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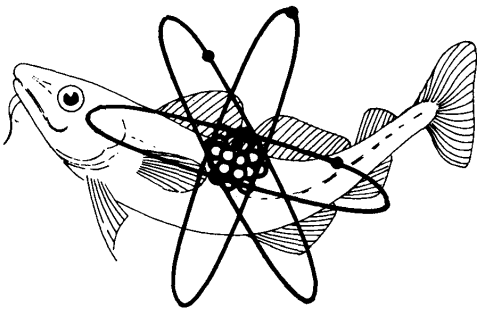
DIRECTORATE OF FISHERIES RESEARCH

AQUATIC ENVIRONMENT MONITORING REPORT



NUMBER 12

RADIOACTIVITY IN SURFACE AND COASTAL WATERS OF THE BRITISH ISLES, 1983

G.J. HUNT

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CONTENTS

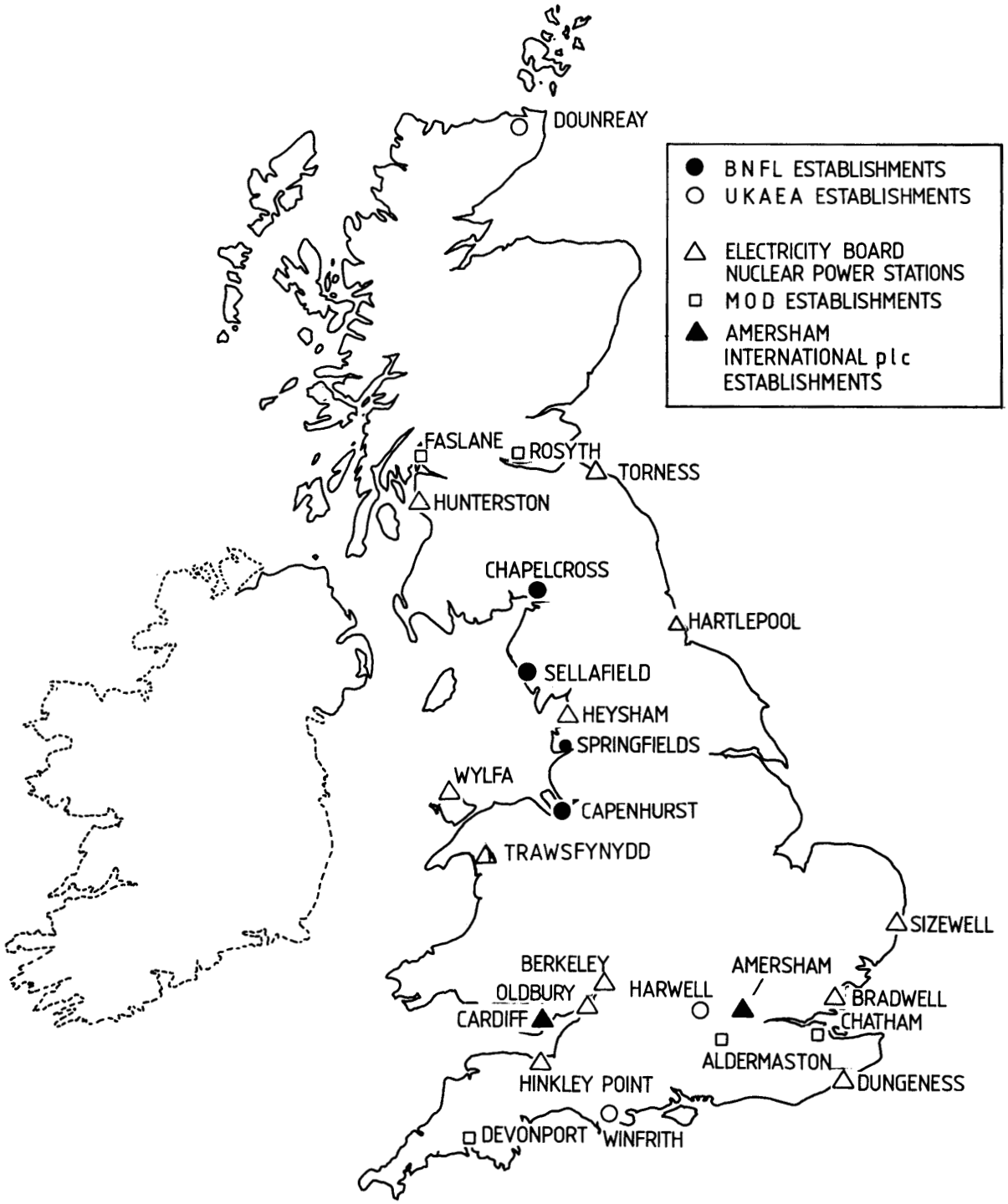

Figure 1 UK nuclear establishments giving rise to principal discharges of liquid radioactive waste.

1. Introduction

This report presents the results of the environmental monitoring programme carried out during 1983 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 1983 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 Department of the Environment (DOE). Data for 1983 have been published (DOE, 1985) 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 1983. 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 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 lower (often 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 1983 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 1983 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 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 1983 due to industrial action, following which an independent UK review of these disposals was commissioned by the Government and the Trades Union Congress. 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 — previously reviewed in 1980 (OECD (NEA), 1980) — has been carried out and is now in press. The ad-hoc review by the London Dumping Convention, of the scientific and technical considerations is well advanced, as is the IAEA review of the Definition and Recommendations referred to above. The BPEO study is also in progress.

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 undetectable; CRESP has reported that comparison of the concentration of radionuclides in sediments and fish collected within and outside the dumpsite shows no evidence of contamination from any source other

Table 1 Principal discharges of liquid radioactive waste from UK nuclear establishments, 1983

Establishment	Radioactivity	Discharge limit (annual equivalent), Ci*	Discharges during 1983		
			TBq	Ci	% of limit
BRITISH NUCLEAR FUELS plc					
Sellafield					
Sea pipeline	Total beta	300 000	2 490	67 290	22
	Ruthenium-106	60 000	553	14 948	25
	Strontium-90	30 000	204	5 500	18
	Total alpha	6 000	14	378	6.3
Seaburn sewer	Total activity	4	0.0071	0.19	4.8
Springfields	Total alpha	360	0.68	18.4	5.1
	Total beta	12 000	215	5 800	48
Chapelcross	Total activity[1]	700	3.1	83	12
	Tritium	150	0.56	15	10
Capenhurst					
Rivacre Brook	Total activity[2]	0.04	0.00033	0.009	23
Meols outfall	Technetium-99	4	0.0034	0.092	2.3
UNITED KINGDOM ATOMIC ENERGY AUTHORITY					
Winfrith	Total activity	30 000	125	3 383	11
	Ruthenium-106	9 000	0.30	8.1	<1
	Strontium-90	1 200	0.35	9.5	<1
	Total alpha	1 200	0.072	2.0	<1
Harwell	Total activity[1,3]	240	0.74	20	8.3
	Tritium	240	3.3	88	37
Dounreay	Total activity	24 000	84	2 276	9.5
	Strontium-90	2 400	16	443	18
	Total alpha	240	1.6	42	18
CENTRAL ELECTRICITY GENERATING BOARD					
Berkeley	Total activity[1]	200	0.68	18	9.2
	Tritium	1 500	0.085	2.3	<1
Bradwell	Total activity[1]	200	0.96	26	13
	Zinc-65	5	0.00074	0.02	<1
	Tritium	1 500	1.0	27	1.8
Dungeness					
"A" Station	Total activity[1]	200	1.1	30	15
	Tritium	2 000	1.3	35	1.8
"B" Station	Total activity[1,4]	4 TBq	<0.0046	<0.12	<1
	Sulphur-35	25 TBq	<0.0012	<0.032	<1
	Tritium	650 TBq	<0.11	<3.0	<1
Hartlepool[5]	Total activity[1,4]	4 TBq	<0.005	<0.13	<1
	Sulphur-35	7.5 TBq	<0.0002	<0.007	<1
	Tritium	1 850 TBq	<0.0007	<0.02	<1
Heysham[6]	Total activity[1,4]	4 TBq	<0.002	<0.05	<1
	Sulphur-35	7.5 TBq	<0.0006	<0.02	<1
	Tritium	1 850 TBq	<0.005	<0.14	<1
Hinkley Point[7]					
"A" Station	Total activity[1]	200	1.3	35	18
	Tritium	2 000	0.70	19	<1
"B" Station	Total activity[1,4]	100	0.041	1.1	1.1
	Sulphur-35	700	1.0	27	3.5
	Tritium	18 000	313	8 470	47
Oldbury	Total activity[1]	100	2.6	71	71
	Tritium	2 000	1.1	29	1.5
Sizewell	Total activity[1]	200	0.84	23	11
	Tritium	3 000	0.81	22	<1
Trawsfynydd	Total activity[1]	40	0.45	12	30
	Caesium-137	7	0.033	0.9	13
	Tritium	2 000	0.96	26	1.3
Wylfa	Total activity[1]	65	0.093	2.5	2.6
	Tritium	4 000	14	365	9.1

Table 1 (continued)

Establishment	Radioactivity	Discharge limit (annual equivalent), Ci*	Discharges during 1983		
			TBq	Ci	% of limit
SOUTH OF SCOTLAND ELECTRICITY BOARD					
Hunterston					
"A" Station[8]	Total activity[1]	432	2.8	76	18
	Tritium	1 200	2.2	59	4.9
"B" Station	Total activity[1,4]	100	0.13	3.5	3.5
	Sulphur-35	700	2.5	68	9.7
	Tritium	40 000	264	7 144	18
MINISTRY OF DEFENCE (PROCUREMENT EXECUTIVE)					
Aldermaston	Total activity[1,3]	156	0.099	2.7	1.7
	Tritium	156	0.085	2.3	1.5
MINISTRY OF DEFENCE (NAVY DEPARTMENT)					
Chatham	Total activity[1]	20	0.00089	0.024	<1
	Cobalt-60	10	0.00089	0.024	<1
	Tritium	20	0.0	0.0	0.0
Devonport	Total activity[1]	4	0.0075	0.20	5.1
	Cobalt-60	1	0.0055	0.15	15
	Tritium	10	0.045	1.2	12
Faslane	Total activity[1]	1	0.00011	0.0030	<1
Rosyth	Total activity[1]	30	0.0093	0.250	<1
AMERSHAM INTERNATIONAL plc					
Amersham	Total activity[1,3]	72	0.29	7.8	11
	Tritium	400	0.086	2.3	<1
Cardiff	Beta/gamma activity[9]	96 GBq	0.017	0.46	18
	Carbon-14	2 TBq	1.0	28	50
	Tritium	1 400 TBq	317	8 568	23

[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 commenced in June 1983.
[6]Discharges are from Heysham I and commenced in April 1983.
[7]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.
[8]The total activity limit was changed in June 1980 and during the period of this report both this limit and the one for tritium have referred to the 12 month period commencing on 16 June each year.
[9]Excluding tritium, carbon-14 and radioisotopes of calcium and strontium.
*Unless otherwise stated.

than weapons-test fallout (OECD (NEA), 1983). In the absence of 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), 1980).

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

3.1 SI units

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

3.2 Summary of analytical methods

Although some of the analytical methods which we have used are detailed elsewhere (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.

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

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. 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 (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 section 3.4. The appropriate integration period for comparison with recommended limits is one year; standard practice is to combine annual rates of consumption or occupancy of members of the public more highly exposed (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 individuals 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 section 3.4).

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

Measurements on biota are given in terms of concentrations in wet material as collected. For fish and shellfish, because the purpose is assessment of internal exposure of the

consumer, the concentrations apply to the edible fractions. 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:		μGy h^{-1}
	Sand, shingle	0.03 to 0.05
	Mud	0.05 to 0.1

*Except sediments for which dry concentrations apply.

3.4 Methods of interpretation

The monitoring results in this report are interpreted in terms of radiation exposures of the public. The standards against which these exposures are judged are the recommendations of the ICRP. For many years these recommendations have been endorsed for use in the UK by appropriate advisory bodies. UK practice relevant to the general public is now mainly based on the recommendations of ICRP as set out in ICRP Publication 26 (ICRP, 1977). The dose limitation system therein embodied has been accepted as national policy (Great Britain — Parliament, 1982). UK legislation is being amended to comply with the Euratom Directive on basic radiation safety standards, the current version of which (Commission of the European Communities, 1980) is based on the recommendations of ICRP Publication 26. In this report, results have been interpreted also on the basis of these recommendations.

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, *inter alia*, consideration of collective 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 this principal limit. The subsidiary limit of 5 mSv $year^{-1}$ applies for appropriate critical groups of members of the public likely to be the most exposed, and is the limit against which exposures are given first consideration in this report. 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 specific lifetime committed effective dose equivalent does not exceed 70 mSv. Where appropriate, consideration is given in this report to compliance with the ICRP-recommended limitation on lifetime effective dose equivalent. The ICRP has indicated (ICRP, 1984) that because of this limitation, 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, ICRP continues to recommend (ICRP, 1985) the limit for skin of 50 mSv year^{-1}.

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 method is needed. In this report, modifications for members of the public were made including 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 doses from plutonium essentially by this factor, and these higher doses 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 μGy h^{-1} has been taken as producing an effective dose equivalent rate of 0.87 μSv h^{-1} (Spiers *et al.*, 1981).

In order to interpret monitoring results in terms of the recommendations of the ICRP, 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. This is then expressed as a percentage of the ICRP-recommended dose limit of 5 mSv year^{-1} for members of the public.

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 section 3.4 (e.g. Hunt, 1984a).

Discharges from the Sellafield pipelines during 1983 are summarised in Table 1, and were within the limits set by the authorising Departments. Discharges of total beta activity, at 22% of the authorised limit, were less than in 1982 (32%). Total beta discharges are substantially dependent upon releases of radiocaesium which mainly originate from the fuel element storage ponds. In 1983 caesium-137 pipeline discharges totalled 1 200 TBq, a lower total than in 1982 (2000 TBq). This reduction was brought about by the continued optimisation of the use of zeolite skips in the ponds to absorb caesium (Hunt, 1984a), in order to ensure

that doses were ALARA (section 3.4) as required by the authorising Departments. Strontium-90 discharges in 1983 were also less than in 1982. Discharges of ruthenium-106, which derives mainly from operations other than in the ponds, were 553 TBq, a greater amount than for 1982 (419 TBq). This increase was partly due to discharges following an incident in November 1983 when plant washings were accidentally transferred to a sea tank (DOE, 1984; Health and Safety Executive, 1984). Discharges of alpha-emitting plutonium isotopes in 1983 totalled 11.6 TBq, less than in 1982 (20.8 TBq) due to improved filtration and control procedures. Americium-241 discharges in 1983 were also less than in 1982 for the same reasons, and these reductions were reflected in a decrease in total alpha activity discharged.

We maintained a substantial monitoring effort during 1983 and carried out a significant programme of additional monitoring related to the November 1983 incident. The results of this additional monitoring in 1983 have already been published (MAFF, 1983) as well as a subsequent report for 1984 (MAFF, 1984). Briefly, the additional programme 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 anyone has received a dose in excess of the ICRP non-stochastic limit for skin (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 1983.

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 1983, 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. Some of the research was supported by contract with the Commission of the European Communities. 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. 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 0.2—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 (section 3.3).

Concentrations of radiocaesium in 1983 were generally less than in 1982 for fish from the Irish Sea and Scottish waters. This is attributed to reduced concentrations in sea water, following the decreasing trend in radiocaesium discharges from Sellafield since 1975. There was, however, a slight increase in 1983 in concentrations of radiocaesium in fish from the North Sea; this was probably due to the effect of increased flushing of the Irish Sea in 1982 superimposed on this general trend, as described later in this section.

Radiation exposure from consumption of shellfish is due in part to radiocaesium, but other nuclides also make significant contributions owing to 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. 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 were obtained from consumers who collected them at Coulderton and Nethertown, coastal areas typically exploited by this critical group.

Table 4 Beta/gamma radioactivity in fish from the Irish Sea vicinity and further afield, 1983

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	6	690	28	570
	Flounder	1	750	23	590
Sellafield offshore area[1]	Plaice	4	430	15	340
	Dab	4	380	14	310
	Skate	1	500	16	380
	Whiting	1	570	18	400
	Cod	3	610	21	440
Ravenglass[2]	Cod	8	420	14	310
	Plaice	9	370	14	310
Morecambe Bay[1]	Flounder	4	410	13	360
	Bass	1	590	19	540
	Whitebait	2	320	12	240
Whitehaven[2]	Cod	4	310	8.1	190
	Plaice	4	260	6.2	170
	Herring	1	160	2.3	59
Fleetwood[2]	Cod	4	240	5.5	140
	Plaice	4	200	5.4	130
Cumbrian rivers[4]	Sea trout	4	310	9.2	230
Isle of Man[2]	Cod	5	180	2.7	75
	Plaice	3	150	2.5	75
	Herring	3	170	1.7	54
	Witches	1	120	1.6	17
	Lemon sole	2	130	1.8	34
	Whiting	1	370	7.8	250
Inner Solway[1]	Salmon	1	92	ND	1.3
	Flounder	4	340	9.0	300
	Plaice	4	240	4.5	120
North Anglesey[1]	Plaice	1	150	1.4	42
Northern Ireland[2]	Whiting	4	210	3.3	100
Minch[1]	Plaice	3	110	0.6	19
	Cod	3	140	0.6	22
Northern North Sea[1]	Plaice	4	110	0.1	6.6
	Cod	6	130	0.2	7.1
	Haddock	4	NA	0.06	5.1
	Saithe	1	"	ND	2.8
Mid-North Sea[1]	Plaice	8	110	"	4.0
	Cod	10	140	0.2	9.7
	Haddock	3	NA	ND	6.2
	Herring	1	84	"	8.9
	Whiting	1	NA	0.5	21
Southern North Sea[1]	Plaice	4	88	0.04	2.6
	Cod	3	200	0.08	6.2
	Whiting	1	NA	0.4	8.2
	Herring	3	130	0.05	10
Iceland area[1]	Cod	3	91	ND	0.4
	Haddock	1	96	"	0.2
	Plaice	4	85	"	0.4

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.

Table 5 Beta/gamma radioactivity in shellfish from the Irish Sea vicinity and further afield, 1983

Sampling area/landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}											
			Total beta	^{60}Co	^{95}Zr + ^{95}Nb	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu
Sellafield shoreline area[1]	Crabs	8	460	1.8	7.1	ND	200	6.5	ND	8.4	160	3.1	ND	ND
	Lobsters	6	700	1.4	ND	"	100	15	"	15	300	1.9	0.3	"
	Winkles	5	3900	17	340	31	3500	26	6.6	7.4	170	18	ND	"
Sellafield offshore area[1]	Whelks	3	1100	0.7	58	6.3	850	7.4	ND	1.7	95	1.7	0.9	0.9
Coulderton[1]	Winkles	3	2900	16	93	11	2600	29	5.3	11	200	69	2.5	2.7
	Winkles[4]	6	6000	29	1200	39	4400	28	19	20	430	130	10	6.3
	Winkles[5]	1	NA	7.0	ND	ND	430	7.6	2.3	5.2	94	7.9	ND	ND
Nethertown[1]	Winkles[6]	2	5600	28	1500	130	6100	33	14	12	260	63	"	ND
Ravenglass[1]	Cockles	4	3200	17	1000	39	2400	1.5	5.0	6.8	130	55	9.2	4.0
	Mussels	4	3300	6.1	780	63	3200	1.2	8.5	4.5	87	22	ND	ND
St Bees[1]	Limpets	4	3200	12	290	12	1700	16	7.9	7.7	160	38	"	0.6
	Mussels	4	3600	13	970	60	3600	1.8	7.7	3.1	94	37	"	1.2
	Winkles	4	2900	17	350	17	2200	23	5.4	6.6	180	26	"	ND
Whitehaven[2]	*Nephrops*	3	170	ND	ND	ND	2.7	ND	ND	3.0	73	ND	"	"
Morecambe Bay[1]	Shrimps	4	190	"	"	"	2.5	"	"	5.7	130	"	"	"
	Cockles	4	320	1.4	27	1.2	120	"	"	2.2	66	"	"	"
Isle of Man[2]	Scallops	2	93	ND	ND	ND	5.2	0.7	"	0.6	13	"	"	"
	Queens	3	130	"	"	"	ND	ND	"	0.9	20	"	"	"
Inner Solway[1]	Shrimps	4	170	"	"	"	2.0	"	"	4.3	100	"	"	"
Kirkcudbright[2]	Scallops	4	92	"	"	"	ND	"	"	0.3	8.2	"	"	"
	Queens	4	50	"	"	"	"	"	"	0.2	9.7	"	"	"
	Whelks	2	170	0.8	"	"	55	1.4	"	0.7	23	"	"	"
North Solway coast[1]	Winkles	4	430	2.1	11	"	170	ND	ND	1.6	56	1.9	"	"
Wirral[1]	Shrimps	2	110	ND	ND	"	ND	"	"	1.4	48	ND	"	"
	Cockles	2	97	"	"	"	16	"	"	0.6	25	"	"	"
Conwy[2]	Mussels	3	150	"	"	"	2.8	"	"	0.8	20	"	"	"
North Anglesey[1]	Crabs	2	95	"	"	"	17	"	"	0.2	11	"	"	"
Northern Ireland[2]	*Nephrops*	4	120	"	"	"	ND	"	"	0.7	19	"	"	"
Northern North Sea[1]	*Nephrops*	3	100	"	"	"	"	"	"	0.2	6.4	"	"	"
Mid North Sea[1]	*Nephrops*	1	83	"	"	"	"	"	"	0.2	5.9	"	"	"
	Mussels	3	42	"	"	"	"	"	"	ND	1.6	"	"	"
Southern North Sea[1]	Cockles	4	23	0.5	"	"	"	"	"	"	0.5	"	"	"
	Mussels	3	26	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 128.

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 1983, as for fish, showed general reductions as compared with 1982. Concentrations of ruthenium-106 were generally higher however, reflecting the increased discharges of this nuclide. Concentrations of other beta/gamma-emitting radionuclides were generally similar to those in 1982.

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 greater in 1983 than in 1982. Analyses were often carried out on bulked samples (section 3.3). The data for 1983 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 generally reducing trend for 1983 as compared with 1982. The size of the reductions did not proportionately reflect the reduced discharges of alpha-emitting nuclides in 1983. 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. Reduced discharges of alpha-emitters in 1983 are expected to contribute to the generally reducing trend in concentrations over subsequent years.

The radiation dose to consumers of fish and shellfish depends upon the product of the mass of foodstuff

Table 6 Transuranic radioactivity in fish and shellfish from the Irish Sea vicinity and further afield, 1983

Sampling area/landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}					
			^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Sellafield shoreline area[1]	Cod	1	0.0047	0.025	NA	0.020	0.00044	0.00011
	Crabs	3	0.71	2.9	80	7.3	0.097	0.051
	Lobsters	3	0.54	2.2	63	14	0.059	0.062
	Winkles	2	6.6	27	710	37	0.45	0.17
Sellafield offshore area[1]	Plaice	1	0.0085	0.034	NA	0.038	ND	ND
	Cod	1	0.0057	0.026	"	0.030	0.00081	"
	Skate	1	0.011	0.044	"	0.045	0.00054	0.00027
	Whelks	1	1.7	7.3	"	15	ND	ND
Coulderton[1]	Winkles	3	NA	NA	"	31	NA	NA
	Winkles[4]	2	27	110	2800	100	2.9	0.71
	Winkles[5]	1	NA	NA	NA	12	NA	NA
Nethertown	Winkles[6]	1	18	72	2000	69	1.0	0.34
St Bees[1]	Winkles	2	8.8	35	960	39	0.58	0.31
	Mussels	2	11	43	1200	46	0.55	0.24
	Limpets	1	8.9	37	NA	45	ND	0.22
Ravenglass[1]	Cockles	1	14	54	"	75	1.5	0.47
	Mussels	2	9.9	41	1000	55	0.45	0.25
Ravenglass[2]	Plaice	1	0.011	0.043	NA	0.048	0.0012	0.00014
	Cod	1	0.0040	0.016	"	0.015	0.00088	0.00026
Whitehaven[2]	Plaice	1	0.0020	0.0091	"	0.011	ND	0.00008
	Cod	1	0.00072	0.0032	"	0.0029	"	ND
	Herring	1	0.0047	0.019	"	0.024	0.00021	"
	Nephrops	1	0.063	0.27	"	0.51	0.0098	0.0040
Morecambe Bay[1]	Shrimps	1	0.013	0.065	"	0.069	ND	0.00030
	Cockles	1	1.1	4.8	"	9.1	0.065	0.034
Isle of Man[2]	Plaice	1	0.00055	0.0025	"	0.0025	ND	ND
	Cod	1	0.00024	0.0012	"	0.0013	"	"
	Herring	1	0.0011	0.0051	"	0.0059	"	"
	Scallops	1	0.082	0.36	"	0.32	0.0021	0.0013
	Queens	1	0.0041	0.017	"	0.0064	0.00028	0.00014
Inner Solway[1]	Salmon	1	0.00011	0.00044	"	0.00046	ND	ND
Kirkcudbright[2]	Scallops	1	0.048	0.23	"	0.086	"	0.00020
	Queens	1	0.032	0.14	"	0.12	"	0.00038
	Whelks	1	0.28	1.3	"	1.5	0.0040	0.0064
North Solway coast[1]	Plaice	1	0.0017	0.0070	"	0.010	ND	0.00002
	Winkles	1	1.7	7.3	"	9.0	0.066	0.046
Wirral[1]	Cockles	1	0.53	2.4	"	4.9	ND	0.018
Conwy[2]	Mussels	1	0.095	0.43	"	0.61	0.0017	0.0019
Northern Ireland[2]	*Nephrops*	1	0.0028	0.015	"	0.031	ND	0.00010
Minch[1]	Cod	1	0.00012	0.00048	"	0.00053	0.00015	0.00002
Northern North Sea[1]	Cod	1	0.00067	0.0038	"	0.0051	ND	0.00002
	Nephrops	1	0.0019	0.0092	"	0.0074	0.00027	0.00008
Mid North Sea[1]	*Nephrops*	1	0.00075	0.0033	"	0.0025	ND	ND
	Mussels	1	0.0035	0.019	"	0.0045	"	"
Southern North Sea[1]	Mussels	1	0.00077	0.0042	"	0.0013	"	"
	Cockles	1	0.0023	0.013	"	0.0054	"	"
Iceland area[1]	Cod	1	0.000063	0.00027	"	0.00032	"	"

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 " " " " 174.
6 " " " " 128.

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

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 1983. 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. It is considered that for 1983 no change is needed to the results of the 1982 assessment (Hunt, 1983).

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 for 1983 were 36.5 kg year^{-1} (100 g d^{-1}) fish, 6.6 kg year^{-1} (18 g d^{-1}) crustaceans and 16.4 kg year^{-1} (45 g d^{-1}) molluscs (Hunt, 1983). In this report, consumption rates are expressed additionally in kilograms per year to emphasise the importance of assessment over a year, in line with ICRP recommendations.

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. Plaice and cod are overwhelmingly the most popular fish eaten by the high-rate consumers, and the assessment of exposure of the critical group is based upon an equal mix of these species taken from the Sellafield Offshore Area and from landings at Ravenglass. 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 therefore 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, Coulderton, St Bees and Nethertown, including the data from samples collected by local consumers.

Table 7 summarises exposures in 1983. Provided that the ICRP lifetime dose criterion 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 (section 3.4). For each exposed population 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 contributions due to strontium-90 were estimated from the discharges of this nuclide. The contributions due to plutonium-241 were derived from measured concentrations (Table 6) following our increased programme of transuranic analyses.

Comments in 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 1983 would have been at most 45% of the ICRP-recommended dose limit of 5 mSv year^{-1} for members of the public. On the basis of dosimetric factors currently recommended by ICRP, but now subject to review, the committed effective dose equivalent would have been 29% of this limit. These results represent decreases from 54% and 34% respectively reported for 1982 (Hunt, 1984b). The decreases are due to lower concentrations of transuranics and radiocaesium, as described earlier in this section. The greater contribution due to ruthenium-106 following the increased discharges of this nuclide in 1983 was not sufficient to offset these decreases markedly.

The dose to the critical group has also been considered in the context of the ICRP's advice on lifetime exposure (section 3.4). Committed effective dose equivalent rates to the critical group in excess of 1 mSv year^{-1} (20% of the ICRP-recommended dose limit of 5 mSv year^{-1} for members of the public) have only been reported for the last few years. As a result of measures already implemented by BNFL, discharges of radiocaesium and actinides are declining, and further measures to reduce these discharges are planned. It is expected that doses to the critical group will fall below the 1 mSv year^{-1} level in the next few years. Dose rates above this level will not then have obtained for long enough for lifetime exposures to have exceeded, on average, 1 mSv year^{-1}.

Table 7 Individual radiation exposures due to consumption of Irish Sea fish and shellfish, 1983

Exposed population	Consumption rate used in assessment (see text)			Nuclide	Committed effective dose equivalent (as % of ICRP-recommended dose limit of 5 mSv $year^{-1}$ for members of the public)	
		kg y^{-1}	(g d^{-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	0.3	0.3
	crustaceans:	6.6	(18)	^{106}Ru	6.8	6.8
	molluscs:	16.4	(45)	^{134}Cs	0.3	0.3
				^{137}Cs	5.0	5.0
				^{238}Pu	0.5	2.5
				$^{239}Pu + ^{240}Pu$	2.3	11.5
				^{241}Pu	1.3	6.3
				^{241}Am	12.3	12.3
				Total	29	45
Consumers associated with commercial fisheries (Whitehaven, Fleetwood, Morecambe Bay)	fish:	131	(360)	^{90}Sr	0.3	0.3
	crustaceans:	18	(50)	^{106}Ru	0.2	0.2
	molluscs:	15	(40)	^{134}Cs	0.4	0.4
				^{137}Cs	6.5	6.5
				^{238}Pu	0.04	0.2
				$^{239}Pu + ^{240}Pu$	0.2	0.9
				^{241}Pu	0.1	0.5
				^{241}Am	1.6	1.6
				Total	9	11
Typical member of the fish-eating public consuming fish landed at Whitehaven/Fleetwood	fish:	15	(40)	^{134}Cs	0.04	0.04
				^{137}Cs	0.6	0.6
				Total	0.7	0.7

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. These data include revised consumption rates for crustaceans and molluscs for 1983 following a habits survey of Morecambe Bay in connection with Heysham Power Station (section 6.5). 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 1983 is given in Table 7. The total of 11% of the ICRP-recommended dose limit of 5 mSv $year^{-1}$ for members of the public, on the basis of the enhanced gut uptake factor for plutonium, represents a decrease from 13% of this limit reported for 1982 (Hunt, 1984b). 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 1983 was 0.7% of the ICRP-recommended dose limit of 5 mSv $year^{-1}$ for members of the public, which represents a decrease from 0.9% reported for 1982 (Hunt, 1983), due to the reduced concentrations of radiocaesium in Irish Sea fish.

Collective doses from fish and shellfish have been estimated for 1983 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 1983 are provisional, relying on preliminary landings statistics provided by the International Council for the Exploration of the Sea (ICES). The provisional results will be reviewed in future reports as updated statistics are received. We have adjusted the result for 1982 to take account of further data becoming available; the only change is for other European countries where the small increase in collective dose from 100 man-Sv to 120 man-Sv is due to additional data being provided on landings.

Table 8 Collective doses from fish and shellfish, 1982 and 1983

Population	Size of population	Collective effective dose equivalent, man-Sv	
		1982	1983 (provisional)
UK	5.6×10^7	90	70
Other European countries	7.0×10^8	110	110

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 (section 3.4). The contribution of pathways other than fish and shellfish consumption, e.g. external exposure, to the collective dose from Sellafield liquid discharges is relatively small (Hunt and Jefferies, 1981).

The provisional result of 70 man-Sv for the UK in 1983 represents a decrease in collective dose as compared with 90 man-Sv in 1982 (Hunt, 1984b). This decrease was due to the generally lower radiocaesium concentrations, noted above, in fish and shellfish from the Irish Sea and Scottish waters, combined with reductions in fish landings from these areas. The provisional result of 110 man-Sv for the collective dose to inhabitants of other countries in 1983 was the same as in 1982. The slight increases, noted above, in radiocaesium concentrations in North Sea fish were offset by overall reductions in landings of edible fish.

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 section 3.4) as a result of all waste management practices. In 1983 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.

It is clear from the statements above which compare the 1982 and 1983 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 September 1983 is shown in Figure 2. Comparison with the data for November 1982 (Hunt, 1984b) shows that concentrations of caesium-137 in sea water of the Irish Sea were generally similar in 1983. This observation, despite the reductions in radiocaesium discharges from Sellafield in 1983, suggests that the flow of sea water through the Irish Sea reduced to more normal levels following the increased flow postulated for 1982 (Hunt, 1984b). Concentrations of radiocaesium in fish, however, which lag behind those in water because of the time for biological uptake, declined in 1983 following the reduced concentrations in the Irish Sea for 1982. The distribution of caesium-137 in Scottish waters in October 1983 is shown in Figure 3. This shows the usual behaviour of the radiocaesium-labelled water in remaining relatively close to the coastline with rapid reductions off the continental shelf. The distribution of caesium-137 in sea water of the North Sea during August and September 1983 is shown in Figure 4. Comparison with the distribution observed in February and March 1982 (Hunt, 1984b) shows that the intrusion then observed off north-east Scotland of water slightly richer in caesium-137 has extended down the east coast; this effect is believed to be due to increased flushing of the Irish Sea in 1982, as noted above. The slightly higher concentrations of radiocaesium in fish from the North Sea in 1983 as compared with 1982 are probably a result of the generally increased concentrations in the western North Sea following this flushing. Nevertheless, there is a generally reducing trend in radiocaesium concentrations in sea water and fish from all areas, reflecting the general decrease in radiocaesium discharges from Sellafield since 1975 achieved particularly by the use of zeolite skips in the magnox fuel storage ponds in pursuance of the ALARA principle (section 3.4) as required by the authorising Departments (Hunt, 1984a).

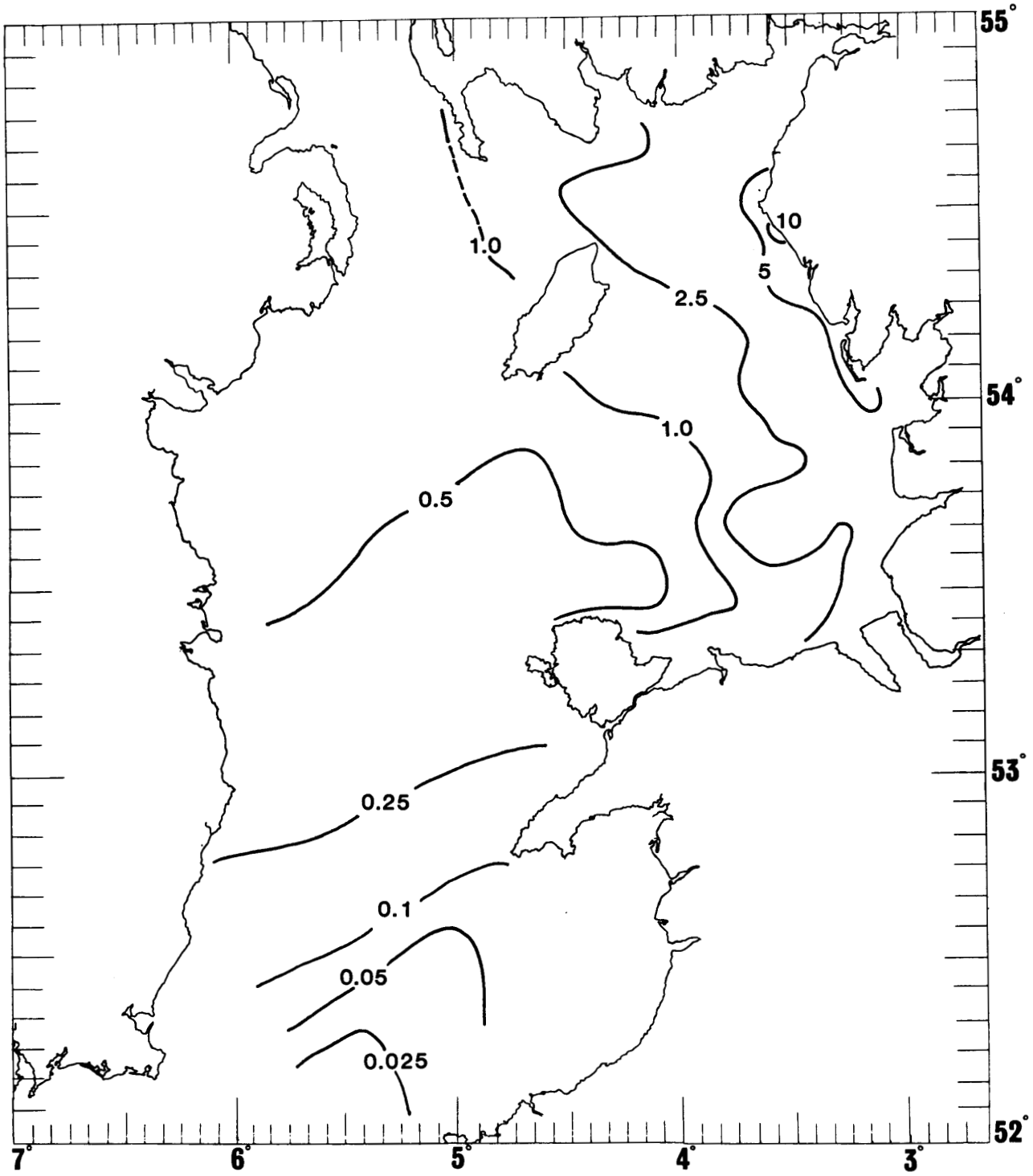

Figure 2 Concentration (Bq kg^{-1}) of caesium-137 in filtered surface water from the Irish Sea, September 1983.

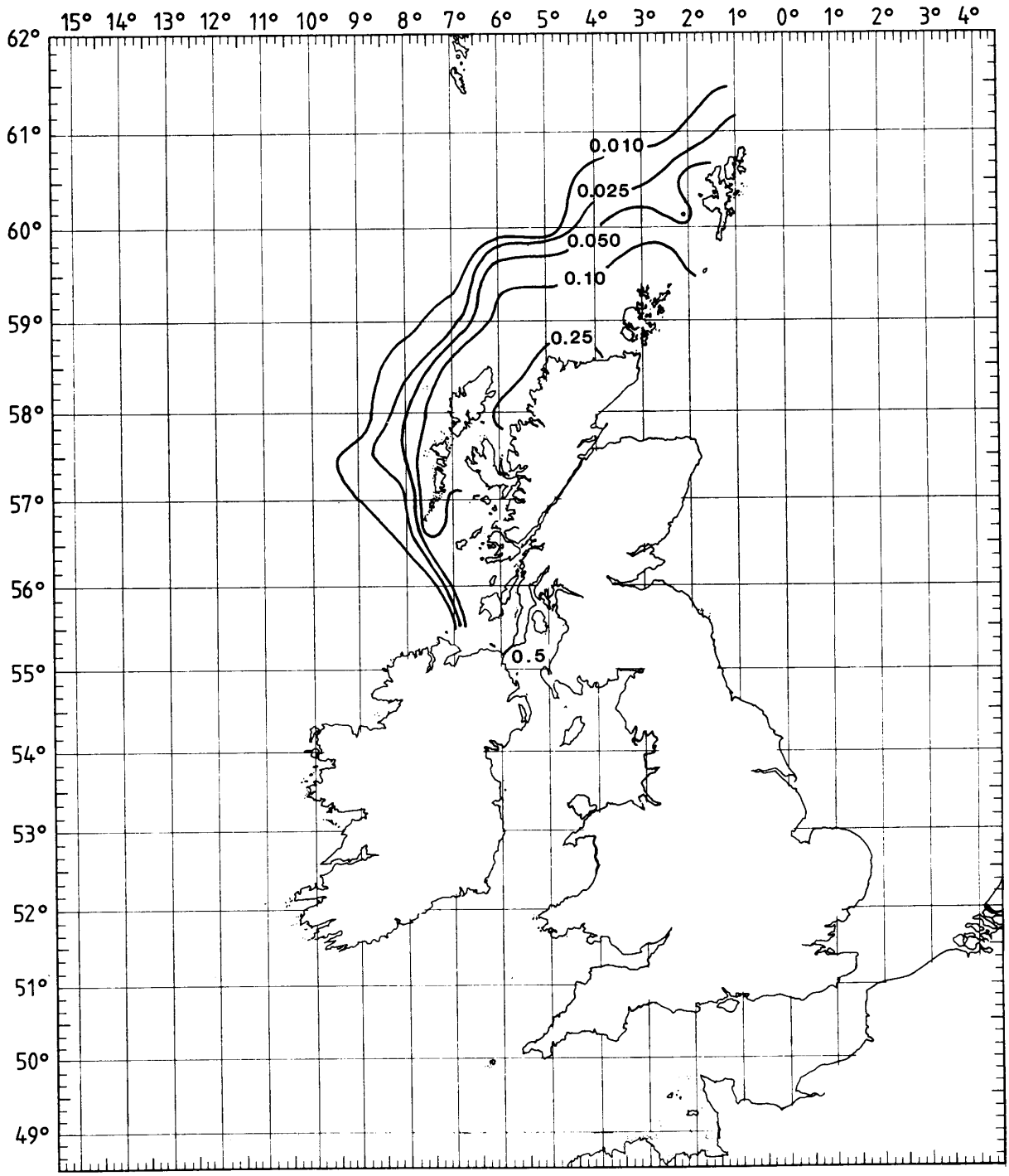

Figure 3 Concentration (Bq kg^{-1}) of caesium-137 in filtered surface water from the north-west of Scotland, October 1983.

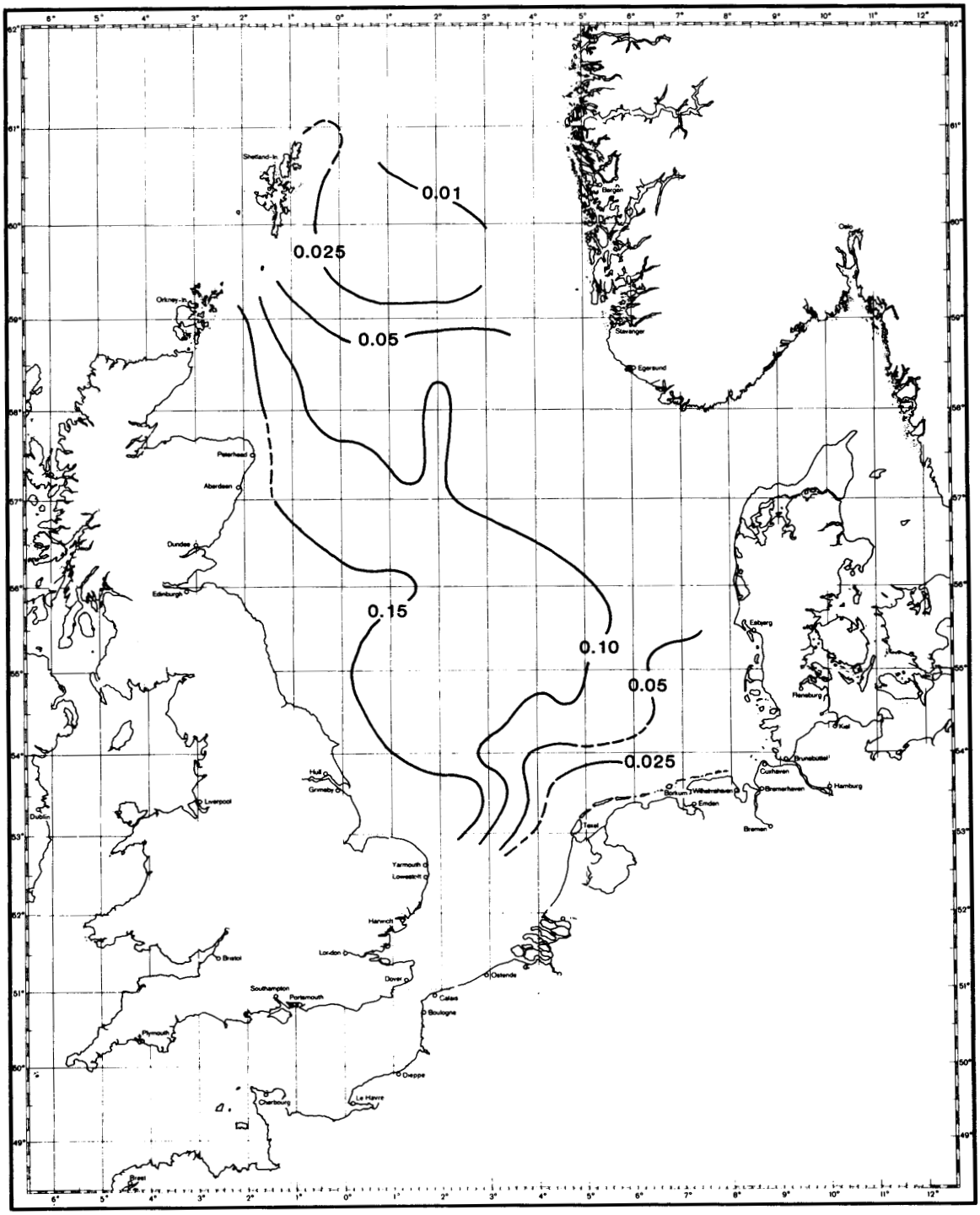

Figure 4 Concentration (Bq kg^{-1}) of caesium-137 in filtered surface water from the North Sea, August–September 1983.

Table 9 Gamma radiation dose rates over intertidal areas of the Cumbrian coast and further afield, 1983

Location	Ground type	No. of sampling observations†	Mean gamma dose rate in air at 1 m, μGy h^{-1}
Burgh Marsh	Salt marsh	4	0.16
Greenend	" "	4	0.14
"	Sand	4	0.13
Maryport harbour	Silt	4	0.32
Workington harbour	"	4	0.31
Whitehaven outer harbour	"	12	0.32
" " "	Sand	11	0.28
Whitehaven yacht basin	Silt	12	0.71
Coulderton winkle beds	Rock	4	0.17
Sellafield	Sand	12	0.21
Drigg	"	4	0.16
Ravenglass - Salmon Garth	"	12	0.20
" "	Silt	12	0.52
" "	Mussel beds	12	0.62
Ravenglass - boats area	Sand	12	0.18
" " "	Silt	12	0.29
Ravenglass - ford area	"	12	0.66
Ravenglass - Ravenvilla	"	12	0.67
" "	Salt marsh	12	0.96
Newbiggin	Silt	13	0.88
Newbiggin - west of bridge	Sand/silt	12	0.44
" east " "	Salt marsh	12	0.95
Haverigg	Sand	4	0.21
"	Silt	4	0.43
Millom	Sand	4	0.15
"	Silt	4	0.35
Walney Channel	Sand	4	0.25
" "	Silt	4	0.34
" west shore	Sand	4	0.088
Flookburgh	Sand	3	0.12
Fleetwood	"	5	0.089
Blackpool	"	5	0.075
Ainsdale	"	4	0.078
New Brighton	"	4	0.082
Mersey (Rock Ferry)	Silt	4	0.16
Llandudno	Shingle	4	0.062
Prestatyn	Sand	4	0.054
Garlieston	Silt	1	0.18
Kippford - slipway	"	4	0.20
" - jetty	"	4	0.18
" - merse	"	3	0.26
" - "	Salt marsh	3	0.28

†See section 3.3 for definition.

4.1.2 External exposure

A further important pathway leading to radiation exposure as a result of Sellafield discharges arises 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 sections 4.2, 4.3, 4.4, 6.5, 6.11). Variations in sediment type account for the quite marked fluctuations in dose rate, superimposed on a general decrease with increasing distance from Sellafield. Dose rates over intertidal areas in 1983 showed general slight reductions as compared with 1982 (Hunt, 1984b).

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 1982 (Hunt, 1984b) shows general slight 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).

Table 10 Radioactivity in sediment from the Cumbrian coast and further afield, 1983

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	9 300	28	1 600	3.1	4 300	49	120	3 700	270
Whitehaven	(")	4	15 000	29	3 400	110	5 200	62	220	5 900	440
Sellafield	(sand)	10	1 500	8.2	290	2.5	390	ND	32	720	41
Newbiggin	(silt)	4	17 000	70	3 000	20	6 900	180	190	6 000	540
Walney Island	(")	4	5 200	20	1 800	40	3 600	37	60	1 600	160
Flookburgh	(sand)	4	1 600	3.3	98	ND	390	1.4	26	790	5.3
Heysham	(silt)	4	2 500	5.9	320	14	1 100	9.1	44	1 200	38
Sunderland Pt	(")	4	1 700	2.6	200	5.9	530	ND	30	840	19
Fleetwood	(sand)	4	340	ND	ND	ND	ND	"	4.1	120	ND
Blackpool	(")	5	310	"	"	"	204	"	3.6	96	"
New Brighton	(")	4	430	"	"	"	21	"	3.5	110	"
Rock Ferry	(silt)	4	1 900	3.2	53	"	290	"	32	1 200	7.6
Garlieston	(sand)	4	1 000	0.9	40	"	140	1.9	9.9	300	6.9
"	(silt)	4	2 200	5.7	210	4.7	750	5.1	32	960	31
Kippford slipway	(")	4	3 400	11	600	ND	1 600	5.4	48	1 500	87
" merse	(")	4	3 900	18	170	"	1 200	4.3	60	2 000	53
" jetty	(")	4	3 300	8.6	450	"	1 100	3.1	42	1 100	60

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}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Maryport	(silt)	4	69	55	210	900	1 000	4.6	4.6
Whitehaven	(")	4	78	66	260	1 100	1 100	13	4.8
Sellafield	(sand)	10	14	8.7	47	220	320	1.1	1.0
Newbiggin	(silt)	4	200	190	730	3 000	2 700	4.1	12
Walney Island	(")	4	35	30	NA	NA	450	NA	NA
Flookburgh	(sand)	4	4.4	1.0	18	81	96	0.28	0.36
Heysham	(silt)	4	9.7	4.3	53	230	260	1.2	1.7
Sunderland Pt	(")	4	5.3	7.7	NA	NA	80	NA	NA
Fleetwood	(sand)	4	ND	ND	1.1	6.1	5.9	0.027	0.019
Blackpool	(")	4	"	"	NA	NA	4.0	NA	NA
New Brighton	(")	4	"	"	"	"	6.0	"	"
Rock Ferry	(silt)	4	6.9	5.0	31	130	150	ND	0.52
Garlieston	(sand)	4	3.0	1.9	NA	NA	50	NA	NA
"	(silt)	4	13	7.4	37	170	200	0.67	0.74
Kippford slipway	(")	4	22	16	66	300	330	1.3	1.3
" merse	(")	4	27	19	88	410	450	1.1	2.0
" jetty	(")	4	8.6	4.3	45	220	240	1.6	0.68

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

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 1983 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 1983 was 7% of the ICRP-recommended limit of 5 mSv year^{-1} for members of the public. This result makes use (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 total exposure related to Sellafield liquid discharges; other exposure pathways, such as handling of fishing gear, are negligible by comparison (section 4.1.3). This addition is estimated to be 4% of the ICRP-recommended dose limit of 5 mSv year^{-1} for members of the public, on the basis of the enhanced value of gut uptake factor for plutonium described in section 3.4. Total exposure of the externally exposed critical group is thus estimated to be 11% of this limit. This exposure is less than that of the critical group of fish and shellfish consumers given earlier.

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 section 4.1.1; additions of this small order are considered to be adequately taken into account by the maximising process of summing exposures from the consumption of fish, crustaceans and molluscs.

4.1.3 Fishing gear

During immersion in sea water fishing gear may entrain particles of sediment on which radioactivity is adsorbed. Fishermen handling this gear may be 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 been of very minor radiological significance, but to provide additional reassurance, early in 1983 we began an enhanced programme of monitoring of fishing gear. Results are presented in Table 11. Monitoring of fishing gear after the incident of November 1983 did not detect contamination significantly different from normal levels (MAFF, 1983). 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 1983 would have been less than 1% of the ICRP-recommended dose limit appropriate for exposures to skin of members of the public, based on non-stochastic effects (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, 1983

Vessel	Type of gear	No. of sampling observations†	Mean beta dose rate in tissue, μGy h^{-1}
A	Nets	4	0.33
	Ropes	4	0.36
B	Nets	4	0.66
	Ropes	4	0.38
C	Nets	1	0.21
	Ropes	1	0.07
D	Nets	1	0.20

†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 1983; this pathway has therefore remained essentially dormant. However, in view of its potential importance and the value of *Porphyra* as an indicator, monitoring has continued. Samples of *Porphyra* are regularly collected from selected locations along the Cumbrian coast. Results of analyses for 1983 are presented in Table 12. Samples of

Table 12 Radioactivity in *Porphyra* from the Cumbrian coast, 1983

Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}								
		Total beta	^{60}Co	^{95}Zr + ^{95}Nb	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs
Braystones South	12	5 500	6.0	1 100	140	5 500	ND	7.5	6.3	140
Seascale	52*	NA	2.3	280	98	3 000	0.4	2.9	4.2	76

Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}							
		^{144}Ce	^{154}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Braystones South	12	39	0.4	10	40	1 200	32	1.0	0.16
Seascale	52*	8.0	ND	NA	NA	NA	5.6	NA	NA

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

laverbread from the major manufacturers are regularly collected from markets in South Wales and analysed. Results for 1983 are presented in Table 13. The exposure of critical laverbread consumers was less than 0.1% of the ICRP-recommended dose limit of 5 mSv year^{-1}, confirming the virtual abeyance of this pathway.

Table 13 Radioactivity in laverbread from South Wales, 1983

Manufacturer	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}			
		Total beta	^{106}Ru	^{137}Cs	^{144}Ce
A	4	90	12	3.1	ND
B	3	60	ND	2.1	"
C	5	82	4.3	0.8	0.2

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

4.1.5 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 14 presents the

Table 14 Radioactivity in seaweeds from UK shorelines of the Irish Sea, 1983

Type of seaweed and sampling point	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}										
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{95}Zr + ^{95}Nb	^{99}Tc	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs
Fucus vesiculosus												
Sellafield	12	3 200	0.6	34	0.3	610	2 300	13	580	6.7	2.6	31
Heysham	4	550	ND	0.6	ND	22	NA	ND	23	ND	ND	6.5
Port William	4	560	"	-0.5	"	3.2	"	"	10	"	0.2	2.6
Garlieston	4	490	"	1.2	"	ND	"	"	24	"	0.7	4.1
Auchencairn	4	610	"	1.2	"	9.9	"	"	20	"	ND	5.4
Ardglass	2	480	"	ND	"	ND	"	"	4.2	"	"	1.7
Portrush	4	300	"	"	"	"	"	"	ND	"	"	0.1
Rhodymenia palmata												
Millisle	4	760	"	"	"	"	"	"	11	"	"	1.5
Ascophyllum nodosum												
Ardglass	1	710	"	"	"	"	"	"	5.9	"	"	1.5
Fucus spiralis												
Ardglass	1	330	"	"	"	"	"	"	ND	"	"	1.2

Type of seaweed and sampling point	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}								
		^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Fucus vesiculosus										
Sellafield	12	530	19	0.9	ND	16	61	18	0.48	0.11
Heysham	4	140	ND	ND	"	1.0	4.5	2.1	ND	0.0078
Port William	4	58	"	"	"	NA	NA	0.4	NA	NA
Garlieston	4	93	"	"	"	"	"	3.0	"	"
Auchencairn	4	130	0.3	0.2	0.1	"	"	3.0	"	"
Ardglass	2	42	ND	ND	ND	"	"	ND	"	"
Portrush	4	7.0	"	"	"	"	"	"	"	"
Rhodymenia palmata										
Millisle	4	41	"	"	"	"	"	"	"	"
Ascophyllum nodosum										
Ardglass	1	29	"	"	"	"	"	"	"	"
Fucus spiralis										
Ardglass	1	28	"	"	"	"	"	"	"	"

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

results of measurements in 1983 on seaweeds from UK shorelines of the Irish Sea. Although small quantities of *Rhodymenia palmata* 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).

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 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; Freckleton is typical of an area of muddy creeks where houseboats are moored. Dose rates are also monitored close to the Springfields outfall, and these measurements are supported by analyses of sediment.

Results for 1983 are shown in Table 15(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 1983, including the Sellafield component, was about 6% of the ICRP-recommended dose limit of 5 mSv year^{-1}, slightly less than for 1982 (Hunt, 1984b). The exposure is mainly due to Sellafield discharges; the contribution due to Springfields would have been a small fraction of the total.

Table 15(a) Radioactivity in sediment near the Springfields pipeline, 1983

Location	No. of sampling observations†	Mean radioactivity concentration (dry), Bq kg^{-1}								
		Total beta	^{60}Co	^{95}Zr + ^{95}Nb	^{103}Ru	^{106}Ru	^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu
Pipeline outlet	4	13 000	13	470	6.5	1600	99	2 800	60	22

Location	No. of sampling observations†	Mean radioactivity concentration (dry), Bq kg^{-1}						
		^{155}Eu	^{234m}Pa	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Pipeline outlet	4	6.5	87 000	76	320	350	2.0	2.4

†See section 3.3 for definition.

Table 15(b) Gamma dose rates in air at 1 m over intertidal areas near the Springfields pipeline, 1983

Location	No. of sampling observations†	μGy h^{-1}
Pipeline outlet	4	0.31
460 m upstream	4	0.28
Freckleton boatyard	4	0.23

†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

Table 16 Radioactivity in environmental materials in the vicinity of the Wirral, 1983

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
			Total beta	^{99}Tc	^{106}Ru	^{134}Cs	^{137}Cs	^{238}Pu
Shrimps	Hoylake	2	110	0.8	ND	1.4	48	NA
Cockles	Dee Estuary	2	100	1.9	16	0.6	25	0.53
Fucus spiralis	Hoylake	2	410	54	2.2	2.3	63	NA
" "	Little Orme	2	500	310	5.0	2.0	50	"
Sand	Hoylake	2	460	0.3	20	7.3	200	1.1

Material	Sampling point	No. of sampling observations†	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	4.9	ND	0.018
Fucus spiralis	Hoylake	2	NA	0.6	NA	NA
" "	Little Orme	2	"	0.4	"	"
Sand	Hoylake	2	6.4	5.2	ND	0.015

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

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 which reflects 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 1983 are presented in Table 16. 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 due to decay-stored liquors not being released. Discharges of technetium-99 from Capenhurst were reduced in 1983 as compared with 1982. Exposure of critical shellfish consumers in the vicinity of the Wirral in 1982 amounted to less than 2% of the ICRP-recommended dose limit of 5 mSv year^{-1}; this was mainly due to radiocaesium and transuranic nuclides from Sellafield. Only a tiny fraction of this exposure 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 1983, such that discharges were at a higher level than for a year in which no such operations took place, but were slightly less than in 1982 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 catches. 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 1983 are presented in Table 17(a) and (b).

Table 17(a) Radioactivity in environmental materials in the vicinity of Chapelcross, 1983

Material	Sampling point	No. of sampling observations†	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	340	ND	ND	ND	9.0	300	ND	ND
Salmon	"	1	92	"	"	"	ND	1.3	"	"
Shrimps	"	4	170	"	"	2.0	4.3	100	"	"
Fucus vesiculosus	Seafield	4	530	0.6	5.8	16	5.5	160	"	"
Silt	"	4	2200	3.7	290	690	42	1300	45	6.4
Sand	"	4	1900	3.1	100	400	34	1100	18	6.3

Material	Sampling point	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
Flounder	Seafield	4	ND	NA	NA	ND	NA	NA
Salmon	"	1	"	0.00011	0.00044	0.00046	ND	ND
Shrimps	"	4	"	NA	NA	ND	NA	NA
Fucus vesiculosus	Seafield	4	"	1.1	4.8	3.9	0.032	0.014
Silt	"	4	1.4	26	120	130	0.89	0.72
Sand	"	4	6.7	3.8	17	20	0.23	0.06

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

Table 17(b) Gamma dose rates in air at 1 m over intertidal areas in the vicinity of Chapelcross, 1983

Location and sediment type	No. of sampling observations†	μGy h^{-1}
Seafield (silt)	4	0.22
Torduff Point (silt)	4	0.12
Dornoch Brow (silt)	4	0.14
Dornoch Brow (merse)	4	0.14

†See section 3.3 for definition.

Concentrations of artificial radionuclides in the Chapelcross vicinity are mostly due to Sellafield discharges, and the general levels given in Table 17(a) are consistent with values to be expected at this distance from Sellafield. Radiocaesium concentrations in 1983 were generally less than those in 1982, reflecting reductions in Sellafield discharges. Exposure of the critical group in 1983, making the maximising assumption of additivity of the two pathways, amounted to less than 6% of the ICRP-recommended dose limit of 5 mSv year^{-1}. The magnitude of the Chapelcross discharges indicate that the local contribution would have been a tiny fraction of this exposure; most is due to Sellafield discharges.

5. United Kingdom Atomic Energy Authority

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

Table 18 Radioactivity in environmental materials from the vicinity of Winfrith, 1983

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
			Total beta	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn	^{137}Cs	^{238}Pu
Plaice	Weymouth	2	100	ND	ND	0.6	5	1.8	NA
Crabs	Lulworth	2	92	0.7	"	22	34	0.1	"
Oysters	Poole	2	91	ND	"	9.1	490	ND	"
Scallops	Weymouth	2	74	"	"	0.7	1.6	"	0.0008
Fucus serratus	Kimmeridge	2	310	27	16	230	33	"	NA
	Weymouth	2	280	11	10	140	15	0.3	"
	Swanage	2	320	8.0	9.5	140	19	0.2	"
	Hengistbury Head	2	260	2.0	2.1	82	6.8	0.1	"
	Bognor Regis	2	310	0.2	ND	24	0.8	0.1	"
	Sandgate	2	250	0.1	"	22	ND	0.5	"
Silt	Poole Harbour	2	210	2.5	"	36	"	1.9	0.15
	Kimmeridge	2	360	3.0	"	150	32	4.6	NA
Sand	Kimmeridge	1	140	ND	"	20	2.0	0.9	"
	Swanage	2	100	0.8	"	18	2.4	ND	"
	Hengistbury Head	2	49	ND	"	2.6	ND	"	"
	Bognor Regis	2	450	0.7	"	1.7	"	0.6	"
	Sandgate	2	84	ND	"	2.1	"	0.2	"

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}			
			$^{239}Pu + ^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm + ^{244}Cm$
Plaice	Weymouth	2	NA	ND	NA	NA
Crabs	Lulworth	2	"	"	"	"
Oysters	Poole	2	"	"	"	"
Scallops	Weymouth	2	0.0071	0.0015	ND	ND
Fucus serratus	Kimmeridge	2	NA	ND	NA	NA
	Weymouth	2	"	"	"	"
	Swanage	2	"	"	"	"
	Hengistbury Head	2	"	"	"	"
	Bognor Regis	2	"	"	"	"
	Sandgate	2	"	"	"	"
Silt	Poole Harbour	2	0.69	0.42	ND	0.0065
	Kimmeridge	2	NA	ND	"	NA
Sand	Kimmeridge	1	"	"	NA	"
	Swanage	2	"	"	"	"
	Hengistbury Head	2	"	"	"	"
	Bognor Regis	2	"	"	"	"
	Sandgate	2	"	"	"	"

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

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

5.1 Atomic Energy Establishment, Winfrith, Dorset

The principal source of liquid radioactive wastes at this establishment is the Steam Generating Heavy Water Reactor. Most of the activity is due to tritium from the moderator and coolant, but small amounts of activation products, including manganese-54, cobalt-60 and zinc-65, are removed during decontamination of the reactor pressure circuit. These wastes are disposed of under authorisation to deep water in Weymouth Bay. It is the activation products rather than tritium which are of greater, but still small, environmental significance. Reconcentration of activation products by shellfish, followed by local consumption, constitutes the critical exposure pathway; this is reflected in our monitoring programme. External gamma radiation dose rates are monitored in Poole Harbour where the fine silt has the potential to adsorb radioactivity. Monitoring of the indicator material *Fucus serratus* and of sediments from a number of locations along the south coast provides additional information on the distribution of activation products. Data are presented in Table 18.

The impact of Winfrith discharges was, as in previous years, mainly observed in the concentrations of activation products. In 1983 the total radiation dose to the critical group of fish and shellfish consumers near this establishment was low, at less than 2% of the ICRP-recommended dose limit of 5 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 Nuclear Propulsion Test Establishment) operated by the Ministry of Defence (Procurement Executive). Reprocessing of Prototype Fast Reactor (PFR) fuel has taken place since 1980. In 1983, discharges were more than in previous recent years following decontamination of this reprocessing plant prior to refurbishment, but were still well within the terms of Authorisation. 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 (Flew, 1985) has confirmed that the exposure of these fishermen remained low, at less than 4% of the ICRP-recommended dose limit of 5 mSv year^{-1}.

Table 19 Radioactivity in environmental materials from the vicinity of Dounreay, 1983

Sampling point and material	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}								
		Total beta	^{54}Mn	^{60}Co	^{95}Zr + ^{95}Nb	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs
Sandside Bay										
Winkles	4	440	ND	2.2	ND	320	83	6.2	ND	6.3
Limpets	5	1100	"	1.6	1.5	870	33	23	"	5.5
Fucus vesiculosus	5	540	1.8	4.3	4.3	91	11	2.1	0.4	12
Fucus serratus	4	620	1.8	5.8	5.5	190	14	4.1	0.6	13
Shell sand	4	510	ND	0.3	ND	27	ND	0.7	ND	13

Sampling point and material	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}							
		^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Sandside Bay									
Winkles	4	40	ND	2.3	1.5	4.4	3.9	2.2	0.086
Limpets	5	50	"	3.4	1.9	5.5	6.4	4.7	0.18
Fucus vesiculosus	5	35	0.9	2.8	NA	NA	5.3	NA	NA
Fucus serratus	4	57	1.2	7.3	"	"	9.6	"	"
Shell sand	4	44	6.5	8.7	4.6	17	19	1.1	0.22

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

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 (Flew, 1985). Public radiation exposure via this pathway was low, at less than 2% of the ICRP-recommended dose limit of 5 mSv year^{-1}.

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 19. Radiocaesium concentrations are mostly due to discharges from Sellafield. Other radionuclides detected, including transuranics, mainly reflect Dounreay discharges. Concentrations of fission products and transuranics were generally greater than in 1982 because of the increased discharges noted above. However, the radiological significance of shellfish consumption continued to be low; for high-rate winkle consumers the radiation dose was less than 1% of the ICRP-recommended dose limit of 5 mSv year^{-1}. This pathway therefore remained of sub-critical importance.

6. Nuclear power stations operated by the electricity boards

All but two of these power stations are in England and 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 towards the end of 1983 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 beach gamma dose rates. In addition, measurements of external exposure are supported by analyses of intertidal mud, and *Fucus vesiculosus* is collected as an indicator material.

Data for 1983 are presented in Table 20. 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 0.1% of the ICRP-recommended limit of 5 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.

Table 20 Radioactivity in environmental materials and gamma dose rates near Berkeley and Oldbury nuclear power stations, 1983

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{60}Co	^{65}Zn	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{155}Eu
Dab	1	89	ND	ND	ND	ND	ND	1.3	ND
Flounders	2	100	"	"	"	"	"	2.1	"
Mullet	2	120	"	"	"	"	"	2.5	"
Eels	2	65	"	"	"	"	"	0.4	"
Shrimps	4	110	"	"	"	"	0.05	2.3	"
Fucus vesiculosus	2	670	3.2	0.4	2.4	1.8	4.6	68	"
Mud: area of outfalls	4	1400	0.5	ND	ND	ND	62	670	"
Guscar rock	2	840	ND	"	"	"	1.7	75	2.1

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

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

Table 21 Radioactivity in environmental materials and gamma dose rates near Bradwell nuclear power station, 1983

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs
Mixed fish	4	100	ND	ND	ND	ND	ND	0.2	6.0
Oysters	2	79	"	"	3.9	"	"	ND	1.3
Whelks	1	110	"	0.8	ND	"	"	"	1.3
Fucus vesiculosus	2	190	"	1.2	"	"	"	0.3	4.9
Sediment	4	910	0.5	11	"	6.3	0.9	3.0	71

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
Mixed fish	4	ND	NA	NA	ND	NA	NA
Oysters	2	"	0.0022	0.0071	0.025	ND	0.0010
Whelks	1	"	NA	NA	ND	NA	NA
Fucus vesiculosus	2	"	"	"	"	"	"
Sediment	4	0.6	"	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediments (7 sampling observations†): 0.076 μGy h^{-1}

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

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

Measurements for 1983 are summarised in Table 21. In fish, the only artificial radioactivity detected was due to radiocaesium, for which concentrations 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 0.3% of the ICRP-recommended dose limit of 5 mSv 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 at this establishment: the "A" station is powered by magnox-type reactors and the "B" station by AGRs. Liquid radioactive waste discharges from the "B" station, which began raising power at the end of 1982, continued to be very small (see Table 1). 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

Table 22 Radioactivity in environmental materials and gamma dose rates near Dungeness nuclear power station, 1983

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{106}Ru	^{137}Cs
Plaice	1	88	ND	ND	ND	ND	1.4
Cod	1	160	"	"	"	"	3.3
Mixed dab, flounder, plaice	1	100	"	"	"	"	1.3
Whelks	2	95	"	4.4	4.4	3.4	ND
Fucus serratus	2	250	0.1	22	ND	ND	0.5
Sand	2	310	ND	5.6	"	"	1.7

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

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

Table 23 Radioactivity in environmental materials and gamma dose rates near Hartlepool nuclear power station, 1983

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}				
		Total beta	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu
Cod	4	120	0.3	11	ND	NA
Shrimps	2	54	ND	2.2	"	0.00040
Crabs	2	50	"	2.4	"	0.00078
Fucus vesiculosus	4	250	"	4.7	"	NA
Sand	4	110	"	5.4	"	"
Silt	4	660	1.1	83	1.8	"

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	2	0.0016	0.00084	ND	ND
Crabs	2	0.0039	0.0018	"	"
Fucus vesiculosus	4	NA	ND	NA	NA
Sand	4	"	"	"	"
Silt	4	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediment (12 sampling observations†): 0.081 μGy h^{-1}

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

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 1983 are given in Table 22.

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. The radiation dose to members of the critical group of fish consumers was very low, at less than 0.1% of the ICRP-recommended dose limit of 5 mSv year^{-1}. Gamma dose rates over sand were indistinguishable from natural background. Whelks, seaweed and sand all showed trace levels of cobalt-60, and whelks showed trace levels of zinc-65. The indicator sampling programme described in 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. Our monitoring programme in the Channel Islands (section 9) shows that the French reprocessing plant at Cap de la Hague may be the source of this nuclide. The concentrations of radionuclides in whelks were, however, of negligible radiological significance.

6.4 Hartlepool, Cleveland

This twin-AGR station became operational in 1983, but discharges of liquid radioactive wastes were very small (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 of fishermen who operate in muddy areas near the mouth of the Tees.

Results of our monitoring programme carried out in 1983 are shown in Table 23. 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 0.4% of the ICRP-recommended dose limit of 5 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 became operational in 1983; the second is still under construction. Discharges of liquid radioactive waste in 1983 were very small (Table 1). In view of this station becoming operational, the pathways leading to radiation exposures of the public from liquid discharges were re-investigated during 1983. It was reaffirmed that 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.

The results for 1983 are given in Table 24. 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 1983 of members of the critical group of fish and shellfish consumers associated with commercial fisheries (which include the Morecambe Bay area) are given in section 4.1.1. External exposure of members of the public was less than 1% of the ICRP-recommended dose limit of 5 mSv year^{-1}.

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 purpose 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.

The results for 1983, presented in Table 25, indicate concentrations of radiocaesium representing the combined effect of discharges from the station and from Sellafield, in addition to fallout. Aportionment 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 0.1% of the ICRP-recommended dose limit of 5 mSv year^{-1}. The concentration 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 indistinguisable from the natural background.

Table 24 Radioactivity in environmental materials and gamma dose rates near Heysham nuclear power station, 1983

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{60}Co	^{95}Zr + ^{95}Nb	^{103}Ru	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs
Flounders	4	410	ND	ND	ND	ND	ND	13	360
Shrimps	4	190	"	"	"	2.5	"	5.7	130
Cockles	4	320	1.4	27	1.2	120	"	2.2	66
Fucus vesiculosus	4	550	0.6	22	ND	23	"	6.5	140
Sediment:									
Sunderland Point	4	1700	2.6	200	5.9	530	"	30	840
Half Moon Bay	4	2500	6.0	310	14	1100	9.2	44	850

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Flounders	4	ND	ND	ND	NA	NA	ND	NA	NA
Shrimps	4	"	"	"	0.013	0.065	0.069	ND	0.00030
Cockles	4	"	"	"	1.1	4.8	9.1	0.065	0.034
Fucus vesiculosus	4	"	"	"	1.0	4.5	2.1	ND	0.0078
Sediment:									
Sunderland Point	4	19	5.3	7.7	NA	NA	80	NA	NA
Half Moon Bay	4	38	9.6	4.3	"	"	140	"	"

Mean gamma dose rate in air at 1 m over intertidal sediment:
Heysham vicinity (12 sampling observations†): 0.14 μGy h^{-1}
Sunderland Point (4 sampling observations†): 0.13 μGy h^{-1}

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

Table 25 Radioactivity in environmental materials and gamma dose rates near Hinkley Point nuclear power station, 1983

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta	^{90}Sr	^{134}Cs	^{137}Cs	^{144}Ce	^{155}Eu	^{238}Pu
Flounders	2	130	NA	ND	1.8	ND	ND	NA
Eels	1	73	"	"	3.2	"	"	"
Shrimps	2	110	0.9	"	2.4	"	"	0.0032
Fucus vesiculosus	2	350	NA	0.2	3.2	"	"	NA
Sediment	2	790	"	1.6	54	3.9	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
Flounders	2	NA	ND	NA	NA
Eels	1	"	"	"	"
Shrimps	2	0.012	0.011	0.0022	0.0011
Fucus vesiculosus	2	NA	ND	NA	NA
Sediment	2	"	"	"	"

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

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

Table 26 Radioactivity in environmental materials and gamma dose rates near Hunterston nuclear power station, 1983

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	^{125}Sb	^{134}Cs	^{137}Cs
Cod	2	170	ND	ND	ND	ND	ND	ND	ND	2.0	57
Turbot (fish farm A)	2	120	"	"	"	"	"	"	"	1.6	31
Eel (fish farm B)	2	60	"	"	"	"	"	"	"	0.5	13
Cockles	4	120	"	"	12	"	13	"	"	ND	6.9
Winkles	4	160	1.8	"	15	5.3	36	9.9	0.5	0.5	17
Fucus spiralis	3	450	5.1	1.1	32	11	18	0.5	ND	4.3	49
Sand	4	250	0.6	ND	5.8	ND	12	ND	"	5.8	87

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Cod	2	ND	ND	ND	NA	NA	ND	NA	NA
Turbot (fish farm A)	2	"	"	"	"	"	"	"	"
Eel (fish farm B)	2	"	"	"	"	"	"	"	"
Cockles	4	19	"	0.3	0.14	0.29	0.48	0.42	0.12
Winkles	4	14	"	0.6	0.20	0.40	0.45	0.29	0.094
Fucus spiralis	3	4.6	0.3	0.3	0.34	0.90	ND	0.20	0.068
Sand	4	19	0.6	0.4	NA	NA	"	NA	NA

Mean gamma dose rate in air at 1 m over intertidal sediment (12 sampling observations†): 0.12 μGy h^{-1}

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

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. For various reasons, storage of irradiated magnox fuel resulted in higher than usual concentrations of radionuclides (mainly radiocaesium) in pond water. The authorisation for the "A" station was changed in 1980 to allow increased discharges of these radionuclides, and this authorisation was renewed in 1981 and again in 1982, each time for a further year; a final extension to allow completion of pond refurbishment was granted in 1983 (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 spiralis* as indicators. The results of monitoring in 1983 are shown in Table 26.

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 1983 was low, at less than 2% of the ICRP-recommended dose limit of 5 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 brought from further afield. 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 1983 are shown in Table 27.

The radiocaesium concentrations in fish and shellfish represent the combined effect of discharges from the station

Table 27 Radioactivity in environmental materials and gamma dose rates near Sizewell nuclear power station, 1983

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{60}Co	^{65}Zn	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{155}Eu
Cod	1	170	ND	ND	ND	ND	0.2	8.7	ND	ND
Plaice	1	110	"	"	"	"	ND	2.0	"	"
Crabs	2	75	0.5	"	"	"	"	1.8	"	"
Shrimps	1	130	ND	"	"	"	"	5.4	"	"
Mussels	2	64	0.9	"	"	"	"	2.2	"	"
Oysters	2	66	ND	0.9	"	"	"	0.8	"	"
Whelks	1	130	1.1	ND	"	"	"	1.9	"	"
Silt	2	770	10	"	9.3	0.7	1.6	82	1.6	1.2

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

Mean gamma dose rate in air at 1 m over intertidal silt in Southwold harbour (2 sampling observations†): 0.080 μGy h^{-1}

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

and from Sellafield, as well as of fallout. Apportionment is difficult at the low levels detected. Trace levels of cobalt-60 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 0.2% of the ICRP-recommended dose limit of 5 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 operational. In 1983 we carried out a survey on behalf of departments of the Scottish Office to investigate potential critical pathways and to establish reliable sources of supply of environmental materials so that a regular monitoring programme can be set up. Potential critical pathways for radiation exposure of the public near this station, 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 will form the basis of our regular monitoring programme, which will commence prior to station operation in order to establish background levels. At the same time as our survey in 1983, measurements were made of gamma dose rates and samples of seaweed and sand were collected and analysed as indicator materials.

Results of this monitoring are shown in Table 28. Concentrations of radiocaesium in seaweed and sand are due to discharges from Sellafield and to fallout. The measured gamma dose rate is consistent with that to be expected from natural background.

Table 28 Radioactivity in environmental materials and gamma dose rates near Torness nuclear power station, 1983

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}		
		Total beta	^{134}Cs	^{137}Cs
Fucus vesiculosus	1	300	0.5	7.8
Sand	1	210	1.1	19

Mean gamma dose rate in air at 1 m over intertidal sand (1 sampling observation†): 0.06 μGy h^{-1}

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

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 flow 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 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 1983 are shown in Table 29.

Radiocaesium concentrations in fish in 1983 were less than in 1982 (Hunt, 1984b), reflecting reduced discharges of radiocaesium in recent years. Concentrations of strontium-90 in fish were less than in 1982 owing to decreased discharges of this nuclide. 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 1983 members of the critical group of fish consumers received at most about 5% of the ICRP-recommended dose limit of 5 mSv year^{-1}. This reduced exposure as compared with 1982 (Hunt, 1984b) reflects the lower radiocaesium concentrations in fish noted above.

Table 29 Radioactivity in environmental materials near Trawsfyndd nuclear power station, 1983

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
Brown trout	5	390	ND	ND	14	ND	ND	30	260
Rainbow trout	7	130	"	"	7.4	"	"	1.1	10
Perch	2	2000	"	"	620	"	"	100	1100
Mud	2	1900	"	6.5	NA	"	120	21	1000
Peat	2	2000	"	16	"	14	190	41	430
Fontinalis									
Afon Prysor	2	250	"	ND	"	ND	ND	0.3	10
Gwylan Stream	2	1400	4.1	11	"	11	82	39	580
Water									
Hot Lagoon	4	NA	NA	NA	0.2	NA	NA	0.04	0.4
Cold Lagoon	4	"	"	"	0.2	"	"	0.02	0.1

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
Brown trout	5	ND	ND	0.00011	0.00050	0.00066	0.000090	ND
Rainbow trout	7	"	"	0.00022	0.0012	0.0015	0.000080	0.000037
Perch	2	"	"	0.00043	0.0019	0.0032	ND	0.00013
Mud	2	"	10	3.2	13	17	0.35	0.38
Peat	2	23	ND	1.4	5.8	6.2	0.63	0.20
Fontinalis								
Afon Prysor	2	ND	1.8	NA	NA	ND	NA	NA
Gwylan Stream	2	10	1.8	"	"	"	"	"
Water								
Hot Lagoon	4	NA	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.

Table 30 Radioactivity in environmental materials and gamma dose rates near Wylfa nuclear power station, 1983

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta	^{60}Co	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{155}Eu
Plaice	1	150	ND	ND	ND	1.4	42	ND
Crabs	2	95	"	17	"	0.2	11	"
Mussels	3	150	"	2.8	"	0.8	20	"
Fucus vesiculosus	4	290	"	1.5	"	0.9	25	"
Sediment: Cemlyn Bay	3	1800	2.3	210	"	24	930	3.5
: Amlwch Harbour	3	1100	1.2	150	1.8	9.4	340	3.5

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}				
		^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Plaice	1	NA	NA	ND	NA	NA
Crabs	2	"	"	"	"	"
Mussels	3	0.095	0.43	0.61	0.0017	0.0019
Fucus vesiculosus	4	NA	NA	0.42	NA	NA
Sediment: Cemlyn Bay	3	17	78	88	0.20	0.33
: Amlwch Harbour	3	NA	NA	35	NA	NA

Mean gamma dose rate in air at 1 m over intertidal sediment (12 sampling observations†): 0.085 μGy h^{-1}

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

6.11 Wylfa, Gwynedd

Liquid radioactive wastes from this station are discharged to the Irish Sea under authorisation of the Welsh Office. The two 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 mud are analysed in support of the gamma dose rate measurements, and the indicator seaweed *Fucus vesiculosus* is also sampled. The results of monitoring in 1983 are presented in Table 30.

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 1983 was about 3% of the ICRP-recommended dose limit of 5 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 relatively small quantities of radioactivity are discharged from the following establishments: Chatham, Devonport, Faslane and Rosyth, all of which were operated during 1983 by the Ministry of Defence (Navy Department). The US naval base at Holy

Table 31 Radioactivity in environmental materials and gamma dose rates near naval establishments, 1983

Establishment	Material	No. of sampling observations†	Mean radioactivity concentration, (wet)*, Bq kg^{-1}				Mean gamma dose rate in air at 1 m	
			^{60}Co	^{134}Cs	^{137}Cs	^{155}Eu	No. of sampling observations†	μGy h^{-1}
Chatham	Sediment	4	8.9	0.6	39	ND	10	0.072
Devonport	Mussels	2	0.2	ND	ND	"	NP	NP
	Fucus vesiculosus	2	0.6	"	0.3	"	"	"
	Sediment	6	1.3	"	8.9	2.1	10	0.085
Faslane	Sediment	4	6.9	2.9	150	ND	10	0.078
Rosyth	Sediment	2	2.2	0.8	43	0.5	4	0.067
Holy Loch	Sediment	2	1.4	0.6	34	ND	13	0.075

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

Loch also discharges small quantities of radioactive waste. We monitor the effects of all these discharges, in the case of Faslane and Rosyth on behalf of departments of the Scottish Office.

The critical pathway for public radiation exposure due to these discharges 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 anyalyses of sediments. Indicator shellfish aned seaweed are also analysed.

Results of monitoring in 1983 are presented in Table 31. The small concentrations of activation product nuclides including cobalt-60 mainly reflect discharges from the establishments; levels of other artificial nuclides are largely 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 0.1% of the ICRP-recommended dose limit of 5 mSv year^{-1}.

8. Amersham International plc

Amersham International plc is engaged in the manufacture of radioactive materials for use in medicine, research and industry. The company's parent establishment is located in Amersham, Buckinghamshire, from which radioactive discharges are made into the catchment of the River Thames. As explained in section 5, environmental monitoring in respect of these discharges is carried out by the DOE. A further laboratory, situated near Cardiff, is engaged in the production of labelled compounds used in research and of diagnostic kits used in medicine for the *in vitro* testing of clinical samples. An authorisation issued by the Welsh Office regulates disposals of liquid radioactive wastes from this establishment to a sewer discharging into the Severn Estuary.

Our monitoring programme, carried out on behalf of the Welsh Office, reflects the two potentially critical pathways due to consumption of fish and shellfish and to external exposure over muddy intertidal areas. Measurements of external exposure are supported by analyses of intertidal sediment, and *Fucus* seaweed is collected as an indicator material. The environmental consequences of discharges from this establishment are very small and difficult to detect above the background levels due to fallout, other nuclear facilities which discharge small amounts of radioactive waste to the Severn Estuary and the Bristol Channel, and possibly Sellafield.

The results of monitoring in 1983 are presented in Table 32. None of the separate nuclides listed was processed or discharged by this establishment in 1983: the results were therefore due to the combined background effects noted above. Small amounts of iodine-131 detected in seaweed are likely to have been due to discharges from a local hospital. The exposure of the critical group of fish and shellfish consumers due to these effects in 1983 was very low, at less than 0.1% of the ICRP-recommended dose limit of 5 mSv year^{-1}. Gamma dose rates over sediment were indistinguishable from those to be expected from natural background.

Table 32 Radioactivity in environmental materials and gamma dose rates near the outfall of the sewer serving Amersham International plc, Cardiff, 1983

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}				
		Total beta	^{131}I	^{134}Cs	^{137}Cs	^{155}Eu
Flounders	2	750	ND	ND	1.1	ND
Fucus spiralis	4	210	30	"	0.8	"
Sediment	4	1 100	ND	0.6	30	1.8

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.

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 1983 are given in Table 33. 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.

Table 33 Radioactivity in marine environmental materials from the Channel Islands, 1983

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	140	ND	ND	NA	ND	ND	ND	0.3	3.9
Crabs	Guernsey	1	81	"	"	"	"	"	"	ND	0.6
	Jersey	1	82	0.6	ND	"	7.0	2.7	"	"	ND
Oysters	Jersey	1	77	0.5	1.4	"	24	2.4	"	"	0.6
Limpets	Jersey	1	85	0.9	ND	"	8.8	0.4	"	"	ND
	Guernsey	1	67	0.5	"	"	3.5	ND	"	"	"
	Alderney	1	150	2.1	"	"	37	"	2.0	"	2.2
Porphyra	Jersey										
	Greve de Lecq	4	210	0.5	"	"	22	"	ND	"	ND
	La Rozel	4	270	0.4	"	"	28	"	"	"	0.5
	Guernsey										
	Fort Doyle	3	180	0.6	"	"	11	"	"	"	ND
	Fermain Bay	4	200	0.2	"	"	9.4	"	0.3	"	0.2
	Alderney										
	Telegraph Bay	4	210	0.4	"	"	24	"	"	"	0.3
	Quenard Point	3	190	2.3	"	"	62	"	"	0.2	2.1
Fucus serratus	Jersey										
	La Rozel	4	350	4.0	"	1.3	9.2	"	0.1	ND	0.6
	Guernsey										
	Fermain Bay	4	280	2.1	"	0.7	3.7	"	ND	"	0.4
	Alderney										
	Quenard Point	4	370	8.9	"	1.5	30	"	0.4	0.1	1.2
Sediment	Jersey										
	St Helier Harbour	1	790	1.3	"	NA	78	"	3.3	ND	5.4
	Guernsey										
	Bordeaux Harbour	1	440	ND	"	"	ND	"	ND	"	3.2
	Alderney										
	Braye Harbour	1	410	"	"	"	15	"	2.9	"	3.1

Table 33 (continued)

Material	Sampling area	No. of sampling observations†	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	0.00005	0.00020	0.00018	ND	0.00003
Crabs	Guernsey	1	"	0.00093	0.0023	0.0080	0.00037	0.0039
	Jersey	1	"	0.0039	0.0079	0.011	0.0020	0.0085
Oysters	Jersey	1	"	0.020	0.046	0.028	0.0055	0.015
Limpets	Jersey	1	"	0.0086	0.019	0.015	0.0020	0.0076
	Guernsey	1	"	0.0037	0.010	0.0064	0.0012	0.0029
	Alderney	1	"	0.042	0.061	0.016	0.019	0.10
Porphyra	Jersey							
	Greve de Lecq	4	"	NA	NA	ND	NA	NA
	La Rozel	4	"	"	"	"	"	"
	Guernsey							
	Fort Doyle	3	0.5	"	"	"	"	"
	Fermain Bay	4	ND	"	"	"	"	"
	Alderney							
	Telegraph Bay	4	0.3	"	"	"	"	"
	Quenard Point	3	1.8	"	"	"	"	"
Fucus serratus	Jersey							
	La Rozel	4	ND	0.049	0.099	0.032	0.0030	0.014
	Guernsey							
	Fermain Bay	4	"	0.027	0.068	0.021	0.0033	0.010
	Alderney							
	Quenard Point	4	2.1	0.085	0.14	0.13	0.016	0.086
Sediment	Jersey							
	St Helier Harbour	1	31	0.90	2.7	2.2	0.14	0.42
	Guernsey							
	Bordeaux Harbour	1	ND	0.10	0.44	0.35	0.011	0.035
	Alderney							
	Braye Harbour	1	ND	0.13	0.44	0.30	0.018	0.054

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

10. Summary and conclusions

A summary of estimated public radiation exposures in 1983 resulting from liquid radioactive waste discharges from nuclear establishments which we monitor is presented in Table 34. The exposures are expressed in terms of the committed effective dose equivalent to members of the critical group as percentages of the ICRP-recommended dose equivalent limit of 5 mSv year^{-1}. Results for internal exposures incorporate the higher gut uptake factor for plutonium (section 3.4), except where otherwise indicated.

All exposure remained within the ICRP-recommended limit for members of the public of 5 mSv year^{-1}. Discharges from Sellafield have, as in previous years, given rise to the highest exposures. The most important contribution to these exposures was due to transuranic radionuclides from the reprocessing operations; a further contribution was from radiocaesium which is discharged mainly from the fuel element storage ponds. Exposures near Sellafield decreased in 1983 as compared with 1982, following the generally reducing trend in discharges. It is expected that this trend will continue, such that lifetime exposures of the critical group will be well within an annual average of 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 34, with appropriate footnotes.

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 section 4.1.1. The provisional collective effective dose equivalent to the UK population in 1983 was 70 man-Sv, a decrease from 90 man-Sv reported for 1982. This reduction was due to generally lower radiocaesium concentrations in fish and shellfish from the Irish Sea and Scottish waters combined with reduced fish landings from these areas. For the population of other European countries the provisional

Table 34 Summarised estimates of public radiation exposure from discharges of liquid radioactive waste in the UK, 1983

Establishment	Radiation exposure pathway	Critical group	% of ICRP recommended dose limit for members of the public[+]
BRITISH NUCLEAR FUELS LIMITED			
Sellafield	Fish and shellfish consumption	Local fishing community	45(29)*
		Commercial fishing community	11(9)*
	External	Whitehaven boat dwellers	11
	Handling of fishing gear	Local fishing community	<1‡
	Porphyra/laverbread consumption	Consumers in South Wales	<0.1
Springfields	External	Houseboat dwellers	6[a]
Capenhurst (Meols outfall)	Shellfish consumption	Local fishing community	<2[a]
Chapelcross	External Fish and shellfish consumption	Local fishermen	<6[a]
UNITED KINGDOM ATOMIC ENERGY AUTHORITY			
Winfrith	Fish and shellfish consumption	Local fishing community	<2
Dounreay	Handling of fishing gear	Local fishermen	<4‡[b]
	External	Local community	<2[b]
	Shellfish consumption	Local fishing community	<1[b]
NUCLEAR POWER STATIONS OPERATED BY THE ELECTRICITY BOARDS			
Berkeley and Oldbury	Fish and shellfish consumption External	Local fishing community	<0.1[b]
Bradwell	Fish and shellfish consumption	Local fishing community	<0.3[b]
	External	Houseboat dwellers	
Dungeness	Fish consumption External	Local fishing community	<0.1
Hartlepool[c]	Fish and shellfish consumption	Local fishing community	<0.4[a]
	External	Coal collectors	<0.1[a]
Heysham[c]	Fish and shellfish consumption	Local fishing community	11[a]
	External		<1[a]
Hinkley Point	Fish and shellfish consumption External	Local fishing community	<0.1[b]
Hunterston	Fish and shellfish consumption External	Local fishing community	<2[a]
Sizewell	Fish and shellfish consumption External	Local fishing community	<0.2[b]
Trawsfynydd	Fish consumption	Local fishing community	5
Wylfa	Fish and shellfish consumption External	Local community	3[a]
NAVAL ESTABLISHMENTS			
Chatham	External	Houseboat dwellers	<0.1
Devonport	External	Bait diggers	<0.1
Faslane	External	Boatyard workers	<0.1[b]
Rosyth	External	Dredgermen	<0.1[b]
Holy Loch	External	Local community	<0.1[b]
AMERSHAM INTERNATIONAL plc			
Cardiff	Fish and shellfish consumption External	Local fishing community	<0.1[a]

[+]Unless otherwise stated represents the committed effective dose equivalent and the ICRP-recommended limit referred to is 5 mSv year^{-1}.
*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.
‡Percentage of appropriate ICRP-recommended limit for skin exposures (see section 3.4).
[a]Mainly due to discharges from Sellafield.
[b]Partly due to discharges from Sellafield.
[c]No radioactive discharges made in 1981. Potential critical pathways given; exposures are due to other sources of artificial radioactivity.

collective effective dose equivalent was 110 man-Sv in 1983, the same as in 1982. Reduced landings of edible fish from the North Sea in 1983 offset slight increases observed in radiocaesium concentrations in these fish. These slight increases occurred as a result of enhancement of radiocaesium concentrations in water of the western North Sea in 1983, probably following the increased flushing of the Irish Sea in 1982. Nevertheless, underlying such environmental fluctuations there is an overall reducing trend in radiocaesium concentrations in all areas following declining discharges from Sellafield. This trend is mainly a result of the optimised use, as required by the authorising Departments, of zeolite skips in the magnox fuel element storage ponds.

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