ISSN 0142-2499

MINISTRY OF AGRICULTURE FISHERIES AND FOOD

DIRECTORATE OF FISHERIES RESEARCH

AQUATIC ENVIRONMENT MONITORING REPORT

NUMBER 13

RADIOACTIVITY IN SURFACE AND COASTAL WATERS OF THE BRITISH ISLES, 1984

G.J. HUNT

LOWESTOFT 1985

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD
DIRECTORATE OF FISHERIES RESEARCH

AQUATIC ENVIRONMENT MONITORING REPORT
NUMBER 13

Radioactivity in surface and coastal waters of the British Isles, 1984

G J HUNT

LOWESTOFT 1985

The author:

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

Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft, (13) 46 pp.

CONTENTS

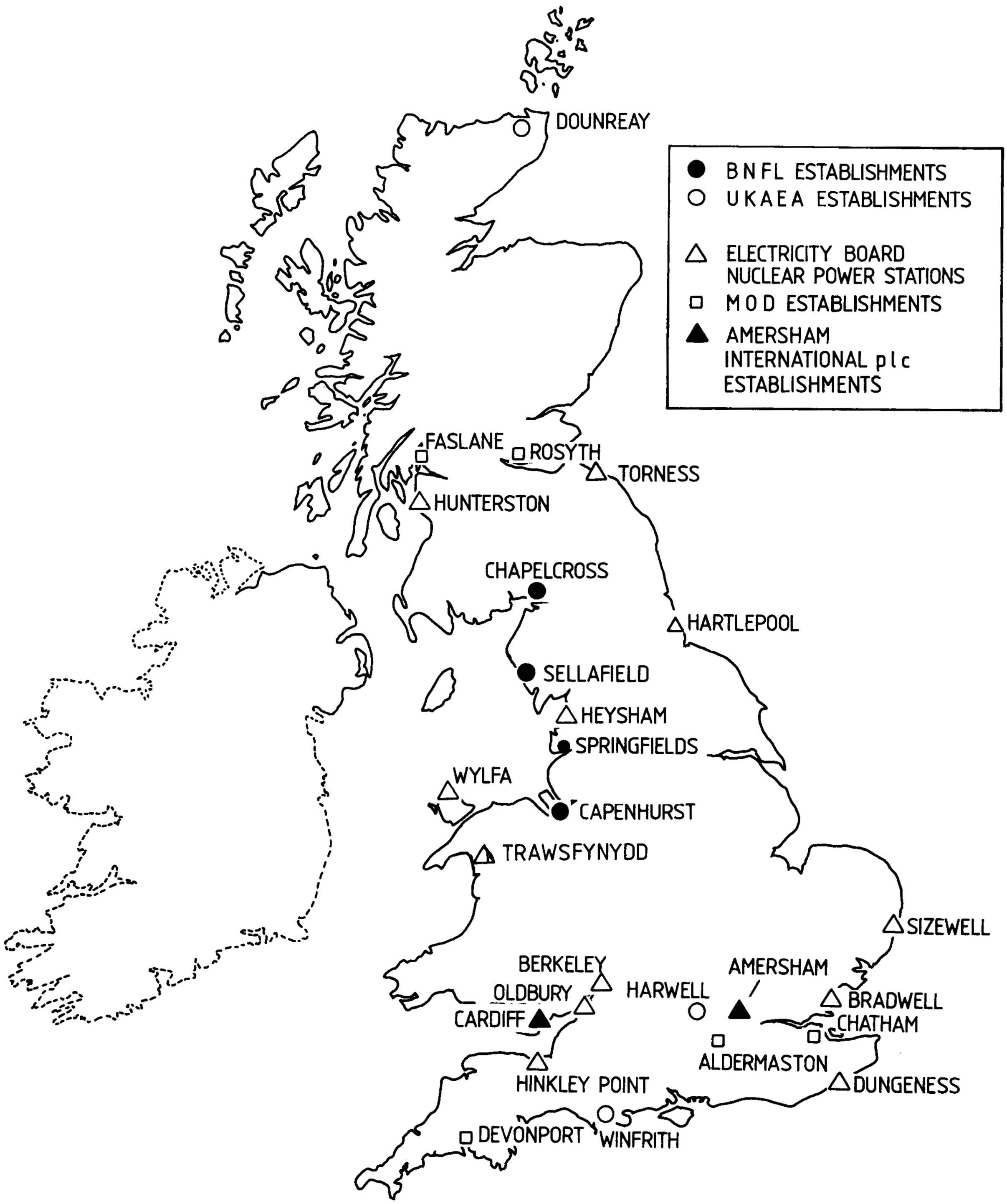

Figure 1 UK nuclear establishments giving rise to principal discharges of liquid radioactive waste.

1. Introduction

This report presents the results of the environmental monitoring programme carried out during 1984 by staff of the Directorate of Fisheries Research, Lowestoft. The monitoring programme is part of the Ministry's responsibilities 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.

To set the monitoring results in proper context, liquid radioactive discharges from UK nuclear establishments to the aquatic environment in 1984 are first summarised. Before exposition of the monitoring results, an explanatory section gives details of how the results are presented and 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 1984 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 1984. 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 establishments, administratively agreed. Discharges are given both in terabecquerels (see sub-section 3.1) and curies. The limits are given in the units specified in the relevant authorisation. 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, 1982). For each discharge the percentage of the authorised (or agreed) limit taken up in 1984 is 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 1984 the radioactivity released into the waters of Holy Loch was less than 0.04 GBq (1 mCi) of long-lived gamma radioactivity, primarily cobalt-60; less than 0.04 GBq (1 mCi) of short-lived radionuclides; less than 0.04 GBq (1 mCi) of fission product radionuclides; and less than 0.4 GBq (10 mCi) of tritium.

2.2 Solid radioactive waste

In addition to receiving most of the above liquid discharges the marine environment has also received low specific activity packaged solid waste, disposed of not in coastal waters but in an area of the deep Atlantic Ocean. The disposals have conformed to the requirements of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (The London Dumping Convention), including the Definition of high-level radioactive waste unsuitable for dumping at sea and Recommendations on dumping procedure promulgated by the International Atomic Energy Agency (IAEA) for contracting parties to the Convention. Disposals have been organised within the Multilateral Consultation and Surveillance Mechanism operated by the Nuclear Energy Agency (NEA) of the Organisation for Economic Cooperation and Development (OECD). No disposal operation was carried out in 1984 whilst an independent UK review of these disposals, commissioned by the Government and the Trades Union Congress, was in progress. The recommendations of this review (Holliday, 1984), which have been broadly accepted by the Government, include that disposals should not be resumed until current international reviews have been completed and an examination of Best Practicable Environmental Option (BPEO) for different wastes has been carried out. The quinquennial review by the OECD (NEA) of the suitability of the dumpsite is now complete (OECD (NEA), 1985), and has concluded that the site could continue to be used for the next five years although its suitability should be reconsidered if disposal rates should exceed ten times those in recent years. The IAEA review of the Definition and Recommendations referred to above is also complete (International Maritime Organisation, 1985a), as is the *ad hoc* review by the London Dumping Convention of the scientific and technical considerations (International Maritime Organisation, 1985b). The expert panel who carried out this *ad hoc* review concluded that no scientific or technical grounds could be found to treat the option of sea dumping differently from other available options when applying internationally accepted principles of radiological protection to radioactive waste disposal. The BPEO study is in progress, and an interim report has been published (DOE, 1985).

Table 1 Principal discharges of liquid radioactive waste from UK nuclear establishments, 1984.

Establishment	Radioactivity	Discharge limit (annual equivalent), Ci*	Discharges during 1984 TBq	Ci	% of limit
BRITISH NUCLEAR FUELS plc					
Sellafield					
Sea pipeline	Total beta	300 000	1 190	32 166	11
	Ruthenium-106	60 000	348	9 408	16
	Strontium-90	30 000	72	1 933	6.4
	Total alpha	6 000	14	368	6.1
Seaburn sewer	Total activity	4	0.0038	0.10	2.6
Springfields	Total alpha	360	0.80	22	6.0
	Total beta	12 000	152	4 120	34
Chapelcross	Total activity[1]	700	0.48	13	1.9
	Tritium	150	0.24	6.5	4.4
Capenhurst					
Rivacre Brook	Total activity[2]	0.04	0.00024	0.0064	16
Meols outfall	Technetium-99	4	0.0018	0.050	1.2
UNITED KINGDOM ATOMIC ENERGY AUTHORITY					
Winfrith	Total activity	30 000	113	3 057	10
	Ruthenium-106	9 000	0.52	14	<1
	Strontium-90	1 200	0.33	8.8	<1
	Total alpha	1 200	0.052	1.4	<1
Harwell	Total activity[1,3]	240	0.70	19	7.9
	Tritium	240	1.7	47	20
Dounreay	Total activity	24 000	52	1 414	5.9
	Strontium-90	2 400	13	340	14
	Total alpha	240	0.63	17	7.1
CENTRAL ELECTRICITY GENERATING BOARD					
Berkeley	Total activity[1]	200	0.36	9.8	4.9
	Tritium	1 500	1.3	35	2.3
Bradwell	Total activity[1]	200	0.82	22	11
	Zinc-65	5	0.0025	0.068	1.4
	Tritium	1 500	8.0	215	14
Dungeness					
"A" Station	Total activity[1]	200	1.7	47	24
	Tritium	2 000	0.37	9.9	<1
"B" Station	Total activity[1,4]	4 TBq	0.012	0.32	<1
	Sulphur-35	25 TBq	0.041	1.1	<1
	Tritium	650 TBq	5.4	146	<1
Hartlepool	Total activity[1,4]	4 TBq	<0.014	<0.39	<1
	Sulphur-35	7.5 TBq	0.11	2.8	1.4
	Tritium	1 850 TBq	19	514	1.0
Heysham[5]	Total activity[1,4]	4 TBq	0.0044	0.12	<1
	Sulphur-35	7.5 TBq	0.055	1.5	<1
	Tritium	1 850 TBq	17	453	<1
Hinkley Point[6]					
"A" Station	Total activity[1]	200	2.2	61	30
	Tritium	2 000	0.53	14	<1
"B" Station	Total activity[1,4]	100	0.046	1.2	1.2
	Sulphur-35	700	0.88	24	3.4
	Tritium	18 000	339	9 164	51
Oldbury	Total activity[1]	100	1.7	46	46
	Tritium	2 000	1.0	28	1.4
Sizewell	Total activity[1]	200	0.90	24	12
	Tritium	3 000	1.2	34	1.1
Trawsfynydd	Total activity[1]	40	0.37	10	25
	Caesium-137	7	0.034	0.91	13
	Tritium	2 000	0.78	21	1.1
Wylfa	Total activity[1]	65	0.095	2.6	4.0
	Tritium	4 000	12	330	8.2

Table 1 Continued

Establishment	Radioactivity	Discharge limit (annual equivalent), Ci*	Discharges during 1984		
			TBq	Ci	% of limit
SOUTH OF SCOTLAND ELECTRICITY BOARD					
Hunterston "A" Station[7]	Total activity[1]	7.5 TBq	2.7	72	36
	Tritium	48 TBq	1.3	34	2.8
"B" Station	Total activity[1,4]	100	0.14	3.7	3.7
	Sulphur-35	700	3.2	86	12
	Tritium	40 000	301	8 146	20
MINISTRY OF DEFENCE (PROCUREMENT EXECUTIVE)					
Aldermaston	Total activity[1,3]	156	0.089	2.4	1.5
	Tritium	156	0.10	2.8	1.8
MINISTRY OF DEFENCE (NAVY DEPARTMENT)					
Chatham[8]	Total activity[1]	20	0.0	0.0	0.0
	Cobalt-60	10	0.0	0.0	0.0
	Tritium	20	0.0	0.0	0.0
Devonport	Total activity[1]	4	0.0047	0.13	3.2
	Cobalt-60	1	0.0045	0.12	12
	Tritium	10	0.030	0.82	8.2
Faslane	Total activity[1]	1	0.00024	0.0065	<1
Rosyth	Total activity[1]	30	0.0038	0.103	<1
AMERSHAM INTERNATIONAL plc					
Amersham	Total activity[1,3]	72	0.47	13	17
	Tritium	400	0.040	1.1	<1
Cardiff	Beta/gamma activity[9]	96 GBq	0.019	0.52	20
	Carbon-14	2 TBq	1.1	29	54
	Tritium	1 400 TBq	543	14 676	39

[1]Excluding tritium.
[2]Excluding uranium and its decay products.
[3]Authorisation or agreement specifies a control formula in which the total activity is calculated in equivalent curies, intended to allow for the relative radiotoxicities of different nuclides. The sums of the actual discharges in curies were lower than the values indicated. Column 4 gives equivalent terabecquerels.
[4]Excluding sulphur-35.
[5]Discharges are from Heysham I.
[6]A single site authorisation applies at Hinkley Point. The table format represents the way in which it has been agreed that the authorisation should be apportioned in practice.
[7]The total activity limit reverted to 7.5 TBq year^{-1} from 16 TBq year^{-1} with effect from June 1984.
[8]Discharges due to routine operations ceased in 1983 prior to closure of the site on 31 March 1984.
[9]Excluding tritium, carbon-14 and radioisotopes of calcium and strontium.
*Unless otherwise stated.

International surveillance of the effects of these disposals is coordinated by the OECD (NEA) by means of a Coordinated Research and Environmental Surveillance Programme (CRESP) (OECD (NEA), 1981). Routine environmental monitoring does not provide an effective means of assessing radiation exposure from these disposals as their effects are largely undetectable (OECD (NEA), 1985). In the absence of readily detectable effects radiation exposure is assessed mainly by the use of mathematical modelling. The emphasis of surveillance within CRESP has been to improve, by means of appropriate research, the data for modelling assessments. These assessments indicate that the environmental impact of these disposals is negligible (OECD (NEA), 1985).

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

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.

Table 2 Radiological units used in this report.

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

3.2 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(T1) 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 strontium-90 and technetium-99, 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 dispersion conditions in the receiving environment. The presentation of the summarised results reflects the purpose of this monitoring which is interpretation in terms of public radiation exposures. The method of interpretation is described more fully in sub-section 3.4. The appropriate integration period for comparison with recommended limits is at least one year; standard practice is to combine annual rates of consumption or occupancy of the more highly exposed members of the public (the critical group) with the arithmetic means of observed radioactivity concentrations or dose rates, respectively, during the year. The use of, say, the highest observed (but unsustained) radioactivity concentration with an annual consumption rate would not provide a realistic comparison with the recommended limits. Therefore, the tables present the arithmetic means of observations made during the year.

The frequency of sampling reflects the resolution (which affects the accuracy) judged to be necessary in the assessment of dose and is largely governed by the radiological importance. 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 gamma dose rates, which are measured using portable instruments, each observation consists of the mean of a number of individual readings at a given location. This number again depends upon the radiological importance of the observation; the locations chosen are generally those where there is likely to be occupancy by persons as determined by habits surveys (see sub-section 3.4).

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

Measurements on biota are given in terms of concentrations in wet material in the state in which it is collected. For fish and shellfish the concentrations apply to the edible fractions, because the purpose is assessment of internal exposure of the consumer. 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.

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 Methods of interpretation

The monitoring results in this report are interpreted in terms of radiation exposures of the public. The standards against which these exposures are judged are the recommendations of the ICRP. For many years these recommendations have been endorsed for use in the UK by appropriate advisory bodies. Current UK practice relevant to the general public is mainly based on the recommendations of the ICRP as set out in ICRP Publication 26 (ICRP, 1977). The dose limitation system embodied therein has been accepted as national policy (Great Britain — Parliament, 1982). 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. In this report, results have been interpreted also on the basis of these recommendations, taking account of recent explanatory statements by the ICRP.

The effect of these recommendations on the interpretation of the results will be briefly described. The ICRP prescribes a system of dose limitation which includes, within appropriate dose limits to individuals, that "all exposures shall be kept as low as reasonably achievable...." (ALARA). The requirement for ALARA involves consideration of collective as well as individual doses in radiological control procedures. As in previous reports in this series, collective doses from liquid radioactive waste discharges continue to be kept under review. ICRP Publication 26 does not recommend a dose limit for populations; such a limit might be regarded as suggesting the acceptability of a higher population exposure than is either necessary or probable. The ICRP concludes that its system of dose limitation is likely to ensure that the annual dose equivalent averaged over the population from all sources, excluding natural and medical irradiation, will not exceed 0.5 mSv. The NRPB considers (NRPB, 1978) that maintenance of the annual dose equivalent below this value when averaged over the whole UK population is a reasonable objective; further, that the contribution from all UK waste management practices is unlikely to exceed one tenth of this, that is 0.05 mSv $year^{-1}$. In this report an annual average dose equivalent of 0.05 mSv has been used for reference purposes regarding collective doses. By comparison, the average annual effective dose equivalent in the UK from natural radiation is approximately 2 mSv (Hughes and Roberts, 1984).

ICRP Publication 26 recommends that doses should meet the ALARA objective, subject to compliance with appropriate individual dose limits. Control of individual exposures is intended to limit stochastic effects (i.e. those whose probability depends on the dose) to an acceptable level and to prevent non-stochastic (threshold) effects. For stochastic effects, it is recommended that the risk should be equal whether the whole body is irradiated uniformly or non-uniformly; weighting factors proportional to the risk are defined for different organs. The weighted sum 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 includes the integrated exposure over 50 years following an intake. The ICRP has recently (ICRP, 1985) made known its present view that the principal limit for the committed effective dose equivalent received by a member of the public is 1 mSv in a year. However, it is permissible to use a subsidiary dose limit of 5 mSv in a year for some years provided that the average annual committed effective dose equivalent over a lifetime does not exceed 1 mSv $year^{-1}$. The ICRP-recommended dose limits for members of the public apply to appropriate critical groups of people likely to be the most exposed. The NRPB (NRPB, 1978) notes that the use of a limit of 5 mSv $year^{-1}$ combined with the technique of optimisation (the ALARA principle) will in most cases result in an average dose equivalent to a critical group of less than 1 mSv $year^{-1}$ of whole body exposure over a lifetime. This advice has more recently been strengthened (NRPB, 1984a) to indicate that procedures leading to exposure of the public should be controlled deliberately to ensure that the lifetime committed effective dose equivalent does not exceed 70 mSv. The ICRP has indicated (ICRP, 1984) that because of the limitation on lifetime exposure, non-stochastic effects in members of the public will be avoided. This applies for those organs included in assessment of effective dose; for a few special cases, specific non-stochastic limits are appropriate. For example, the ICRP continues to recommend (ICRP, 1985) the limit for skin of 50 mSv $year^{-1}$.

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

Only general guidance has been given by the ICRP (ICRP, 1984) on the calculation of committed effective dose equivalents following intakes of radionuclides by members of the public. In this report, the data on committed effective dose equivalents per unit intake for workers, derived from supplements to ICRP publication 30 (ICRP, 1979, 1981, 1982a, 1982b), have been used, together with modifications for members of the public described below. This basic procedure, which we have used since the inception of ICRP-26 rather than the direct use of Annual Limits on Intake, has essentially been reaffirmed by the ICRP statement on avoidance of non-stochastic effects (ICRP, 1984), and no change in methods is needed. Our methods include appropriate modifications for members of the public incorporating consideration of children where they are known to be members of critical groups and the use of appropriate gut uptake factors. In advance of a review by the ICRP, the NRPB has recently published (NRPB, 1984b) advice on gut uptake factors for actinides. This advice is that, for adult members of the public ingesting low concentrations of plutonium in food, an appropriate value of absorption factor by the gut is a factor of 5 higher than that currently used in ICRP Publication 30 for relevant forms of plutonium, except when a lower value can be justified. The effect is to enhance estimates of dose from plutonium essentially by this factor, and these higher values are quoted in this report; alongside are given, in important cases, the doses derived using the unenhanced gut uptake factors used in ICRP Publication 30. It is re-emphasised that especially for nuclides with long body retention times, such as the transuranics, committed doses are not completely received in the year of intake but over a longer period; a limit to integration of 50 years is used by the ICRP. Thus doses actually received in one year will be less than the committed doses.

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 a group (the critical group) of persons most highly exposed through a particular pathway or pathways. In this report, critical group habits data relevant to a given establishment are combined with the results of environmental monitoring and appropriate dosimetric data as above to estimate the committed effective dose equivalent to the critical group, which may then be compared with the ICRP-recommended dose limits.

4. British Nuclear Fuels plc (BNFL)

BNFL is concerned mainly with the design and production of fuel for nuclear reactors and its reprocessing after irradiation. The company also operates nuclear power plant supplying electricity to the national grid. We regularly monitor the environmental consequences of discharges of liquid radioactive waste from four BNFL sites, namely Sellafield, Springfields, Capenhurst and, on behalf of departments of the Scottish Office, Chapelcross.

4.1 Sellafield, Cumbria

Operations and facilities at this establishment include fuel element storage and decanning, the Windscale nuclear fuel reprocessing plant and the Calder Hall magnox-type nuclear power station. The most significant liquid radioactive waste discharges are from the fuel element storage ponds and the reprocessing plant, through which passes all the irradiated Magnox fuel from the UK nuclear power programme, and some fuel from abroad. Most of the nuclear waste separated from the fuel is presently stored on site; relatively small quantities of radioactivity are discharged to the north-east Irish Sea, through pipelines which terminate 2.1 km beyond low-water mark. With effect from 16 February 1983 the authorisation to discharge these wastes was varied to reflect the need to limit discharges such that radiation exposures are as low as reasonably achievable (ALARA). This need had been recognised in the past to comply with ICRP principles, as described in sub-section 3.4 (e.g. Hunt, 1984).

Discharges from the Sellafield pipelines during 1984 are summarised in Table 1, and were within the limits set by the authorising Departments. Discharges of total beta activity, at 11% of the authorised limit, were less than in 1983 (22%). Total beta discharges are substantially dependent upon releases of radiocaesium which mainly originate from the fuel element storage ponds. In 1984 caesium-137 pipeline discharges totalled 434 TBq, a lower total than in 1983 (1 200 TBq). This reduction was brought about by the continued optimisation of the use of zeolite skips in the ponds to absorb caesium (Hunt, 1984) and the use of other measures, in order to ensure that doses were ALARA (sub-section 3.4) as required by the authorising Departments. Strontium-90 discharges in 1984 were less than in 1983. Discharges of ruthenium-106, which derives mainly from operations other than in the ponds, were 348 TBq, also less than for 1983 (553 TBq). Discharges of alpha-emitting radionuclides in 1984 totalled 13.6 TBq, slightly less than in 1983 (14 TBq).

Our total monitoring effort increased during 1984 mainly as a result of the incident in November 1983 (DOE, 1984; Health and Safety Executive, 1984); in addition to the incident-related monitoring our regular monitoring programme has been revised and increased. The results of the incident-related monitoring up to July 1984 have already been published (MAFF, 1983, 1984; DOE and MAFF, 1985). Briefly, this monitoring showed that the effects of incident-related contamination through the marine pathways which are significant in the case of routine discharges gave no cause for concern. Items of localised contamination were detected on the beaches but considering all the relevant factors it is not considered likely that anybody has received a dose in excess of the ICRP non-stochastic limit for skin (sub-section 3.4). In this report incident-related monitoring is not considered further but results of measurements which were also part of our regular monitoring are included so as to derive a balanced picture for the whole of 1984.

The two critical radiation exposure pathways continued to be from consumption of fish and shellfish and from external exposure to gamma rays from occupancy over sediments. Following established practice, the largest monitoring effort has been expended on these pathways. In 1984, 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 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 materials may not be available commercially, we also carry out specific surveys sampling fish and shellfish from the Sellafield vicinity. The location "Sellafield Shoreline Area" is close inshore in this vicinity. "Sellafield Offshore Area" represents a rectangle, one nautical mile wide and two nautical miles long, situated south of the pipeline with the long side parallel to the shoreline; this Area 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, such that the ratio of caesium-137 to caesium-134 (half-lives 30 years and 2 years respectively) increases with distance. At large distances, and remote from the smaller discharges from elsewhere, concentrations of artificial radioactivity tend towards those from weapons-test fallout. For caesium-137 in fish, measurements remote from land run-off indicate a value of about 0.1—0.4 Bq kg^{-1} from this source. Variations between 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 radiocaesium in 1984 were generally less than in 1983 for fish from all sea areas but particularly those close to Sellafield. This is attributed to reduced concentrations in sea water, following the decreasing trend in radiocaesium discharges, and particularly the large reduction for 1984 most of which has yet to be reflected in concentrations in areas further afield.

Table 4(a) Beta/gamma radioactivity in fish from the Irish Sea vicinity and further afield, 1984.

Sampling area/landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}		
			Total beta	^{134}Cs	^{137}Cs
Sellafield shoreline area[1]	Cod	11	540	20	450
	Grey mullet	1	390	13	315
Sellafield offshore area[1]	Plaice	4	320	9.1	220
	Flounder	1	390	11	320
	Dab	4	290	8.2	200
	Skate	2	300	9.2	200
	Whiting	1	480	18	410
	Cod	2	420	12	270
Ravenglass[2]	Cod	9	340	11	250
	Plaice	11	270	7.9	180
Morecambe Bay[1]	Flounder	4	400	9.5	310
Whitehaven[2]	Cod	4	280	6.8	170
	Plaice	5	220	5.6	150
	Herring	4	170	2.7	75
Fleetwood[2]	Cod	4	220	4.9	130
	Plaice	4	170	3.6	110
Cumbrian rivers[4]	Sea trout	6	260	6.1	190
Isle of Man[2]	Cod	3	180	2.9	74
	Plaice	2	120	2.0	47
	Herring	2	140	1.7	51
	Saithe	1	190	2.3	66
	Lemon sole	2	120	0.5	27
	Whiting	1	130	1.2	42
Inner Solway[1]	Salmon	1	110	ND	1.5
	Sea trout	2	200	4.3	120
	Flounder	4	290	5.9	220
Kirkcudbright[2]	Plaice	4	170	2.9	81
North Anglesey[1]	Pollack	1	170	2.6	84
Northern Ireland[2]	Whiting	4	190	3.2	95
Ayr[2]	Plaice	4	NA	1.0	35
	Cod	4	"	1.8	62
Minch[1]	Plaice	4	130	0.5	15
	Cod	4	150	0.7	23
	Herring	1	96	0.3	7.8
Northern North Sea[1]	Plaice	5	100	0.08	5.1
	Cod	7	120	0.09	5.9
	Haddock	4	NA	0.08	3.2
	Saithe	2	"	ND	4.1
	Whiting	1	"	"	5.6
	Herring	1	110	"	5.1
Mid-North Sea[1]	Plaice	10	89	0.03	4.5
	Cod	9	130	0.1	9.5
	Haddock	5	NA	0.1	5.7
	Herring	1	110	ND	6.4
	Whiting	1	NA	0.5	21
Southern North Sea[1]	Plaice	4	100	0.06	4.0
	Cod	4	130	0.1	5.8
	Whiting	2	NA	ND	5.0
Barents Sea[1]	Cod	2	110	"	1.4
Iceland area[1]	Cod	4	110	"	0.6
	Plaice	3	90	"	0.1

ND = not detected; NA = not analysed; [1]Sampling area; [2]Landing point; [3]See section 3.3 for definition; [4]Samples collected from a number of rivers by the North West Water Authority.

Analyses of samples of fish for strontium-90 and technetium-99 were included in our monitoring programme for 1984, to enable 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. Estimates of concentrations of these nuclides in past years were based on discharge data, and showed that their radiological significance was low, and much less than for radiocaesium. The data for 1984, shown in Table 4(b), confirm this observation, giving only very small contributions to the total exposures presented later in this report.

Table 4(b) Strontium-90 and technetium-99 in fish from the Irish Sea vicinity, 1984.

Sampling area/landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}	
			^{90}Sr	^{99}Tc
Sellafield offshore area[1]	Plaice	1	0.87	NA
	Cod	1	0.59	0.30
Ravenglass[2]	Plaice	1	1.2	0.94
	Cod	1	0.62	0.32
Whitehaven[2]	Plaice	4	0.86	NA
	Cod	1	0.61	NA

NA = not analysed; [1]Sampling area; [2]Landing point;
[3]See section 3.3 for definition.

For shellfish, a wide range of radionuclides contributes to radiation exposure of consumers owing to generally higher concentration factors in these foods 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 strontium-90 and technetium-99 are included for 1984. Winkles are of particular radiological importance to the critical group of shellfish consumers 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 at Coulderton and St Bees, coastal areas typically exploited by this critical group.

Concentrations of radionuclides in shellfish, as with fish and as in previous years, diminished with increasing distance from Sellafield; the rate of reduction was least for nuclides which are conservative to sea water, such as isotopes of caesium. There were also, as previously, substantial variations between species: in general, molluscs tend to concentrate the less conservative nuclides to a greater extent than do crustaceans, which in turn tend to concentrate them more than fish; the reverse behaviour is generally observed for conservative nuclides.

Concentrations of radiocaesium in shellfish in 1984, as for fish, showed general reductions as compared with 1983, reflecting the trend of discharges. This trend was also observed for most other nuclides including ruthenium-106.

Public radiation exposure from transuranic nuclides in fish is lower than from radiocaesium. Analyses for transuranics are also labour-intensive. Therefore, a selection of samples of fish and shellfish chosen mainly on the basis of potential radiological significance were analysed for transuranic nuclides; the number of transuranic analyses was further increased in 1984. Analyses were often carried out on bulked samples (sub-section 3.3). The data for 1984 are presented in Table 6. Transuranics are less conservative to sea water than is radiocaesium; this is reflected in higher concentrations of transuranics in shellfish as compared with fish, and a rapid reduction with distance in concentrations of transuranics, particularly in shellfish.

Concentrations of transuranics in fish and shellfish from the Irish Sea fluctuated about a reducing trend for 1984 as compared with 1983. The reductions were generally proportionately more than the decreases in discharges of alpha-emitting nuclides between 1983 and 1984. This was probably because the non-conservative nature of these nuclides causes a delayed effect in the environment, such that present levels are a reflection of discharges in earlier years. As predicted in our previous report (Hunt, 1985), reduced discharges of alpha-emitters in 1983 and previous years are contributing to the generally reducing trend in concentrations, and this trend is expected to continue as further reductions in discharges are effected.

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 dose rates. 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 the local fishing 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 Cumbrian coastal community, the larger population in Cumbria and north Lancashire of those associated with commercial fisheries based primarily at Whitehaven, Fleetwood and in the Morecambe Bay area contains consumers of large quantities of fish and shellfish. This therefore represents a second exposed population which is kept under review, even though, in general, the relevant fishing grounds are further afield than the Cumbrian coastal area and concentrations of radioactivity in fish landed are lower.

The consumption rates of the Cumbrian coastal community described above were kept under review in 1984. 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).

Table 5 Beta/gamma radioactivity in shellfish from the Irish Sea vicinity and further afield, 1984.

Sampling area/landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}													
			Total beta	^{54}Mn	^{60}Co	^{90}Sr	$^{95}Zr + ^{95}Nb$	^{99}Tc	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu
Sellafield shoreline area[1]	Crabs	6	520	ND	4.1	9.9	4.0	8.2	ND	350	4.9	ND	3.4	66	0.5	ND	ND
	Lobsters	9	730	0.2	3.1	2.9	2.7	370	"	170	15	"	6.6	130	4.9	1.2	0.6
	Winkles	16	5500	0.3	20	47	590	77	52	3800	20	4.4	4.6	110	22	1.2	0.5
	Mussels	18	4100	ND	15	NA	510	NA	52	3800	2.0	2.7	1.6	54	27	3.0	1.5
Sellafield offshore area[1]	Whelks	1	910	"	ND	"	25	"	4.1	770	8.3	ND	1.6	40	ND	ND	ND
Seascale[1]	Shrimps	1	330	"	2.2	"	ND	"	ND	63	ND	"	9.7	180	"	"	"
Nethertown[1]	Winkles	4	7100	1.6	23	42	2600	45	88	5400	21	11	7.4	150	55	3.8	2.4
Coulderton[1]	Winkles[4]	12	4100	0.2	22	36	1000	50	48	3200	24	3.4	4.7	120	27	2.1	0.7
	Winkles[5]	1	3200	ND	21	NA	1200	NA	60	2600	34	10	5.9	130	26	4.1	ND
	Winkles[6]	2	3600	"	18	"	890	"	38	2400	28	5.6	4.3	120	28	2.9	3.1
	Mussels[4]	5	3000	"	13	"	680	"	38	2800	1.3	0.6	2.3	57	31	3.0	1.3
	Limpets[4]	6	2800	"	10	"	650	"	27	2000	9.8	5.1	5.7	140	24	2.8	3.1
Ravenglass[1]	Cockles	5	1800	ND	27	NA	380	NA	14	1700	0.5	3.8	3.2	62	26	3.1	5.1
	Mussels	5	2300	"	7.9	9.6	250	47	27	2100	ND	3.5	2.7	46	15	4.0	2.1
St Bees[1]	Winkles	5	4100	ND	16	56	1200	32	44	2700	14	7.5	5.6	140	39	2.3	2.8
	Winkles[7]	4	2300	"	10	NA	510	NA	22	1600	12	3.3	3.3	95	14	ND	1.2
	Winkles[8]	1	1400	"	6.3	"	110	"	ND	1200	16	ND	ND	76	ND	"	ND
	Mussels	4	4100	0.5	14	24	1300	41	36	2700	6.2	1.7	2.1	47	34	5.3	2.3
	Limpets	4	3000	ND	11	NA	680	NA	23	1800	11	8.0	3.9	117	25	3.8	4.4
	Limpets[7]	4	3100	"	8.2	"	500	"	15	1500	9.0	6.7	3.3	110	18	2.1	1.2
Whitehaven[2]	*Nephrops*	5	200	"	0.05	"	ND	"	"	2.8	ND	"	3.3	90	"	"	"
	Queens	1	140	"	0.7	"	"	"	"	35	"	"	ND	18	"	"	"
Roosebeck[1]	Oysters	4	370	"	0.5	"	4.2	"	0.9	290	11	"	2.4	46	"	"	"
	Pacific oysters	1	150	"	ND	"	ND	"	ND	45	ND	"	ND	34	"	"	"
Morecambe Bay[1]	Shrimps	4	170	"	0.2	0.9	"	1.3	"	2.3	"	"	3.7	98	"	"	"
	Cockles	4	320	"	2.6	2.6	12	2.6	"	140	"	0.5	1.4	46	1.4	"	0.4
Isle of Man[2]	Scallops	12	110	"	0.05	NA	ND	NA	ND	1.0	"	ND	0.4	11	ND	"	ND
Inner Solway[1]	Shrimps	4	140	"	ND	"	"	"	"	3.2	"	"	2.6	75	"	"	"
Kirkcudbright[2]	Scallops	4	63	ND	0.03	NA	ND	NA	ND	0.7	ND	ND	0.2	5.4	ND	ND	ND
	Queens	4	76	"	0.1	"	"	"	"	5.2	0.1	0.2	0.3	10	"	"	"
North Solway coast[1]	Winkles	4	180	"	ND	"	"	"	"	73	ND	ND	0.4	19	"	"	"
Loch Ryan[1]	Oysters	4	NA	"	"	"	"	"	"	ND	"	"	ND	7.3	"	"	"
	Mussels	2	"	"	"	"	"	"	"	"	"	"	"	0.5	"	"	"
Ayr[2]	*Nephrops*	1	"	"	"	"	"	"	"	"	"	"	"	13	"	"	"
Wirral[1]	Shrimps	2	91	"	"	"	"	0.76	"	"	"	"	0.8	39	"	"	"
	Cockles	2	144	"	0.9	"	"	1.6	"	14	"	"	1.4	33	"	"	"
Conwy[2]	Mussels	2	99	"	ND	"	"	NA	"	4.0	"	"	ND	11	"	"	"
North Anglesey[1]	Crabs	2	100	"	"	"	"	"	"	ND	"	"	"	14	"	"	"
Northern Ireland[2]	*Nephrops*	4	110	"	"	"	"	"	"	"	"	"	0.5	17	"	"	"
Northern North Sea[1]	*Nephrops*	4	94	"	"	"	"	"	"	"	"	"	ND	5.4	"	"	"
Mid North Sea[1]	*Nephrops*	2	110	"	"	"	"	"	"	"	"	"	"	5.5	"	"	"
	Mussels	1	42	"	"	"	"	"	"	"	"	"	"	1.5	"	"	"
	Mussels[9]	4	35	"	0.02	"	"	"	"	"	"	"	"	0.3	"	"	"
Southern North Sea[1]	Cockles	4	17	"	1.4	"	"	"	"	0.6	"	"	"	0.6	"	"	"
	Cockles[10]	3	31	"	0.3	"	"	"	"	0.6	"	"	0.03	0.8	"	"	"
	Mussels	2	43	"	ND	"	"	"	"	ND	"	"	ND	0.5	"	"	"

NA = not analysed; ND = not detected.
[1]Sampling area; [2]Landing point; [3]See section 3.3 for definition; [4]Samples collected by Consumer 116; [5]Samples collected by Consumer 174; [6]Samples collected by Consumer 460; [7]Samples collected by Consumer 311; [8]Samples collected by Consumer 471; [9]Landed in Denmark; [10]Landed in Holland.

Radioactivity concentrations in fish and shellfish eaten by the two exposed populations vary with the species involved, so in estimation of doses it is not sufficient to determine only the total consumption rates of fish and shellfish together. Our experience (illustrated by Tables 4—6) has shown, however, that for a given area, within each of the classes, fish, crustaceans and molluscs, the concentrations of given nuclides in representative samples are relatively constant. For each of the two exposed populations, therefore, critical sub-groups were identified for each class of foodstuff and mean consumption rates of the sub-groups were determined. For the Cumbrian coastal community these consumption rates appropriate to fish and crustaceans in 1984 were 36.5 kg $year^{-1}$ (100 g d^{-1}) and 6.6 kg $year^{-1}$ (18 g d^{-1}) respectively, as for 1983 (Hunt, 1985). Our surveys have revealed, however, a reduction in consumption of molluscs, from 16.4 kg $year^{-1}$ (45 g d^{-1}) in 1983 to 5.8 kg $year^{-1}$ (16 g d^{-1}) in 1984. This reduction was due to personal factors, partly a repercussion of the Sellafield incident in November 1983. Following this incident the Government issued advice to the public to avoid unnecessary use of local beaches. This advice was later modified and finally withdrawn in July 1984. The effect of this and other factors in 1984 was a reduction in use of the intertidal areas by mollusc collectors. In this report, exposures due to mollusc consumption have been assessed on the basis of the reduced consumption rate of 5.8 kg $year^{-1}$ (16 g d^{-1}); however, for comparison with previous years and because consumption rates may increase again in the future, an assessment is also presented on the basis of the previous consumption rate of 16.4 kg $year^{-1}$ (45 g d^{-1}).

Table 6 Transuranic radioactivity in fish and shellfish from the Irish Sea vicinity and further afield, 1984.

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 shoreline area[1]	Cod	4	NA	0.012	0.047	NA	0.049	0.00034	0.00056
	Crabs	2	0.025	0.55	2.1	"	5.3	0.023	0.12
	Lobsters	4	0.072	0.34	1.4	"	12	0.033	0.066
	Winkles	2	0.34	17	61	1900	53	0.78	0.24
Sellafield offshore area[1]	Plaice	1	0.00054	0.0061	0.022	NA	0.027	ND	0.000085
	Cod	1	NA	0.0075	0.033	"	0.036	"	0.00014
	Skate	1	"	0.0076	0.033	"	0.035	"	0.00026
	Whelks	1	"	1.2	5.2	"	11	0.063	0.052
Nethertown	Winkles	2	0.72	26	86	3000	57	0.97	0.32
Coulderton[1]	Winkles[4]	2	0.26	15	57	1700	54	0.49	0.21
	Mussels[4]	1	NA	13	47	NA	58	0.48	0.15
	Limpets[4]	1	"	12	46	"	50	0.32	0.32
St Bees[1]	Winkles	2	0.38	18	65	2100	54	0.74	0.32
	Winkles[5]	1	0.077	4.9	21	"	27	0.20	0.17
	Winkles[6]	1	0.14	8.6	32	NA	34	0.30	0.21
	Mussels	1	0.65	16	60	"	56	0.58	0.26
	Limpets	1	NA	12	46	"	47	0.43	0.31
	Limpets[6]	1	0.18	10	38	"	44	0.42	0.22
Ravenglass[1]	Cockles	1	NA	10	41	"	57	0.24	0.45
	Mussels	2	0.42	11	44	"	61	0.24	0.23
Ravenglass[2]	Plaice	1	0.00065	0.0079	0.031	"	0.041	ND	0.00018
	Cod	1	0.00015	0.0031	0.012	"	0.015	0.00010	0.000069
Whitehaven[2]	Plaice	1	NA	0.0029	0.012	"	0.016	ND	0.000040
	Cod	1	"	0.0022	0.0084	"	0.0071	"	0.000041
	Herring	1	"	0.0042	0.019	"	0.021	"	0.00010
	Nephrops	1	"	0.090	0.40	"	1.4	0.0066	0.0067
Roosebeck	Oysters	1	"	0.80	3.2	"	2.3	0.014	0.013
Morecambe Bay[1]	Shrimps	1	0.0015	0.019	0.081	"	0.084	ND	0.00030
	Cockles	1	0.22	1.1	4.9	"	8.9	0.037	0.035
Isle of Man[2]	Cod	1	NA	0.00011	0.00070	"	0.00091	ND	ND
	Plaice	1	"	0.00024	0.0010	"	0.0013	"	"
	Herring	1	"	0.00044	0.0021	"	0.0024	"	"
	Scallops	3	"	0.040	0.17	"	0.068	0.00024	0.00045
Inner Solway[1]	Sea trout	1	"	0.00031	0.0016	"	0.0019	ND	0.000010
Kirkcudbright[2]	Plaice	1	"	0.0010	0.0047	"	0.0063	"	ND
	Scallops	1	"	0.033	0.16	"	0.073	"	0.00036
	Queens	1	"	0.058	0.24	"	0.21	0.0013	0.0010
North Solway coast[1]	Winkles	1	"	0.71	2.8	"	3.6	ND	0.019
River Nith	Winkles	1	"	0.39	1.8	"	2.6	"	0.010
Loch Ryan	Oysters	1	"	0.018	0.090	"	0.17	"	0.00043
Wirral[1]	Cockles	1	"	0.56	2.4	"	4.6	ND	0.011
Conwy[2]	Mussels	1	"	0.048	0.20	"	0.29	"	0.0020
Northern Ireland[2]	*Nephrops*	1	"	0.0023	0.0094	"	0.026	ND	0.00010
Minch[1]	Cod	1	"	0.000062	0.00028	"	0.00038	"	ND
Northern North Sea[1]	Cod	1	"	0.000033	0.00013	"	0.00012	"	"
	Nephrops	1	"	0.0014	0.0058	"	0.0068	0.00027	0.000093
Mid North Sea[1]	*Nephrops*	1	"	0.00072	0.0030	"	0.0022	ND	0.00032
	Mussels	1	"	0.0032	0.015	"	0.0036	"	ND
	Mussels[7]	1	"	0.00028	0.0037	"	0.0012	"	"
Southern North Sea[1]	Mussels	1	"	0.0011	0.0070	"	0.0029	"	"
	Cockles	1	"	0.0040	0.020	"	0.010	"	0.00042
	Cockles[8]	1	"	0.0024	0.012	"	0.0069	"	0.00039
Iceland area[1]	Cod	1	"	0.000080	0.00028	"	0.00025	"	ND

ND = not detected.
NA = not analysed.

[1]Sampling area; [2]Landing point; [3]See section 3.3 for definition; [4]Samples collected by Consumer 116; [5]Samples collected by Consumer 471; [6]Samples colleted by Consumer 311; [7]Landed in Denmark; [8]Landed in Holland.

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

Table 7 Individual radiation exposures due to consumption of Irish Sea fish and shellfish, 1984.

Exposed population	Consumption rate used in assessment (see text)	kg $year^{-1}$	($g\ d^{-1}$)	Nuclide	Committed effective dose equivalent, mSv $year^{-1}$: On basis of current ICRP recommendations	Effect of Pu enhanced by a factor of 5 (see text)
Consumers in local fishing community	fish:	36.5	(100)	^{90}Sr	0.01	0.01
	crustaceans:	6.6	(18)	^{106}Ru	0.11	0.11
	molluscs:	5.8	(16)	^{134}Cs	0.01	0.01
				^{137}Cs	0.13	0.13
				^{238}Pu	0.01	0.05
				$^{239}Pu + ^{240}Pu$	0.04	0.20
				^{241}Pu	0.02	0.12
				^{241}Am	0.20	0.20
				Total	0.54	0.84
Consumers in local fishing community	fish:	36.5	(100)	^{90}Sr	0.03	0.03
	crustaceans:	6.6	(18)	^{106}Ru	0.28	0.28
	molluscs:	16.4	(45)	^{134}Cs	0.01	0.01
				^{137}Cs	0.15	0.15
	(Consumption rates in 1983)			^{238}Pu	0.03	0.14
				$^{239}Pu + ^{240}Pu$	0.11	0.55
				^{241}Pu	0.07	0.33
				^{241}Am	0.49	0.49
				Total	1.20	2.00
Consumers associated with commercial fisheries (Whitehaven, Fleetwood, Morecambe Bay)	fish:	131	(360)	^{90}Sr	0.01	0.01
	crustaceans:	18	(50)	^{106}Ru	0.01	0.01
	molluscs:	15	(40)	^{134}Cs	0.02	0.02
				^{137}Cs	0.28	0.28
				^{238}Pu	0.002	0.01
				$^{239}Pu + ^{240}Pu$	0.01	0.04
				^{241}Pu	0.01	0.03
				^{241}Am	0.08	0.08
				Total	0.41	0.47
Typical member of the fish-eating public consuming fish landed at Whitehaven/Fleetwood	fish:	15	(40)	^{134}Cs	0.002	0.002
				^{137}Cs	0.028	0.028
				Total	0.03	0.03

popular fish eaten by the high-rate consumers, and the assessment of exposure of the critical group is based upon an equal mix of these species taken from the Sellafield Offshore Area and from landings at Ravenglass. Consumption data indicate that it would be unreasonable to base the assessment on fish from the Shoreline Area. The exposure due to consumption of crustaceans is based on an equal mix of crabs and lobsters from the Shoreline Area, whilst the exposure from consumption of molluscs is based upon averaged radionuclide concentrations in winkles from the Shoreline Area, Nethertown, Coulderton and St Bees, including the data from samples collected by local consumers.

Table 7 summarises exposures in 1984. Provided that the ICRP requirement on lifetime dose is met, as addressed later in this section, the occurrence of non-stochastic effects will be avoided; thus the primary need is to consider stochastic effects on the basis of committed effective dose equivalent (sub-section 3.4). For each exposed group considered this quantity is given together with the contributions of individual nuclides. For simplicity, only the more important nuclides are listed; hence it is not to be expected that the sums of the listed contributions will necessarily equal the totals presented. The contribution due to strontium-90 was derived from measured concentrations (Tables 4b and 5) following our increased programme of analyses.

Comments in sub-section 3.4 on the dose estimates for transuranics are relevant here; in particular the effect of applying the enhanced gut uptake factor for plutonium, following NRPB's advice, is shown in the last column of Table 7. Using this advice on gut uptake factors which are still under review by the ICRP, the committed effective dose equivalent to the critical group of local consumers in 1984 would have been at most 0.84 mSv. On the basis of dosimetric factors currently recommended by ICRP, but now subject to review, the committed effective dose equivalent would have been 0.54 mSv. On the basis of the higher consumption rate for molluscs which obtained in 1983, these committed effective dose equivalents would have been 2.0 mSv and 1.2 mSv respectively. These results represent decreases from 2.3 mSv and 1.5 mSv respectively reported for 1983 (Hunt, 1985). The decreases are due to lower concentrations of transuranics, ruthenium-106 and radiocaesium, as described earlier in this section.

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 1984 the exposures were within the principal dose limit of 1 mSv $year^{-1}$, the main factor of relevance being the reduction in consumption of molluscs. For a few previous years, exposures have been in excess of 1 mSv $year^{-1}$ but within the ICRP-recommended subsidiary dose limit of 5 mSv $year^{-1}$. This condition might also obtain during the next year or so if consumption rates of molluscs should increase towards their earlier levels. However, as a result of measures already implemented by BNFL, discharges of radiologically significant nuclides are declining, and further plants to reduce these discharges have become operational in 1985. It is expected that exposures of the critical group will be permanently below the 1 mSv $year^{-1}$ level within the next few years. At that time, dose rates above this level will not have occurred for long enough for lifetime exposures to have exceeded, on average, 1 mSv $year^{-1}$.

Habits surveys carried out in relation to the consumers associated with commercial fisheries based mainly on Whitehaven, Fleetwood and the Morecambe Bay area indicate critical sub-group consumption rates for fish, crustaceans and molluscs to be 131 kg $year^{-1}$ (360 g d^{-1}), 18 kg $year^{-1}$ (50 g d^{-1}) and 15 kg $year^{-1}$ (40 g d^{-1}) respectively. As for the Cumbrian coastal community, the overall critical group has been defined by the maximising procedure of summing exposures due to these component consumption rates. The dose rate due to intake of fish has been assessed using activity concentrations of an equal mix of plaice and cod landed at Whitehaven and Fleetwood. Consumption of crustaceans has been based on shrimps from Morecambe Bay, and consumption of molluscs has been based on Morecambe Bay cockles. The effective dose equivalent to members of this critical group in 1984 is given in Table 7. The total of 0.47 mSv, on the basis of the enhanced gut uptake factor for plutonium, represents a decrease from 0.53 mSv reported for 1983 (Hunt, 1985). The decrease was mainly due to the lower concentrations of radiocaesium in Irish Sea fish.

The effective dose appropriate to a consumption rate of 15 kg $year^{-1}$ (40 g d^{-1}) of fish from landings at Whitehaven and Fleetwood is also given in Table 7. This consumption rate represents an average for typical fish-eating members of the public. The effective dose in 1984 was 0.03 mSv, which represents a decrease from 0.035 mSv reported for 1983 (Hunt, 1985), due to the reduced concentrations of radiocaesium in Irish Sea fish.

Collective doses from consumption of fish and shellfish during 1984 have been estimated for the UK and other European countries. In general, the method used has been to combine data on fish and shellfish landings from relevant sea areas with average radioactivity concentrations in fish and shellfish caught in these areas. Sea areas considered included the Irish Sea, Scottish waters, the North Sea, Baltic Sea, Norwegian Sea, Spitzbergen/Bear Island area and Barents Sea. Corrections were made for the fraction of fish or shellfish consumed. The contribution for weapons-test fallout to the radioactivity concentrations was subtracted. Consideration has been given to the pathway due to fish offal and industrial fisheries, the product of both of which is fish meal which is fed to pigs and poultry. Consumption of food products from these animals gives rise to a small contribution to the collective dose, and this has been included. The results are presented in Table 8; the results for 1984 are provisional, relying on preliminary landings statistics provided by the International Council for the Exploration of the Sea (ICES), and 1983 landings statistics where these are unavailable. The provisional results will be reviewed in future reports as updated statistics are received. The results for 1983, given as provisional in our previous report (Hunt, 1985), are now confirmed.

Table 8 Collective doses from fish and shellfish, 1983 and 1984.

Population	Size of population	Collective effective dose equivalent, man-Sv	
		1983	1984 (provisional)
UK	5.6×10^7	70	70
Other European countries	7.0×10^8	110	100

Liquid radioactive discharges from Sellafield are the main source of collective dose reported here; by comparison the effect of liquid discharges from other establishments is very small. Most of the collective dose 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 ruthenium-106 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).

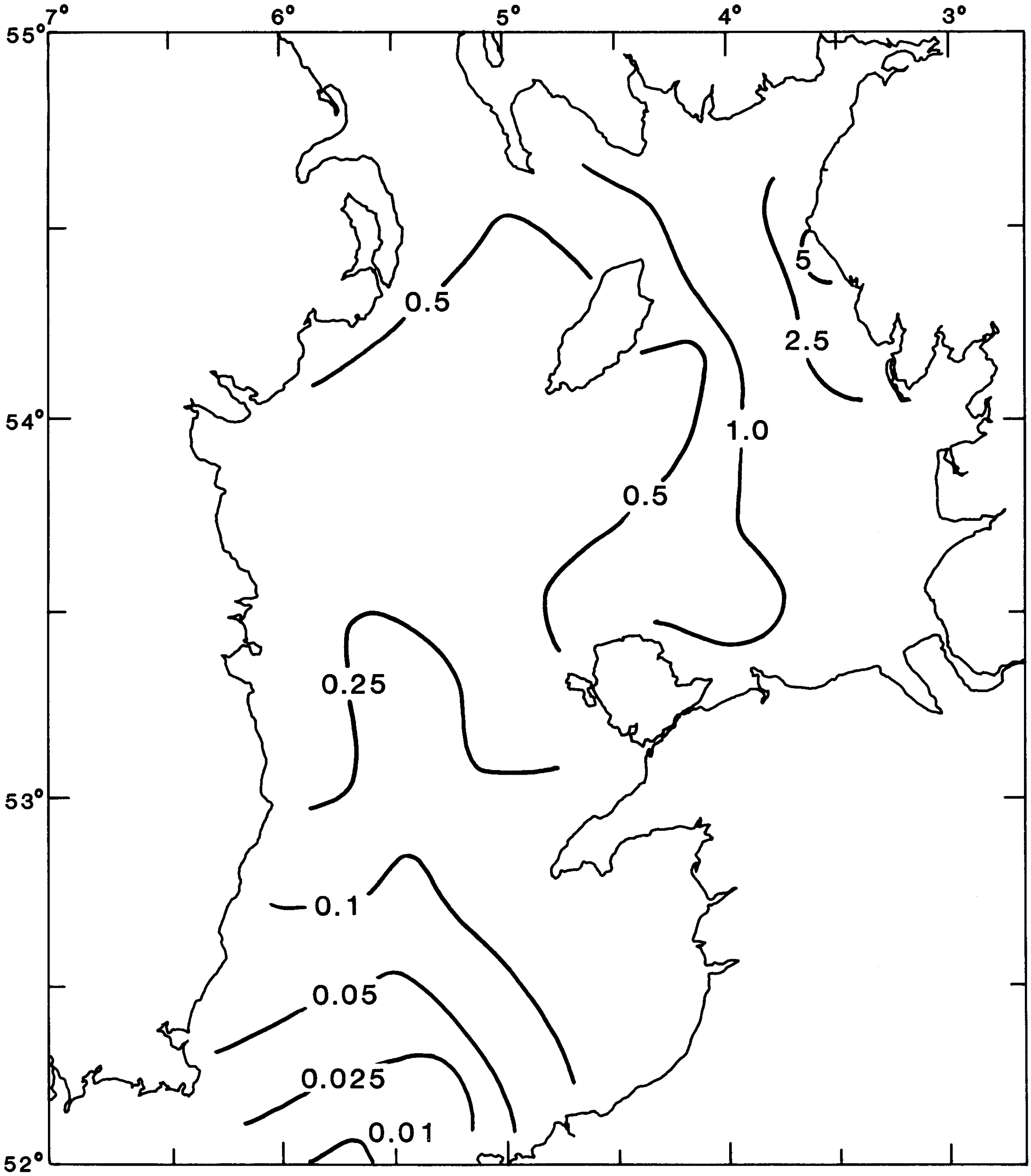

Figure 2 Concentration (Bq kg^{-1}) of caesium-137 in filtered water from the Irish Sea, November 1984.

The provisional result of 70 man-Sv for the UK in 1984 is the same as the result for 1983. The generally lower radiocaesium concentrations, noted above, in fish and shellfish from the Irish Sea and further afield were balanced by generally greater rates of fish landings from these areas. The provisional result of 100 man-Sv for the collective dose to inhabitants of other countries in 1984 was less than 1983 (110 man-Sv), reflecting the general reductions in radiocaesium concentrations in fish and shellfish from the Irish Sea and further afield.

The collective dose for the UK given in Table 8 may be compared with the annual dose equivalent averaged over the population of 0.05 mSv considered unlikely to be exceeded (NRPB, 1978) (see sub-section 3.4) as a result of all waste management practices. In 1984 the UK collective dose through the fish and shellfish pathway as a result of liquid radioactive waste disposal operations amounted to less than 3% of this value.

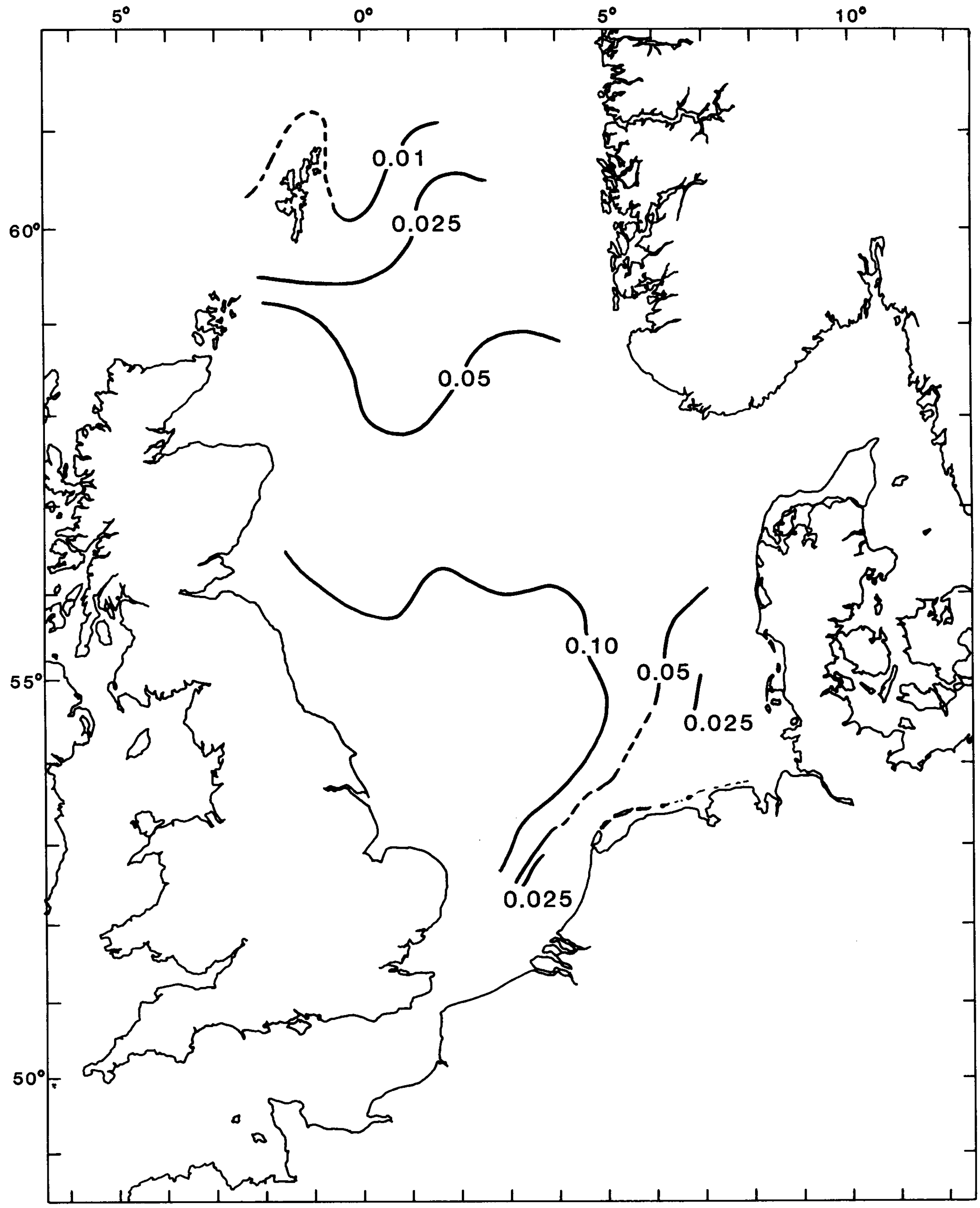

Figure 3 Concentration (Bq kg^{-1}) of caesium-137 in filtered water from the North Sea, August—September 1984.

It is clear from the statements above which compare the 1983 and 1984 results for both critical group and collective dose rates that an important factor determining exposures is the distribution of radioactivity in the marine environment. We maintain a continuing programme of research on marine behaviour and distribution (including budget assessments) of significant radionuclides. Data on the distribution of caesium-137 in sea water are regularly collected by research vessel cruises; the distribution observed in the Irish Sea in November 1984 is shown in Figure 2. Comparison with the data for September 1983 (Hunt, 1985) shows that concentrations of caesium-137 in sea water of the Irish Sea reduced significantly during 1984, reflecting the decreased discharges from Sellafield. Concentrations of radiocaesium in fish from the Irish Sea generally also declined, but not by the same proportion as did those in sea water. This is likely to

Table 9 Gamma radiation dose rates over intertidal areas of the Cumbrian coast and further afield, 1984.

Location	Ground type	No. of sampling observations†	Mean gamma dose rate in air at 1 m, $\mu Gy\ h^{-1}$
Burgh Marsh	Salt marsh	4	0.17
Greenend	" "	4	0.15
"	Sand	4	0.12
Maryport harbour	Silt	4	0.28
" "	Dried silt	4	0.41
Workington harbour	Silt	4	0.36
Harrington harbour	"	2	0.27
Whitehaven outer harbour	"	12	0.27
" " "	Sand	12	0.22
Whitehaven yacht basin	Silt	12	0.65
St Bees	Sand	4	0.13
Coulderton winkle beds	Rock	4	0.22
Sellafield	Sand	12	0.18
Seascale	"	4	0.15
Drigg	"	4	0.13
"	Mussel bed	2	0.28
Ravenglass - Salmon Garth	Sand	12	0.17
" "	Silt	12	0.45
" "	Mussel bed	12	0.55
Ravenglass - boats area	Sand	12	0.22
" " "	Silt	12	0.29
Ravenglass - ford area	"	6	0.56
Ravenglass - Ravenvilla	"	12	0.56
" "	Salt marsh	12	0.85
Newbiggin	Silt	12	0.76
Newbiggin - west of bridge	Sand/silt	6	0.44
" " " "	Salt marsh	6	0.96
Haverigg	Sand	4	0.16
"	Silt	4	0.51
Millom	Sand	4	0.13
"	Silt	4	0.36
Walney Channel	Sand	4	0.16
" "	Silt	4	0.27
" west shore	Sand	4	0.085
Low Shaw	Salt marsh	4	0.23
Flookburgh	Sand	4	0.12
Skipool Creek	Silt	2	0.33
Fleetwood	Sand	4	0.083
Blackpool	"	4	0.079
Ainsdale	"	4	0.076
New Brighton	"	4	0.075
Mersey (Rock Ferry)	Silt	4	0.15
Llandudno	Sand	5	0.083
Prestatyn	"	4	0.071
Garlieston	Silt	4	0.14
Kippford - slipway	"	4	0.19
" - jetty	"	4	0.14
" - merse	Salt marsh	4	0.28

†See section 3.3 for definition.

be due to the lag period for biological uptake; consequent reductions in radiocaesium concentrations in fish are expected to continue in 1985. The distribution of caesium-137 in sea water of the North Sea during August and September 1984 is shown in Figure 3. Comparison with the distribution observed in August and September 1983 (Hunt, 1985) shows a general reduction in concentrations. This was reflected in general decreases in concentrations of radiocaesium in fish and shellfish from the North Sea. Overall, there is a reducing trend in radiocaesium concentrations in sea water and fish from all areas, reflecting the general decrease in radiocaesium discharges from Sellafield since 1975. This decrease has been achieved particularly by the use of zeolite skips in the magnox fuel storage ponds in pursuance of the ALARA principle (sub-section 3.4) as required by the authorising Departments (Hunt, 1984).

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, ruthenium-106 and zirconium-95 plus niobium-95.

We regularly monitor a range of coastal locations both in the Sellafield vicinity and further afield using portable gamma-radiation dosemeters. Locations are chosen on account of both dose rates themselves and levels of occupancy by members of the public. Table 9 lists the locations monitored together with the dose rates in air at 1 m above ground level. Monitoring in Scotland is carried out on behalf of the departments of the Scottish Office. Dose rates on Irish Sea shorelines near other nuclear establishments which reflect Sellafield discharges are given later in this report (see sub-sections 4.2, 4.3, 4.4, 6.5, 6.11). Variations in sediment type

Table 10 Radioactivity in sediment from the Cumbrian coast and further afield, 1984.

Sampling point and sediment type		No. of sampling observations†	Mean radioactivity concentration (dry), Bq kg^{-1}								
			Total beta	^{60}Co	^{95}Zr + ^{95}Nb	^{103}Ru	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
Maryport	(silt)	4	9 200	26	1 200	22	5 000	25	80	2 700	190
Harrington	"	2	10 000	43	2 500	50	6 700	61	91	3 000	260
Whitehaven	(")	4	13 000	26	1 600	28	5 200	41	140	4 500	230
Sellafield	(sand)	12	1 200	6.8	170	1.8	360	0.3	14	450	23
Newbiggin	(silt)	4	15 000	70	2 700	13	11 000	110	110	4 400	390
Walney Island	(")	4	4 000	13	680	13	2 700	20	33	980	82
Flookburgh	(sand)	4	980	1.4	5.2	ND	150	ND	14	470	ND
Heysham	(silt)	3	3 500	11	310	"	1 900	7.3	33	1 200	53
Sunderland Pt	(")	4	2 800	7.7	92	"	900	1.6	34	1 300	16
Skipool Creek	"	3	5 700	15	200	"	1 900	10	80	3 000	38
Fleetwood	(sand)	4	360	ND	1.1	"	13	ND	2.6	93	ND
Blackpool	(")	4	250	"	ND	"	1.7	"	2.7	81	"
New Brighton	(")	4	290	"	"	"	ND	"	1.5	59	"
Rock Ferry	(silt)	4	2 400	3.6	5.0	"	350	"	32	1 300	5.3
Garlieston	(sand)	4	520	ND	ND	"	14	0.5	4.0	170	ND
"	(silt)	4	2 300	6.6	120	"	960	3.7	28	1 000	46
Kippford slipway	(")	4	2 500	8.7	180	"	1 100	ND	30	1 100	44
" merse	(")	4	5 100	17	190	"	1 400	14	58	2 400	71
" jetty	(")	4	2 400	6.8	200	"	970	6.2	27	890	49
Palnackie	(")	1	NA	11	340	"	1 200	ND	42	1 500	64
Groomsport	(sand)	1	190	ND	ND	"	ND	"	1.1	45	ND
Island Hill	(")	1	640	"	"	"	"	"	1.7	55	"
Maltings	(silt)	1	770	"	"	"	"	"	4.1	120	"

Sampling point and sediment type		No. of sampling observations†	Mean radioactivity concentration (dry), Bq kg^{-1}							
			^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Maryport	(silt)	4	49	35	200	860	NA	1 100	6.7	5.1
Harrington	"	2	65	46	NA	NA	"	820	NA	NA
Whitehaven	(")	4	55	40	210	930	"	930	3.9	5.4
Sellafield	(sand)	12	10	6.6	45	220	"	280	ND	0.75
Newbiggin	(silt)	4	150	110	560	2 300	61 000	2 400	9.3	11
Walney Island	(")	4	21	15	NA	NA	NA	360	NA	NA
Flookburgh	(sand)	4	0.9	1.0	"	"	"	48	"	"
Heysham	(silt)	4	9.6	8.7	54	250	"	270	1.1	1.2
Sunderland Pt	(")	4	9.8	2.2	NA	NA	"	180	NA	NA
Skipool Creek	"	3	24	15	"	"	"	390	"	"
Fleetwood	(sand)	4	ND	ND	"	"	"	7.6	"	"
Blackpool	(")	4	"	"	"	"	"	2.1	"	"
New Brighton	(")	4	"	"	"	"	"	0.40	"	"
Rock Ferry	(silt)	4	7.2	4.8	"	"	"	140	"	"
Garlieston	(sand)	4	ND	ND	"	"	"	18	"	"
"	(silt)	4	15	12	49	230	"	260	0.63	0.96
Kippford slipway	(")	4	14	9.4	48	220	"	280	0.82	1.1
" merse	(")	4	27	26	110	530	"	550	0.89	2.1
" jetty	(")	4	12	11	44	210	"	240	0.90	0.78
Palnackie	(")	1	ND	ND	60	270	"	330	ND	1.4
Groomsport	(sand)	1	"	"	NA	NA	"	ND	NA	NA
Island Hill	(")	1	"	"	"	"	"	"	"	"
Maltings	(silt)	1	"	"	"	"	"	"	"	"

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

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 1984 showed general reductions as compared with 1983 (Hunt, 1985).

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 1983 (Hunt, 1985) shows general reductions, in line with the behaviour of dose rates. It is to be noted that these levels of radionuclide concentrations give rise to negligible exposure following inhalation of resuspended sediment (Pattenden *et al.*, 1981).

To identify those members of the public subject to the highest external exposures, occupancies of different locations need to be considered. We keep under review the amounts of time spent by members of the public on intertidal areas of coastline bordering the north-east Irish Sea. This includes a review of exposure at the Ravenglass salmon garth which was fished during the 1984 season; however, it is still considered that, combining dose rates and occupancy times, the critical group for external exposure is represented by persons who live on board their boats in Whitehaven harbour. Taking account of the time the boats are shielded from the mud by tidal effects and the shielding afforded by the boats themselves, their exposure is equivalent to that from spending 650 h year^{-1} over unshielded mud. From Table 9, making an allowance for natural background, their external exposure in 1984 was 0.31 mSv. This result makes use (sub-section 3.4) of the factor of 0.87 Sv Gy^{-1} to convert absorbed dose rate 'free-in-air' to effective dose equivalent rate (Spiers *et al.*, 1981). These persons also consume fish and shellfish, and an addition is necessary to derive their total exposure related to Sellafield liquid discharges; other exposure pathways, such as handling of fishing gear, are negligible by comparison (sub-section 4.1.3). This addition is estimated to be 0.12 mSv for 1984 on the basis of the enhanced value of gut uptake factor for plutonium described in sub-section 3.4. Total exposure of the externally exposed critical group in 1984 is thus estimated to be 0.43 mSv, as compared with 0.51 mSv in 1983 (Hunt, 1984). This exposure is less than that of the critical group of fish and shellfish consumers given earlier, and within the ICRP-recommended principal dose limit of 1 mSv year^{-1} for members of the public.

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

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 thus be exposed to external radiation, mainly to skin from beta particles. We have monitored fishing gear using portable beta dosemeters for many years and results have always been of very minor radiological significance, but we increased our programme of monitoring of fishing gear to provide additional reassurance, in 1984. Results are presented in Table 11. Our habits surveys keep under review the amounts of time spent by fishermen handling their gear; for the critical group, 500 h year^{-1} is appropriate. The maximum exposure from handling of fishing gear in 1984 would have been 0.3 mSv, less than 1% of the ICRP-recommended dose limit appropriate for exposures to skin of members of the public, based on non-stochastic effects (sub-section 3.4). Handling of fishing gear therefore continues to be a minor radiation exposure pathway.

Table 11 Beta radiation dose rates on contact with fishing gear on vessels operating off Sellafield, 1984.

Vessel	Type of gear	No. of sampling observations†	Mean beta dose rate in tissue, $\mu Gy\ h^{-1}$
B	Nets	3	0.50
	Ropes	3	0.47
C	Nets	1	0.13
	Ropes	1	0.16
D	Nets	8	0.63
	Pots	2	0.47
E	Nets	4	0.54
F	Nets	4	0.06
G	Nets	8	0.37
	Ropes	4	0.49
H	Nets	4	0.24

†See section 3.3 for definition.

4.1.4 Porphyra/laverbread pathway

No harvesting of *Porphyra* in the Sellafield vicinity for consumption after being made into laverbread was reported in 1984; 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 the Cumbrian coast. Results of analyses for 1984 are presented in Table 12, and showed similar reductions to those observed in other materials as compared with results for 1983. Samples of laverbread from the major manufacturers are regularly collected from markets in South Wales and analysed. Results for 1984 are presented in Table 13. The exposure of critical laverbread consumers in 1984 was less than 0.01 mSv, confirming the virtual abeyance of this pathway.

4.1.5 Contact beta dose-rate monitoring of intertidal areas

Following the Sellafield incident in November 1983 (Department of the Environment, 1984; Health and Safety Executive, 1984), items contaminated with radioactivity were discovered on local beaches. Extensive programmes of contact beta dose-rate monitoring to detect such items prior to removal were carried out by BNFL and the Authorising Departments. Reports of this monitoring up to July 1984, i.e. during the post-incident phase and whilst Government advice concerning use of local beaches was in effect, have already been published (MAFF, 1983, 1984; DOE and

Table 12 Radioactivity in *Porphyra* from the Cumbrian coast, 1984.

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	^{125}Sb	^{134}Cs	^{137}Cs
Braystones South	12	4 100	0.4	7.1	3.6	480	12	56	3 900	4.9	3.5	67
Seascale	53*	NA	ND	2.2	NA	200	NA	42	2 600	2.1	1.6	42

Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}								
		^{144}Ce	^{154}Eu	^{237}Np	^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Pu	^{241}Am	^{242}Cm	$^{243}Cm + ^{244}Cm$
Braystones South	12	14	ND	0.12	6.9	26	790	25	0.44	0.11
Seascale	53*	2.9	0.3	NA	NA	NA	NA	6.2	NA	NA

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

Table 13 Radioactivity in laverbread from South Wales, 1984.

Manufacturer	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}			
		Total beta	^{106}Ru	^{137}Cs	^{241}Am
A	3	83	4.9	2.2	ND
B	1	97	10	2.6	"
C	4	98	4.4	1.7	0.3
D	1	91	5.9	2.3	ND

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

Table 14 Summary of contact beta dose-rate monitoring of intertidal areas of west Cumbria, 1984.

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
August	40	Allonby: 0.16, 0.18, 0.21
September	20	Drigg Point: 0.10
October	25	Ravenglass estuary: 0.16, 0.16, 0.26 Drigg (Low Moor): 0.13, 0.15, 0.90
November	3	Esk estuary: 0.10, 0.10, 0.12, 0.15, 2.9
December	18	St Bees: 0.18 Coulderton: 0.12 Nethertown: 0.13 Ravenglass estuary: 0.14

MAFF, 1985). Monitoring of contact beta dose rates has now been incorporated into our regular programme, and a summary of items detected by MAFF for the period August to December 1984 is presented in Table 14.

The rate of detection of contaminated items continued to decline in the latter part of 1984. 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 (subsection 3.4). It is not considered likely that anyone has received a dose to skin in excess of this.

4.1.6 Other surveys

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

Seaweeds are useful indicator materials; they may concentrate certain radionuclides so that they greatly facilitate measurement and assist in the tracing of these radionuclides in the environment. Table 15 presents the results of measurements in 1984 on marine plants from UK shorelines of the Irish Sea. Although small quantities of samphire and *Rhodymenia* may be eaten, radioactivity concentrations are of negligible radiological significance. *Fucus* seaweeds are useful indicators particularly of fission product radioactivity other than from ruthenium-106; samples of *Fucus vesiculosus* are collected both in the Sellafield vicinity and further afield, and the results are presented here. Monitoring in Scotland is carried out on behalf of departments of the Scottish Office. Analyses of samples collected in Northern Ireland are carried out on behalf of the DOE(NI).

Table 15 Radioactivity in marine plants from UK shorelines of the Irish Sea, 1984.

Type of seaweed and sampling point	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}									
		Total beta	^{54}Mn	^{60}Co	^{95}Zr + ^{95}Nb	^{99}Tc	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs
Fucus vesiculosus											
Sellafield	12	2 700	0.9	28	340	1 800	8.2	560	10	1.5	15
Heysham	4	730	ND	1.7	7.8	360	ND	32	ND	0.3	5.6
Port William	4	390	"	0.2	0.7	NA	"	3.6	"	ND	1.3
Garlieston	4	420	"	0.8	4.9	"	"	17	"	"	2.2
Auchencairn	4	630	"	1.1	5.6	"	"	17	"	"	3.7
Ardglass	1	200	"	ND	ND	"	"	ND	"	"	ND
Portrush	4	250	"	"	"	"	"	"	"	"	0.05
Laminaria											
St Bees	1	660	"	1.5	64	210	4.9	280	1.1	"	4.5
Samphire											
Ravenglass	1	69	"	ND	9.6	NA	ND	14	ND	ND	0.7
Rhodymenia spp.											
St Bees	1	1 500	"	3.1	170	0.92	12	530	"	"	16
Millisle	4	550	0.2	2.8	ND	NA	ND	7.5	"	"	0.6
Ascophyllum nodosum											
Ardglass	1	490	ND	ND	"	"	"	ND	"	"	1.0
Fucus spiralis											
Ardglass	2	320	"	"	"	"	"	"	"	"	0.2

Type of seaweed and sampling point	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}							
		^{137}Cs	^{144}Ce	^{154}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Fucus vesiculosus									
Sellafield	12	260	5.4	0.3	12	46	14	0.15	0.061
Heysham	4	140	ND	ND	1.5	6.3	2.3	0.012	0.0085
Port William	4	35	"	"	NA	NA	ND	NA	NA
Garlieston	4	54	"	"	"	"	2.7	"	"
Auchencairn	4	94	"	"	"	"	3.5	"	"
Ardglass	1	22	"	"	"	"	1.0	"	"
Portrush	4	3.8	"	"	"	"	ND	"	"
Laminaria									
St Bees	1	90	"	"	"	"	3.0	"	"
Samphire									
Ravenglass	1	8.7	0.5	"	"	"	1.8	"	"
Rhodymenia spp.									
St Bees	1	330	ND	"	"	"	13	"	"
Millisle	4	26	"	"	"	"	ND	"	"
Ascophyllum nodosum									
Ardglass	1	25	"	"	"	"	"	"	"
Fucus spiralis									
Ardglass	2	20	"	"	"	"	0.27	"	"

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

4.2 Springfields, Lancashire

This establishment is mainly concerned with manufacture of fuel elements for nuclear reactors and production of uranium hexafluoride. Radioactive waste arisings are small and consist mainly of uranium and its daughter 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

Table 16(a) Radioactivity in sediment near the Springfields pipeline, 1984.

Location	No. of sampling observations†	Mean radioactivity concentration (dry), Bq kg^{-1}									
		Total beta	^{60}Co	$^{95}Zr + ^{95}Nb$	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
Pipeline outlet	4	25 000	15	220	1.7	2 400	3.4	7.1	78	2 500	34
Becconsall	4	11 000	8.9	120	1.0	1 300	1.5	15	61	2 000	26

Location	No. of sampling observations†	Mean radioactivity concentration (dry), Bq kg^{-1}							
		^{154}Eu	^{155}Eu	^{234m}Pa	^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm + ^{244}Cm$
Pipeline outlet	4	22	2.8	73 000	97	400	450	ND	1.6
Becconsall	4	16	2.2	35 000	NA	NA	320	NA	NA

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

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. 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.

Results for 1984 are shown in Table 16(a) and (b). The only detectable radionuclide due to Springfields discharges is protactinium-234m; other radionuclides present are mainly from Sellafield. Exposure of the critical group of houseboat dwellers in 1984, including the Sellafield component, was about 0.20 mSv, slightly less than for 1983 (Hunt, 1985), and within the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$ for members of the public. The exposure is mainly due to Sellafield discharges; the contribution due to Springfields would have been a small fraction of the total.

Table 16(b) Gamma dose rates in air at 1 m over intertidal areas near Springfields, 1984.

Location	No. of sampling observations†	μGy h^{-1}
Pipeline outlet	4	0.28
Freckleton	4	0.18
Becconsall	4	0.17
Lytham	4	0.18

†See section 3.3 for definition.

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, are very small; the Works have an authorisation to dispose of liquid wastes to the Rivacre Brook. Uranium recovered from irradiated fuel is also recycled; this may contain small quantities of fission products, of which technetium-99 is the only component of potential significance. Waste arisings in this second category are again very low; their disposal to Liverpool Bay from the North Wirral outfall at Meols is regulated by authorisation. It is not expected that the environmental consequences of these small disposals would be detectable above background levels due both to natural sources of radioactivity and to Sellafield discharges. However, we have established an environmental monitoring programme related to the potentially critical pathway due to consumption of locally-caught shellfish. *Fucus*-type seaweed is also sampled, being a good indicator for technetium-99. It is to be noted that the programme is much more extensive than is technically justified by the potential radiological hazard from Capenhurst discharges.

Results for 1984 are presented in Table 17. The concentrations of artificial radioactivity are mainly due to Sellafield discharges and are consistent with values to be expected at this distance from Sellafield. Technetium-99 concentrations continued to be low, reflecting the much reduced discharges of technetium-99 from Sellafield because decay-stored liquors were not being released. Discharges of technetium-99 from Meols decreased in 1984 as compared with 1983, and were at a low percentage of the authorised limit. Exposure of critical shellfish consumers in the vicinity of the Wirral in 1984 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

Table 17 Radioactivity in environmental materials in the vicinity of the Wirral, 1984.

Material	Sampling point	No. of sampling observa-tions†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
			Total beta	^{60}Co	^{99}Tc	^{106}Ru	^{134}Cs	^{137}Cs	^{238}Pu
Shrimps	Hoylake	2	91	ND	0.76	ND	0.8	39	NA
Cockles	Dee Estuary	2	140	0.9	1.6	14	1.4	33	0.6
Fucus spiralis	Hoylake	2	370	ND	106	11	3.6	87	NA
" "	Little Orme	2	430	0.2	NA	3.9	2.9	72	"
Sand	Hoylake	2	230	ND	0.82	7.6	1.7	61	0.45

Material	Sampling point	No. of sampling observa-tions†	Mean radioactivity concentration (wet)*, Bq kg^{-1}			
			^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Shrimps	Hoylake	2	NA	ND	NA	NA
Cockles	Dee Estuary	2	2.4	4.6	ND	0.011
Fucus spiralis	Hoylake	2	NA	3.1	NA	NA
" "	Little Orme	2	"	0.46	"	"
Sand	Hoylake	2	2.5	2.4	0.019	0.0049

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

mainly due to radiocaesium and transuranic nuclides from Sellafield; only a tiny fraction was due to technetium-99, which was almost entirely from Sellafield discharges.

4.4 Chapelcross, Dumfriesshire

At this establishment BNFL operates a magnox-type nuclear power station. Liquid waste arisings are discharged to the Solway Firth under authorisation of the Scottish Development Department. Pond cleaning operations continued in 1984, such that discharges were at a higher level than for a year in which no such operations take place, but were less than in 1983 and 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 a critical group in view of their regular occupancy of intertidal areas and consumption of local seafood. Our monitoring, which is carried out on behalf of departments of the Scottish Office, continued to reflect these pathways. Samples of *Fucus vesiculosus*, as a useful indicator, are also analysed. The results of monitoring in 1984 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 given in Table 18(a) are consistent with values to be expected at this distance from Sellafield. Radiocaesium concentrations in 1984 were generally less than those in 1983, reflecting reductions in Sellafield discharges. Exposure of the critical group in 1984, 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.

Table 18(a) Radioactivity in environmental materials in the vicinity of Chapelcross, 1984.

Material	Sampling point	No. of sampling observa- tions†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			Total beta	^{60}Co	$^{95}Zr + ^{95}Nb$	^{106}Ru	^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu
Flounder	Seafield	4	290	ND	ND	ND	5.9	220	ND	ND
Salmon	"	1	110	"	"	"	ND	1.5	"	"
Sea trout	"	2	200	"	"	"	4.3	110	"	"
Shrimps	"	4	140	"	"	3.2	2.6	75	"	"
Fucus vesiculosus	"	4	520	0.1	"	8.1	3.4	130	"	"
Silt	"	4	2300	4.4	96	470	36	1500	11	6.1
Sand	"	4	1100	1.2	16	110	16	640	0.9	1.8

Material	Sampling point	No. of sampling observa- tions†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
			^{155}Eu	^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm + ^{244}Cm$
Flounder	Seafield	4	ND	NA	NA	ND	NA	NA
Salmon	"	1	"	"	"	"	"	"
Sea trout	"	2	"	0.00031	0.0016	0.0019	ND	0.00001
Shrimps	"	4	"	NA	NA	ND	NA	NA
Fucus vesiculosus	"	4	"	0.80	3.7	3.1	0.015	0.016
Silt	"	4	1.2	31	140	150	0.53	0.55
Sand	"	4	0.4	3.9	19	22	ND	0.09

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

Table 18(b) Gamma dose rates in air at 1 m over intertidal areas in the vicinity of Chapelcross, 1984.

Location and sediment type	No. of sampling observa- tions†	μGy h^{-1}
Seafield (silt)	4	0.21
Torduff Point (silt)	4	0.11
Dornoch Brow (silt)	4	0.12
Dornoch Brow (merse)	3	0.13

†See section 3.3 for definition.

5. United Kingdom Atomic Energy Authority

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

5.1 Atomic Energy Establishment, Winfrith, Dorset

The principal source of liquid radioactive wastes at this establishment is the Steam Generating Heavy Water Reactor. Most of the activity is due to tritium from the moderator and coolant, but small amounts of activation products, including manganese-54, cobalt-60 and zinc-65,

Table 19 Radioactivity in environmental materials from the vicinity of Winfrith, 1984.

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			Total beta	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn	^{106}Ru	^{137}Cs	^{144}Ce
Plaice	Weymouth	2	110	ND	ND	0.3	7.3	ND	0.4	ND
Crabs	Lulworth	2	84	2.3	0.6	43	118	"	ND	"
Oysters	Poole	2	81	ND	ND	1.5	65	"	"	"
Scallops	Weymouth	2	110	16	0.7	11	81	2.3	0.07	"
Fucus serratus	Arish Mell	1	380	44	26	255	121	ND	ND	"
	Kimmeridge	2	290	35	13	143	37	"	"	"
	Weymouth	2	260	7.9	3.9	66	14	"	0.2	"
	Swanage	2	300	9.0	7.1	97	25	"	ND	"
	Hengistbury Head	2	210	2.8	2.9	54	6.4	"	0.3	"
	Bognor Regis	2	250	0.4	ND	18	ND	1.5	0.3	"
	Sandgate	2	260	0.3	"	19	0.5	2.4	0.7	"
Silt	Poole Harbour	2	270	4.7	1.0	49	1.8	2.1	4.4	"
Sand	Arish Mell	1	49	2.0	0.4	20	4.1	ND	ND	"
	Kimmeridge	3	290	5.7	1.1	57	21	1.7	1.6	7.4
	Swanage	2	35	0.5	ND	14	2.7	ND	0.3	ND
	Hengistbury Head	2	53	ND	"	2.8	ND	"	ND	"
	Bognor Regis	2	290	"	"	1.3	"	"	0.4	"

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}				
			^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm + ^{244}$[illegible]
Plaice	Weymouth	2	NA	NA	ND	NA	NA
Crabs	Lulworth	2	"	"	"	"	"
Oysters	Poole	2	"	"	"	"	"
Scallops	Weymouth	2	0.0045	0.010	0.0030	0.0062	0.00072
Fucus serratus	Arish Mell	1	NA	NA	ND	NA	NA
	Kimmeridge	2	"	"	"	"	"
	Weymouth	2	"	"	"	"	"
	Swanage	2	"	"	"	"	"
	Hengistbury Head	2	"	"	"	"	"
	Bognor Regis	2	"	"	"	"	"
	Sandgate	2	"	"	"	"	"
Silt	Poole Harbour	2	"	"	"	"	"
Sand	Arish Mell	1	"	"	"	"	"
	Kimmeridge	1	"	"	"	"	"
	Swanage	2	"	"	"	"	"
	Hengistbury Head	2	"	"	"	"	"
	Bognor Regis	2	"	"	"	"	"

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

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

are removed during decontamination of the reactor pressure circuit. These wastes are disposed of under authorisation to deep water in Weymouth Bay. It is the activation products rather than tritium which are of greater, but still small, environmental significance. Reconcentration of activation products by shellfish, followed by local consumption, constitutes the critical exposure pathway; this is reflected in our monitoring programme. External gamma radiation dose rates are monitored in Poole Harbour where the fine silt has the potential to adsorb radioactivity. Monitoring of the indicator material *Fucus serratus* and of sediments from a number of locations along the south coast provides additional information on the distribution of activation products. Data are presented in Table 19.

The impact of Winfrith discharges was, as in previous years, mainly observed in the concentrations of activation products. In 1984 the total radiation dose to the critical group of fish and shellfish consumers near this establishment was low, at less than 0.04 mSv, or less than 4% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}. External gamma radiation dose rates continued to be indistinguishable from natural background.

5.2 Dounreay Nuclear Power Development Establishment, 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). Reprocessing of Prototype Fast Reactor (PFR) fuel has taken place since 1980. In 1984, discharges were less than in 1983 following completion of decontamination of this reprocessing plant prior to refurbishment, and were well within the terms of Authorisation. Within the total alpha discharge, there was a slight increase in the contribution from americium-241. Our monitoring near Dounreay is carried out on behalf of departments of the Scottish Office.

There are two critical exposure pathways, both involving external radiation. The first pathway 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 critical group is represented by a small number of people who operate a salmon fishery from Sandside Bay, close to Dounreay. Our regular measurements prior to 1981 have shown that at current rates of discharge the average dose rates on nets will be low. Monitoring by the UKAEA has confirmed that the exposure of these fishermen remained low, at about 0.3 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 critical pathway arises also from the uptake of radioactivity by particulate material which accumulates in rocky areas of the foreshore and presents a potential source of exposure mainly to gamma radiation of those who visit these areas. Monitoring of the foreshore dose rates is also carried out by the UKAEA. Public radiation exposure via this pathway also remained low, at less than 0.05 mSv or less than 5% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}.

Table 20 Radioactivity in environmental materials from the vicinity of Dounreay, 1984.

Sampling point and material	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}								
		Total beta	^{54}Mn	^{60}Co	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
Sandside Bay										
Winkles	6	200	ND	3.1	64	75	0.9	ND	2.2	8.6
Limpets	4	220	"	1.8	123	33	1.6	"	3.1	18
Fucus vesiculosus	4	340	1.3	5.8	19	7.1	0.3	0.1	12	13
Fucus serratus	4	300	1.3	7.4	21	7.5	0.1	0.3	11	15
Shell sand	4	390	ND	ND	31	ND	0.5	0.3	18	31

Sampling point and 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
Sandside Bay								
Winkles	6	ND	0.2	0.57	1.8	6.0	0.24	0.034
Limpets	4	"	1.0	0.63	2.1	8.4	0.38	0.052
Fucus vesiculosus	4	"	0.7	NA	NA	3.8	NA	NA
Fucus serratus	4	"	0.5	"	"	4.5	"	"
Shell sand	4	6.3	9.1	5.6	20	22	0.81	0.22

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

We sample winkles from Sandside Bay to enable the sub-critical pathway of shellfish consumption to be kept under direct review. Additionally, as in previous years, limpets and seaweed were sampled as indicator materials. Results are presented in Table 20. Radiocaesium concentrations are mostly due to discharges from Sellafield. Other radionuclides detected, including transuranics, mainly reflect Dounreay discharges. Concentrations of fission products and transuranics except for americium-241 were generally less than in 1983 reflecting the changes in discharges noted above. The radiological significance of shellfish consumption continued to be low; for high-rate winkle consumers the radiation dose was about 0.03 mSv or 3% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$.

6. Nuclear power stations operated by the electricity boards

All but two of these power stations are in England or Wales and are operated by the Central Electricity Generating Board. The power station at Hunterston is operated by the South of Scotland Electricity Board. Results are also presented for measurements made near the second Scottish nuclear power station which is presently under construction at Torness.

6.1 Berkeley, Gloucestershire and Oldbury, Avon

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

Data for 1984 are presented in Table 21. The only artificial radioactivity detected in fish and shellfish was due to radiocaesium. Concentrations of radiocaesium represent the combined effect of discharges from the stations and fallout, and possibly include a small Sellafield-derived component, but apportionment is difficult at the low levels detected. Radiation exposure of the critical group of fish and shellfish consumers was very low, at less than 0.001 mSv or 0.1% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$. Very small concentrations of other artificial radionuclides, in addition to radiocaesium, were detected in mud and seaweed but taken together were of negligible radiological significance. 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 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 1984 are summarised in Table 22. In fish, the only artificial radioactivity detected was due to radiocaesium, for which concentrations given represent the combined effects of discharges from the station, Sellafield discharges and fallout. Apportionment is difficult because of the low levels detected. The dose to members of the critical group of fish and shellfish consumers, however, was low, totalling less than 0.01 mSv or 1% of the ICRP-recommended principal dose limit of 1mSv $year^{-1}$. The concentrations of zinc-65 and transuranic nuclides in oysters were low, such that the contributions to dose from these nuclides remained small. Concentrations of artificial radionuclides detected in mud and seaweed were also low and of negligible radiological significance. Gamma dose rates, as directly measured, were indistinguishable from the natural background.

6.3 Dungeness, Kent

There are two, essentially separate, "A" and "B" nuclear power stations on this site: the "A" station is powered by magnox-type reactors and the "B" station by AGRs. Discharges from both "A" and "B" stations are made via the same outfall and for the purposes of our environmental monitoring are considered together. There are two critical radiation exposure pathways as a result of liquid radioactive waste discharges: internal irradiation due to consumption of locally-caught fish, and external exposure from occupancy of the foreshore. Our monitoring programme therefore includes analyses of fish and shellfish and gamma dose rate surveys of the generally sandy beach. Samples of sand are also collected and analysed. Local whelks and seaweed have been analysed mainly for their value as indicator materials. The results for 1984 are given in Table 23.

Concentrations of caesium-137 in fish are attributable to discharges from the station and from Sellafield, with a small contribution due to fallout. Apportionment is difficult at these low levels. All materials sampled showed trace levels of cobalt-60, and whelks and seaweed showed trace levels of zinc-65. The indicator sampling programme described in sub-section 5.1 shows that AEE Winfrith rather than Dungeness may be the source of these nuclides. Trace amounts of ruthenium-106 were also detected in whelks 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. However, the

Table 21 Radioactivity in environmental materials and gamma dose rates near Berkeley and Oldbury nuclear power stations, 1984.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta	^{54}Mn	^{60}Co	^{125}Sb	^{134}Cs	^{137}Cs	^{155}Eu
Dab	1	89	ND	ND	ND	ND	1.3	ND
Flounders	3	99	"	"	"	"	2.2	"
Mullet	1	130	"	"	"	"	0.8	"
Eels	2	72	"	"	"	"	0.2	"
Shrimps	1	86	"	"	"	"	1.9	"
Fucus vesiculosus	2	400	0.1	2.9	2.7	4.1	99	"
Mud: area of outfalls	4	870	ND	0.2	ND	2.6	68	0.7
Guscar rock	2	920	"	0.3	"	2.1	71	2.9

Mean gamma dose rate in air at 1 m over intertidal mud (10 sampling observations†): 0.10 µGy h^{-1}

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

Table 22 Radioactivity in environmental materials and gamma dose rates near Bradwell nuclear power station, 1984.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{106}Ru	^{134}Cs	^{137}Cs
Mixed fish	3	95	ND	ND	ND	ND	ND	3.1
Oysters	2	67	"	"	7.7	"	"	1.1
Whelks	2	150	"	1.2	ND	1.1	"	0.8
Fucus vesiculosus	2	250	"	1.5	"	ND	0.3	6.2
Sediment	4	900	0.5	14	"	16	2.7	78

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}				
		^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm + ^{244}Cm$
Mixed fish	3	NA	NA	ND	NA	NA
Oysters	2	0.0019	0.0063	0.017	0.00080	0.00089
Whelks	2	NA	NA	ND	NA	NA
Fucus vesiculosus	2	"	"	"	"	"
Sediment	4	"	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediments (6 sampling observations†): 0.074 µGy h^{-1}

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

Table 23 Radioactivity in environmental materials and gamma dose rates near Dungeness nuclear power station, 1984.

Material	No. of sampling observa- tions†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{106}Ru	^{137}Cs
Plaice	3	110	ND	0.1	ND	ND	1.4
Whelks	1	93	"	2.9	2.4	2.8	ND
Fucus serratus	2	260	0.3	19	0.5	2.4	0.7
Sand	2	170	ND	4.6	ND	ND	2.9

Mean gamma dose rate in air at 1 m over intertidal sediment (9 sampling observations†): 0.067 μGy h^{-1}

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

radiation dose to members of the critical group of fish consumers near Dungeness was very low, at less than 0.002 mSv or 0.2% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$. Gamma dose rates over sand were indistinguishable from natural background.

6.4 Hartlepool, Cleveland

This twin-AGR station came into operation in 1983, and discharges of liquid radioactive wastes were still small in 1984 (Table 1). Potential critical pathways of radiation exposure for the public near this station, likely to result from these discharges, 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 1984 are shown in Table 24. Concentrations of radiocaesium and transuranics were mainly due to discharges from Sellafield and to fallout; any effects of station operation were not detectable above the background due to these sources. The radiation exposure of the critical group of local fish and shellfish consumers was low, at less than 0.02 mSv or 2% 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 will comprise two, essentially separate, nuclear power stations both powered by AGRs. The first station came into operation in 1983; the second is still under construction. Discharges of liquid radioactive waste in 1984 were still small (Table 1). The 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 beach gamma dose rates. Samples of sediment are also analysed, and *Fucus vesiculosus* is monitored as an indicator material. In 1984 samphire was also collected and analysed because of potential use as a foodstuff.

The results for 1984 are given in Table 25. These mainly reflect discharges from Sellafield; the effect of discharges from Heysham was not detectable above the Sellafield-derived background. Estimates of the radiation exposure in 1984 of members of the critical group of fish and shellfish consumers associated with commercial fisheries (which include the Morecambe Bay area) are given in sub-section 4.1.1. External exposure of members of the public was less than 0.06 mSv or 6% of 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 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 the foreshore. Our monitoring programme includes analyses of locally-caught fish and shrimps. External exposure is monitored by means of gamma dose rate measurements, supported by analyses of sediment. In addition, *Fucus vesiculosus* is monitored as an indicator.

Table 24 Radioactivity in environmental materials and gamma dose rates near Hartlepool nuclear power station, 1984.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}				
		Total beta	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu
Cod	4	140	0.3	12	ND	NA
Shrimps	1	109	0.1	3.8	"	0.00010
Crabs	3	77	ND	2.0	"	0.00088
Winkles	3	89	"	3.0	"	NA
Fucus vesiculosus	3	210	0.04	4.2	"	"
Sand	4	200	ND	7.7	"	"
Silt	3	1000	2.0	100	0.9	"

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}			
		^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Cod	4	NA	ND	NA	NA
Shrimps	1	0.00061	0.00091	ND	ND
Crabs	3	0.0041	0.0029	"	0.000021
Winkles	3	NA	NA	NA	NA
Fucus vesiculosus	3	"	ND	"	"
Sand	4	"	"	"	"
Silt	3	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediment (12 sampling observations†): 0.083 μGy h^{-1}

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

Table 25 Radioactivity in environmental materials and gamma dose rates near Heysham nuclear power station, 1984.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{60}Co	^{95}Zr + ^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{152}Eu
Plaice	4	270	ND	ND	ND	ND	5.2	165	ND	ND
Shrimps	4	170	0.2	"	2.3	"	3.7	98	"	"
Cockles	4	350	4.9	5.4	200	"	1.7	41	1.9	"
Mussels	3	180	0.2	ND	96	"	0.7	26	ND	"
Fucus vesiculosus	4	730	1.7	7.8	32	0.3	5.6	140	"	"
Samphire	1	11	ND	ND	ND	ND	ND	1.0	"	"
Sediment:										
Sunderland Point	4	2800	7.7	92	900	1.6	34	1300	16	0.7
Half Moon Bay	4	3900	12	374	2324	12	39	1300	71	ND
Morecambe Pier	4	1000	1.6	35	320	0.6	12	411	6.3	"

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		^{154}Eu	^{155}Eu	^{237}Np	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Plaice	4	ND	ND	NA	NA	NA	ND	NA	NA
Shrimps	4	"	"	0.0015	0.019	0.081	0.084	ND	0.00030
Cockles	4	"	"	NA	1.8	7.5	13	"	0.051
Mussels	3	"	"	"	0.48	2.1	2.4	0.019	0.0081
Fucus vesiculosus	4	"	"	0.45	1.5	6.3	2.3	0.012	0.0085
Samphire	1	"	"	NA	0.017	0.079	0.11	0.00031	0.00028
Sediment:									
Sunderland Point	4	9.8	2.2	"	NA	NA	80	NA	NA
Half Moon Bay	4	13	11	"	54	250	270	1.1	1.2
Morecambe Pier	4	ND	ND	"	NA	NA	56	NA	NA

Mean gamma dose rate in air at 1 m over intertidal sediment:
Heysham vicinity (20 sampling observations†): 0.13 μGy h^{-1}
Sunderland Point (8 sampling observations†): 0.12 μGy h^{-1}

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

Table 26 Radioactivity in environmental materials and gamma dose rates near Hinkley Point nuclear power station, 1984.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta	^{54}Mn	^{60}Co	^{90}Sr	^{134}Cs	^{137}Cs	^{155}Eu
Flounders	2	110	ND	ND	NA	ND	2.6	ND
Eels	1	73	"	"	"	"	1.8	"
Shrimps	2	110	"	"	0.5	"	1.7	"
Fucus vesiculosus	2	350	1.1	0.2	NA	1.7	17	"
Sediment	2	790	ND	ND	"	6.3	63	0.3

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}				
		^{238}Pu	$^{239}Pu + {}^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm + {}^{244}Cm$
Flounders	2	NA	NA	ND	NA	NA
Eels	1	"	"	"	"	"
Shrimps	2	0.00036	0.0016	0.0013	ND	0.000049
Fucus vesiculosus	2	NA	NA	ND	NA	NA
Sediment	2	"	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediment (8 sampling observations†): 0.10 μGy h^{-1}

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

The results for 1984, presented in Table 26, indicate concentrations of radiocaesium representing the combined effect of discharges from the station and from Sellafield, in addition to fallout. Apportionment is difficult in view of the low levels detected. The total radiation exposure of members of the critical group through the fish and shellfish pathway was low, at less than 0.005 mSv or less than 0.5% 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.

6.7 Hunterston, Ayrshire

This establishment also comprises "A" and "B" stations and the latter is powered by AGRs. Liquid radioactive waste discharges are made to the Firth of Clyde under authorisation of the Scottish Development Department. The authorisation for the "A" station was reduced in June 1984 to its pre-1980 level following completion of pond refurbishment (see Table 1). There are two 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 1984 are shown in Table 27.

The concentrations of artificial radioactivity in this area are predominantly due to Sellafield discharges, the general values being consistent with those to be expected at this distance from Sellafield. However, the resulting exposure of members of the critical group of fish and shellfish consumers in 1984 was low, at about 0.05 mSv or 5% of the principal ICRP-recommended dose limit of 1 mSv $year^{-1}$. Radiocaesium concentrations detected in fish from farms which are supplied by station cooling water were lower than in fish caught in the open sea; this is because the farmed fish are fed on manufactured food which has a lower radioactivity concentration. The concentrations of activation products observed in molluscs, seaweed and sand were due to discharges from the "B" station. However, they gave rise to but a small fraction of the above exposure and their radiological significance was negligible.

6.8 Sizewell, Suffolk

Our monitoring near this station reflects the two 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 1984 are shown in Table 28.

Table 27 Radioactivity in environmental materials and gamma dose rates near Hunterston nuclear power station, 1984.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn	^{106}Ru	^{110m}Ag	^{134}Cs	^{137}Cs
Cod	4	170	ND	ND	ND	ND	ND	ND	1.4	55
Grey mullet	1	160	"	"	"	"	"	"	1.3	44
Saithe	1	180	"	"	"	"	"	"	2.0	63
Turbot (fish farm)	4	100	"	"	"	"	"	"	0.7	16
Cockles	4	94	"	"	11	1.5	6.5	"	ND	6.4
Winkles	4	100	3.1	"	12	7.0	4.5	3.9	0.5	9.0
Fucus spp.	4	370	12	1.1	25	9.2	8.4	ND	3.6	37
Sand	4	280	1.2	ND	3.7	ND	4.7	"	7.5	107

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		^{144}Ce	^{155}Eu	^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm + ^{244}Cm$
Cod	4	ND	ND	NA	NA	ND	NA	NA
Grey mullet	1	"	"	"	"	"	"	"
Saithe	1	"	"	"	"	"	"	"
Turbot (fish farm)	4	"	"	"	"	"	"	"
Cockles	4	3.7	"	0.11	0.29	0.33	0.040	0.062
Winkles	4	1.1	"	0.10	0.25	0.16	0.023	0.026
Fucus spp.	4	1.5	0.1	0.34	0.78	0.24	0.039	0.033
Sand	4	5.9	0.9	NA	NA	ND	NA	NA

Mean gamma dose rate in air at 1 m over intertidal sediment (18 sampling observations†): 0.10 μGy h^{-1}

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

Table 28 Radioactivity in environmental materials and gamma dose rates near Sizewell nuclear power station, 1984.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{54}Mn	^{60}Co	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{155}Eu
Cod	1	130	ND	ND	ND	ND	0.2	7.6	ND
Plaice	1	110	"	"	"	"	ND	2.9	"
Crabs	2	70	"	0.7	"	"	"	1.8	"
Shrimps	1	99	"	ND	"	"	0.5	9.3	"
Mussels	2	42	"	0.5	"	"	ND	0.8	"
Oysters	2	54	"	ND	"	"	"	6.8	"
Whelks	1	110	"	0.5	3.6	"	"	1.8	"
Silt	2	850	0.4	8.5	9.9	1.3	1.3	67	2.0

Mean gamma dose rate in air at 1 m over intertidal sand/shingle (10 sampling observations†): 0.062 μGy h^{-1}

Mean gamma dose rate in air at 1 m over intertidal silt in Southwold harbour (2 sampling observations†): 0.082 μGy h^{-1}

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

The radiocaesium concentrations in fish and shellfish represent the combined effect of discharges from the 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 are likely to have been due to discharges from the station, but their radiological significance was negligible. The total radiation exposure of local fish and shellfish consumers was low, at less than 0.01 mSv or 1% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$. Gamma dose rates, as in previous years, were indistinguishable from the natural background.

6.9 Torness, East Lothian

This station, which will be powered by two AGRs, is not yet in operation. Our investigations have shown that potential critical pathways for radiation exposure of the public, likely to be associated with future liquid discharges, are internal irradiation from consumption of local fish and shellfish and external exposure from occupancy of intertidal areas. These pathways form the basis of our regular monitoring programme, which has commenced prior to station operation in order to establish background levels and reliable sources of supply of environmental materials. In 1984, samples of shellfish were collected and analysed, and samples of seaweed and sand were monitored as indicator materials. Measurements were also made of gamma dose rates over intertidal areas.

Table 29 Radioactivity in environmental materials and gamma dose rates near Torness nuclear power station, 1984.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}		
		Total beta	^{134}Cs	^{137}Cs
Whelks	1	110	ND	1.8
Winkles	1	90	"	1.9
Crabs	3	70	"	2.2
Nephrops	1	81	"	6.4
Fucus vesiculosus	1	160	"	3.9
Fucus serratus	1	180	"	3.1
Sediment	4	440	1.3	50

Mean gamma dose rate in air at 1 m over intertidal sediment (21 sampling observation†): 0.076 µGy h^{-1}

*Except for sand where dry concentrations apply.
†See section 3.3 for definition.

Table 30 Radioactivity in environmental materials near Trawsfynydd nuclear power station, 1984.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{54}Mn	^{60}Co	^{90}Sr	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{154}Eu
Brown trout	4	400	ND	ND	11	ND	ND	37	300	ND
Rainbow trout	5	210	"	"	5.7	"	"	16	98	"
Perch	1	1300	"	"	390	"	"	57	610	"
Mud	2	4100	"	21	NA	"	400	36	3500	15
Peat	2	2600	"	16	"	"	302	30	1500	ND
Fontinalis										
Afon Prysor	2	175	"	ND	"	ND	ND	ND	4.8	"
Gwylan Stream	2	1200	7.4	18	"	16	370	15	220	"
Water										
Hot Lagoon	4	NA	NA	NA	0.55	NA	NA	0.015	0.15	NA
Cold Lagoon	4	"	"	"	0.52	"	"	0.026	0.21	"

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
		^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm+^{244}Cm$
Brown trout	4	ND	0.00013	0.00052	0.00063	ND	0.000010
Rainbow trout	5	"	0.00013	0.00051	0.00055	"	0.000010
Perch	1	"	0.00026	0.0010	0.0018	"	ND
Mud	2	9.5	8.4	41	51	0.32	0.96
Peat	2	ND	2.6	13	16	0.35	0.31
Fontinalis							
Afon Prysor	2	"	NA	NA	ND	NA	NA
Gwylan Stream	2	"	"	"	"	"	"
Water							
Hot Lagoon	4	NA	"	"	NA	"	"
Cold Lagoon	4	"	"	"	"	"	"

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

Results of this monitoring are shown in Table 29. The very low concentrations of artificial radionuclides are due to fallout and the distant effects of Sellafield discharges. The measured gamma dose rate is consistent with that to be expected from natural background.

6.10 Trawsfynydd, Gwynedd

Discharges from this station are made to the freshwater Lake Trawsfynydd under authorisation of the Welsh Office. Because of the limited volume of water available for dispersion they are of greater radiological significance than those from other UK nuclear power stations which discharge to estuarine or coastal waters. The critical radiation exposure pathway is due to consumption of fish caught in the lake, leading to internal irradiation; the important radionuclides are those of caesium and, to a lesser extent, strontium-90. Species of fish consumed are brown trout, rainbow trout and, in very small amounts, perch. Perch and most brown trout are indigenous to the lake but rainbow trout are regularly introduced from a hatchery. Because of the limited period which they spend in the lake, rainbow trout generally exhibit lower radiocaesium concentrations than indigenous fish.

Our monitoring programme reflects the exposure pathways. Samples of rainbow trout, brown trout and perch 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. The results of these measurements for 1984 are shown in Table 30.

Radiocaesium concentrations in brown trout in 1984 were similar to those in 1983 (Hunt, 1985), reflecting similar discharges of radiocaesium. Concentrations of radiocaesium in rainbow trout, however, were greater than in 1983; this is believed to be due to these fish remaining generally rather longer in the lake before being caught, and possibly becoming indigenous themselves. Samples of perch were analysed including skin and bone to simulate the way in which consumers usually prepare these fish as fish cakes, thus the radioactivity concentrations are greater than in trout, but the amounts of perch eaten are so small that they are of much lower radiological significance than are trout. As in previous years, low concentrations of transuranic nuclides from station operations were observed in fish; these continued to be of negligible radiological significance.

It is estimated that in 1984 members of the critical group of fish consumers received at most about 0.32 mSv, within the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$.

Table 31 Radioactivity in environmental materials and gamma dose rates near Wylfa nuclear power station, 1984.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{60}Co	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{154}Eu	^{155}Eu
Mixed white fish	4	150	ND	ND	ND	1.8	56	ND	ND
Crabs	2	100	"	"	"	ND	14	"	"
Lobsters	2	120	"	"	"	"	15		"
Mussels	2	99	"	4.0	"	"	11	"	"
Fucus vesiculosus	4	330	0.1	3.8	"	1.3	36	"	"
Sediment: Cemlyn Bay	4	2000	2.9	150	"	22	1000	"	3.3

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}				
		^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm + ^{244}Cm$
Mixed white fish	4	NA	NA	ND	NA	NA
Crabs	2	"	"	"	"	"
Lobsters	2	"	"	"	"	"
Mussels	2	0.048	0.20	0.29	ND	0.0020
Fucus vesiculosus	4	NA	NA	0.42	NA	NA
Sediment: Cemlyn Bay	4	19	84	88	ND	ND

Mean gamma dose rate in air at 1 m over intertidal sediment (12 sampling observations†): 0.091 μGy h^{-1}

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

This slightly increased exposure as compared with 1983 (Hunt, 1985) reflects the greater radiocaesium concentrations in rainbow trout noted above.

6.11 Wylfa, Gwynedd

Liquid radioactive wastes from this station are discharged to the Irish Sea under authorisation of the Welsh Office. The two 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 1984 are presented in Table 31.

Any effects of discharges from this station are masked by Sellafield-derived radioactivity. Concentrations of artificial radionuclides in environmental materials were consistent with those to be expected at this distance from Sellafield. The total radiation exposure of members of the critical group in 1984 was about 0.20 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. Naval establishments

Liquid wastes containing small quantities of radioactivity are discharged from the establishments at Devonport, Faslane and Rosyth, all of which are operated by the Ministry of Defence (Navy Department). There were no discharges from Chatham during 1984; discharges due to routine operations had ceased in 1983 prior to closure of this establishment at the end of March 1984, and discharges from decommissioning procedures had not yet begun in 1984. The US naval base at Holy Loch discharges small quantities of radioactive waste. We carry out monitoring programmes near all these establishments, in the case of Faslane and Rosyth on behalf of departments of the Scottish Office.

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 1984 are presented in Table 32. The small concentrations of cobalt-60 mainly reflect discharges from the establishments; levels of other artificial nuclides are due to fallout and 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 $year^{-1}$.

Table 32 Radioactivity in environmental materials and gamma dose rates near naval establishments, 1984.

Establishment	Material	No. of sampling observa-tions†	Mean radioactivity concentration (wet)*, Bq kg^{-1}			Mean gamma dose rate in air at 1 m	
			^{60}Co	^{134}Cs	^{137}Cs	No. of sampling observa-tions†	µGy h^{-1}
Chatham	Sediment	4	6.9	1.0	43	10	0.073
Devonport	Mussels	2	0.2	ND	ND	NP	NP
	Fucus vesiculosus	2	0.4	"	0.2	"	"
	Sediment	6	1.6	"	7.2	11	0.085
Faslane	Sediment	4	26	3.6	179	10	0.085
Rosyth	Sediment	2	1.0	0.9	23	4	0.073
Holy Loch	Sediment	2	5.0	1.1	36	12	0.076

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

8. Amersham International plc

Amersham International plc is engaged in the manufacture of radioactive materials for use in medicine, research and industry. The company's parent establishment is located in Amersham, Buckinghamshire, from which radioactive discharges are made into the catchment of the River Thames. As explained in section 5, environmental monitoring in respect of these discharges is carried out by the DOE. A further laboratory, situated near Cardiff, is engaged in the production of labelled compounds 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 to external exposure over muddy intertidal areas. Measurements of external exposure are supported by analyses of intertidal sediment, and *Fucus* seaweed is collected as an indicator material. The radiological consequences of discharges from this establishment are small and mainly due to carbon-14. Additional artificial radionuclides detected are due to fallout, other nuclear facilities which discharge small amounts of radioactive wastes to the Severn Estuary and the Bristol Channel, and possibly Sellafield.

The results of monitoring in 1984 are presented in Table 33. None of the separate nuclides listed was processed or discharged by this establishment in 1984: their presence 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. Approximate concentrations of carbon-14 may be derived from the total beta concentrations after subtracting the contribution due to natural radionuclides (see Table 3) and the small effect of the separate artificial beta-emitting radionuclides. The exposure of the critical group of fish consumers in 1984 was low, at about 0.06 mSv, or 6% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}. Gamma dose rates over sediment were indistinguishable from those to be expected from natural background.

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 1984 are given in Table 34. Concentrations of caesium-137 in fish and shellfish were not significantly in excess of those to be expected from other sources, including fallout. The presence of transuranics and ruthenium-106 in environmental materials may be attributed to discharges from the plant at Cap de la Hague. However, the concentrations of artificial radionuclides in each of these materials were of negligible radiological significance.

10. Summary and conclusions.

A summary of estimated public radiation exposures in 1984 resulting from liquid radioactive waste discharges from nuclear establishments which we monitor is presented in Table 35. 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 higher gut uptake factor for plutonium (sub-section 3.4), except where otherwise indicated.

Committed effective dose equivalents were all within the ICRP-recommended principal dose limit of 1 mSv year^{-1} to members of the public. Discharges from Sellafield have, as in

Table 33 Radioactivity in environmental materials and gamma dose rates near the outfall of the sewer serving Amersham International plc, Cardiff, 1984.

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}				
		Total beta	^{131}I	^{134}Cs	^{137}Cs	^{155}Eu
Flounders	2	810	ND	ND	1.0	ND
Fucus spiralis	4	230	0.9	"	1.2	"
Sediment	4	1 000	ND	1.2	64	1.6

Mean gamma dose rate in air at 1 m over intertidal sediment (4 sampling observations†): 0.092 µGy h^{-1}

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

previous years, given rise to the highest exposures. The most important contributions to these exposures were due to transuranic radionuclides and ruthenium-106 from the reprocessing operations; a further contribution was from radiocaesium which is discharged mainly from the fuel element storage ponds. Details are given in sub-section 4.1.1. Exposures near Sellafield decreased in 1984 as compared with 1983, following a reduction in consumption of locally-caught molluscan shellfish, but the generally reducing trend in discharges also contributed to this decrease. The reduction in consumption was partly caused by less use of intertidal areas by shellfish collectors following the Sellafield incident of November 1983. It should be noted that consumption rates could increase again in the next year or so, such that for a short period exposures may exceed the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$ for members of the public, though they will remain within the subsidiary dose limit of 5 mSv $year^{-1}$. However, it is expected that the trend of reductions in discharges will continue, especially following the operation of new treatment plants in 1985, such that exposures of the critical group will be permanently below the 1 mSv $year^{-1}$ level within the next few years.

At that time, dose rates above this level will not have occurred for long enough for lifetime exposure to have exceeded, on average, 1 mSv $year^{-1}$.

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 sources (including the small contribution due to fallout) are quoted in Table 35, with appropriate footnotes.

Table 34 Radioactivity in marine environmental materials from the Channel Islands, 1984.

Material	Sampling area	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
			Total beta	^{60}Co	^{65}Zn	^{90}Sr	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs
Ray	Guernsey	1	94	ND	ND	NA	ND	ND	ND	0.3	2.6
Crabs	Guernsey	1	79	1.2	"	"	"	"	"	ND	ND
	Jersey	1	87	1.7	"	"	5.2	1.0	"	"	0.5
Oysters	Jersey	1	110	1.5	7.0	"	20	3.3	"	"	0.3
Limpets	Jersey	1	100	1.6	ND	"	8.6	0.5	"	"	0.2
	Guernsey	1	90	0.9	"	"	4.6	ND	"	"	0.3
	Alderney	1	120	2.6	1.0	"	48	"	1.0	"	0.6
Porphyra	Jersey										
	Greve de Lecq	4	250	1.6	ND	"	34	"	ND	"	ND
	La Rozel	3	160	0.9	"	"	31	"	"	"	0.4
	Guernsey										
	Fort Doyle	1	190	0.5	"	"	13	"	"	"	ND
	Fermain Bay	4	220	0.6	"	"	16	"	"	"	0.1
	Alderney										
	Telegraph Bay	1	390	1.0	"	"	49	"	"	"	0.7
	Quenard Point	4	260	2.1	0.2	"	95	"	"	"	0.4
Fucus serratus	Jersey										
	La Rozel	4	400	8.9	ND	1.2	11	"	"	"	0.5
	Guernsey										
	Fermain Bay	4	330	5.2	"	0.7	6.6	"	"	"	0.2
	Alderney										
	Quenard Point	4	470	18	0.7	1.3	28	"	0.2	"	0.5
Sediment	Jersey										
	St Helier Harbour	1	660	5.3	ND	NA	89	"	4.5	0.8	8.7
	Guernsey										
	Bordeaux Harbour	1	390	1.0	"	"	11	"	0.9	ND	3.1
	Alderney										
	Crabbe Harbour	1	410	0.7	"	"	11	"	1.7	"	4.3

Table 34 Continued.

Material	Sampling area	No. of sampling observa- tions†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
			^{144}Ce	^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm + ^{244}Cm$
Ray	Guernsey	1	ND	0.00011	0.00069	0.00038	ND	0.00002
Crabs	Guernsey	1	"	0.00054	0.0013	0.0077	0.00072	0.0050
	Jersey	1	"	0.0027	0.0061	0.025	0.0017	0.018
Oysters	Jersey	1	"	0.013	0.028	0.022	0.0029	0.014
Limpets	Jersey	1	"	0.013	0.029	0.034	0.0040	0.021
	Guernsey	1	"	0.0044	0.012	0.013	0.0021	0.0089
	Alderney	1	"	0.015	0.029	0.13	0.011	0.083
Porphyra	Jersey							
	Greve de Lecq	4	"	NA	NA	ND	NA	NA
	La Rozel	3	"	"	"	"	"	"
	Guernsey							
	Fort Doyle	1	"	"	"	"	"	"
	Fermain Bay	4	"	"	"	"	"	"
	Alderney							
	Telegraph Bay	1	"	"	"	"	"	"
	Quenard Point	4	"	"	"	"	"	"
Fucus serratus	Jersey							
	La Rozel	4	"	0.048	0.098	0.037	0.0036	0.018
	Guernsey							
	Fermain Bay	4	"	0.034	0.082	0.041	0.0043	0.022
	Alderney							
	Quenard Point	4	"	0.046	0.089	0.071	ND	0.040
Sediment	Jersey							
	St Helier Harbour	1	14	0.99	2.6	2.8	0.19	1.1
	Guernsey							
	Bordeaux Harbour	1	ND	0.10	0.40	0.33	0.020	0.11
	Alderney							
	Crabbe Harbour	1	"	NA	NA	ND	NA	NA

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

As in previous years, collective doses from UK liquid radioactive discharges have also been considered. The most significant 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. The provisional collective effective dose equivalent to the UK population in 1984 was 70 man-Sv, the same as reported for 1983. There were generally lower radiocaesium concentrations in fish and shellfish from the Irish Sea and further afield but these were balanced by generally greater fish landings from these areas. For the population of other European countries the provisional collective effective dose equivalent was 100 man-Sv in 1984, less than in 1983 (110 man-Sv), reflecting the general reductions in radiocaesium concentrations in fish and shellfish from the Irish Sea and further afield. There is an overall reducing trend in radiocaesium concentrations in all areas following declining discharges from Sellafield. This trend was, in 1984, mainly a result of the optimised use, as required by the authorising Departments, of zeolite skips in the magnox fuel element storage ponds.

Table 35 Summarised estimates of public radiation exposure from discharges of liquid radioactive waste in the UK, 1984.

Establishment	Radiation exposure pathway	Critical group	Exposure+, mSv
BRITISH NUCLEAR FUELS LIMITED			
Sellafield	Fish and shellfish consumption	Local fishing community Commercial fishing community	0.84(0.54)* 0.47(0.41)*
	External Handling of fishing gear *Porphyra*/laverbread consumption	Whitehaven boat dwellers Local fishing community Consumers in South Wales	0.43 <0.3‡ <0.01
Springfields	External	Houseboat dwellers	0.20[a]
Capenhurst (Meols outfall)	Shellfish consumption	Local fishing community	<0.1[a]
Chapelcross	Fish and shellfish consumption External	Local fishermen	<0.2[a]
UNITED KINGDOM ATOMIC ENERGY AUTHORITY			
Winfrith	Fish and shellfish consumption	Local fishing community	<0.04
Dounreay	Handling of fishing gear External Shellfish consumption	Local fishermen Local community Local fishing community	0.3‡[b] <0.05[b] 0.03[b]
NUCLEAR POWER STATIONS OPERATED BY THE ELECTRICITY BOARDS			
Berkeley and Oldbury	Fish and shellfish consumption External	Local fishing community	<0.001[b]
Bradwell	Fish and shellfish consumption External	Local fishing community Houseboat dwellers	<0.01[b]
Dungeness	Fish consumption External	Local fishing community	<0.002
Hartlepool	Fish and shellfish consumption External	Local fishing community Coal collectors	<0.02[a] <0.01[a]
Heysham	Fish and shellfish consumption External	Local fishing community	<0.43[a] <0.06[a]
Hinkley Point	Fish and shellfish consumption External	Local fishing community	<0.005[b]
Hunterston	Fish and shellfish consumption External	Local fishing community	0.05[a]
Sizewell	Fish and shellfish consumption External	Local fishing community	<0.01[b]
Trawsfynydd	Fish consumption	Local fishing community	0.32
Wylfa	Fish and shellfish consumption External	Local community	0.20[a]
NAVAL ESTABLISHMENTS			
Chatham	External	Houseboat dwellers	<0.01
Devonport	External	Bait diggers	<0.01
Faslane	External	Boatyard workers	<0.01[b]
Rosyth	External	Dredgermen	<0.01[b]
Holy Loch	External	Local community	<0.01[b]
AMERSHAM INTERNATIONAL plc			
Cardiff	Fish and shellfish consumption External	Local fishing community	0.06

+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 section 3.4).
*See section 4.1.1. The first value is based on the enhanced gut uptake factor for plutonium; the value using the ICRP-recommended factor follows in parentheses.
‡Exposure to skin, to be compared with the ICRP-recommended dose limit of 50 mSv year^{-1} (see section 3.4).
[a]Mainly due to discharges from Sellafield.
[b]Partly due to discharges from Sellafield.

11. References

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

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

DEPARTMENT OF THE ENVIRONMENT, 1984. An incident leading to contamination of the beaches near to the British Nuclear Fuels Limited Windscale and Calder Works, Sellafield, November 1983. DOE, London, 36pp. + Annexes.

DEPARTMENT OF THE ENVIRONMENT, 1985. Assessment of best practicable environmental options (BPEOs) for management of low- and intermediate-level radioactive wastes. Interim report on methodology and data. DOE, London, 55pp. + tables.

DEPARTMENT OF THE ENVIRONMENT and MINISTRY OF AGRICULTURE, FISHERIES AND FOOD, 1985. Monitoring of beach contamination following an incident at BNFL, Sellafield, Cumbria in November 1983. Results to July 1984. DOE and MAFF, London, 20pp. + tables.

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

DUTTON, J.W.R., 1969. Gamma-spectrometric analysis of environmental materials. Tech. Rep. Fish. Radiobiol. Lab., MAFF Direct. Fish. Res., Lowestoft, (FRL) (4): 18pp.

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

GREAT BRITAIN — PARLIAMENT, 1982. Radioactive Waste Management. HMSO, London, 20pp. (Cmnd 8607).

HEALTH AND SAFETY EXECUTIVE, 1984. The contamination of the beach incident at British Nuclear Fuels Limited, Sellafield, November 1983. HSE, Bootle, 16pp.

HOLLIDAY, F.G.T. (Chairman) 1984. Report of the Independent Review of Disposal of Radioactive Waste in the Northeast Atlantic. HMSO, London, 60pp.

HUGHES, J.S. and ROBERTS, G.C., 1984. The radiation exposure of the UK population — 1984 review. National Radiological Protection Board, NRPB-R173. HMSO, London, 82pp.

HUNT, G.J. 1984. Experience of ALARA in controlling radiocaesium discharges to the Irish Sea. Proceedings of the 2nd European Seminar on Radiation Protection Optimisation. CEC, Luxembourg, EUR 9173 en: 437—450.

HUNT, G.J., 1985. Radioactivity in surface and coastal waters of the British Isles, 1983. Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft, (12): 46pp.

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

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

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

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1979. Limits for intakes of radionuclides by workers. (Annal. ICRP 3(1/4)). Pergamon Press, Oxford, 555pp. (ICRP Publ. (30) Suppl. to Part I).

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1981. Limits for intakes of radionuclides by workers. (Annal. ICRP 5(1—6)). Pergamon Press, Oxford, 751pp. (ICRP Publ. (30) Suppl. to Part II).

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1982a. Limits for intakes of radionuclides by workers. (Annal. ICRP 7 (1/3). Pergamon Press, Oxford, 440pp. (ICRP Publ. (30) Suppl. A to Part III).

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1982b. Limits for intakes of radionuclides by workers. (Annal. ICRP 8(1/3). Pergamon Press, Oxford, 948pp. (ICRP Publ. (30) Suppl. B to Part III).

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

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1985. Statement from the 1985 Paris meeting of the International Commission on Radiological Protection. J. Soc. Radiol. Prot., *5* (2): 87—88.

INTERNATIONAL MARITIME ORGANISATION, 1985a. Report of intersessional activities relating to the disposal of radioactive wastes at sea, including the final report of the scientific review. LDC 9/INF14. IMO, London, 27pp.

INTERNATIONAL MARITIME ORGANISATION, 1985b. Report of intersessional activities relating to the disposal of radioactive wastes at sea, including the final report of the scientific review. LDC 9/4. IMO, London, 171pp.

LEONARD, D.R.P., 1984. Investigation of individual radiation exposures: comparative use of interview and logging techniques in habits surveys of the Cumbrian coastal fishing community. pp.763—766 In 'Radiation-Risk-Protection'. Proceedings of the 6th International Congress of the International Radiological Protection Association, Berlin, 2. A.Kaul *et al.* (eds.). Fachverband für Strahlenschutz e.V., Julich, 947pp.

LEONARD, D.R.P. and HUNT, G.J., 1985. A study of fish and shellfish consumers near Sellafield: assessment of the critical groups including consideration of children. J. Soc. Radiol. Prot., *5* (3): 129—139.

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

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

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD, 1983. Incident leading to contamination of beaches near British Nuclear Fuels plc, Sellafield, November 1983. Monitoring and assessment of environmental consequences undertaken by MAFF. MAFF, London, 16pp + tables.

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD, 1984. Incident leading to contamination of beaches near British Nuclear Fuels plc, Sellafield, November 1983. Monitoring and assessment of environmental consequences undertaken by MAFF. 2. Supplement for the period 1 January—28 February 1984. MAFF, London, 5pp. + figures.

NATIONAL RADIOLOGICAL PROTECTION BOARD, 1978. The application of ICRP recommendations: Advice to the expert group reviewing the White Paper Command 884 "The Control of Radioactive Wastes". HMSO, London, 3pp. (NRPB-ASP 2).

NATIONAL RADIOLOGICAL PROTECTION BOARD, 1984a. Statement by the National Radiological Protection Board on the non-stochastic dose limit for members of the public. HMSO, London, 3pp. (NRPB-ASP 6).

NATIONAL RADIOLOGICAL PROTECTION BOARD, 1984b. Metabolic and dosimetric models for application to members of the public. HMSO, London, 6pp. (NRPB-GS 3).

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

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

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

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

12. Recent publications on radioactivity in the aquatic environment by staff of the Directorate of Fisheries Research

1983

BAKER, C.W. and YOUNG, A.K. The determination of radium and radon isotopes in marine environmental materials. 4th Symp. on the Determ. of Radionucl. In 'Environ. and Biol. Materials'. Glazebrook Hall, National Physical Laboratory, Teddington, 18/19 April 1983. Paper (8): 14pp.

DUTTON, J.W.R. Seawater radionuclide analyses. pp.82—84. In 'Interim Oceanographic Description of the North-East Atlantic Site for the Disposal of Low-Level Radioactive Waste', P.A.Gurbutt and R.R.Dickson (Eds.). NEA/OECD, Paris, 132pp.

HILL, H.W. A physical oceanography program to examine the feasibility of radioactive waste disposal in the deep ocean. pp.123—131. In 'Wastes in the Ocean. *3.* Radioactive Wastes and the Ocean', P.K.Park, *et al.* (Eds.). Wiley-Interscience, New York and Chichester, 522pp.

HUNT, G.J. Radioactivity in surface and coastal waters of the British Isles, 1981. Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft, (9): 36pp.

KERSHAW, P.J., SWIFT, D.J., PENTREATH, R.J. and LOVETT, M.B. Plutonium redistribution by biological activity in Irish Sea sediments. Nature, Lond., *306:* 774—775.

MAFF. Incident leading to contamination of beaches near British Nuclear Fuels Ltd., Sellafield, November 1983. Monitoring and assessment of environmental consequences undertaken by MAFF. MAFF, London, 16pp. + tables.

MITCHELL, N.T. Disposal of high-activity nuclear wastes. (Letter.) Mar. Pollut. Bull., *14:* 358—361.

MITCHELL, N.T. History of dumping and description of waste. pp.8—12. In 'Interim Oceanographic Description of the North-east Atlantic Site for the Disposal of Low-level Radioactive Waste', P.A.Gurbutt and R.R.Dickson (Eds.). NEA/OECD, Paris, 132pp.

PENTREATH, R.J. Biological studies. pp.101-118. In 'Interim Oceanographic Description of the North-east Atlantic Site for the Disposal of Low-level Radioactive Waste', P.A.Gurbutt and R.R.Dickson (Eds.). NEA/OECD, Paris, 132pp.

PENTREATH, R.J. Future requirements in environmental research. J. Soc. Radiol. Prot., *3* (4): 15—20.

PRESTON, A. Deep-sea disposal of radioactive wastes. pp.107—122. In 'Wastes in the Ocean. *3.* Radioactive Wastes and the Ocean', P.K.Park *et al.* (Eds.). Wiley-Interscience, New York and Chichester, 522pp.

PRESTON, A. use of the oceans for waste disposal. The Siren, (21): 9—14.

WOODHEAD, D.S. and PENTREATH, R.J. A provisional assessment of radiation regimes in deep ocean environments. pp.133—152. In 'Wastes in the Ocean. *3.* Radioactive Wastes and the Ocean', P.K.Park *et al.* (Eds.). Wiley-Interscience, New York and Chichester, 522pp.

1984

BAKER, C.W. Radiochemical techniques for determining some naturally-occurring radionuclides in marine environmental materials. Nucl. Instrum. Meth. in Phys. Res., *223:* 218—223.

HARVEY, B.R. and KERSHAW, P.J. Physico-chemical interactions of long-lived radionuclides in coastal marine sediments and some comparisons with the deep-sea environment. pp.131—141. In 'International Symposium on the Behaviour of Long-lived Radionuclides in the Marine Environment', A.Cigna and C.Myttenaere, (Eds.). Commission of the European Communities, Luxembourg, 462pp.

HARVEY, B.R. and LOVETT, M.B. The use of yield tracers in the determination of alpha-emitting actinides in the marine environment. Nucl. Instrum. Meth. in Phys. Res., *223:* 224—234.

HILL, M.D. and MITCHELL, N.T. Principles used in assessing the impact of radionuclide releases to the environment and in establishing release limits. pp.109—125. In 'Radioactive Waste Management, *5,* Proc. IAEA Conf., Seattle. May 1983'. IAEA, Vienna.

HUNT, G.J. Statistical characterisation of a critical group. Radiat. Prot. Dosim., *8:* 188—189.

HUNT, G.J. Simple models for prediction of external radiation exposure from aquatic pathways. Radiat. Prot. Dosim., *8:* 215-244.

HUNT, G.J. Radioactivity in surface and coastal waters of the British Isles, 1982. Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft, (11): 36pp.

HUNT, G.J. Experience of ALARA in controlling radiocaesium discharges to the Irish Sea. Proc. 2nd Eur. Seminar on Radiation Protection Optimisation. Commission of the European Communities, Luxembourg, 437—450 (EUR 9173 en).

HUNT G.J. Variable values of unit collective dose equivalent for members of the public: difficulties when applied to UK fish and shellfish consumption. pp.759—762. In '6th Int. Congr. Int. Radiat. Prot. Assoc., *2.* W. Berlin, 7—12 May 1984', A.Kaul *et al.* (Eds.). Fachverband für Strahlenschutz e.V., Jülich, 947pp.

HUNT, G.J. Radioactivity in the vicinity of Sizewell nuclear power station: marine environmental monitoring 1983. Sizewell Inq. Ser., MAFF Direct. Fish. Res., Lowestoft, (11): 3pp.

KERSHAW, P.J. Detecting compositional variations in fine-grained sediments by transmission electron microanalysis. pp.87—108. In 'Transfer Processses in Cohesive Sediment Systems', W.R.Parker and D.J.J.Kinsman (Eds.). Plenum, Press, New York and London, 239pp.

KERSHAW, P.J., SWIFT, D.J., PENTREATH, R.J. and LOVETT, M.B. The incorporation of plutonium, americium and curium into the Irish Sea bed by biological activity. Sci. Total Environ., *40:* 61—81.

LEONARD, D.R.P. Investigation of individual radiation exposures: comparative use of interview and logging techniques in habits surveys of the Cumbrian coastal fishing community. pp.763—766. In '6th Int. Congr. Int. Radiat. Prot. Assoc., *2,* W. Berlin, 7—12 May 1984', A.Kaul *et al.* (Eds.). Fachverband für Stahlenschutz e.V., Jülich, 947pp.

MAFF, Incident leading to contamination of beaches near British Nuclear Fuels plc, Sellafield, November 1983. Monitoring and assessment of environmental consequences undertaken by MAFF. 2. Supplement for the period 1 January—28 February 1984. MAFF, London, 5pp. + figures.

NEWTON, D., JOHNSON, P., LALLY, A.E., PENTREATH, R.J. and SWIFT, D.J. The uptake by man of cadmium ingested in crab meat. 1. Human Toxicol., *3:* 23—28.

PENTREATH, R.J. Alpha-emitting nuclides in the marine environment. Nucl. Instrum. and Meth. in Phys. Res., *223:* 493—501.

PENTREATH, R.J. Radioactive discharges from Sellafield (UK). Annex 1, IAEA Vienna Tech. Doc., (329): 67—110.

PENTREATH, R.J. The accumulation of long-lived radionuclides by marine organisms: problems past, present and future. pp.257—269. In 'International Symposium on the Behaviour of Long-lived Radionuclides in the Marine Environment', A.Cigna and C.Myttenaere (Eds.). Commission of the European Communities, Luxembourg, 462pp.

PENTREATH, R.J., LOVETT, M.B., JEFFERIES, D.F., WOODHEAD, D.S., TALBOT, J.W. and MITCHELL, N.T. The impact on radiation exposure of transuranium nuclides discharged in liquid wastes from fuel element reprocessing at Sellafield, UK. pp.315—329. In 'Radioactive Waste Management, *5,* Proc. Conf., Seattle, May 1983'. IAEA, Vienna, 466pp.

RACKHAM, B.D. and WOODHEAD, D.S. Effects of chronic γ-irradiation on the gonads of adult *Ameca splendens* (Osteichthyes: Teleostei). Int. J. Radiat. Biol., *45:* 645—656.

WOODHEAD, D.S. Contamination due to radioactive materials. Mar. Ecol., *5:* 1111—1287.

1985

DEPARTMENT OF THE ENVIRONMENT AND MINISTRY OF AGRICULTURE, FISHERIES AND FOOD, 1985. Monitoring of beach contamination following an incident at BNFL, Sellafield, Cumbria in November 1983. Results to July 1984. DOE and MAFF, London, 20pp., + tables.

HILL, M.D. and PENTREATH, R.J. The science of sea dumping. Nature, London., *316:* 672.

HUNT, G.J. Radioactivity in surface and coastal waters of the British Isles, 1983. Aquat. Environ. Monit. Rep., MAFF Direct. Fish. Res., Lowestoft, (12): 46pp.

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

KERSHAW, P.J. ^{14}C and ^{210}Po in NE Atlantic sediments: evidence of biological reworking in the context of radioactive waste disposal. J.Environ. Radioact., *2:* 87—106.

KERSHAW, P.J. Geological research and marine waste disposal. Br. Geol., *11* (2): 48—51.

LEONARD, D.R.P. and HUNT, G.J. A study of fish and shellfish consumers near Sellafield: assessment of the critical groups including consideration of children. J. Soc. Radiol. Prot., *5* (3): 129—139.

SWIFT, D.J. The accumulation of ^{95m}Tc from sea water by juvenile lobsters (*Homarus gammarus* L.). J. Environ. Radioact. *2:* 229—243.

WOODHEAD, D.S., JEFFERIES, D.F. and BARKER, C.J. Contamination of beach debris following an incident at British Nuclear Fuels plc, Sellafield, November 1983. J. Soc. Radiol. Prot., *5:* 21—32.