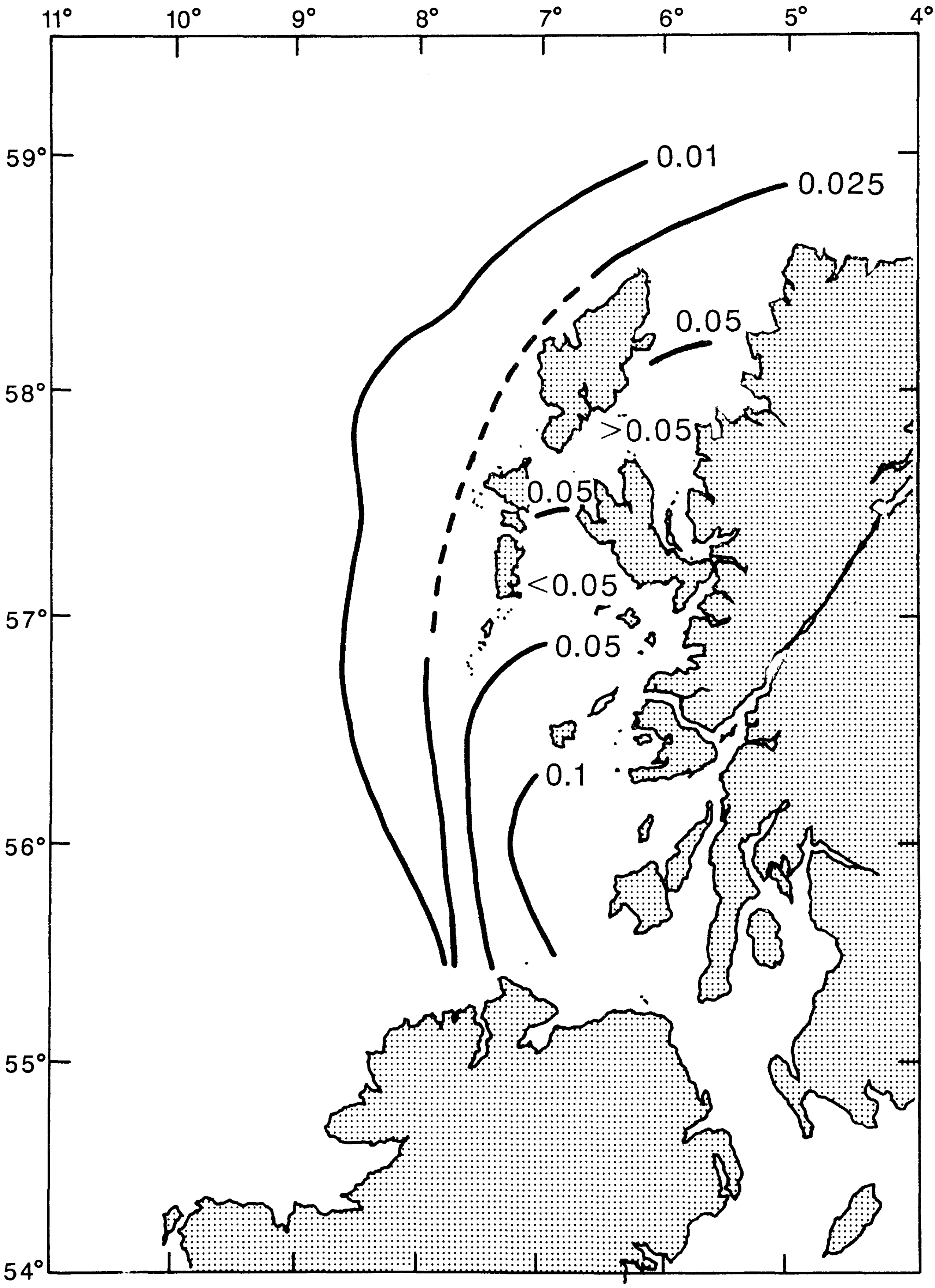


Figure 3 Concentration (Bq kg^{-1}) of caesium – 137 in filtered water from the west of Scotland, April 1987.

radioactivity in the marine environment. We maintain a continuing programme of research on marine behaviour and distributions (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 1987 is shown in Figure 2. Comparison with the data for April 1986 (Hunt, 1987) shows that concentrations of caesium-137 in sea water of the eastern Irish Sea have continued to decrease, reflecting the reductions in discharges from Sellafield since 1985, following operation of SIXEP. Our cruise programme in April 1987 included collection of data on the distribution of caesium-137 in sea water west of Scotland; the data are shown in Figure 3 and reflect the pattern expected due to Atlantic water off the continental shelf. Data for the North Sea during August and September 1987 are shown in Figure 4. Comparison with the distribution observed in August and September 1986 (Hunt, 1987) shows a general reduction in concentrations of caesium -137 in most areas of the North Sea. Some of this caesium-137 is due to the effect of fallout from Chernobyl (Mitchell and Steele, 1988).

We also regularly monitor radioactivity concentrations in sediments. This is both because of relevance to dose rates and in order to keep under review distributions of adsorbed radioactivity. Concentrations of beta/gamma radioactivity and transuranics, in most cases at the same locations as the dose rate measurements, are given in Table 10. Variations similar in cause to those of the dose rates are observed, and comparison with results for 1986 (Hunt, 1987) 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. The short-lived radionuclides due to fallout from Chernobyl, which were detected in 1986, had decayed to negligible levels in 1987; residual concentrations of ruthenium-103 (half-life $\simeq$ 40 d) were still observable in a few samples from the south-west coast of Scotland, but these were of negligible radiological significance. It is 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).

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 1m above ground level. Monitoring in Scotland is carried out on behalf of the departments of the Scottish Office. Dose rates on Irish Sea shorelines, near other nuclear establishments which reflect Sellafield discharges, are given later in this report (see sub-sections 4.2, 4.3, 4.4, 6.5, 6.11). Variations in sediment type account for the quite marked fluctuations in dose rate, superimposed on a general decrease with increasing distance from Sellafield. Dose rates over intertidal areas in 1987 showed general reductions as compared with 1986 (Hunt, 1987), particularly for locations in Scotland where contributions to dose rates in 1986 were due to the effects of short-lived fallout from Chernobyl, which had decayed to negligible levels in 1987.

To identify those members of the public subject to the highest external exposures, occupancies of different locations need to be considered. We keep under review the amounts of time spent by members of the public on intertidal areas of coastline bordering the north-east Irish Sea; activities leading to significant external exposures are sparse and our surveys cover a wide area including Cumbria, Lancashire and the north Solway coast. In west Cumbria, combining dose rates and occupancy times, it is still considered that those who occupy boats are representative of those who receive the highest external exposures. The maximum exposure, allowing for addition of dose due to other pathways such as fish consumption, would have been 0.11 mSv, as compared with 0.12 mSv reported for 1986 (Hunt, 1987). In the wider area including Cumbria, Lancashire and the north Solway coast, on the basis of dose rates and occupancy times, it is considered that persons who live on board boats in the Ribble estuary are representative of those who receive the highest external exposures from the effects of discharges from Sellafield (see sub-section 4.2). Taking account of the time that the boats are shielded from the mud by tidal effects and the shielding afforded by the boats themselves, their exposure in 1987 was equivalent to that from spending 2850 h year^{-1} over unshielded mud. Making an allowance for natural background, their external exposure in 1987 was 0.24 mSv. Additional exposure of these people, due to consumption of fish and shellfish and handling of fishing gear, is negligible. This exposure is within the ICRP-recommended principal dose limit of 1 mSv year^{-1} for members of the public.

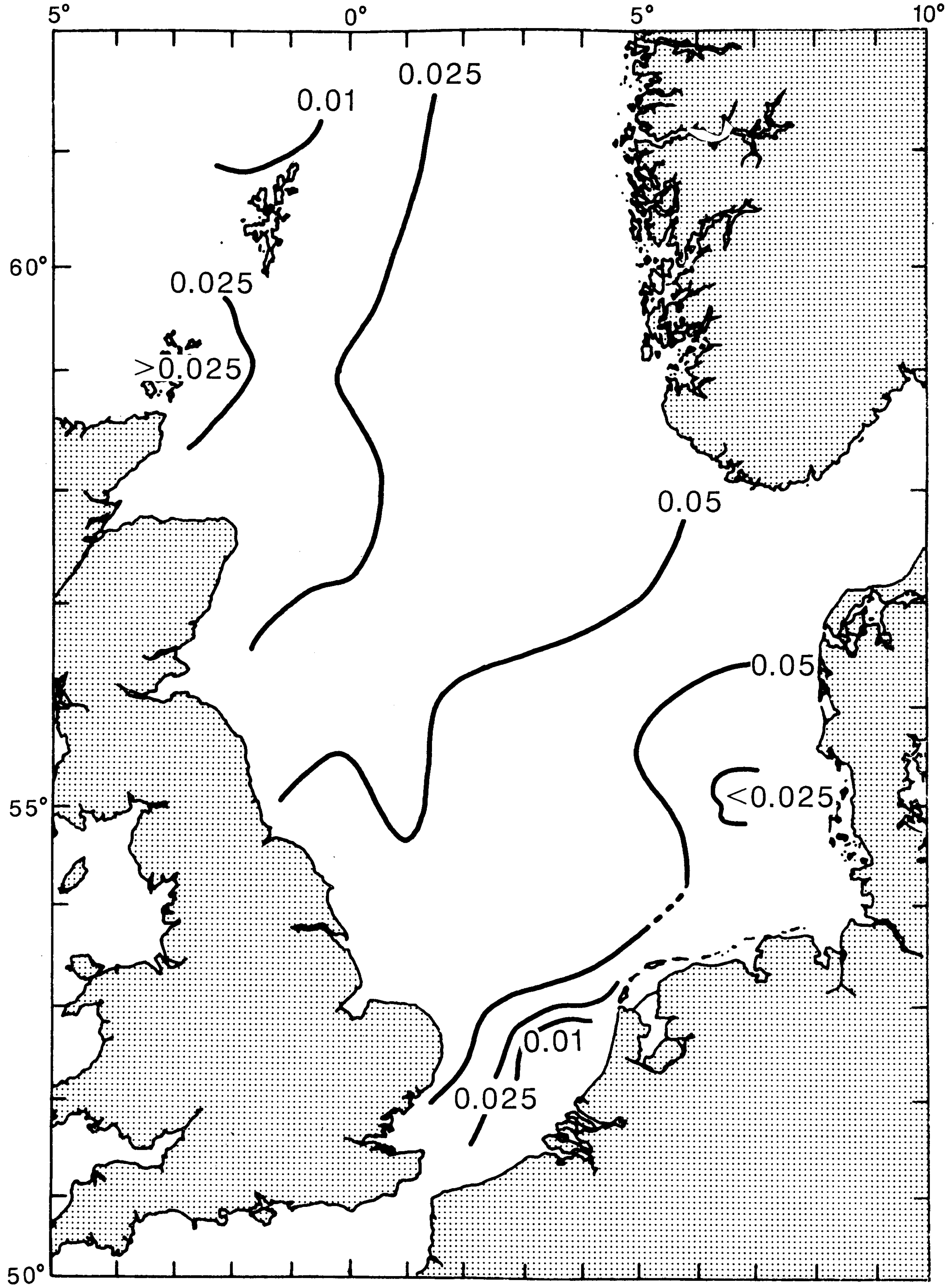


Figure 4 Concentration (Bq kg^{-1}) of caesium – 137 in filtered water from the North Sea, August – September 1987.

Table 9 Gamma radiation dose rates over intertidal areas of the Cumbrian coast and further afield, 1987.

Location	Ground type	No. of sampling observations†	Mean gamma dose rate in air at 1 m, μGy h^{-1}
Burgh Marsh	Salt marsh	4	0.11
Greenend	" "	4	0.12
"	Sand	4	0.096
Maryport harbour	Silt	4	0.27
" "	Dried silt	4	0.16
Workington harbour	Silt	4	0.23
Harrington harbour	"	4	0.23
Whitehaven outer harbour	"	12	0.22
" " "	Coal/sand	12	0.18
" inner "	Silt	12	0.30
Whitehaven yacht basin	Silt	12	0.45
St Bees	Sand	4	0.086
Nethertown winkle beds	Rock	4	0.14
Sellafield	Sand	5	0.11
Seascale	"	4	0.10
" - beach	"	4	0.095
Drigg	"	4	0.091
Kokoarrah rocks - bait digging area	Mussel bed	3	0.14
Ravenglass - salmon garth	Sand	12	0.12
" " "	Silt	12	0.23
" " "	Mussel bed	12	0.17
Ravenglass - boats area	Sand	4	0.087
" " "	Silt	12	0.20
Ravenglass - ford area	"	4	0.20
Ravenglass - Ravenvilla	"	12	0.28
" "	Salt marsh	12	0.51
Newbiggin	Silt	12	0.36
Newbiggin - west of bridge	Sand/silt	4	0.23
" " " "	Salt marsh	4	0.57
Haverigg	Sand	4	0.12
"	Silt	4	0.20
Millom	"	4	0.17
Walney Channel	Sand	2	0.16
" "	Silt	2	0.16
" Vickers shore	"	4	0.11
" west shore	Sand	4	0.079
Low Shaw	Salt marsh	4	0.18
Flookburgh	Sand	4	0.12
Skipool Creek	Silt	4	0.20
Lytham	"	5	0.19
Freckleton	"	5	0.19
Becconsall	"	6	0.17
Fleetwood	Sand	4	0.081
Blackpool	"	4	0.066
Ainsdale	"	4	0.067
New Brighton	"	4	0.078
Rock Ferry	Silt	4	0.15
Llandudno	Shingle	4	0.079
Prestatyn	"	4	0.056
Garlieston	Silt	4	0.12
Kippford - slipway	"	4	0.13
" - jetty	"	4	0.12
" - merse	Salt marsh	4	0.24
Palnackie harbour	Silt	4	0.18

†See sub-section 3.3 for definition.

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

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

Table 10 Radioactivity in sediment from the Cumbrian coast and further afield, 1987.

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	^{134}Cs	^{137}Cs
Maryport	(silt)	4	5 100	ND	26	96	ND	460	ND	15	42	2 700
Harrington	(")	4	4 300	1.9	39	410	"	890	"	27	45	1 300
Whitehaven	(")	4	7 500	ND	31	350	"	800	"	25	58	2 600
St Bees	(sand)	4	530	"	4.0	1.7	"	20	"	ND	1.9	130
Sellafield	(")	4	820	"	5.4	2.0	"	31	"	"	3.6	330
Seascale	(")	4	740	"	4.1	ND	"	22	"	"	2.6	270
Newbiggin	(silt)	4	4 200	1.5	59	200	"	1 200	"	35	32	1 500
Millom	(")	4	1 900	1.6	23	110	"	460	"	14	16	660
Walney Island	(")	4	1 400	0.4	9.9	41	"	210	"	8.5	9.9	480
Flookburgh	(sand)	4	860	ND	2.0	2.9	"	35	"	1.1	6.0	390
Heysham	(silt)	4	1 800	0.4	10	22	"	170	"	6.7	16	760
Sunderland Pt	(")	4	1 100	0.3	3.1	5.9	"	56	"	ND	8.9	420
Skipool Creek	(")	4	2 900	ND	8.9	ND	"	180	"	5.7	37	1 600
Fleetwood	(sand)	4	380	"	ND	"	"	ND	"	ND	1.2	51
Blackpool	(")	4	280	"	"	"	"	"	"	"	0.4	27
New Brighton	(")	4	300	"	"	"	"	"	"	"	0.7	27
Rock Ferry	(silt)	4	2 100	"	4.9	"	"	85	"	2.1	22	1 100
Garlieston	(silt)	4	1 800	0.4	11	20	1.4	250	0.9	6.6	38	600
Kippford slipway	(")	4	1 700	0.4	12	2.8	1.1	240	ND	4.0	22	670
" merse	(marsh)	4	4 000	0.8	22	16	ND	510	2.9	24	180	2 300
Palnackie	(silt)	4	2 600	1.2	17	31	1.5	340	1.0	9.3	41	1 000

Sampling point and sediment type		No. of sampling observations†	Mean radioactivity concentration (dry), Bq kg^{-1}								
			^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Maryport	(silt)	4	50	48	31	280	1 300	NA	1 800	ND	5.0
Harrington	(")	4	150	35	23	NA	NA	"	1 200	NA	NA
Whitehaven	(")	4	87	44	30	230	1 000	"	1 300	ND	4.3
St Bees	(sand)	4	0.9	5.4	3.1	NA	NA	"	140	NA	NA
Sellafield	(")	4	3.1	9.0	5.1	"	"	"	230	"	"
Seascale	(")	4	ND	7.4	5.5	"	"	"	230	"	"
Newbiggin	(silt)	4	130	65	41	310	1 300	25 000	1 700	ND	4.9
Millom	(")	4	51	19	14	NA	NA	NA	470	NA	NA
Walney Island	(")	4	17	14	10	"	"	"	400	"	"
Flookburgh	(sand)	4	1.2	2.3	3.2	"	"	"	84	"	"
Heysham	(silt)	4	6.4	7.6	6.0	38	190	"	240	ND	0.86
Sunderland Pt	(")	4	ND	2.9	1.0	NA	NA	"	87	NA	NA
Skipool Creek	(")	4	"	13	6.6	"	"	"	330	"	"
Fleetwood	(sand)	4	"	ND	0.3	"	"	"	12	"	"
Blackpool	(")	4	"	"	ND	"	"	"	4.0	"	"
New Brighton	(")	4	"	"	"	"	"	"	0.8	"	"
Rock Ferry	(silt)	4	"	1.5	4.8	"	"	"	210	"	"
Garlieston	(silt)	4	9.5	7.5	5.6	52	240	"	340	0.49	1.2
Kippford slipway	(")	4	13	13	7.3	68	300	"	360	0.85	0.88
" merse	(marsh)	4	21	29	16	140	600	"	780	1.3	2.4
Palnackie	(silt)	4	23	19	14	87	400	"	520	ND	1.9

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

exposed to external radiation, mainly to skin from beta particles. We regularly monitor fishing gear using portable beta dosemeters. Results for 1987 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 1987 would have been less than 0.1 mSv, well within 1% of the ICRP-recommended dose limit appropriate for exposures to skin of members of the public, based on non-stochastic effects (sub-section 3.4). Handling of fishing gear therefore continues to be a minor radiation exposure pathway.

4.1.4 Porphyra/laverbread pathway

No harvesting of *Porphyra* in the Sellafield vicinity for consumption after being made into laverbread was reported in 1987; 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 shorelines of the Irish Sea. Results of analyses for 1987 are presented in Table 12, and showed similar reductions to those observed in other materials as compared with results for 1986. Samples of laverbread from the major manufacturers are regularly collected from markets in South Wales and analysed. Results for

Table 11 Beta radiation dose rates on contact with fishing gear on vessels operating off Sellafield, 1987.

Vessel	Type of gear	No. of sampling observations†	Mean beta dose rate in tissue, $\mu Gy\ h^{-1}$
A	Nets	4	0.09
	Ropes	4	0.05
B	Nets	8	0.06
	Ropes	8	0.08
C	Nets	1	0.04
	Ropes	1	0.02
D	Nets	3	0.09
	Pots	4	0.12
E	Nets	4	0.10
	Gill nets	4	0.10
F	Nets	3	0.03
I	Nets	4	0.04
J	Nets	1	0.02
	Pots	2	0.04
K	Nets	5	0.12
	Pots	1	0.04
L	Nets	2	0.08
	Pots	1	0.06
M	Nets	4	0.05
	Ropes	4	0.04
N	Nets	4	0.04
	Pots	3	0.06
O	Nets	1	0.02

†See sub-section 3.3 for definition.

Table 12 Radioactivity in *Porphyra* from UK shorelines of the Irish Sea, 1987.

Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}									
		Total beta	^{54}Mn	^{60}Co	^{90}Sr	^{95}Zr + ^{95}Nb	^{99}Tc	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb
Braystones South	12	300	0.08	1.9	NA	12	NA	0.7	110	0.2	1.4
Seascale	52*	NA	ND	3.1	"	15	"	1.0	150	0.2	6.4
St Bees	4	270	0.05	1.3	0.72	11	1.3	0.1	53	ND	2.3
Knock Bay	4	220	ND	ND	NA	ND	NA	ND	3.3	"	ND

Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}									
		^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Braystones South	12	0.2	7.9	2.3	0.1	1.3	5.6	230	9.2	0.14	0.043
Seascale	52*	0.09	12	3.5	0.1	NA	NA	NA	16	NA	NA
St Bees	4	0.2	6.7	1.5	ND	1.4	6.0	"	11	ND	0.020
Knock Bay	4	0.06	2.5	ND	"	NA	NA	"	0.9	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.

1987 are presented in Table 13. The exposure of critical laverbread consumers was less than 0.01 mSv, confirming the virtual abeyance of this exposure pathway.

Table 13 Radioactivity in laverbread from South Wales, 1987.

Manufacturer	No. of sampling observa- tions†	Mean radioactivity concentration (wet), Bq kg^{-1}		
		Total beta	^{106}Ru	^{137}Cs
A	4	62	ND	0.4
C	4	58	2.0	0.8
D	4	48	1.0	0.8
E	1	120	ND	1.0

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

4.1.5 Contact dose-rate monitoring of intertidal areas

We regularly monitor contact beta and gamma dose rates in intertidal areas to locate and remove any material with unusual levels of contamination. A summary of items detected during 1987 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 with them. The appropriate standard with which to compare the dose rates is the ICRP-recommended dose limit of 50 mSv $year^{-1}$ for exposures to skin of members of the public (sub-section 3.4). It is not considered likely that anyone has received a dose to skin in excess of this limit.

Table 14 Summary of contact beta and gamma dose-rate monitoring of intertidal areas of Cumbria, 1987.

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	Braystones: 0.5
February	9	Drigg: 0.2
March	4	Sellafield: 1.3
April	2	Sellafield: 0.64
May	1	
June	0	
July	0	
August	0	Coulderton: 0.11
September	0	Eskmeals: 0.40
October	1	
November	0	
December	0	

4.1.6 Other surveys

In addition to the monitoring described above which is related to the more (or potentially more) significant radiation exposure pathways as a consequence of Sellafield discharges, we undertake a number of further investigations. Some of these are of a research nature; however, they also enable pathways of lower current importance to be kept under review.

Seaweeds are useful indicator materials; they may concentrate certain radionuclides so they greatly facilitate measurement and assist in the tracing of these radionuclides in the environment. Table 15 presents the results of measurements in 1987 on marine plants from shorelines of the Irish Sea and further afield. Small concentrations of radionuclides, partly attributable to the Chernobyl accident (e.g. silver-110m), were still evident. 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 radionuclides other than ruthenium-106; samples of *Fucus vesiculosus* are collected both in the Sellafield vicinity and further afield, and the results are presented here. Monitoring in Scotland is carried out on behalf of departments of the Scottish Office. Analyses of samples collected in Northern Ireland are carried out on behalf of the DOE(NI).

4.2 Springfields, Lancashire

This establishment is mainly concerned with manufacture of fuel elements for nuclear reactors and production of uranium hexafluoride. Radioactive waste arisings are of low radiological significance, consisting mainly of uranium and thorium and their decay products; liquid discharges are made by pipeline to the Ribble estuary. Public radiation exposure in this vicinity, as a result of these discharges, is very low; there is, however, a greater contribution due to Sellafield discharges. The critical pathway is external exposure, due to adsorption of radioactivity on the muddy areas of river banks. The amounts of time for which members of the public are subject to such exposure is kept under review. The critical group consists of people who live on houseboats moored in muddy creeks of the Ribble estuary, and is the same group which is affected by the discharges from Sellafield (sub-section 4.1.2). We regularly monitor dose rates in relevant areas including muddy creeks where houseboats are moored, and some of these measurements are supported by analyses of sediment. In 1987 we continued to investigate the fish and shellfish consumption pathway by analysing locally-obtained samples, including analyses for isotopes of thorium.

Table 15 Radioactivity in marine plants from shorelines of the Irish Sea and further afield, 1987.

Type of seaweed and sampling point	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}									
		Total beta	^{54}Mn	^{60}Co	^{90}Sr	^{95}Zr + ^{95}Nb	^{99}Tc	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs
Fucus vesiculosus											
Sellafield	4	1 600	0.8	19	7.6	19	2 000	30	5.1	4.3	1.4
St Bees	4	850	0.3	8.2	4.0	12	770	12	1.5	1.8	1.1
Heysham	4	390	ND	1.0	NA	ND	NA	0.6	ND	0.9	0.8
Port William	4	310	"	0.5	"	"	"	1.0	1.6	0.12	0.7
Garlieston	4	390	"	2.1	"	0.9	"	5.6	1.5	1.6	1.4
Auchencairn	4	430	"	2.0	"	ND	"	2.2	1.8	0.5	1.3
Ardglass	1	260	"	ND	"	"	"	ND	ND	ND	1.6
Portrush	4	240	"	"	"	"	"	"	1.1	"	0.19
Millisle	1	210	"	"	"	"	"	"	4.6	"	ND
Scilly Is	1	240	"	"	"	"	"	"	ND	"	0.14
Cape Wrath	1	260	"	"	"	"	"	"	0.8	"	ND
Fucus serratus											
St Bees	4	580	0.4	14	3.3	11	380	22	1.2	2.5	1.1
Fishguard	1	180	ND	ND	NA	ND	NA	ND	0.3	ND	0.19
Fucus spiralis											
St Bees	4	450	0.1	6.3	2.9	13	300	8.3	0.9	2.0	0.9
Laminaria											
St Bees	4	470	ND	0.5	2.0	9.4	180	17	1.3	0.9	0.8
Samphire											
Ravenglass	1	49	"	ND	NA	ND	NA	ND	ND	ND	ND
Heysham	1	61	"	0.1	"	"	"	1.2	"	"	0.3
Rhodymenia spp.											
St Bees	4	490	"	1.9	1.4	28	1.2	69	0.5	0.6	1.6
Millisle	4	690	"	ND	NA	ND	NA	ND	0.2	ND	0.7
Strangford Lough	1	530	"	"	"	"	"	4.1	1.5	"	1.0
Ascophyllum nodosum											
St Bees	4	930	"	4.4	2.2	9.2	950	11	0.9	2.4	0.7
Ardglass	1	240	"	0.1	NA	ND	NA	ND	ND	ND	0.2
Millisle	1	400	"	0.3	"	"	"	"	1.2	"	0.6
Chondrus crispus											
St Bees	4	270	0.11	2.0	2.7	18	1.2	30	0.7	0.3	0.7
Enteromorpha spp.											
St Bees	4	190	0.05	2.1	3.8	21	1.2	35	ND	0.4	1.1

Type of seaweed and sampling point	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}									
		^{137}Cs	^{144}Ce	^{147}Pm	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Fucus vesiculosus											
Sellafield	4	32	3.3	11	0.4	ND	6.7	27	12	0.11	0.031
St Bees	4	23	1.3	NA	ND	0.1	2.9	13	7.7	0.026	0.019
Heysham	4	30	ND	"	"	ND	0.64	2.9	1.5	ND	0.0043
Port William	4	10	"	"	"	"	NA	NA	0.7	NA	NA
Garlieston	4	23	"	"	"	0.1	"	"	7.1	"	"
Auchencairn	4	30	"	"	"	ND	"	"	4.5	"	"
Ardglass	1	6.9	"	"	"	"	"	"	ND	"	"
Portrush	4	1.8	"	"	"	"	"	"	"	"	"
Millisle	1	6.6	"	"	"	"	"	"	"	"	"
Scilly Is	1	0.4	"	"	"	"	"	"	"	"	"
Cape Wrath	1	1.2	"	"	"	"	"	"	"	"	"
Fucus serratus											
St Bees	4	21	1.1	"	"	"	4.0	18	7.6	0.030	0.028
Fishguard	1	0.8	ND	"	"	"	NA	NA	ND	NA	NA
Fucus spiralis											
St Bees	4	17	0.8	"	0.2	0.2	2.1	9.0	5.2	0.041	0.014
Laminaria											
St Bees	4	16	0.2	"	ND	ND	1.9	8.1	3.0	0.016	0.0091
Samphire											
Ravenglass	1	7.2	ND	"	"	"	NA	NA	2.2	NA	NA
Heysham	1	11	"	"	"	"	"	"	1.9	"	"
Rhodymenia spp.											
St Bees	4	32	5.1	"	0.4	0.4	2.9	12	15	0.11	0.055
Millisle	4	8.6	ND	"	ND	ND	0.10	0.48	0.48	ND	0.0009
Strangford Lough	1	11	"	"	"	"	NA	NA	ND	"	NA
Ascophyllum nodosum											
St Bees	4	16	0.3	"	0.3	"	2.5	10	4.2	0.012	0.0082
Ardglass	1	3.9	ND	"	ND	"	NA	NA	ND	NA	NA
Millisle	1	8.6	"	"	"	"	"	"	"	"	"
Chondrus crispus											
St Bees	4	30	4.9	"	0.3	0.5	2.1	8.4	15	0.082	0.038
Enteromorpha spp.											
St Bees	4	30	4.8	"	0.2	0.4	3.5	16	28	0.16	0.089

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

Table 16(a) Radioactivity in environmental materials near Springfields, 1987.

Material	Sampling point	No. of sampling observa- tions†	Mean radioactivity concentration (dry), Bq kg^{-1}									
			Total beta	^{60}Co	^{95}Zr + ^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu
Bass	Ribble estuary	1	200	ND	ND	ND	ND	1.4	39	ND	ND	ND
Grey mullet	" "	1	160	"	"	"	"	3.4	91	"	"	"
Sea trout	River Ribble	1	150	"	"	"	"	3.4	63	"	"	"
Shrimps	Ribble estuary	1	100	"	"	"	"	ND	15	"	"	"
Cockles	Lytham	1	120	"	"	"	"	"	17	"	"	"
Silt	Pipeline outlet	4	18 000	7.6	27	120	"	27	840	21	4.6	"
	Becconsall	4	13 000	8.8	11	170	10	34	1 300	23	11	"
	Skipool Creek	4	2 900	8.9	ND	180	5.7	37	1 600	ND	13	6.6
	Rock Ferry	4	2 100	4.9	"	85	2.1	22	1 100	"	1.5	4.8
	Penwortham	1	65 000	9.9	37	140	16	34	1 300	180	10	22
Sand	Lytham	1	650	1.4	ND	26	ND	6.0	230	ND	ND	ND

Material	Sampling point	No. of sampling observa- tions†	Mean radioactivity concentration (dry), Bq kg^{-1}								
			^{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	0.015	0.010	0.016	ND	NA	NA	ND	NA	NA
Grey mullet	" "	1	0.011	0.0069	0.0066	"	"	"	"	"	"
Sea trout	River Ribble	1	ND	ND	ND	"	"	"	"	"	"
Shrimps	Ribble estuary	1	0.027	0.073	0.0079	"	"	"	"	"	"
Cockles	Lytham	1	0.72	1.1	0.35	"	"	"	7.7	"	"
Silt	Pipeline outlet	4	110	900	160	110 000	34	160	230	1.9	1.1
	Becconsall	4	NA	NA	NA	44 000	NA	NA	560	NA	NA
	Skipool Creek	4	37	88	41	ND	"	"	330	"	"
	Rock Ferry	4	42	77	46	"	"	"	200	"	"
	Penwortham	1	NA	NA	NA	130 000	"	"	890	"	"
Sand	Lytham	1	20	39	23	ND	"	"	43	"	"

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

Table 16(b) Gamma dose rates in air at 1m over intertidal areas near Springfields, 1987.

Location	No. of sampling observa- tions†	μGy h^{-1}
Pipeline outlet	4	0.16
Freckleton	5	0.19
Becconsall	6	0.17
Lytham	5	0.19
Penwortham	1	0.11

†See sub-section 3.3 for definition.

Results for 1987 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. Exposure of the critical group of houseboat dwellers in 1987, including the Sellafield component, was about 0.24 mSv, a lower result than for 1986 (0.34 mSv), mainly due to decreased dose rates, following reduced discharges from Sellafield. The contribution due to Springfields discharges would have been a small fraction of the total. Exposures were within the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$ for members of the public. Concentrations of thorium in fish from the Ribble estuary were not significantly different from those expected from natural sources. Any exposures due to Springfields-derived radionuclides in shellfish would have been a small fraction of the total, most of which is due to Sellafield discharges, as considered in sub-section 4.1.1. The concentrations of thorium 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 enrichment of uranium. Radioactive waste arisings, mainly of uranium and its daughter products and technetium-99 from recycled fuel, are minor; the Works have authorisations to dispose of small amounts of radioactivity in liquid wastes to the Rivacre Brook and to the North Wirral sewage outfall at Meols. The radiological consequences of these disposals are negligible; moreover, no discharges from Capenhurst took place via Meols in 1987 (Table 1). However, we have established an environmental monitoring programme related to the pathways which could be of radiological significance; in 1987, this included monitoring the Rivacre Brook. Aquatic plants are also sampled as indicator materials. It is to be noted that the programme is much more extensive than is technically justified by the potential radiological hazard from Capenhurst discharges.

Results for 1987 are presented in Table 17. The concentrations of artificial radioactivity in marine samples are mainly due to Sellafield discharges and are consistent with values expected at this distance from Sellafield. Technetium-99 concentrations were low, reflecting in seaweeds the much reduced discharges of technetium-99 from Sellafield because decay-stored liquors were not being released. Exposure of potentially critical shellfish consumers in the vicinity of the Wirral in 1987 amounted to less than 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.

Table 17 Radioactivity in environmental materials in the vicinity of the Wirral, 1987.

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
			Total beta	^{60}Co	^{99}Tc	^{106}Ru	^{110m}Ag	^{125}Sb
Shrimps	Hoylake	2	55	ND	ND	ND	ND	ND
Cockles	Dee Estuary	2	84	"	1.9	"	"	"
Fucus spiralis	Hoylake	2	230	0.085	30	"	"	0.20
Fucus serratus	Little Orme	2	220	0.10	30	"	0.74	ND
Chlorophyceae	Rivacre Brook	1	310	0.41	77	3.1	ND	"
Silt	"	1	780	1.6	230	ND	"	"

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
			^{134}Cs	^{137}Cs	^{238}Pu	$^{239}Pu + {}^{240}Pu$	^{241}Am	$^{243}Cm + {}^{244}Cm$
Shrimps	Hoylake	2	0.33	8.3	NA	NA	ND	NA
Cockles	Dee Estuary	2	ND	6.5	0.22	1.1	2.3	0.0098
Fucus spiralis	Hoylake	2	0.77	21	NA	NA	1.7	NA
Fucus serratus			0.39	6.8	"	"	ND	"
Chlorophyceae	Rivacre Brook	1	1.3	7.6	"	"	1.9	"
Silt	"	2	11	28	"	"	ND	"

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

Table 18(a) Radioactivity in environmental materials in the vicinity of Chapelcross, 1987.

Material	Sampling point	No. of sampling observa-tions†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			Total beta	^{54}Mn	^{60}Co	^{95}Zr + ^{95}Nb	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs
Flounder	Seafield	4	210	ND	ND	ND	ND	ND	ND	3.6	99
Salmon	"	1	120	"	"	"	"	"	"	ND	1.1
Sea trout	"	2	180	"	"	"	"	"	"	0.9	23
Shrimps	"	4	100	"	"	"	"	2.4	"	0.7	30
Fucus spiralis	"	2	300	"	0.9	"	1.4	ND	"	1.1	62
Fucus vesiculosus	"	2	210	0.08	0.8	0.2	0.7	0.3	"	0.8	40
Silt	"	4	1200	0.3	6.9	15	130	ND	23	23	910
Sand	"	4	1100	ND	2.9	ND	41	"	ND	9.6	470

Material	Sampling point	No. of sampling observa-tions†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Flounder	Seafield	4	ND	ND	ND	NA	NA	ND	NA	NA
Salmon	"	1	"	"	"	"	"	"	"	"
Sea trout	"	2	"	"	"	0.0015	0.0069	0.10	ND	ND
Shrimps	"	4	"	"	"	NA	NA	ND	NA	NA
Fucus spiralis	"	2	"	"	0.2	0.74	3.4	3.8	ND	0.022
Fucus vesiculosus	"	2	"	"	ND					
Silt	"	4	6.9	6.2	3.9	33	150	200	0.34	0.54
Sand	"	4	ND	4.2	2.1	13	59	76	ND	0.23

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, 1987.

Location and sediment type	No. of sampling observa-tions†	μGy h^{-1}
Seafield (silt)	4	0.12
Seafield (merse)	4	0.13
Browhouses (silt)	5	0.12
Dornoch Brow (silt)	5	0.11
Dornoch Brow (merse)	4	0.13

†See sub-section 3.3 for definition.

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 radioactivity in liquid discharges in 1987 was greater than in 1986 mainly because of pond cleaning operations as in some previous years, but discharges were still well within authorised limits. There are two pathways leading to public radiation exposures which are of potential importance. These are internal irradiation from consumption of locally-caught fish and shellfish and external exposure from use of intertidal areas by fishermen and turf cutters; fishermen continue to constitute the critical group in view of their regular occupancy of intertidal areas and consumption of local seafood. Our monitoring, which is carried out on behalf of departments of the Scottish Office, continued to reflect these pathways. Samples of *Fucus* seaweeds, as a useful indicator, are also analysed. The results of monitoring in 1987 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 nuclides given in Table 18(a) are consistent with values expected at this distance from Sellafield. Radiocaesium concentrations in 1987 were generally less than those in 1986, reflecting reductions in Sellafield discharges. Exposure of the critical group in 1987, making the maximising assumption of additivity of the two pathways, 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 (UKAEA)

We have continued our regular monitoring of the environmental impact of liquid radioactive discharges from the Atomic Energy Establishment, Winfrith and from the Dounreay Nuclear Power Development Establishment. Liquid radioactive wastes also arise at the UKAEA Harwell Laboratory. In common with such wastes from other nuclear establishments in the Thames Valley area, these are discharged into the River Thames catchment; whilst the critical exposure pathway is likely to be from drinking water, and monitoring is carried out by the DOE (DOE, 1988), we have begun a small programme of monitoring of fish and other aquatic materials, and the results are presented in this section.

5.1 Harwell Laboratory, Oxfordshire

At this establishment the UKAEA operates research facilities, including low-power nuclear reactors. Liquid radioactive waste arisings are small and discharges are made under authorisation to the River Thames at Sutton Courtenay. The critical exposure pathway is likely to be from drinking water, as stated above. However, in 1987 we began a small programme of monitoring of fish and other aquatic materials from the Thames catchment in surveillance of fisheries-related exposure pathways. This included monitoring at locations remote from nuclear establishments and upstream of them (e.g. at Donnington on the River Lambourn). Analyses were carried out of available fish species, with *Nuphar lutea* (yellow water lily), *Ranunculus penicillatus* (water crowfoot) and sediments as indicator materials.

The results of this monitoring are shown in Table 19. The concentrations of artificial radioactivity detected were very low. At remote upstream locations these would have been solely due to weapons-test fallout and/or the accident at Chernobyl. Concentrations of some nuclides, most notably caesium-137, were slightly enhanced close to the outfall, but concentrations of plutonium were not significantly different from the level expected due to fallout. The effect of the

Table 19 Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Harwell, 1987.

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
			Total beta	^{60}Co	^{134}Cs	^{137}Cs	^{239}Pu + ^{240}Pu	^{241}Am
Chub	Sutton Courtenay	1	130	ND	ND	2.7	0.00023	0.00024
	Marlow	2	100	"	0.16	0.8	NA	ND
	Staines	2	100	"	ND	0.6	0.00077	0.0011
Perch	Sutton Courtenay	1	150	"	"	7.8	NA	ND
Roach	" "	1	120	"	"	3.9	"	"
Grayling	Donnington (R. Lambourn)	1	97	"	"	0.3	"	"
Nuphar lutea	Sutton Courtenay	1	50	0.6	"	0.9	"	"
	Marlow	1	47	ND	"	0.6	"	"
	Staines	1	40	"	"	0.5	"	"
Ranunculus penicillatus	Donnington (R. Lambourn)	1	56	"	"	ND	"	"
Sediment	Sutton Courtenay	1	400	1.6	"	12	"	"
	Marlow	1	85	ND	1.0	5.4	"	"
	Staines	1	220	1.3	1.2	31	"	"
	Donnington (R. Lambourn)	1	230	ND	ND	13	"	"

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

discharge was of very low radiological significance: if any fish were eaten even at rates typical of enthusiastic trout consumers, the radiation dose in 1987, including that due to occupancy of the river bank near the outfall for times typical of enthusiastic anglers, would have been less than 0.01 mSv, or less than 1% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$.

5.2 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 in these wastes (Table 1) is due to tritium from the moderator and coolant, but small amounts of activation products, including manganese-54, cobalt-60 and zinc-65, are removed during decontamination of the reactor pressure circuit. These wastes are disposed of under authorisation to deep water in Weymouth Bay. Their radiological significance is small and mainly due to the activation products rather than to tritium. Reconcentration of activation products by shellfish, followed by local consumption, constitutes the critical exposure pathway; this is reflected in our monitoring programme. External gamma radiation dose rates are monitored at Kimmeridge and in Poole Harbour where the inter-tidal sediment 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 20.

The impact of Winfrith discharges, as in previous years, was mainly observed in the concentrations of activation products. The slightly greater concentration of zinc-65 in crabs, as compared with 1986, may have been contributed to by an increase, well within authorised limits, in discharges of this nuclide. Further information on the consumption rates of fish and shellfish eaters became available for 1987. The radiation dose to the critical group was about 0.11 mSv, or 11% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$. External gamma radiation dose rates continued to be indistinguishable from those of the natural background.

5.3 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 1987, discharges of total activity from DNPDE were slightly more than in 1986 reflecting the campaigns of reprocessing of reactor fuel. However, releases of alpha activity were reduced, and all discharges remained well within authorised limits. Our surveys near Dounreay are carried out on behalf of departments of the Scottish Office. Monitoring in 1987 continued to increase, including sampling of fish from the area of the Dounreay outfall and other materials further afield, with associated gamma dose rate measurements. The results are presented in Table 21.

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 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 1987 has confirmed that the exposure of these fishermen remained low, at less than 0.1 mSv or less than 1% of the ICRP-recommended dose limit of 50 mSv $year^{-1}$ for skin exposures (see sub-section 3.4).

The second potentially critical pathway arises also from the uptake of radioactivity by particulate material which accumulates in rocky areas of the foreshore and presents a potential source of exposure, mainly to gamma radiation, of those who visit these areas. In 1987 we carried out monitoring of sludge and seaweed at Oigin's Geo; concentrations of radioactivity were consistent with levels expected in these materials. We also carried out measurements of gamma dose rates above areas of the foreshore. Public radiation exposure via this pathway also remained low, at less than 0.01 mSv or less than 1% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$.

The third potentially critical pathway involves internal exposure of consumers of locally-collected fish and shellfish; we sample fish, crabs and lobsters from the outfall area and winkles from Sandside Bay to enable this pathway to be kept under review. Additionally, as in previous years, limpets and seaweed were sampled as indicator materials. Radiocaesium concentrations are mainly due to discharges from Sellafield. Other radionuclides detected, including transuranics, mainly reflect Dounreay discharges. The radiological significance of fish and shellfish consumption continued to be low: for high-rate consumers the radiation dose was less than 0.02 mSv or 2% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$.

Table 20 Radioactivity in environmental materials from the vicinity of Winfrith, 1987.

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, $Bq\ kg^{-1}$									
			Total beta	^{54}Mn	^{58}Co	^{59}Fe	^{60}Co	^{65}Zn	^{106}Ru	^{110m}Ag	^{125}Sb	^{131}I
Plaice	Weymouth Bay	1	67	ND	ND	ND	ND	8.6	ND	ND	ND	ND
Pout whiting	Weymouth Bay	1	110	0.4	"	"	0.4	18	"	"	"	"
Crabs	Weymouth Bay	8	110	4.8	4.3	2.2	27	290	"	0.2	"	"
	Studland	1	130	2.6	2.1	ND	16	150	"	ND	"	"
Lobsters	Weymouth Bay	2	110	2.9	4.9	"	25	170	"	"	"	"
Oysters	Poole	2	74	ND	ND	"	1.6	66	"	"	"	"
Cockles	Poole	2	65	"	1.3	"	24	7.0	"	"	"	"
Clams	Poole	1	59	0.4	ND	"	4.4	5.5	"	"	"	"
Scallops	Weymouth Bay	3	120	35	1.0	"	12	180	"	"	"	"
Whelks	Weymouth Bay	4	140	3.4	2.1	0.5	29	430	"	"	"	"
Squid	Portland	1	85	ND	ND	ND	0.2	19	"	"	"	"
Fucus serratus	Arish Mell	1	160	80	60	"	330	210	"	"	"	"
	Kimmeridge	2	260	46	39	"	140	74	"	"	"	"
	Swanage	2	300	15	20	"	97	56	"	"	"	"
	Hengistbury Head	2	210	3.3	5.0	"	32	12	"	"	"	"
	Bognor Regis	2	250	0.4	ND	"	12	0.8	2.1	"	"	"
	Sandgate	2	320	0.2	"	"	14	0.8	1.4	"	"	"
	Weymouth	2	240	15	17	"	72	31	ND	"	"	"
	Chesil	2	210	0.1	0.4	"	4.1	1.4	"	"	"	"
	Lyme Regis	2	230	ND	0.2	"	2.6	0.3	"	"	"	1.5
Silt	Kimmeridge	2	560	5.6	14	"	86	82	"	"	"	ND
	Poole Harbour	2	410	5.4	1.5	"	44	3.2	"	"	"	"
	Calshot	2	710	ND	ND	"	35	2.9	"	"	"	"
	Hardway	2	740	2.9	"	"	29	4.8	11	"	1.5	"
	Littlehampton	2	600	2.3	"	"	26	1.5	12	"	2.3	"
	Rye Harbour	2	730	2.3	"	"	23	ND	28	"	1.9	"

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, $Bq\ kg^{-1}$							
			^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm + ^{244}Cm$
Plaice	Weymouth Bay	1	ND	0.9	ND	NA	NA	ND	NA	NA
Pout whiting	Weymouth Bay	1	"	0.4	"	"	"	"	"	"
Crabs	Weymouth Bay	8	"	ND	"	"	"	"	"	"
	Studland	1	"	"	"	"	"	"	"	"
Lobsters	Weymouth Bay	2	"	0.4	"	"	"	"	"	"
Oysters	Poole	2	"	ND	"	"	"	"	"	"
Cockles	Poole	2	"	"	"	"	"	"	"	"
Clams	Poole	1	"	"	"	"	"	"	"	"
Scallops	Weymouth Bay	3	"	"	"	0.0027	0.0089	0.0028	ND	ND
Whelks	Weymouth Bay	4	"	"	"	NA	NA	ND	NA	NA
Squid	Portland	1	"	0.1	"	"	"	"	"	"
Fucus serratus	Arish Mell	1	"	ND	"	"	"	"	"	"
	Kimmeridge	2	"	"	"	"	"	"	"	"
	Swanage	2	"	"	"	"	"	"	"	"
	Hengistbury Head	2	"	0.1	"	"	"	"	"	"
	Bognor Regis	2	"	0.3	"	"	"	"	"	"
	Sandgate	2	"	0.4	"	"	"	"	"	"
	Weymouth	2	"	ND	"	"	"	"	"	"
	Chesil	2	"	0.2	"	"	"	"	"	"
	Lyme Regis	2	"	0.2	"	"	"	"	"	"
Silt	Kimmeridge	2	"	3.3	"	"	"	"	"	"
	Poole Harbour	2	"	6.8	"	0.24	1.1	0.72	ND	0.019
	Calshot	2	"	7.2	1.1	NA	NA	ND	NA	NA
	Hardway	2	1.1	5.9	ND	"	"	"	"	"
	Littlehampton	2	0.7	7.3	1.2	"	"	"	"	"
	Rye Harbour	2	1.3	6.3	ND	0.24	0.88	0.63	0.0096	0.071

Mean gamma dose rate in air at 1 m over intertidal sediments:
Poole Harbour (2 sampling observations†): 0.073 $\mu Gy\ h^{-1}$
Kimmeridge (2 sampling observations†): 0.084 $\mu Gy\ h^{-1}$

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

Table 21 Radioactivity in environmental materials from the vicinity of Dounreay, 1987.

Sampling point and material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1} Total beta	^{54}Mn	^{58}Co	^{60}Co	^{95}Zr + ^{95}Nb	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs
Area of outfall												
Cod	4	130	ND	ND	ND	ND	ND	ND	ND	ND	1.1	7.4
Crabs	5	87	"	"	0.6	"	"	2.5	15	0.2	0.2	1.4
Lobsters	4	120	"	"	1.4	"	"	14	58	ND	0.4	2.4
Sandside Bay												
Winkles	4	160	"	"	4.5	"	"	42	130	"	ND	1.3
Limpets	4	170	"	"	4.3	"	0.3	41	57	"	"	1.0
Fucus vesiculosus	3	420	2.5	"	6.9	4.8	ND	12	17	"	0.8	4.2
Fucus serratus	4	300	2.0	"	7.7	1.4	"	9.4	13	"	0.5	3.4
Shell sand	4	360	ND	"	1.6	ND	"	6.8	ND	"	0.7	9.0
Oigins Geo												
Enteromorpha spp	1	1500	59	1.4	72	9.5	"	320	41	6.0	2.5	8.1
Sludge	4	11000	71	2.9	190	2500	"	3900	1400	210	140	640
Brims Ness												
Limpets	4	160	ND	ND	5.4	2.1	"	37	62	ND	ND	0.3
Fucus vesiculosus	1	340	3.1	"	4.6	12	"	9.1	30	"	0.2	2.0
Fucus serratus	3	350	2.9	0.1	11	ND	"	6.3	15	"	0.8	3.1

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										
Cod	4	ND	ND	ND	0.0002	0.0006	NA	0.0011	0.0006	0.00003
Crabs	5	0.7	"	"	0.011	0.028	0.47	0.23	0.13	0.0082
Lobsters	4	ND	"	"	0.033	0.085	1.5	0.31	0.27	0.015
Sandside Bay										
Winkles	4	3.8	"	"	0.17	0.40	7.1	0.80	0.34	0.027
Limpets	4	6.6	"	0.5	0.25	0.63	11	1.4	0.86	0.045
Fucus vesiculosus	3	4.3	"	ND	NA	NA	NA	ND	NA	NA
Fucus serratus	4	3.7	"	0.2	"	"	"	"	"	"
Shell sand	4	9.0	4.5	6.1	5.9	22	240	24	1.6	0.46
Oigins Geo										
Enteromorpha spp.	1	310	10	25	NA	NA	NA	36	NA	NA
Sludge	4	2700	120	300	240	490	9000	540	460	24
Brims Ness										
Limpets	4	6.9	ND	0.5	NA	NA	NA	ND	NA	NA
Fucus vesiculosus	1	2.9	"	ND	"	"	"	"	"	"
Fucus serratus	3	2.9	"	0.2	"	"	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediment:
Sandside Bay (2 sampling observations†): 0.09 μGy h^{-1}
Oigins Geo (4 sampling observations†): 0.17 μGy h^{-1}

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

6. Nuclear power stations operated by the electricity boards

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

6.1 Berkeley, Gloucestershire and Oldbury, Avon

Liquid radioactive wastes from both of these stations are generally similar in composition and are discharged to the same stretch of the Severn Estuary. The stations are therefore considered together for the purpose of our environmental monitoring. The two potentially critical pathways for public radiation exposure are internal irradiation following consumption of locally-caught fish and shellfish, and external exposure from occupancy of muddy intertidal areas. We therefore analyse samples of fish and shellfish and monitor gamma dose rates over silt. In addition, measurements of external exposure are supported by analyses of intertidal mud, and *Fucus vesiculosus* is collected as an indicator material.

Data for 1987 are presented in Table 22. The only artificial radioactivity detected in fish and shellfish was due to radiocaesium and carbon-14. Concentrations of these radionuclides represent the combined effect of discharges from the stations, other nuclear establishments discharging into the Bristol Channel, fallout, and possibly include a small Sellafield-derived component. Apportionment is difficult at the low levels detected. Radiation exposure of the critical group of fish and shellfish consumers was very low, at less than 0.003 mSv or 0.3% 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. 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. Gamma dose rate measurements are supported by analyses of intertidal sediment, and *Fucus vesiculosus* is analysed as an indicator material.

Measurements for 1987 are summarised in Table 23. In fish and shellfish, artificial radioactivity was detected due to the combined effects of discharges from the station, Sellafield discharges, and fallout. During 1986, the Water Research Centre carried out, under authorisation, an offshore tracer test to investigate dispersion of sewage sludge; this test used silver-110m and may have contributed to the measured concentrations of this nuclide, but silver-110m was also characteristic of the fallout from Chernobyl. Apportionment of the effects of all these sources is difficult because of the low levels detected. The overall dose to members of the critical group of fish and shellfish consumers was low, totalling about 0.01 mSv or 1% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}. Concentrations of artificial radionuclides detected in sediment 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 advanced gas-cooled reactors (AGRs). Discharges from both "A" and "B" stations are made via the same outfall and for the purposes of our environmental monitoring are considered together. There are two potentially critical radiation exposure pathways as a result of liquid radioactive waste discharges: internal irradiation due to consumption of locally-caught fish and shellfish, and external exposure from occupancy of

Table 22 Radioactivity in environmental materials and gamma dose rates near Berkeley and Oldbury nuclear power stations, 1987.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}										
		Total beta	^{14}C	^{95}Zr + ^{95}Nb	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Bass	1	120	96	ND	0.7	3.7	ND	NA	NA	ND	NA	NA
Flounders	2	98	NA	"	0.3	1.3	"	"	"	"	"	"
Grey mullet	2	130	"	"	ND	1.7	"	"	"	"	"	"
Eels	2	75	"	"	"	0.4	"	"	"	"	"	"
Shrimps	2	91	"	"	0.1	1.1	"	"	"	"	"	"
Fucus vesiculosus	2	190	"	"	ND	1.2	"	"	"	"	"	"
Mud: area of outfalls	4	820	"	0.8	2.3	41	0.5	"	"	"	"	"
Lydney	2	810	"	ND	2.4	47	ND	0.15	0.78	0.62	0.046	0.048

Mean gamma dose rate in air at 1 m over intertidal mud (10 sampling observations†): 0.083 μGy h^{-1}

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

Table 23 Radioactivity in environmental materials and gamma dose rates near Bradwell nuclear power station, 1987.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{106}Ru	^{110m}Ag	^{125}Sb
Mixed fish	7	130	ND	ND	ND	ND	ND	ND
Oysters	2	95	"	0.5	19	7.2	29	"
Whelks	1	98	"	ND	ND	ND	7.9	"
Fucus vesiculosus	2	290	"	1.0	"	"	1.1	"
Sediment	8	890	0.4	8.0	"	19	2.0	3.2

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{243}Cm + ^{244}Cm
Mixed fish	7	0.4	4.0	ND	NA	NA	ND	NA
Oysters	2	ND	1.0	"	0.0012	0.0050	0.010	0.00034
Whelks	1	"	ND	"	NA	NA	ND	NA
Fucus vesiculosus	2	0.3	3.3	"	"	"	"	"
Sediment	8	5.3	59	0.9	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediments (7 sampling observations†): 0.063 μGy h^{-1}

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

the foreshore. Our monitoring programme therefore includes analyses of fish and shellfish and gamma dose rate surveys of the intertidal areas. Samples of sediment are also collected and analysed. Seaweed has been analysed as an indicator material. The results for 1987 are given in Table 24.

Concentrations of radiocaesium are attributable to discharges from the station and from Sellafield, with a small contribution due to weapons-test fallout and perhaps from the Chernobyl accident. Apportionment is difficult at these low levels. Trace levels of manganese-54, cobalt-60 and zinc-65 in some materials are likely to be due mainly to discharges from AEE Winfrith rather than to Dungeness, as demonstrated by the indicator sampling programme described in sub-section 5.2. Trace amounts of ruthenium-106 were also detected in 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 concentrations of transuranics in silt were similar to levels observed at other sites remote from Sellafield. Our review of exposure pathways confirmed that the critical group are local fish and shellfish consumers, and their exposure during 1987 was very low, at less than 0.004 mSv or 0.4% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$. Gamma dose rates over intertidal sediments were indistinguishable from natural background.

6.4 Hartlepool, Cleveland

This station is powered by twin AGRs. Discharges of liquid radioactive wastes are made under authorisation to the North Sea. Potentially critical pathways for radiation exposure of the public near the station are internal irradiation following consumption of local fish and shellfish and external exposure from occupancy 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 1987 are shown in Table 25. Concentrations of radiocaesium and transuranics were mainly due to discharges from Sellafield and to fallout including, for radiocaesuim, a contribution due to the Chernobyl

Table 24 Radioactivity in environmental materials and gamma dose rates near Dungeness nuclear power station, 1987.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}												
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Cod	2	110	ND	ND	ND	ND	ND	0.2	1.9	NA	NA	ND	NA	NA
Dab	2	120	"	"	0.1	"	"	0.1	1.1	"	"	"	"	"
Flounder	1	99	"	"	ND	"	"	0.4	2.1	"	"	"	"	"
Plaice	3	120	"	"	0.1	"	"	0.3	0.7	"	"	"	"	"
Shrimps	2	98	"	0.4	0.7	"	"	ND	ND	"	"	"	"	"
Cockles	2	78	"	7.9	0.9	4.0	"	"	0.3	"	"	"	"	"
Scallops	1	93	0.6	1.4	9.0	ND	"	"	0.2	"	"	"	"	"
Whelks	1	110	ND	3.5	3.1	"	"	"	ND	"	"	"	"	"
Fucus serratus	2	32	0.2	14	0.8	1.4	"	"	0.4	"	"	"	"	"
Sand	3	200	ND	2.0	ND	ND	"	"	0.9	"	"	"	"	"
Silt	2	730	2.3	23	"	28	1.9	1.3	6.3	0.24	0.88	0.63	0.0096	0.71

Mean gamma dose rate in air at 1 m over intertidal sand (6 sampling observations†): 0.055 μGy h^{-1}
Mean gamma dose rate in air at 1 m over intertidal silt in Rye Harbour (2 sampling observations†): 0.074 μGy h^{-1}

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

Table 25 Radioactivity in environmental materials and gamma dose rates near Hartlepool nuclear power station, 1987.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}									
		Total beta	^{54}Mn	^{110m}Ag	^{134}Cs	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Cod	2	140	ND	ND	0.5	5.2	0.00013	0.00060	0.00051	ND	ND
Plaice	2	97	"	"	0.2	2.4	NA	NA	ND	NA	NA
Haddock	1	120	"	"	ND	2.2	"	"	"	"	"
Mackerel	1	140	"	"	0.5	3.7	"	"	"	"	"
Whiting	1	120	"	"	0.7	5.4	"	"	"	"	"
Crabs	4	72	"	2.8	ND	0.9	0.00064	0.0030	0.0030	ND	ND
Winkles	2	99	"	ND	"	1.8	NA	NA	ND	NA	NA
Fucus vesiculosus	2	310	"	"	0.3	2.2	"	"	"	"	"
Sand/coal	2	320	"	"	1.1	6.8	"	"	"	"	"
Silt	2	1000	0.5	"	6.0	65	"	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediment (6 sampling observations†): 0.078 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.

accident. The radiation exposure of the critical group of local fish and shellfish consumers was low, at less than 0.01 mSv or 1% of the ICRP-recommended principal dose limit of 1 mSv year[1]. Gamma radiation dose rates over intertidal sediments continued to be indistinguishable from natural background.

6.5 Heysham, Lancashire

This establishment comprises two, essentially separate, nuclear power stations both powered by AGRs. The first station came into operation in 1983; the second has commenced operation during 1988, and no discharges were made during 1987. Discharges of liquid radioactive waste from both stations are made under authorisation to Morecambe Bay via the adjacent outfalls, and for the purposes of our environmental monitoring will be considered together. The potentially critical radiation exposure pathways are due to internal irradiation following consumption of locally-caught fish and shellfish and external exposure from occupancy of intertidal areas. Our monitoring programme includes analyses of fish and shellfish and measurements of gamma dose rates over intertidal areas. Samples of sediment are also analysed, and *Fucus vesiculosus* is monitored as an indicator material. Samphire is also collected and analysed because of its use as a foodstuff.

The results for 1987 are given in Table 26. These mainly reflect discharges from Sellafield; the effect of discharges from Heysham was not detectable above this background. The radiation exposure in 1987 of members of the critical group of fish and shellfish consumers in the Morecambe Bay area was about 0.12

Table 26 Radioactivity in environmental materials and gamma dose rates near Heysham nuclear power station, 1987.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{54}Mn	^{60}Co	^{95}Zr + ^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
Plaice	4	120	ND	ND	ND	ND	ND	0.82	23	ND
Bass	1	200	"	"	"	"	"	3.5	94	"
Whitebait	1	130	"	"	"	"	"	1.7	39	"
Cockles	4	130	"	4.0	"	17	"	0.44	19	"
Mussels	4	87	"	ND	"	9.2	"	ND	8.7	"
Fucus vesiculosus	4	390	"	1.0	"	0.6	88	0.77	30	"
Samphire	1	61	"	0.1	"	1.2	ND	0.3	11	"
Sediment:										
Sunderland Point	4	1100	0.3	3.1	5.9	56	"	8.9	420	"
Half Moon Bay	4	1800	0.4	10	22	170	6.7	16	760	6.4

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Plaice	4	ND	ND	NA	NA	ND	NA	NA
Bass	1	"	"	"	"	"	"	"
Whitebait	1	"	"	0.055	0.27	0.34	ND	0.0015
Cockles	4	"	0.2	1.05	4.97	11.1	"	0.035
Mussels	4	"	ND	0.45	2.1	3.1	"	0.0088
Fucus vesiculosus	4	"	"	0.641	2.9	1.5	"	0.0043
Samphire	1	"	"	NA	NA	1.9	NA	NA
Sediment:								
Sunderland Point	4	2.9	1.0	"	"	87	"	"
Half Moon Bay	4	7.6	6.0	38	185	244	ND	0.86

Mean gamma dose rate in air at 1 m over intertidal sediment:
Heysham vicinity (24 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.

mSv, as given in sub-section 4.1.1. External exposure of members of the public was less than 0.1 mSv. Both of these exposures are within the ICRP-recommended principal dose limit of 1 mSv year^{-1}. Concentrations of radioactivity in samphire were of negligible radiological significance.

6.6 Hinkley Point, Somerset

At this establishment there are two essentially separate "A" and "B" nuclear power stations; the "A" station is powered by magnox-type reactors and the "B" station by AGRs. Liquid radioactive waste discharges are made via the same outfall and for the purposes of our environmental monitoring they are considered together. 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 (Doddington *et al.*, 1988). 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 material.

The results for 1987, presented in Table 27, indicate concentrations of radionuclides representing the combined effect of releases from the station, from other establishments which discharge to the Bristol Channel, from Sellafield, and from fallout. Apportionment is difficult at the low levels detected. The radiation exposure of high-rate fish and shellfish consumers was low, at less that 0.003 mSv or 0.3% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}. The concentrations in shrimps of transuranic nuclides from the station and from Sellafield were of negligible radiological significance. Gamma radiation dose rates over intertidal sediment close to the station were indistinguishable from the natural background.

Table 27 Radioactivity in environmental materials and gamma dose rates near Hinkley Point nuclear power station, 1987.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta	^{14}C	^{54}Mn	^{60}Co	^{65}Zn	^{90}Sr	^{110m}Ag
Flounders	2	140	51	ND	ND	ND	NA	ND
Eels	1	66	NA	"	"	"	"	"
Shrimps	2	110	"	"	"	"	0.3	"
Fucus vesiculosus	2	240	"	0.6	1.2	0.3	NA	0.1
Sediment	2	630	"	0.6	0.8	ND	"	ND

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}				
		^{134}Cs	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am
Flounders	2	0.2	2.0	NA	NA	ND
Eels	1	0.8	2.5	"	"	"
Shrimps	2	0.2	1.3	0.00063	0.0021	0.0021
Fucus vesiculosus	2	0.2	2.4	NA	NA	ND
Sediment	2	0.8	23	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediment (8 sampling observations†): 0.096 μGy h^{-1}

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

6.7 Hunterston, Ayrshire

This establishment comprises "A" and "B" stations; the "A" station is powered by magnox-type reactors and the "B" station by AGRs. Liquid radioactive waste discharges are made to the Firth of Clyde under authorisation of the Scottish Development Department. There are two 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 1987 are shown in Table 28.

The concentrations of artificial radioactivity in this area are predominantly due to Sellafield discharges, the general values being consistent with those to be expected at this distance from Sellafield. Concentrations of radiocaesium generally declined in 1987 in line with the reducing trend in Sellafield discharges. In 1987, the exposure of members of the critical group of fish and shellfish consumers near Hunterston 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 small amounts of activation products observed in molluscs, seaweed and sand were mainly due to discharges from the "B" station. However, they gave rise to but a small fraction of the above exposure and their radiological significance was negligible. Gamma radiation dose rates over intertidal sediments were indistinguishable from the natural background.

Table 28 Radioactivity in environmental materials and gamma dose rates near Hunterston nuclear power station, 1987.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{54}Mn	^{58}Co	^{59}Fe	^{60}Co	^{65}Zn	^{106}Ru	^{110m}Ag	^{134}Cs
Cod	1	170	ND	ND	ND	ND	ND	ND	ND	1.1
Grey mullet	1	140	"	"	"	"	"	"	"	1.7
Saithe	3	160	"	"	"	"	"	"	"	2.8
Turbot (fish farm)	5	110	"	"	"	"	"	"	"	3.0
Winkles	4	100	4.2	"	"	3.1	5.3	"	13	ND
Fucus spp.	4	350	16	0.3	1.1	4.7	11	3.2	1.7	6.3
Sand	4	310	3.8	ND	ND	2.5	ND	ND	ND	4.4

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
Cod	1	12	ND	ND	NA	NA	ND	NA	NA
Grey mullet	1	21	"	"	"	"	"	"	"
Saithe	3	30	"	"	"	"	"	"	"
Turbot (fish farm)	5	16	"	"	"	"	"	"	"
Winkles	4	6.2	"	"	0.040	0.14	0.068	0.0028	0.0062
Fucus spp.	4	28	0.2	0.1	0.17	0.67	0.22	0.014	0.021
Sand	4	68	ND	ND	NA	NA	ND	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 29 Radioactivity in environmental materials and gamma dose rates near Sizewell nuclear power station, 1987.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{60}Co	^{65}Zn	^{106}Ru	^{110m}Ag	^{134}Cs	^{137}Cs	^{239}Pu + ^{240}Pu	^{241}Am
Plaice	1	100	ND	ND	ND	ND	0.40	1.9	NA	ND
Grey mullet	1	110	"	"	"	"	0.39	2.2	"	"
Lobsters	1	87	"	"	"	2.0	ND	2.3	"	"
Shrimps	1	130	"	"	"	1.0	0.65	3.8	0.00061	0.00070
Crabs	1	86	0.3	"	"	6.5	ND	0.8	NA	ND
Mussels	2	51	0.3	"	"	ND	"	1.0	"	"
Oysters	1	89	0.5	1.2	"	8.8	"	0.4	"	"
Whelks	1	110	0.7	ND	3.5	7.0	"	1.4	"	"
Silt	2	800	3.6	"	12	ND	5.0	50	"	"

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

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

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

6.8 Sizewell, Suffolk

At this establishment there is an "A" station powered by magnox-type reactors; a "B" station, to be powered by a PWR, is under construction. Radioactive liquid effluent from the "A" station is discharged 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 1987 are shown in Table 29.

The radioactivity concentrations represent the combined effect of discharges from the "A" station and from Sellafield, as well as of fallout. Apportionment is difficult at the low levels detected. Trace levels of cobalt-60 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. The total radiation exposure of local fish and shellfish consumers was low, at less that 0.003 mSv or 0.3% 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 is powered by two AGRs, came into operation at the end of 1987. No discharges of radioactive wastes to the North Sea were made during that year (Table 1), although these discharges are authorised by the Scottish Development Department. Our investigations, on behalf of departments of the Scottish Office, have shown that potentially critical pathways for radiation exposure of the public, likely to be associated with 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 commenced prior to station operation in order to establish background levels and reliable sources of supply of environmental materials. In 1987, samples of fish and shellfish were collected and analysed, and 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 30. The very low concentrations of artificial radionuclides are due to fallout and the distant effects of Sellafield discharges. The measured gamma dose rate is consistent with that expected from the natural background.

6.10 Trawsfynydd, Gwynedd

Discharges from this station are made to the freshwater Lake Trawsfynydd under authorisation of the Welsh Office. Because of the limited volume of water available for dispersion they are of greater radiological significance than those from other UK nuclear power stations which discharge to estuarine or coastal waters. The critical radiation exposure pathway is due to consumption of fish caught in the lake, 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 small amounts, perch. Perch and most brown trout are indigenous to the lake but rainbow trout and, sometimes, brown trout are introduced from a hatchery. Because of the limited period which they spend in the lake, introduced fish generally exhibit lower radiocaesium concentrations than those of indigenous fish.

Our monitoring programme reflects the exposure pathways. Samples of brown trout, rainbow trout, perch and other fish are regularly analysed. As part of our research programme, mud and peat from the lake bed are also analysed; these materials contribute radioactivity to the fishes' diet. Additional information is gained from analyses of the moss *Fontinalis* which is a sensitive indicator for a number of radionuclides, and from analyses of lake water. Gamma dose rates over lake shoreline areas are also kept under review; this monitoring was increased in 1987 following the lowering of the lake water-level and was supported by additional monitoring of mud and peat. Our enhanced monitoring programme, which was increased in 1986 following the Chernobyl accident, continued. The results of our additional monitoring are reported in section 10. Our regular programme of fish monitoring at Trawsfynydd continued during 1987 and is reported here to present a balanced picture of public radiation exposures for the whole year. The results of our regular monitoring are shown in Table 31.

Radiocaesium discharges from the power station decreased slightly in 1987 as compared with 1986 (Table 1). However, there were proportionately larger decreases in concentrations of radiocaesium in lake water, likely to be due to increased dilution as a result of greater rainfall, with the additional effect of a more rapid clearance rate due to the reduced lake volume following lowering of the water level. Despite these decreases, however, radiocaesium concentrations in trout, averaged over the whole year, were greater than in 1986 (Hunt, 1987). This is thought to be due both to the time required for fish to respond to the higher concentrations in lake water in 1986, and to the fact that no brown trout were released from the hatchery in 1987 to contribute to lower average concentrations in

Table 30 Radioactivity in environmental materials and gamma dose rates near Torness nuclear power station, 1987.

Material	No. of sampling observa-tions†	Mean radioactivity concentration (wet)*, $Bq\ kg^{-1}$				
		Total beta	^{106}Ru	^{110m}Ag	^{134}Cs	^{137}Cs
Cod	2	140	ND	ND	0.6	5.4
Crabs	2	76	"	5.4	ND	0.8
Lobster	1	79	"	3.0	"	1.2
Nephrops	4	94	"	2.1	0.1	2.6
Winkles	2	90	"	5.7	ND	1.5
Fucus vesiculosus	2	220	0.9	0.5	0.2	2.0
Silt						
Dunbar inner harbour	2	700	9.5	ND	10	70
Eyemouth harbour	1	790	ND	"	16	78
Aberlady Bay	1	320	"	"	2.5	19
Sand						
Thornton Loch beach	2	180	"	"	0.3	6.0

Material	No. of sampling observa-tions†	Mean radioactivity concentration (wet)*, $Bq\ kg^{-1}$				
		^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm + ^{244}Cm$
Cod	2	NA	NA	ND	NA	NA
Crabs	2	"	"	"	"	"
Lobster	1	"	"	"	"	"
Nephrops	4	0.0017	0.0080	0.0086	0.00017	0.00010
Winkles	2	NA	NA	ND	NA	NA
Fucus vesiculosus	2	"	"	"	"	"
Silt						
Dunbar inner harbour	2	"	"	"	"	"
Eyemouth harbour	1	"	"	"	"	"
Aberlady Bay	1	"	"	"	"	"
Sand						
Thornton Loch beach	2	"	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediment (8 sampling observations†): 0.068 $\mu Gy\ h^{-1}$

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

brown trout, as was the case in 1986. Radiocaesium concentrations in the indigenous perch increased in 1987 as a result of the response-time effect. The contributions during 1987 to caesium-137 concentrations in fish as a result of the input from Chernobyl were difficult to estimate precisely as the ratio of caesium-137 to caesium-134 from the station varied, but are not likely to have exceeded about 10% of the concentrations given. As in previous years, sulphur-35 from station discharges and transuranic nuclides from station discharges and fallout were also observed in fish; these concentrations continued to be of negligible radiological significance.

It is estimated that in 1987 members of the critical group of fish consumers received about 0.25 mSv, within the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$. This increased exposure, as compared with 0.17 mSv in 1986 (Hunt, 1987), reflects the behaviour of radiocaesium concentrations in trout. The decrease in concentrations of radiocaesium in lake water for 1987, noted above, is expected to lead to reduced concentrations in fish, and hence exposures, in 1988. Despite the lowering of the water level in the lake in 1987, gamma dose rates were not significantly changed, still being consistent with values to be expected from the natural background.

Table 31 Radioactivity in environmental materials near Trawsfynydd nuclear power station, 1987.

Material	No. of sampling observa- tions†	Mean radioactivity concentration (wet)*, Bq kg^{-1}									
		Total beta	^{35}S	^{54}Mn	^{60}Co	^{65}Zn	^{90}Sr	^{103}Ru	^{106}Ru	^{125}Sb	^{134}Cs
Brown trout	6	510	100	ND	0.14	ND	8.1	ND	ND	ND	52
Brown trout (hatchery)	2	130	NA	"	ND	"	7.6	"	"	"	0.3
Rainbow trout	6	150	88	"	"	"	4.9	"	"	"	3.6
Rainbow trout (hatchery)	2	140	NA	"	"	"	3.3	"	"	"	0.5
Perch	4	1800	"	"	0.3	"	7.8	"	"	"	191
Eels	1	670	"	"	0.6	"	2.1	"	"	"	110
Rudd	1	510	"	"	ND	"	NA	"	"	"	50
Fontinalis											
Afon Prysor	2	230	"	1.2	"	"	"	0.5	11	1.2	7.1
Gwylan Stream	3	780	"	30	380	1.2	"	0.2	18	34	13
Mud											
Cooling water outfall	2	6100	"	25	750	17	"	ND	470	380	450
Hot lagoon	2	2500	"	ND	10	ND	"	"	ND	57	11
South end of lake	2	2000	"	"	27	"	"	"	"	46	130
Cae Adda boat mooring	2	1800	"	"	26	"	"	"	"	55	120
Peat											
Hot lagoon	2	3500	"	"	120	"	"	"	"	310	54
Gwylan Stream											
Sediment	3	2800	"	0.8	18	"	"	"	"	33	62
Peat	2	4400	"	5.1	130	"	"	"	12	79	180
Water											
Hot Lagoon	4	NA	"	NA	NA	NA	0.14	NA	NA	NA	0.023
Cold Lagoon	15	"	"	"	"	"	0.13	"	"	"	0.027

Material	No. of sampling observa- tions†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Brown trout	6	360	ND	ND	ND	0.00014	0.00077	0.00086	ND	ND
Brown trout (hatchery)	2	2.4	"	"	"	0.00007	0.00024	0.00044	"	"
Rainbow trout	6	25	"	"	"	0.00026	0.0010	0.0017	"	"
Rainbow trout (hatchery)	2	1.9	"	"	"	0.00005	0.00015	0.00033	"	"
Perch	4	1500	"	"	"	0.00007	0.00023	0.00086	"	"
Eels	1	680	"	"	"	0.00004	0.00016	0.00026	"	"
Rudd	1	400	"	"	"	NA	NA	ND	NA	NA
Fontinalis										
Afon Prysor	2	19	"	"	2.1	"	"	"	"	"
Gwylan Stream	3	100	9.3	0.6	3.9	"	"	2.7	"	"
Mud										
Cooling water outfall	2	4700	200	41	27	"	"	92	"	"
Hot lagoon	2	1700	ND	ND	ND	3.4	18	22	0.17	0.43
South end of lake	2	1400	"	"	"	NA	NA	1.1	NA	NA
Cae Adda boat mooring	2	1200	"	"	"	"	"	2.2	"	"
Peat										
Hot lagoon	2	630	20	"	"	6.4	23	35	0.67	1.1
Gwylan Stream										
Sediment	3	2000	ND	"	"	NA	NA	ND	NA	NA
Peat	2	3000	"	"	"	"	"	"	"	"
Water										
Hot Lagoon	4	0.15	NA	NA	NA	"	"	"	"	"
Cold Lagoon	15	0.17	"	"	"	"	"	"	"	"

Mean gamma dose rate in air at 1 m over areas near lake shoreline (12 sampling observations†): 0.11 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.

6.11 Wylfa, Gwynedd

Liquid radioactive wastes from this station are discharged to the Irish Sea under authorisation of the Welsh Office. The two potentially critical pathways are due to consumption of local fish and shellfish and to occupancy of intertidal areas. Monitoring is carried out in respect of these pathways. Samples of sediment are analysed in support of the gamma dose rate measurements, and the indicator seaweed *Fucus vesiculosus* is also sampled. The results of monitoring in 1987 are presented in Table 32.

Any effects of discharges from this station are masked by Sellafield-derived radioactivity. Concentrations of artificial radionuclides in environmental materials were consistent with those expected at this distance from Sellafield, and generally decreased in 1987, particularly for radiocaesium, in line with the reducing trend in Sellafield discharges. The total radiation exposure of members of the critical group in 1987 was less than 0.05 mSv, 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. Defence establishments

We have continued our regular monitoring of the effects of liquid radioactive waste discharges to sea from naval establishments, and the results are reported in this section. Liquid radioactive wastes are also discharged from the Atomic Weapons Establishment, Aldermaston, to the River Thames; the critical public radiation exposure pathway is likely to be from drinking water, and monitoring is carried out by the DOE (DOE, 1988). In 1987, however, we began a small programme of monitoring of fish and other aquatic materials in surveillance of discharges to the Thames catchment from Aldermaston and other nuclear establishments. The relevant results are reported in this section.

Table 32 Radioactivity in environmental materials and gamma dose rates near Wylfa nuclear power station, 1987.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta	^{60}Co	^{106}Ru	^{110m}Ag	^{134}Cs	^{137}Cs	^{155}Eu
Plaice	2	110	ND	ND	ND	0.6	5.2	ND
Spurdog	4	110	"	"	"	0.7	14	"
Crabs	2	85	0.2	2.0	13	0.1	2.5	"
Winkles	2	90	ND	ND	9.0	ND	2.0	"
Mussels	2	53	"	2.9	ND	0.1	2.1	"
Fucus vesiculosus	4	200	0.05	ND	0.4	0.4	4.9	"
Sediment: Cemlyn Bay	2	1500	ND	48	ND	32	530	3.7

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}				
		^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Plaice	2	NA	NA	ND	NA	NA
Spurdog	4	0.00008	0.00027	0.00031	ND	ND
Crabs	2	NA	NA	0.46	NA	NA
Winkles	2	0.036	0.18	0.23	ND	ND
Mussels	2	0.054	0.26	0.46	"	0.0020
Fucus vesiculosus	4	NA	NA	ND	NA	NA
Sediment: Cemlyn Bay	2	11	56	60	ND	0.13

Mean gamma dose rate in air at 1 m over intertidal sediment (12 sampling observations†): 0.079 µGy h^{-1}

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

7.1 Atomic Weapons Establishment, Aldermaston, Berkshire

Liquid radioactive waste discharges are small (Table 1) and are made under agreement with Authorising Departments to the River Thames at Pangbourne. As explained above, the critical exposure pathway is likely to be from drinking water, but in 1987 we began a small programme of fisheries-related monitoring. This included monitoring at locations in the Thames catchment remote from nuclear establishments and upstream of them (e.g. at Donnington on the River Lambourn). Analyses were carried out of available fish species, with *Nuphar lutea* (yellow water lily), *Ranunculus penicillatus* (water crowfoot) and sediments as indicator materials.

The results of this monitoring are shown in Table 33. The concentrations of artificial radioactivity detected were very low. The background due to weapons-test fallout and/or the Chernobyl reactor accident is demonstrated by the concentrations at remote upstream locations. Concentrations of some radionuclides, notably caesium-137, were slightly enhanced close to the outfall, but concentrations of plutonium were not significantly different from the level expected due to fallout. The overall effect was of very low radiological significance: if any fish were eaten even at rates typical of enthusiastic trout consumers, the radiation dose, together with that due to occupancy of the river bank near the outfall for times typical of enthusiastic anglers, would have been less than 0.002 mSv or less than 0.2% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$.

7.2 Naval establishments

Liquid wastes containing small quantities of radioactivity are discharged from the establishments at Devonport, Faslane and Rosyth. During 1987 the Dockyards at Devonport and Rosyth were privatised; discharges are made under authorisation, and also from the naval bases at these establishments by agreement with the Ministry of Defence (Navy Department) (Table 1). The US naval base at Holy Loch discharges small quantities of radioactive waste (sub-section 2.1). We carry out monitoring programmes near all of these establishments, in the case of Faslane and Rosyth on behalf of departments of the Scottish Office. Monitoring near Chatham also continues in surveillance of the effects of past discharges.

Table 33 Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from the Atomic Weapons Establishment, Aldermaston, 1987.

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1})					
			Total beta	^{60}Co	^{134}Cs	^{137}Cs	^{239}Pu + ^{240}Pu	^{241}Am
Chub	Pangbourne	1	110	ND	ND	0.8	0.00022	0.00021
	Marlow	2	100	"	0.16	0.8	NA	ND
	Staines	2	100	"	ND	0.6	0.00077	0.0011
Perch	Pangbourne	1	120	"	"	2.0	NA	ND
Grayling	Donnington (R. Lambourn)	1	97	"	"	0.3	"	"
Nuphar lutea	Pangbourne	1	44	0.2	"	0.9	"	"
	Marlow	1	47	ND	"	0.6	"	"
	Staines	1	40	"	"	0.5	"	"
Ranunculus penicillatus	Donnington (R. Lambourn)	1	56	"	"	ND	"	"
Sediment	Pangbourne	1	310	1.3	"	21	"	"
	Marlow	1	85	ND	1.0	5.4	"	"
	Staines	1	220	1.3	1.2	31	"	"
	Donnington (R. Lambourn)	1	230	ND	ND	13	"	"

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

Table 34 Radioactivity in environmental materials and gamma dose rates near naval establishments, 1987.

Establishment	Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
			Total beta	^{60}Co	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs
Chatham	Sediment	3	910	3.4	ND	ND	ND	3.7
Devonport	Mussels	2	66	0.5	"	"	"	ND
	Fucus vesiculosus	3	180	0.3	"	"	"	"
	Sediment	6	NA	1.5	"	"	"	0.2
Faslane	Sediment	4	"	15	17	"	3.1	15
Rosyth	*Fucus vesiculosus*	2	"	0.3	ND	"	ND	0.4
	Sediment	9	"	1.1	9.7	0.1	0.08	7.2
Holy Loch	Sediment	2	"	6.4	5.8	ND	ND	5.2

Establishment	Material	No. of sampling observations†	Mean radioactivitiy concentration (wet)*, Bq kg^{-1}		Mean gamma dose rate in air at 1 m	
			^{137}Cs	^{155}Eu	No. of sampling observations†	µGy h^{-1}
Chatham	Sediment	3	35	ND	8	0.067
Devonport	Mussels	2	ND	"	NP	NP
	Fucus vesiculosus	3	0.2	"	"	"
	Sediment	6	7.2	1.0	12	0.083
Faslane	Sediment	4	120	0.4	13	0.083
Rosyth	*Fucus vesiculosus*	2	2.3	ND	NP	NP
	Sediment	9	51	1.2	4	0.082
Holy Loch	Sediment	2	52	ND	14	0.078

NA = not analysed.
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 1987 are presented in Table 34. The small concentrations of cobalt-60 mainly reflect discharges from the establishments; levels of radiocaesium are mainly due to discharges from Sellafield. Gamma dose rates over intertidal sediments 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

This company is engaged in the manufacture of radioactive materials for use in medicine, research and industry. The company's parent establishment is located in Amersham, Buckinghamshire, from which radioactive discharges are made into the catchment of the River Thames. As explained in section 5,

Table 35 Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Amersham International plc, Amersham, 1987.

Material	Sampling point	No. of sampling observa- tions†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
			Total beta	^{58}Co	^{60}Co	^{65}Zn	^{131}I	^{134}Cs	^{137}Cs	^{239}Pu + ^{240}Pu	^{241}Am
Chub	Maple Cross (R. Colne)	1	120	ND	ND	ND	ND	ND	1.0	NA	ND
	Staines	2	100	"	"	"	"	"	0.6	0.00077	0.0011
Perch	Maple Cross (R. Colne)	1	110	"	"	"	"	"	ND	NA	ND
Grayling	Chorleywood (R. Chess)	1	91	"	"	"	"	"	0.6	0.00021	0.00025
Nuphar lutea	Maple Cross (R. Colne)	1	76	0.8	"	0.9	"	"	ND	NA	ND
	Chorleywood (R. Chess)	1	45	ND	"	ND	"	"	"	"	"
	Staines	1	40	"	"	"	"	"	0.5	"	"
Sediment	Maple Cross (R. Colne)	1	410	54	"	16	-20	8.1	31	"	"
	Staines	1	220	ND	1.3	ND	ND	1.2	31	"	"

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

environmental monitoring in respect of these discharges is carried out by the DOE (DOE, 1988). However, in 1987 we began a small programme of fisheries-related monitoring in connection with discharges of liquid radioactive wastes to the Thames and its catchment. Results relevant to the Amersham Laboratory are presented in this section. Our monitoring programme in surveillance of discharges from the Cardiff Laboratory has continued, and the results of this programme are also presented.

8.1 Amersham Laboratory, Buckinghamshire

Discharges of liquid radioactive wastes are made under authorisation to the Maple Cross sewage works; releases enter the Grand Union Canal and the River Colne. In 1987 we began a small programme of monitoring of fish and other aquatic materials in surveillance of the effects of these discharges, including monitoring at locations remote from nuclear establishments and upstream of them (e.g. at Chorleywood on the River Chess). Analyses were carried out of available fish species with *Nuphar lutea* (yellow water lily), and sediments as indicator materials.

The results of this monitoring are presented in Table 35. The concentrations of radioactivity detected were very low. The background due to weapons-test fallout and/or the Chernobyl reactor accident is demonstrated by the concentrations at remote upstream locations. Concentrations of some radionuclides were slightly enhanced close to the outfall, but the overall effect was of very low radioligical significance. If any fish were eaten, even at rates typical of enthusiastic trout consumers, the radiation dose, including that due to occupancy of river or canal banks near the outfall for times typical of enthusiastic anglers, would have been less than 0.003 mSv or less than 0.3% of the ICRP-recommended principal dose limit of 1 mSv year $^{-1}$.

8.2 Cardiff Laboratory

A further laboratory, situated near Cardiff, is engaged in the production of labelled compounds used in research and of diagnostic kits used in medicine for the *in vitro* testing of clinical samples. An authorisation issued by the Welsh Office regulates disposals of liquid radioactive wastes from this establishment to a sewer discharging into the Severn Estuary.

Our monitoring programme, carried out on behalf of the Welsh Office, reflects the two potentially critical pathways due to consumption of fish and shellfish and to external exposure over muddy intertidal areas. Measurements of external exposure are supported by analyses of intertidal sediment, and *Fucus* seaweed is collected as an indicator material. The radiological consequences of discharges from this establishment are small and mainly due to carbon-14. Additional artificial radionuclides detected are due to fallout, other establishments which discharge small amounts of radioactive wastes to the Severn Estuary and the Bristol Channel, and possibly to Sellafield.

Table 36 Radioactivity in environmental materials and gamma dose rates near the outfull of the sewer serving Amersham International plc, Cardiff, 1987.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, $Bq\ kg^{-1}$					
		Total beta⁺	^{14}C	^{131}I	^{134}Cs	^{137}Cs	^{155}Eu
Flounders	2	580	2 100	ND	0.025	0.78	ND
Fucus spiralis	4	180	76	3.2	0.09	0.49	"
Sediment	4	980	73	ND	0.36	26	1.9

Mean gamma dose rate in air at 1 m over intertidal sediment (4 sampling observations†): 0.086 $\mu Gy\ h^{-1}$

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 37 Radioactivity in environmental materials from the Channel Islands, 1987.

Material	Sampling area	No. of sampling observations†	Mean radioactivity concentration (wet)*, $Bq\ kg^{-1}$								
			Total beta	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn	^{90}Sr	^{106}Ru	^{110m}Ag	^{125}Sb
Ray	Guernsey	1	98	ND	ND	ND	ND	NA	ND	ND	ND
Crabs	Guernsey	1	88	"	"	3.6	"	"	"	1.4	"
	Jersey	1	97	"	"	2.2	"	"	8.4	0.9	"
Oysters	Jersey	1	94	"	"	1.2	1.8	"	8.9	1.5	"
Limpets	Jersey	1	100	"	"	2.5	ND	"	5.4	ND	"
	Guernsey	1	87	"	"	0.6	"	"	3.3	"	"
	Alderney	1	120	"	"	2.3	"	"	28	"	"
Porphyra	Jersey										
	Greve de Lecq	4	210	"	"	0.5	"	"	14	"	"
	La Rozel	4	210	"	"	0.7	"	"	11	"	"
	Guernsey										
	Fermain Bay	4	390	"	"	0.4	"	"	10	"	"
	Alderney										
	Quenard Point	4	360	0.04	"	1.8	"	"	93	"	0.5
Fucus serratus	Jersey										
	La Rozel	4	325	ND	"	4.4	"	0.57	7.0	"	ND
	Guernsey										
	Fermain Bay	4	390	"	"	4.2	"	0.38	7.1	"	"
	Alderney										
	Quenard Point	4	420	0.22	0.07	12	0.2	0.76	27	0.08	0.32
Sediment	Jersey										
	St Helier Harbour	1	610	ND	ND	7.1	ND	NA	28	ND	ND
	Guernsey										
	Bordeaux Harbour	1	380	"	"	0.6	"	"	ND	"	1.6
	Alderney										
	Crabbe Harbour	1	550	"	"	1.8	"	"	14	"	5.6
	Braye Harbour	1	460	"	"	1.4	"	"	16	"	3.9

Table 37 Continued.

Material	Sampling area	No. of sampling observa-tions†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
			^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Ray	Guernsey	1	0.92	ND	0.00025	0.00027	ND	ND
Crabs	Guernsey	1	ND	0.0009	0.0012	0.018	0.0050	0.0088
	Jersey	1	0.17	0.0015	0.0034	0.0098	0.00035	0.0039
Oysters	Jersey	1	ND	0.011	0.020	0.016	0.00014	0.0057
Limpets	Jersey	1	"	0.011	0.020	0.024	0.00027	0.0073
	Guernsey	1	"	0.0052	0.011	0.014	0.00041	0.0056
	Alderney	1	"	0.023	0.029	0.077	0.0051	0.039
Porphyra	Jersey							
	Greve de Lecq	4	"	NA	NA	ND	NA	NA
	La Rozel	4	0.13	"	"	"	"	"
	Guernsey							
	Fermain Bay	4	0.22	"	"	"	"	"
	Alderney							
	Quenard Point	4	0.28	"	"	"	"	"
Fucus serratus	Jersey							
	La Rozel	4	0.15	0.035	0.060	0.028	0.00054	0.0045
	Guernsey							
	Fermain Bay	4	0.12	0.032	0.065	0.025	0.0013	0.0089
	Alderney							
	Quenard Point	4	0.28	0.063	0.080	0.057	0.0031	0.030
Sediment	Jersey							
	St Helier Harbour	1	3.0	0.69	1.8	2.2	0.023	0.57
	Guernsey							
	Bordeaux Harbour	1	1.5	0.081	0.29	0.22	0.0046	0.061
	Alderney							
	Crabbe Harbour	1	4.3	NA	NA	ND	NA	NA
	Braye Harbour	1	3.6	"	"	"	"	"

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

The results of monitoring in 1987 are presented in Table 36. Of the separate nuclides listed, only carbon-14 was discharged by this establishment in 1987: 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. The exposure of the critical group was less than 0.1 mSv, within the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$. Gamma dose rates over sediment were indistinguishable from those expected from the natural background.

9 Channel Islands monitoring

We have continued to analyse marine environmental samples provided by the Channel Islands States 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 1987 are given in Table 37. Concentrations of caesium-137 in fish and shellfish were not significantly in excess of those 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.

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

An extended monitoring programme continued during 1987 in surveillance of the effects of fallout from this accident. The additional monitoring was restricted to the freshwater environment; because of more limited dispersion rates than in marine situations, parts of this environment continued to show more clearly the effect of Chernobyl fallout during 1987. In most cases, concentrations of radioactivity in the marine environment had by the end of 1986 returned to levels typical of those before the accident, and our additional monitoring of the marine environment was integrated with our normal programme (Hunt, 1987). The results of our additional monitoring of the freshwater environment from January to August 1987 have already been published (MAFF, 1987). The results presented in this section are for the whole of 1987. The sampling locations are shown in Figure 5. They are mostly in areas of relatively high deposition of Chernobyl fallout, namely Cumbria, North Wales and parts of Scotland, but samples from Northern Ireland, the Isle of Man and areas of low deposition were also obtained for completeness and comparison.

Tables 38-46 present concentrations of caesium-134 and -137 in fish and other fauna, giving the averaged results of all analyses carried out at each location on samples taken during the reporting period. The number of samples analysed is specified. The sample size in terms of the number of individual fish varied from one to about ten, depending on availability and radiological importance. The maximum concentrations in samples from a given location varied up to a factor of two or three times the average value. Artificial radionuclides, other than those of radiocaesium, were either undetectable, as in most cases, or of negligible radiological significance.

Concentrations of radiocaesium in freshwater fish varied widely between locations, reflecting the areas of deposition of radioactivity from Chernobyl. Most samples analysed were of brown trout, in recognition of the potential radiological significance of this species; although rainbow trout are more commonly eaten, their radiocaesium concentrations were low compared with wild brown trout because rainbow trout are mostly hatchery-reared and fed on relatively uncontaminated food prior to release. Perch (Table 40) and pike (Table 42) had the highest concentrations of any of the freshwater fish species. However, as perch and pike are not eaten in large quantities their radiological significance is low. Other species (Tables 41, 43-46) had generally lower radiocaesium concentrations, sometimes much lower, than brown trout, perch or pike taken from the same river or lake. Where there are data for the same species and locations to compare with results for 1986 (Hunt, 1987) there are still likely to be fluctuations such as those due to sample size or to the contribution of hatchery-reared fish, and it is therefore only possible using the data presented to state that, on average during 1987, concentrations of radiocaesium were broadly similar to those from May to December 1986. However, there is evidence from our results during 1987 that concentrations began to diminish in the latter part of the year, and we expect these reductions to continue during 1988.

Radiation exposures have been estimated using a procedure based on cautious assumptions, as previously (Hunt, 1987). A consumption rate of brown trout of 100 g d^{-1}, sustained for one year, was taken to be representative of adults subject to the highest exposures. Actual exposures are likely to be lower, not only because this consumption rate is cautious but also because in practice hatchery-reared or farmed fish of much lower radiocaesium concentrations may contribute to the diet. Exposures of children and infants would be likely to be lower that those for adults. Concentrations of radiocaesium in brown trout representative of the highest in each region were chosen; thus, some of the locations were different from those used for 1986. In some cases, locations with the highest concentrations were excluded on grounds of low availabililty 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 47. The major contribution to dose was due to radiocaesium.

The ICRP (ICRP, 1984b) provides guidance in the context of emergencies which includes suggested levels of dose below which particular countermeasures would not be warranted. The suggested level of effective dose equivalent is 5 mSv in the first year. Most of 1987 was outside this period but, as was the case in 1986, the estimated doses for all areas of the UK were less than 1 mSv $year^{-1}$. It can be shown that organ doses (in this case the lower large intestine is the critical organ) are not more limiting. Given that these dose estimates are cautious, it is clear that contamination of freshwater fish from Chernobyl fallout was only of minor radiological importance. The collective dose from consumption of freshwater fish is likely to have been very small, as estimates have shown (Camplin *et al.*, 1986). The more significant contribution to collective dose, but of minor importance, was from consumption of marine fish, as considered in sub-section 4.1.1.

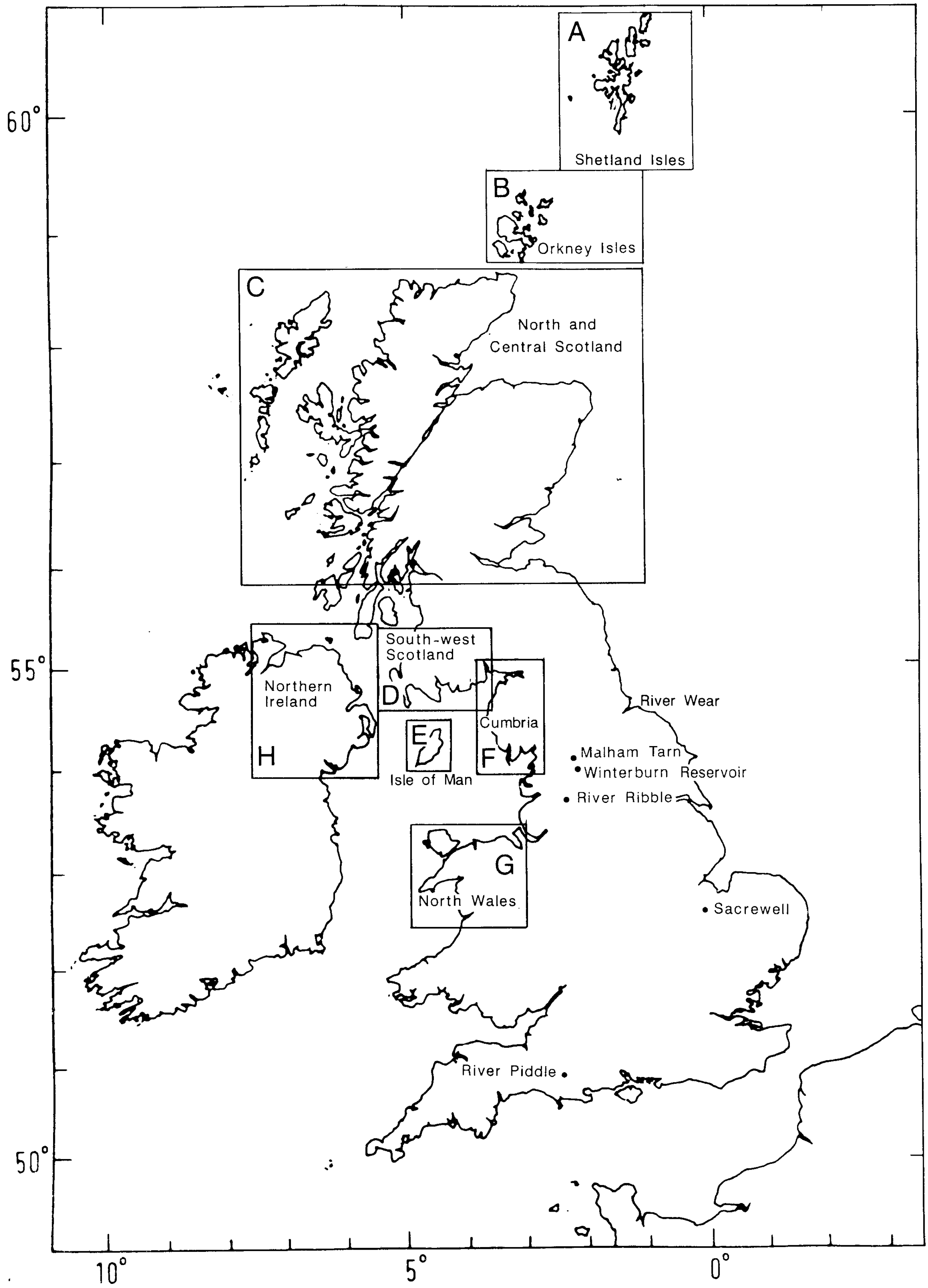


Figure 5 Sampling locations for monitoring of the freshwater environment for radioactivity from Chernobyl.

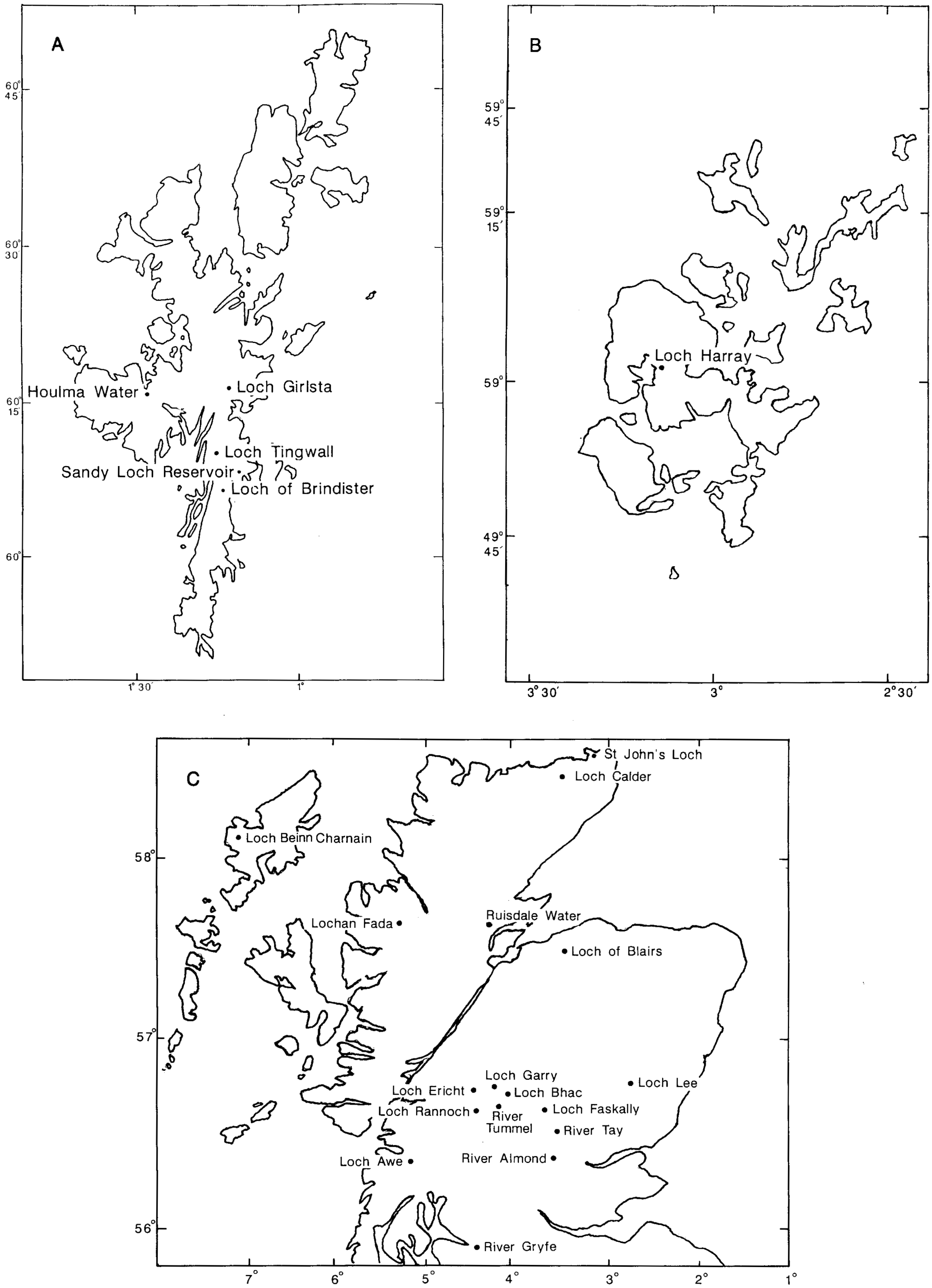
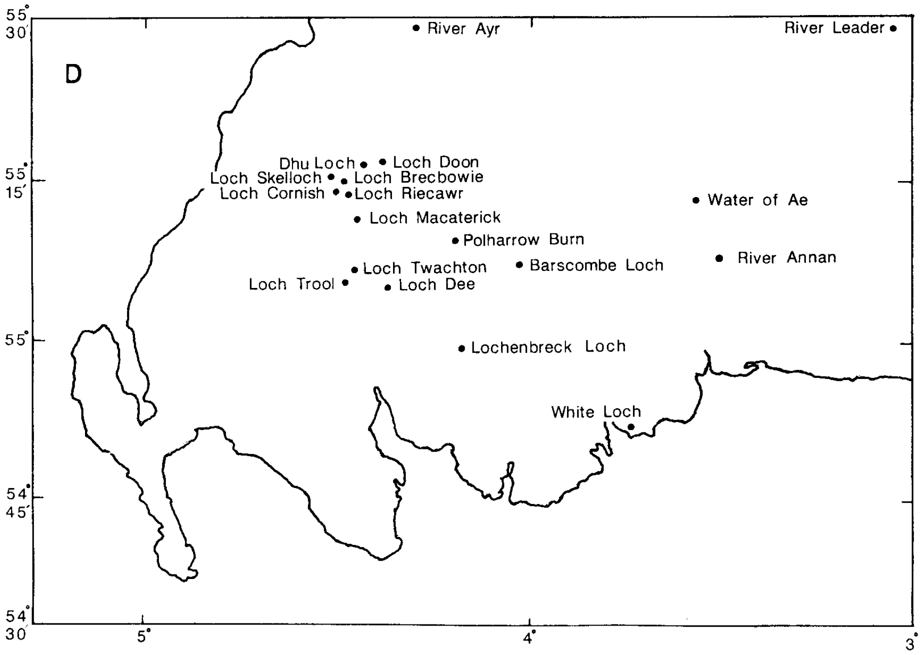


Figure 5: Inset A Sampling locations in the Shetland Isles. **Inset B** Sampling locations in the Orkney Isles.
Inset C Sampling locations in North and Central Scotland.



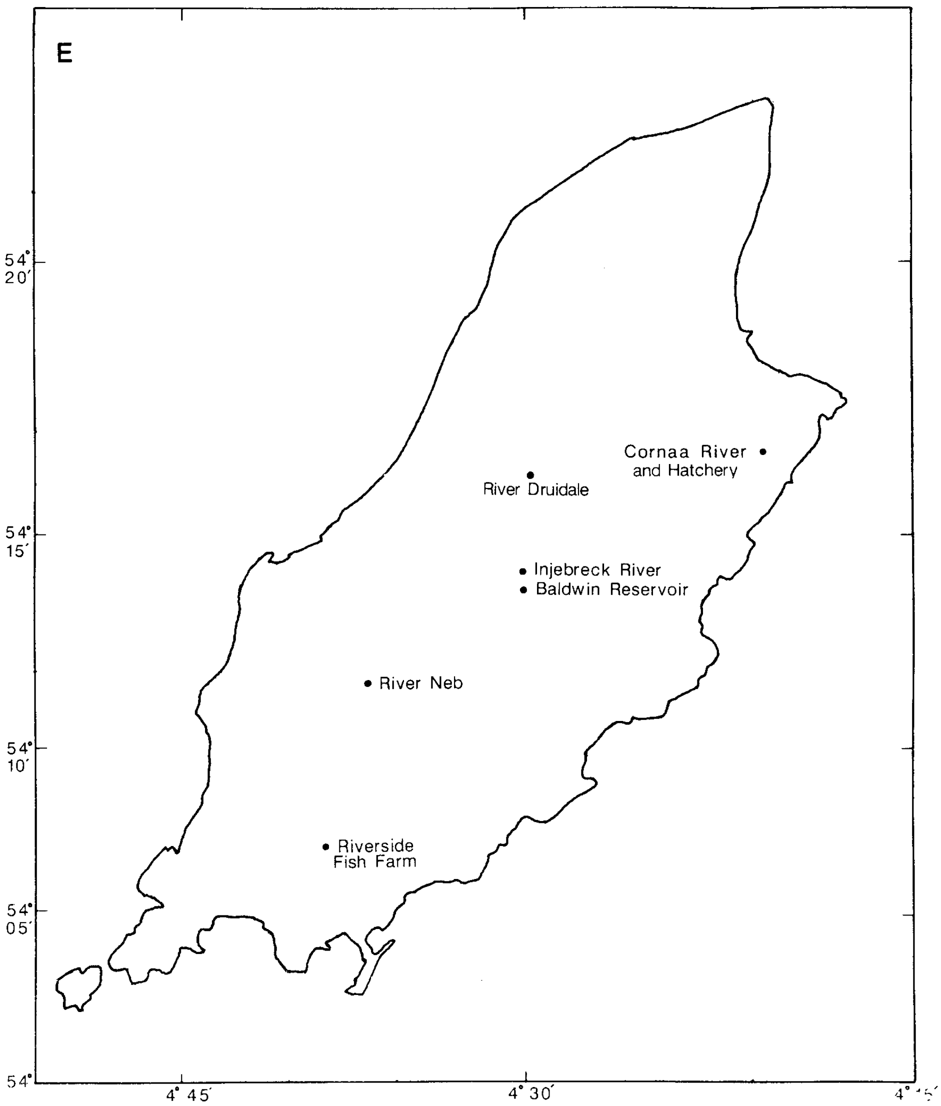
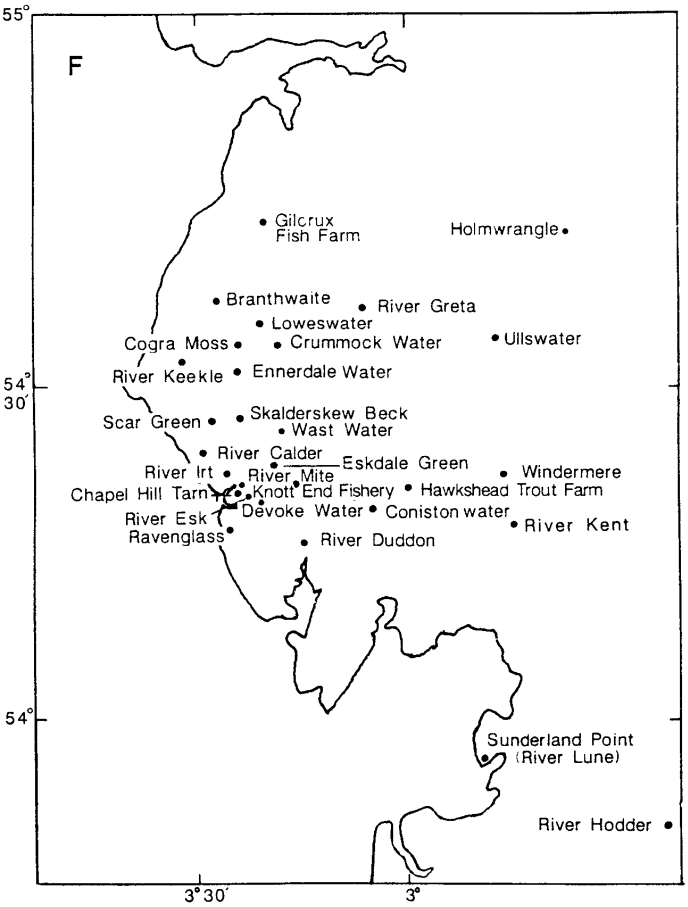


Figure 5: Inset D Sampling locations in South-west Scotland. **Inset E** Sampling locations on the Isle of Man.



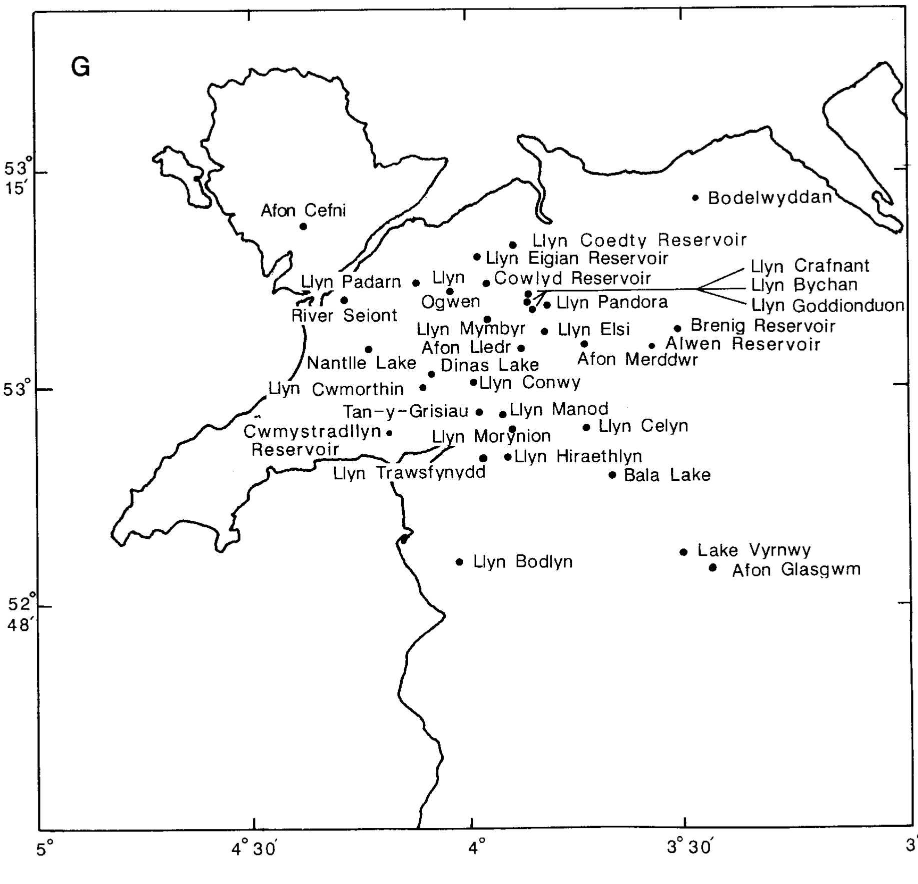


Figure 5: Inset F Sampling locations in Cumbria. **Inset G** Sampling locations in North Wales.

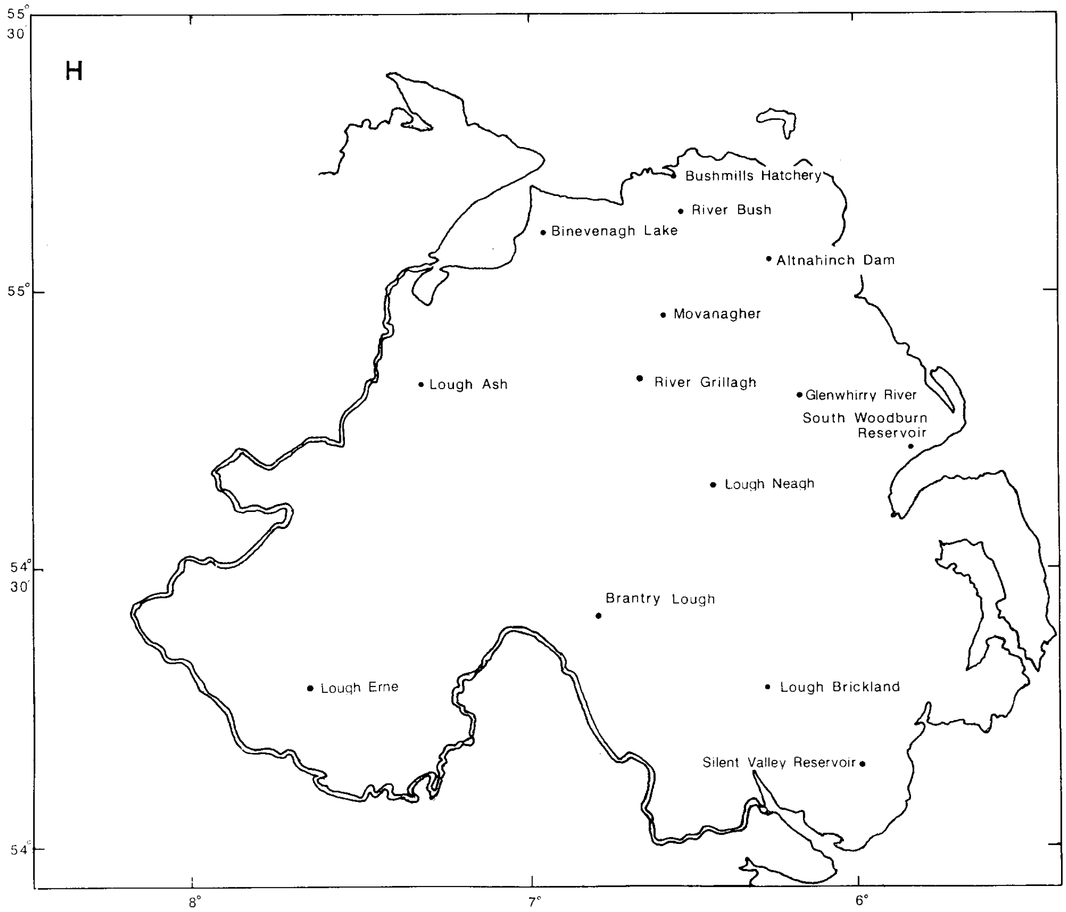


Figure 5: Inset H Sampling locations in Northern Ireland.

Table 38 Caesium radioactivity in brown trout, 1987.

Location	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1} ^{134}Cs	^{137}Cs
ENGLAND			
Windermere	18	25	60
Holmwrangle	2	1.7	6.0
Crummock Water	15	110	320
Wast Water	9	170	450
Ennerdale Water	124	200	520
Devoke Water	95	250	660
Loweswater	116	220	550
Cogra Moss	1	140	460
River Calder	2	52	250
River Wear	5	ND	1.8
River Greta	7	2.2	5.5
Eskdale Green	3	300	780
Coniston Water	1	32	75
River Esk	1	70	150
River Mite	1	20	57
Scar Green	1	51	130
Skalderskew Beck	1	23	55
River Keekle	1	55	150
Hawkshead Trout Farm	1	ND	9.0
Malham Tarn, Yorks	8	20	57
Winterburn Reservoir, Yorks	7	ND	0.8
River Ribble, Worston Beck, Lancs	1	"	ND
" " , Stock Beck, Lancs	1	"	"
" " , Skirden Beck, Lancs	1	"	"
" " , Swanside Beck, Lancs	2	"	"
WALES			
Llyn Trawsfynydd	86	53	310
Afon Merddwr	6	14	40
Afon Cefni	4	4.2	16
Cwmystradllyn Reservoir	6	34	76
Llyn Cwmorthin	19	21	58
Llyn Bodlyn	6	28	71

Table 38 Continued.

Location	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
WALES (continued)			
Llyn Conwy	44	130	350
Alwen Reservoir	23	66	160
Lake Vyrnwy	29	72	190
Afon Glasgwm	16	67	160
Nantlle Lake	6	24	66
Dinas Lake	7	53	140
Cowlyd Reservoir	10	110	280
Afon Lledr	7	160	390
Tan-y-grisiau	6	45	120
Brenig Reservoir	10	2.2	6.3
Bodelwyddan	1	ND	5.0
Llyn Mymbyr	43	140	390
Llyn Morynion	7	150	380
Llyn Manod	5	94	240
Llyn Celyn	15	16	47
Llyn Crafnant	12	130	350
Llyn Padarn	6	25	63
Bala Lake	14	23	60
Llyn Elsi	27	150	410
Llyn Goddionduon	23	390	1100
Llyn Ogwen	67	220	580
Llyn Pandora	6	18	59
Llyn Eigian Reservoir	1	42	120
Llyn Bychan	3	280	740
Llyn Coedty Reservoir	4	19	69
SCOTLAND			
Loch Garry, Tayside Region	5	160	430
Loch Bhac	1	19	53
Water of Ae	1	3.3	5.0
Ruisdale Water	3	92	250
Lochan Fada	2	66	230
Loch of Brindister	10	130	370
Sandy Loch Reservoir	1	30	130
Loch Doon	46	130	350
Loch Dee	64	440	1200
River Tummel	1	220	530
Loch Rannoch	6	150	410
River Leader	2	ND	0.8
St John's Loch	2	12	32
Loch Calder	2	21	64
Loch Awe	2	29	59
Dhu Loch	2	240	690
Lochenbreck Loch	1	210	640
Loch Twachton	1	69	180
Loch Girlsta	7	230	620
Loch Tingwall	11	86	220
Loch Harray	2	16	46
Houlma Water	10	190	510
Polharrow Burn	1	47	140
Loch Brecbowie	1	370	1100
Barscombe Loch	1	110	320
Loch Cornish	1	190	560
Loch Skelloch	1	170	530
Loch Riecawr	1	320	810
Loch Macaterick	1	140	420
Loch Ericht	1	170	440
Loch Beinn Charnain	2	78	240
Loch Lee	1	22	78
Loch of the Blairs	1	130	340
Loch Beinn Charnain	1	65	230
Loch Trool	1	16	46
NORTHERN IRELAND			
Movanagher	6	ND	4.1
River Grillagh	7	2.2	9.0
Altnahinch Dam	19	33	110
River Bush	16	41	140
Binevenagh Lake	3	7.3	26
Bushmills Hatchery	4	ND	4.4
Lough Ash	7	25	66
Lough Brickland	10	2.0	8.8
South Woodburn Reservoir	7	33	75
Brantry Lough	6	2.4	18
Lough Neagh	3	39	94
Silent Valley Reservoir	10	15	42
Glenwhirry River	6	5.6	43
ISLE OF MAN			
River Druidale	1	200	450
Cornaa River	10	64	160
Injebreck River/Reservoir	9	120	300
River Neb	6	43	120
Cornaa Hatchery	1	ND	ND

ND = not detected.

Table 39 Caesium radioactivity in rainbow trout, 1987.

Location	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
Hawkshead	1	6.1	14
Sacrewell	3	ND	0.9
Cogra Moss	19	29	76
River Piddle	1	ND	ND
Branthwaite	2	4.0	12
Gilcrux fish farm	1	ND	4.6
Eskdale Green	2	8.5	21
WALES			
Llyn Trawsfynydd	81	1.1	12
Bodelwyddan	2	ND	6.4
Llyn Celyn	14	1.7	7.9
Alwen Reservoir	1	41	95
Llyn Crafnant	6	5.7	4.1
Tan-y-grisiau	6	3.4	10
Llyn Elsi	27	49	140
Brenig Reservoir	10	4.0	14
Llyn Coedty Reservoir	2	7.8	36
Lake Vyrnwy	1	ND	18
SCOTLAND			
River Almond	2	ND	4.9
Water of Ae	2	"	3.0
Loch Awe	1	"	4.8
Loch of the Blairs	1	2.9	9.0
Loch Harray	1	11	41
NORTHERN IRELAND			
Movanagher	4	ND	1.5
Binevenagh Lake	3	"	6.0
South Woodburn Reservoir	2	"	4.0
ISLE OF MAN			
Cornaa River	3	ND	3.1
Riverside fish farm	1	2.2	7.3

ND = not detected.

Table 40 Caesium radioactivity in perch, 1987.

Location	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
Windermere	5	28	80
Loweswater	25	350	950
Crummock Water	3	160	460
Devoke Water	77	560	1600
Coniston Water	1	24	100
Eskdale Green	1	98	260
River Esk	1	220	540
Malham Tarn, Yorks	4	65	210
WALES			
Llyn Trawsfynydd	38	180	1300
Alwen Reservoir	5	140	350
Llyn Celyn	2	12	57
Bala Lake	2	85	210
Llyn Hiraethlyn	5	610	1600
SCOTLAND			
Loch Doon	3	170	460
Loch Faskally	1	60	170
NORTHERN IRELAND			
Lough Neagh	2	17	46

Table 41 Caesium radioactivity in char, 1987.

Location	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
Windermere	18	24	57
Ennerdale Water	22	62	170
Crummock Water	1	81	310
Coniston Water	1	14	36
WALES			
Llyn Padarn	2	27	73
SCOTLAND			
Loch Doon	6	96	310
Loch Rannoch	4	80	200

Table 42 Caesium radioactivity in pike, 1987.

Location	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
Windermere	14	32	83
Crummock Water	8	130	330
Loweswater	23	270	690
WALES			
Bala Lake	14	29	85
Llyn Celyn	1	27	83
SCOTLAND			
Loch Dee	3	970	2300
Loch Faskally	2	160	450
Loch Trool	1	180	600

Table 43 Caesium radioactivity in salmon, 1987.

Location	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
WALES			
Bala Lake	1	ND	ND
River Seiont	3	"	25
SCOTLAND			
River Tay	2	"	ND
River Annan	1	"	"

ND = not detected.

Table 44 Caesium radioactivity in eels, 1987.

Location	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
River Calder	2	13	99
Windermere	1	10	23
River Mite	1	10	50
River Irt	1	14	38
Devoke Water	1	210	640
Scalderskew Beck	1	ND	25
Knott End fishery	1	"	27
Chapel Hill Tarn	1	120	290
Crummock Water	1	33	80
Scar Green	1	25	67
Eskdale Green	3	190	540
WALES			
Llyn Trawsfynydd	4	83	520
Llyn Mymbyr	1	24	70
Llyn Ogwen	5	52	160
Bala Lake	1	ND	15
Llyn Celyn	1	"	4.9
SCOTLAND			
Loch Faskally	2	24	74
NORTHERN IRELAND			
Lough Neagh	12	ND	12
Lough Erne	1	"	10

ND = not detected.

Table 45 Caesium radioactivity in sea trout, 1987.

Location	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
ENGLAND			
River Calder	1	2.4	41
River Kent	1	3.3	47
River Duddon	1	2.8	40
Ravenglass	1	2.3	25
River Lune	1	ND	65
River Hodder	1	4.0	55
SCOTLAND			
River Tay	3	2.6	10
River Annan	1	ND	15
River Tummel	1	"	10

ND = not detected.

Table 46 Caesium radioactivity in various freshwater fauna, 1987.

Location		No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
			^{134}Cs	^{137}Cs
ENGLAND				
Mussels	Windermere	1	ND	ND
Crayfish	"	1	"	19
Lamprey	River Mite	1	"	33
Powan	Ullswater	6	25	51
WALES				
Rudd	Llyn Trawsfynydd	8	56	390
Grayling	Bala Lake	1	20	51
Brook trout	Alwen Reservoir	2	ND	8.8
"	Llyn Padarn	1	17	38
Chub	Llyn Vyrnwy	9	78	200
Gwyniad	Bala Lake	2	19	51
Roach	" "	7	16	42
Minnow	Llyn Ogwen	1	250	610
"	Llyn Mymbyr	1	140	570
SCOTLAND				
Grayling	River Tummel	2	150	420
"	River Ayr	2	32	60
"	River Gryfe	6	15	47
"	River Leader	1	ND	ND
NORTHERN IRELAND				
Rudd	Lough Brickland	1	29	64
Vendace	Lough Neagh	2	7.0	14

ND = not detected.

Table 47 Estimates of maximum dose* to adults due to consumption of freshwater fish from areas of high deposition of Chernobyl fallout, 1987.

Region	Location	Committed effective dose equivalent, mSv year^{-1}
England	Loweswater	0.4
Wales	Llyn Goddionduon	0.7
Scotland	Loch Dee	0.8
Northern Ireland	River Bush	0.09
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 1987, relating to liquid radioactive waste discharges from nuclear establishments, is presented in Table 48. The exposures are expressed in terms of the committed effective dose equivalents to, or as doses to skin of, members of the critical groups. Results for internal exposures incorporate the cautious value of 0.001 for the gut transfer factor of plutonium and americium (ICRP, 1986) except where a more appropriate value is justified (sub-section 3.4). Committed effective dose equivalents were all within the ICRP-recommended principal dose limit of 1 mSv year^{-1} for members of the public.

The more important contributions to exposures from the effects of discharges from Sellafield were due to radiocaesium and transuranic radionuclides. Details are given in sub-section 4.1.1. Exposures near Sellafield decreased in 1987 as compared with 1986, mainly due to the effect of the reducing trend in discharges, which outweighed the effect of a small increase in consumption of locally-caught molluscan shellfish. Consumption rates could increase again in the future, but is is considered unlikely that exposures, calculated using realistic parameters, will again exceed the 1 mSv $year^{-1}$ level. Even though further significant reductions in discharges are not likely until the Enhanced Actinide Removal Plant (EARP) commences operation, scheduled for 1992, it is expected that exposures will continue to decline in line with our predictions (Hunt, 1986) because of the dispersion time in the environment. Dose rates which were above the 1 mSv $year^{-1}$ level in the past did not occur for long enough for lifetime exposure to have exceeded 1 mSv $year^{-1}$ on average, and thus the dose limitation objectives of the ICRP will be met.

Near Trawsfynydd, exposures were broadly similar to those in recent years, there being a slight increase for 1987 as compared with 1986 (0.17 mSv) because of environmental factors, including the continued contribution of radioactivity from Chernobyl (see sub-

Table 48 Summarised estimates of public radiation exposure from discharges of liquid radioactive waste in the UK, 1987.

Establishment	Radiation exposure pathway	Critical group	Exposure⁺, mSv
BRITISH NUCLEAR FUELS LIMITED			
Sellafield	Fish and shellfish consumption	Local fishing community	0.10 (0.33)*
	External	Houseboat dwellers (River Ribble)	0.24
	Handling of fishing gear	Local fishing community	<0.1[‡]
	Porphyra/laverbread consumption	Consumers in South Wales	<0.01
Springfields	External	Houseboat dwellers (River Ribble)	0.24[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			
Harwell	Fish consumption External	Anglers**	<0.01
Winfrith	Fish and shellfish consumption	Local fishing community	0.11
Dounreay	Handling of fishing gear	Local fishermen	<0.1[‡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	<0.003[b]
Bradwell	Fish and shellfish consumption External	Local fishing community Houseboat dwellers	0.01[b]
Dungeness	Fish and shellfish consumption External	Local fishing community	<0.004
Hartlepool	Fish and shellfish consumption	Local fishing community	<0.01[a]
	External	Coal collectors	<0.01[a]
Heysham	Fish and shellfish consumption External	Local fishing community	0.06 (0.12)*[a] <0.1[a]
Hinkley Point	Fish and shellfish consumption External	Local fishing community	<0.003[b]
Hunterston	Fish and shellfish consumption External	Local fishing community	0.03[a]
Sizewell	Fish and shellfish consumption External	Local fishing community	<0.003[b]
Trawsfynydd	Fish consumption	Local fishing community	0.25
Wylfa	Fish and shellfish consumption External	Local community	<0.05[a]

Table 48 Continued.

Establishment	Radiation exposure pathway	Critical group	Exposure+, mSv
DEFENCE ESTABLISHMENTS			
Aldermaston	Fish consumption External	Anglers**	<0.002
Chatham	External	Houseboat dwellers	<0.01
Devonport	External	Bait diggers	<0.01
Faslane	External	Boatyard workers	<0.01[b]
Rosyth	External	Dredgermen	<0.01[b]
Holy Loch	External	Local community	<0.01[b]
AMERSHAM INTERNATIONAL plc			
Amersham	Fish consumption External	Anglers**	<0.003
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.
**A notional group with maximising consumption and occupancy rates has been assumed (see text).
‡ Exposure to skin, to be compared with the ICRP-recommended dose limit of 50 mSv $year^{-1}$ (see sub-section 3.4).
a Mainly due to discharges from Sellafield.
b Partly due to discharges from Sellafield.

section 6.10). The effect of reduced concentrations of radiocaesium in lake water, observed in 1987, is expected to lead to decreased exposures in 1988.

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 the small contribution due to weapons-test fallout) are quoted in Table 48, with appropriate footnotes. The effects of fallout from the Chernobyl accident are also included, but near coastal establishments there was a negligible contribution to the exposures of critical groups. 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 the continuing radiological effects in 1987 were still minor, conservative estimates of exposures remaining within 1 mSv $year^{-1}$.

As in previous years, collective doses have also been considered. The most significant radioactive waste discharges giving rise to collective dose, compared with which all other discharges may be disregarded, were those from Sellafield, radiocaesium being the most significant component. Details are given in sub-section 4.1.1. In 1987 there was still 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 committed effective dose equivalent to the UK population in 1987 was 30 man-Sv, a significant decrease as compared with 1986 (50 man-Sv) mainly due to reductions in discharges from Sellafield; the contribution due to radioactivity from Chernobyl also decreased. For the population of other European countries the preliminary collective committed effective dose equivalent was 60 man-Sv in 1987, also less than in 1986 (90 man-Sv), reflecting the reductions in discharges from Sellafield.

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