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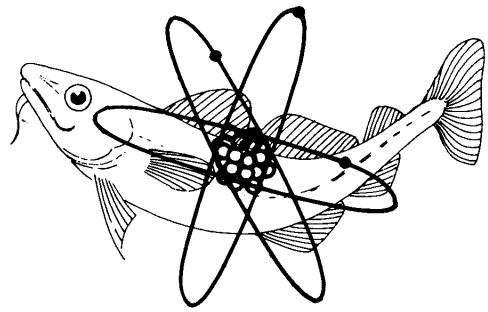
DIRECTORATE OF FISHERIES RESEARCH

AQUATIC ENVIRONMENT MONITORING REPORT



NUMBER 9

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G.J. HUNT

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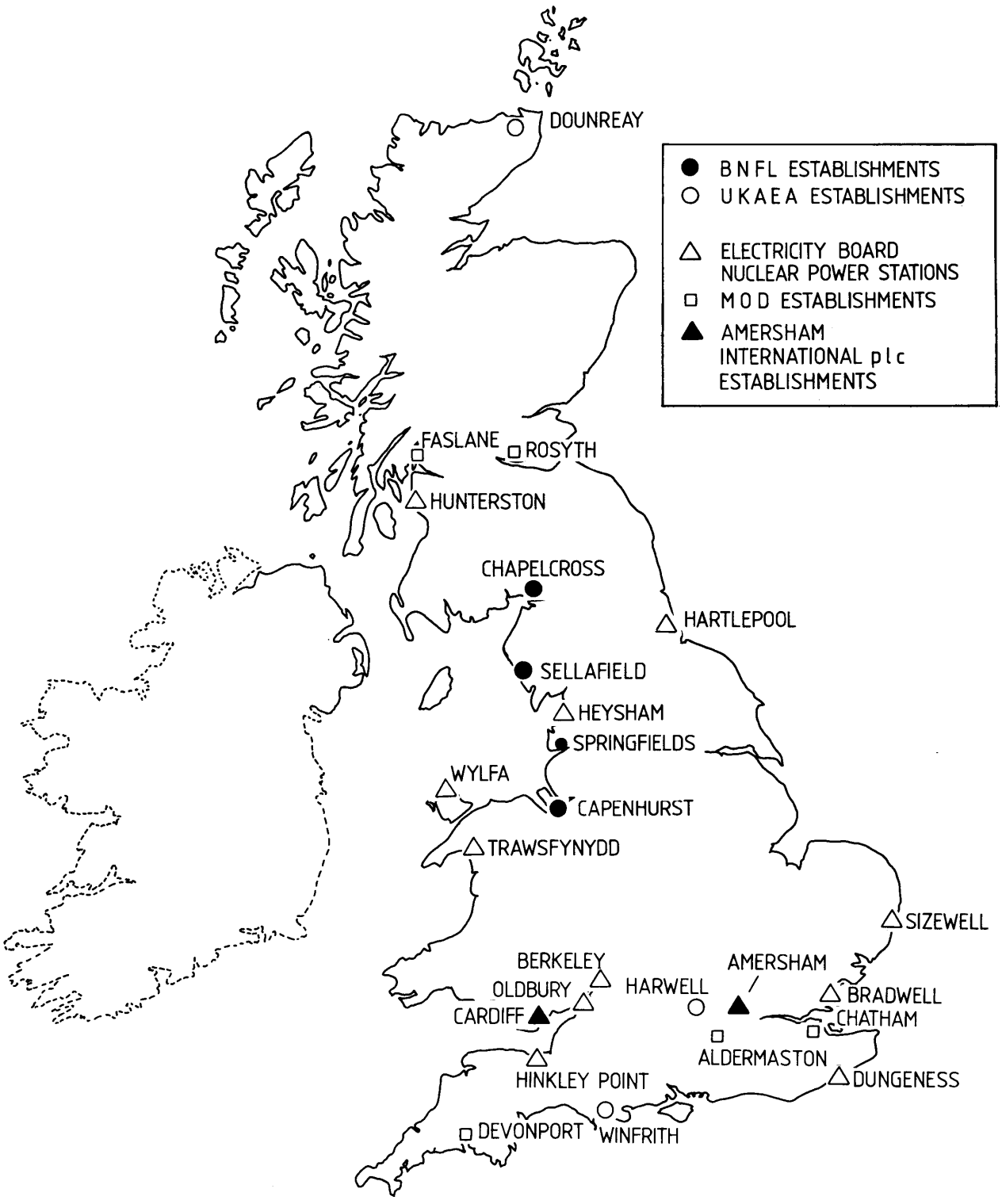

Figure 1. UK nuclear establishments giving rise to principal discharges of liquid radioactive waste.

1. Introduction

This report presents the results of the environmental monitoring programme carried out during 1981 by staff of the Directorate of Fisheries Research, Lowestoft. The monitoring programme is part of this 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, the Channel Islands States and the Republic of Ireland. 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 1981 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

Following the Government's response (Great Britain – Parliament, 1977) to the 6th Report of the Royal Commission on Environmental Pollution (1976), an annual survey of radioactive discharges is published by the Department of the Environment (DOE). The survey for 1981 has been published (DOE, 1983) but to enable the data on environmental levels 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 1981. The locations of these establishments are shown in Figure 1. Discharge data are derived from the operators' returns. 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 1981 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 1981 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 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 also receives low specific activity packaged solid waste. This is disposed of not in coastal waters but in an area of the deep Atlantic Ocean. Solid radioactive waste from some other West European countries is also disposed of in the same area. The current disposals conform to the requirements of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (The London Convention) and are organised within the Multilateral Consultation and Surveillance Mechanism operated by the Nuclear Energy Agency (NEA) of the Organisation for Economic Cooperation and Development (OECD). This Mechanism makes provision for consultation between member states before a disposal operation takes place, and the operation itself is subject to surveillance by a representative of the OECD(NEA). In 1981 the waste was disposed of within an area defined by the two lines of longitude 16°W and 17°30'W and two lines of latitude 10 nautical miles north and 10 nautical miles south respectively of latitude 46°N. The continued suitability of this site has recently been reviewed (OECD (NEA) 1980). Following previous practice, the 1981 UK disposal operation was carried out by the Atomic Energy Research Establishment (AERE) Harwell according to the conditions laid down by this Ministry and the DOE. These conditions embody internationally-agreed safeguards. The operation was observed by a representative of the OECD (NEA). The waste was from several establishments and totalled 2994 packages of 2517 tonnes gross weight containing 75 TBq (2032 Ci) of alpha activity and 3874 TBq (104709 Ci) of beta/gamma activity, including 1415 TBq (38243 Ci) tritium. Routine environmental monitoring does not provide an effective means of assessing public radiation exposure from these disposals. Research data (Mitchell and Pentreath, 1982) show no caesium-137 attributable to sea dumping present in the deep sea fish

Table 1 Principal discharges of liquid radioactive waste from UK nuclear establishments, 1981

Establishment	Radioactivity	Discharge limit (annual equivalent), Ci*	Discharges during 1981		
			TBq	Ci	% of limit utilised
BRITISH NUCLEAR FUELS LIMITED					
Sellafield					
Sea pipeline	Total beta	300 000	3 831	103 543	35
	Ruthenium-106	60 000	530	14 330	24
	Strontium-90	30 000	277	7 498	25
	Total alpha	6 000	30	803	13
Seaburn sewer	Total activity	4	0.0074	0.20	5.0
Springfields	Total alpha	360	0.61	16.5	4.6
	Total beta	12 000	97	2 627	22
Chapelcross	Total activity[1]	700	1.8	48	6.9
	Tritium	150	1.3	36	24
Capenhurst					
Rivacre Brook	Total activity[2]	0.04	0.00093	0.025	63
Meols outfall	Technetium-99	4	0.0063	0.17	4.3
UNITED KINGDOM ATOMIC ENERGY AUTHORITY					
Winfrith	Total activity	30 000	71	1 919	6.4
	Ruthenium-106	9 000	0.35	9.5	<1
	Strontium-90	1 200	0.25	6.7	<1
	Total alpha	1 200	0.026	0.7	<1
Harwell	Total activity[1,3]	240	1.2	31	13
	Tritium	240	0.85	23	9.6
Dounreay	Total activity	24 000	57	1 528	6.4
	Strontium-90	2 400	8.5	229	9.5
	Total alpha	240	1.2	32	13
CENTRAL ELECTRICITY GENERATING BOARD					
Berkeley	Total activity[1]	200	1.3	36	18
	Tritium	1 500	3.0	80	5.3
Bradwell	Total activity[1]	200	1.7	47	24
	Zinc-65	5	0.00037	0.01	<1
	Tritium	1 500	3.1	84	5.6
Dungeness	Total activity[1]	200	1.2	33	17
	Tritium	2 000	0.14	4	<1
Hinkley Point[4]					
"A" Station	Total activity[1]	200	3.4	91	46
	Tritium	2 000	2.0	53	2.7
"B" Station	Total activity[1,5]	100	0.11	3	3.0
	Sulphur-35	700	0.70	19	2.7
	Tritium	18 000	204	5 520	31
Oldbury	Total activity[1]	100	2.3	62	62
	Tritium	2 000	0.52	14	<1
Sizewell	Total activity[1]	200	1.1	31	16
	Tritium	3 000	1.3	35	1.2
Trawsfynydd	Total activity[1]	40	0.30	8	20
	Caesium-137	7	0.037	1.0	14
	Tritium	2 000	11	306	15
Wylfa	Total activity[1]	65	0.037	1	1.5
	Tritium	4 000	11.5	310	7.8
SOUTH OF SCOTLAND ELECTRICITY BOARD					
Hunterston					
"A" Station	Total activity[1]	432[6]	8.4	228	53[6]
	Tritium	1 200	2.2	59	4.9
"B" Station	Total activity[1,5]	100	0.21	5.7	5.7
	Sulphur-35	700	2.1	58	8.3
	Tritium	40 000	144	3 894	9.7

Table 1 (continued)

Establishment	Radioactivity	Discharge limit (annual equivalent), Ci*	Discharges during 1981 TBq	Ci	% of limit utilised
MINISTRY OF DEFENCE (PROCUREMENT EXECUTIVE)					
Aldermaston	Total activity[1,3]	156	0.15	4.05	2.6
	Tritium	156	0.10	2.70	1.7
MINISTRY OF DEFENCE (NAVY DEPARTMENT)					
Chatham	Total activity[1]	20	0.0026	0.069	<1
	Cobalt-60	10	0.0026	0.069	<1
	Tritium	20	0.0	0.0	0
Devonport	Total activity[1]	4	0.0029	0.078	2.0
	Cobalt-60	1	0.0016	0.042	4.2
	Tritium	10	0.015	0.4	4.0
Faslane	Total activity[1]	1	0.00004	0.0011	<1
Rosyth	Total activity[1]	30	0.0031	0.084	<1
AMERSHAM INTERNATIONAL plc					
Amersham	Total activity[1,3]	72	0.35	9.5	13
	Tritium	400	1.4	38	9.5
Cardiff[7]	Beta/gamma activity[8]	96 GBq	0.019	0.51	19
	Carbon-14	2 TBq	0.93	25	47
	Tritium	1 400 TBq	63	1 700	4.5

[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]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.
[5]Excluding sulphur-35.
[6]The temporary authorisation for 432 Ci for the 12 month period to June 1981 was renewed for a further 12 months. In the year to June 1981 the discharges were 358 Ci or 83% of the authorised limit.
[7]The authorisation was changed with effect from 23 September 1981.
[8]Excluding tritium, carbon-14 and radioisotopes of calcium and strontium.
*Unless otherwise stated.

Coryphaenoides (Nematonurus) armatus collected from near the sea bed in the disposal area. These fish are not exploited commercially and their content of radioactivity therefore has no direct significance in terms of public radiation exposure. Concentrations of caesium-137 in these fish are not significantly different from those in the same species at locations remote from the disposal area. The activity is consistent with caesium-137 found through worldwide deposition of fallout and the concentrations are similar to those due to caesium-137 of fallout origin found in commercial fish species from Icelandic waters (section 4). The environmental impact of these disposals, as indicated by calculations using appropriate models, 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 SI (Systeme Internationale) radiological units recommended for use in the UK by the British Committee on Radiation Units and Measurements (BCRU, 1978). Table 2 summarises the radiological units used in this report, and provides relevant conversion factors to relate SI units to the old radiological units.

3.2 Summary of analytical methods

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

Total beta radioactivity is measured using thin sources with

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

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. However, agreement with the total as derived from isotopic analysis is not expected to be exact. The main advantages 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.

Except for ruthenium-106 in laverbread, which is analysed using this nuclide's energetic beta particles (Dutton, 1968), gamma-emitting nuclides are analysed by gamma spectrometry. This is carried out using both NaI(Tl) and Ge(Li) 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 which already embody a number of maximising assumptions. Therefore, the tables present the arithmetic means of observations made during the year. The frequency of sampling reflects the resolution (implying the accuracy) judged to be necessary in the assessment or, as is largely self-evident, its radiological importance. So the number of sampling observations during the year is also given. 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.

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.

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.

3.4 Methods of interpretation

The monitoring results in this report are interpreted in terms of radiation exposures of the public. The bases against which these exposures are judged are the recommendations of the International Commission on Radiological Protection (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 recent 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 will 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. Emphasis is given to the principle that "all exposures shall be kept As Low as Reasonably Achievable ....." (ALARA). Thus the recommendations of ICRP Publication 26 underline the importance of 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 0.5mSv. 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 from radioactive waste discharges. By comparison, the annual average dose equivalent in the UK from natural radiation is approximately 2 mSv (NRPB, 1981).

ICRP Publication 26 recommends that doses should meet the ALARA objectives, subject to compliance with appropriate individual dose limits. Control of individual exposures is intended to prevent non-stochastic (threshold) effects and to limit stochastic effects (i.e. those whose probability depends on the dose) to an acceptable level. To prevent non-stochastic effects, a dose equivalent limit for the public of 50 mSv $year^{-1}$ to any one organ or tissue is prescribed. 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, and the ICRP-recommended limit for members of the public is 5 mSv $year^{-1}$. It is these limits with which ICRP recommends that exposures of critical groups should be compared. This is the procedure which is followed in this report. ICRP also suggests that, in any rare cases where a few individuals are actually found to be receiving high rates of exposure over prolonged periods, it would be prudent to take measures to restrict their lifetime dose so that it corresponds to no more than 1 mSv $year^{-1}$ of life-long whole body exposure. Consideration of this secondary objective has also been given 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.

The ICRP also recommends secondary limits for internal and external irradiation. For internal irradiation, the limits are expressed as Annual Limits of Intake (ALIs). Values for radiation workers for a number of elements have been published in ICRP Publication 30 (ICRP, 1979a, 1980, 1981a). In this report environmental monitoring results are interpreted in terms of doses to members of the public. Thus the data on doses per unit intake, published in supplements to ICRP Publication 30 (ICRP, 1979b, 1981b, 1982a, 1982b), have been used. The following points should be noted. First, metabolic differences may exist between certain age groups of the public and radiation workers. In this report appropriate allowances have been made where children are known to be members of critical groups. Secondly, in advance of a review by ICRP, the NRPB has recently published (NRPB, 1983) 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 given in this report; alongside are given, in important cases, the doses derived using the unenhanced gut uptake factors used in ICRP Publication 30. Thirdly, for nuclides with long body retention times, such as the transuranics, the dose per unit intake is only reached on an annual basis after steady intake for a period of 50 years, taken by the ICRP as a working lifetime. Fourthly, in addition to the estimation of the effective dose equivalent for comparison with the ICRP-recommended dose limit based on stochastic effects, non-stochastic effects also require consideration, and this is given in this report. However, in a given situation, provided the dose equivalent to each tissue from all nuclides is below the non-stochastic limit, the significance of the exposure is in the effective dose equivalent.

In the case of external exposure to penetrating radiation, uniform whole body exposure has been assumed. The measured quantity is absorbed dose rate in the 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. The critical pathway approach has been in use for many years, and is still embodied in the recommendations of the ICRP. 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 annual dose to the critical group. This is then expressed as a percentage of the appropriate ICRP-recommended dose limit for members of the public.

4. British Nuclear Fuels Limited

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 (until 1981, known as Windscale and Calder), Springfields, Capenhurst and, on behalf of Scottish Departments, 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 Windscale Advanced Gas-cooled Reactor (AGR) ceased normal operation in March 1981, although experimental operations continued until the end

of June 1981. The most significant liquid radioactive waste discharges are from the fuel element storage ponds and the reprocessing plant, through which passes all the irradiated fuel from the UK nuclear power programme. 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. Discharges during 1981 are summarised in Table 1, and were within the limits set by the authorising Departments. Discharges of total beta activity, at 35% of the authorised limit, were less than in 1980 (39%). Total beta discharges are substantially dependent upon releases of radiocaesium which mainly originate from the fuel element storage ponds. In 1981 caesium-137 pipeline discharges totalled 2357 TBq, a lower total than in 1980 (2966 TBq). This reduction was brought about by the continued use of zeolite skips in the ponds to absorb caesium, in order to keep doses within ALARA bounds (section 3.4) as required by the authorising departments. Largely for the same reason, strontium-90 discharges in 1981 were less than in 1980. However, discharges of ruthenium-106, which derives mainly from operations other than in the ponds, were slightly more in 1981 than in 1980. Discharges of plutonium isotopes were less in 1981 than in 1980 mainly due to the bringing into operation of new plant. For the same reason, the total alpha activity released in 1981 was also less than in 1980.

We maintained a substantial monitoring effort during 1981. The two critical radiation exposure pathways continued to be from consumption of fish and shellfish and from external exposure. Following established practice, the largest monitoring effort has been expended on these pathways. In 1981, 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" is defined by 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. Table 4 includes the results of analyses of samples collected by authorities in Ireland.

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 cod, measurements remote from land run-off indicate a value of about 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. Because the purpose of the result is dose estimation, results are based on observations which include large numbers of individual fish (section 3.3).

Concentrations of radiocaesium in 1981 were generally similar to those in 1980 for fish from the eastern Irish Sea but higher for fish from the western Irish Sea and Scottish waters. This is attributed to increased radiocaesium concentrations in sea water, probably due to a lower rate of flow through the Irish Sea during 1981. In the North Sea there was a general decrease in radiocaesium concentrations in fish in 1981 reflecting the reductions in radiocaesium discharges from Sellafield prior to 1980.

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. As with fish, concentrations diminish with increasing distance from Sellafield; the rate of reduction is least for nuclides which are conservative to sea water, such as isotopes of caesium. There are substantial variations between species: in general, molluscs tend to concentrate the less conservative nuclides to a greater extent than do crustaceans, whilst in contrast the concentrations of radiocaesium are similar in both classes of shellfish as well as in fish.

Table 4 Beta/gamma radioactivity in fish from the Irish Sea vicinity and further afield, 1981

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[1,3]	Cod	6	2200	89	1500
Sellafield offshore area[1,3]	Plaice	4	600	31	590
	Dab	3	540	27	540
	Cod	3	720	36	600
	Flounder	1	440	16	310
Ravenglass[2]	Plaice	8	660	38	640
	Cod	9	880	51	850
	Whiting	1	NA	85	1200
Whitehaven[2]	Plaice	12	350	14	260
	Cod	12	410	18	300
	Herring	3	260	9.7	180
Morecambe Bay[1]	Flounder	4	420	22	420
Fleetwood[2]	Plaice	4	630	11	220
	Cod	4	410	20	350
Cumbrian rivers[4]	Sea trout	5	330	18	370
Isle of Man[2]	Plaice	5	190	7.3	120
	Cod	5	270	8.4	190
	Herring	5	200	5.7	110
	Whiting	1	260	9.2	160
Irish Sea[1] (Research vessel cruise)	Plaice	5	NA	13	280
	Cod	8	"	11	200
	Whiting	5	"	9.4	210
	Herring	2	"	6.9	140
	Ray	2	"	1.7	46
	Hake	1	"	5.6	140
Solway[1]	Salmon	1	88	ND	2.6
	Flounder	4	380	13	340
North Anglesey[1]	Plaice	4	120	1.1	31
Northern Ireland[2]	Whiting	3	210	6.0	140
	Herring	1	170	4.0	93
Republic of Ireland[2]	Plaice	2	120	2.7	45
	Cod	4	220	4.1	89
	Whiting	3	250	4.4	120
	Herring	2	170	2.5	70
Minch[1]	Plaice	2	130	1.2	25
	Cod	2	170	1.7	44
	Herring	2	170	0.8	20
Northern North Sea[1]	Plaice	6	110	ND	4.7
	Cod	7	120	0.06	6.7
	Haddock	4	NA	0.04	4.4
	Herring	2	130	ND	9.7
Mid-North Sea[1]	Plaice	10	87	"	5.7
	Cod	9	130	0.2	12
	Haddock	5	NA	ND	6.2
	Herring	2	110	"	12
Southern North Sea[1]	Plaice	4	97	"	2.4
	Cod	4	120	0.3	8.0
	Whiting	2	NA	0.2	8.4
Norwegian Sea[1]	Cod	1	110	ND	2.1
Iceland area[1]	Plaice	3	78	ND	0.3
	Cod	3	110	"	0.6

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 and further afield, 1981

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[1,3]	Crabs	5	510	0.4	ND	ND	190	2.6	ND	13	220	10	ND	ND
	Winkles	3	18000	21	750	44	7300	57	"	27	440	65	3.8	5.0
Coulderton[1]	Winkles	15	4600	13	590	54	4000	52	15	18	320	57	2.4	1.5
St Bees[1]	Limpets	4	3400	4.4	52	ND	2100	15	20	11	250	68	5.0	7.0
	Mussels	4	5600	5.3	1200	"	4900	5.4	26	19	240	49	ND	1.7
	Winkles	4	6200	12	390	"	3400	40	16	17	270	60	5.3	ND
Whitehaven[2]	*Nephrops*	3	410	ND	ND	"	4.0	ND	ND	11	180	ND	ND	"
	Queens	1	250	"	"		82	36	"	2.1	27	"	"	"
Morecambe Bay[1]	Shrimps	4	270	"	"	"	ND	ND	"	8.8	170	"	"	"
	Cockles	4	590	1.1	8.9	"	58	"	"	4.9	96	4.7	"	"
Isle of Man[2]	Scallops	4	140	ND	ND	"	2.6	1.2	"	1.6	22	ND	"	"
Inner Soiway[1]	Shrimps	4	200	"	"	"	ND	ND	"	8.4	150	"	"	"
Kirkcudbright[2]	Scallops	3	89	"	"	"	"	"	"	ND	5.5	"	"	"
	Queens	6	110	"	"	"	2.0	3.0	1.0	1.4	26	"	"	"
	Winkles	4	380	0.7	"	"	130	2.3	ND	4.0	60	0.7	"	"
North Solway coast[1]	Winkles	4	580	0.8	"	"	400	6.7	3.4	5.3	72	5.3	"	"
Wirral[1]	Shrimps	4	260	ND	"	"	12	ND	ND	6.9	130	ND	"	"
	Cockles	4	120	"	"	"	12	"	"	2.7	51	"	"	"
Conwy[2]	Mussels	3	130	"	"	"	8.8	"	"	0.8	25	"	"	"
North Anglesey[1]	Crabs	3	110	0.4	"	"	ND	"	"	0.6	22	"	"	"
	Winkles	2	130	ND	"	"	8.3	"	"	0.4	16	"	"	"
Northern Ireland[2]	*Nephrops*	4	150	"	"	"	"	"	"	1.3	30	"	"	"
Northern North Sea[1]	*Nephrops*	2	99	"	"	"	"	"		ND	4.0	"	"	"
Mid North Sea[1]	*Nephrops*	1	99	"	"	"	"	"	"	"	4.9	"	"	"
	Crabs	4	57	"	"	"	"	"	"	"	3.0	"	"	"
	Shrimps	2	64	"	"	"	"	"	"	"	3.1	"	"	"
	Mussels	1	48	"	"	"	"	"	"	"	2.6	"	"	"
Southern North Sea[1]	Cockles	5	31	1.0	"	"	"	"	"	"	1.5	"	"	"
	Mussels	3	42	ND	"	"	"	"	"	"	1.2	"	"	"

ND = not detected.

[1]Sampling area.
[2]Landing point.
[3]See section 3.3 for definition.

Changes between 1980 and 1981 in the radiocaesium concentrations in Irish Sea shellfish showed a generally similar pattern to that in fish. Concentrations of ruthenium-106 in shellfish were higher than in 1980, reflecting the increased discharges of this nuclide. The concentrations of other beta/gamma-emitting radionuclides in shellfish from the Irish Sea were generally similar to those in 1980.

Public radiation exposure from transuranic nuclides in fish is lower than from radiocaesium. Analyses for transuranics are also labour-intensive. Therefore, only a selection of samples of fish and shellfish chosen mainly on the basis of potential radiological significance are analysed for transuranic nuclides. Analyses are often carried out on samples bulked annually (section 3.3). The data for 1981 are presented in Table 6. Concentrations reduce rapidly with distance, consistent with lower retention of transuranics in sea water. Non-conservatism to sea water is also reflected in higher concentrations of transuranics in shellfish as compared with fish.

Concentrations of transuranics in fish and shellfish from the Irish Sea generally were similar in 1981 to those in 1980. However, a small reduction in plutonium concentrations in shellfish from the Western Cumbrian coast was observed in 1981. This reduction may be due to the reduced discharges of plutonium since 1979, but the effect is not in direct proportion to discharges because concentrations of transuranics are influenced by discharges in earlier years.

The radiation dose to consumers of fish and shellfish depends upon the product of the mass of foodstuff consumed and its radioactivity concentration. Because of variations in these two quantities between individual consumers, a wide range of annual doses is to be expected. The critical group approach, which is well established in the UK and recommended by 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

Table 6 Transuranic radioactivity in fish and shellfish from the Irish Sea vicinity and further afield, 1981

Sampling area/landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}				
			^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Sellafield shoreline area[1,3]	Cod	1	0.011	0.040	0.078	0.0016	0.00023
	Crabs	2	1.2	4.3	12	ND	0.053
	Winkles	1	20	75	110	"	0.48
Sellafield offshore area[1,3]	Plaice	4	0.042	0.17	0.17	0.0010	0.00079
	Cod	1	0.0045	0.020	0.035	ND	0.00020
Coulderton[1]	Winkles	5	26	95	104	"	ND
St Bees[1]	Winkles	1	13	52	77	"	0.18
	Mussels	1	24	95	62	"	0.24
	Limpets	1	10	41	56	"	0.17
Ravenglass[2]	Plaice	1	0.023	0.094	0.11	0.0014	0.00052
	Cod	1	0.022	0.081	0.066	ND	0.00028
Whitehaven[2]	Plaice	4	0.0044	0.017	0.018	"	0.00008
	Cod	1	0.0028	0.012	0.014	"	0.00007
	Nephrops	1	0.14	0.55	1.4	"	0.0040
	Queens	1	1.4	6.3	5.9	0.013	0.019
Morecambe Bay[1]	Shrimps	1	0.014	0.066	0.075	ND	ND
	Cockles	1	1.7	8.1	9.1	"	0.036
Isle of Man[2]	Plaice	1	0.00081	0.0036	0.0046	"	0.00003
	Cod	1	0.00036	0.0014	0.0018	"	0.00004
	Herring	1	0.00054	0.0027	0.0029	"	ND
	Scallops	1	0.063	0.30	0.17	"	0.00091
Inner Solway[1]	Salmon	1	0.00055	0.0025	0.0029	"	ND
Kirkcudbright[2]	Scallops	3	0.015	0.082	0.024	"	"
	Queens	4	0.042	0.19	0.12	"	0.00035
	Winkles	1	0.5	2.2	2.6	"	0.017
North Solway coast[1]	Winkles	4	0.89	3.6	5.6	0.027	0.023
Conwy[2]	Mussels	1	0.056	0.28	0.36	ND	0.0013
Northern Ireland[2]	*Nephrops*	1	0.0034	0.018	0.032	"	0.00013
Minch[1]	Cod	1	0.00024	0.0012	0.00098	"	ND
Northern North Sea[1]	Cod	1	0.00011	0.00045	0.00046	"	"
	Nephrops	1	0.00094	0.0053	0.0034	"	0.00010
Mid North Sea[1]	*Nephrops*	1	0.00059	0.0030	0.0021	"	ND
	Mussels	1	0.015	0.070	0.062	"	"
Southern North Sea[1]	Mussels	1	0.0012	0.0071	0.0022	"	"
	Cockles	1	0.0024	0.014	0.0063	"	"
Iceland area[1]	Cod	1	0.00052	0.0022	0.0026	"	"

ND = not detected.

[1]Sampling area.
[2]Landing point.
[3]See section 3.3 for definition.

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 have been recently reassessed. 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). 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. This procedure is likely to lead to more reliable estimates of individual doses to these consumers than is the less reproducible procedure of using the maximum observation.

Radioactivity concentrations in fish and shellfish eaten by the two exposed populations will 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 the mean consumption rates of the sub-groups were determined. For the Cumbrian coastal community the data available in 1981 indicated that these consumption rates were 100 g d^{-1} fish, 18 g d^{-1} crustaceans and 18 g d^{-1} molluscs (Hunt, 1982).

During 1982 further studies of consumption rates, especially of molluscs, were carried out and additional high-rate mollusc consumers were identified. The new observations span a range of consumption rates similar to those found in 1981, but the mean of the consumption rates for the revised critical group of mollusc consumers is increased, to 45 g d^{-1}. No need for change in fish and crustacean consumption rates is indicated. Given the support provided to the earlier mollusc consumption data by the results of the new survey and that the additional high-rate consumers identified have reported that their mollusc consumption rates were essentially similar in 1981 to the surveyed rates in 1982, we believe that the increased critical group consumption rate for molluscs may well provide a better estimate of dose than the results of the 1981 survey alone, and we have therefore calculated dose rates to the critical group using these new data as well as data from the earlier survey. We would, however, have less confidence in applying the 1982 survey data to years prior to 1981, partly because some of the increase in consumption rates observed in recent years may be due to the general effects of the economic recession, such that people have more time to exploit a food supply which is freely available.

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 to avoid underestimating the exposure of the overall critical group, this exposure is derived by combining the exposures of each sub-group additively. Comparison based on individual critical group members' exposures shows that this procedure is not excessively conservative. Plaice and cod are overwhelmingly the fish most 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 from landings at Ravenglass. A more fundamental assumption made here, erring on the conservative side, is that fish from these areas represent the year-round intake of the critical group. During certain seasons of the year it is likely that fish consumed locally are supplemented by supplies from further afield. Consumption data indicate that it is certainly unreasonable to base the assessment on fish from the Shoreline Area. The exposure due to consumption of crustaceans is based upon crabs from this Area, whilst the exposure from consumption of molluscs is based upon meaned radionuclide concentrations in winkles from the Shoreline Area, Coulderton and St Bees.

Table 7 summarises doses in 1981. For each exposed population, the dose equivalent to each tissue from all nuclides is below the non-stochastic limit recommended for members of the public by the ICRP. Hence the significance of the exposures is in the effective dose equivalents (section 3.4). For each exposed population these quantities are 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 and plutonium-241 were estimated from the discharges of these nuclides in 1981. For plutonium-241 in particular, this is likely to be a maximising procedure because of radioactive decay whilst in the environment. 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 the 1982 consumption rate data, and the NRPB advice on gut uptake factors which are still under review by the ICRP, the effective dose to the critical group of local consumers in 1981 would have been at most 69% 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 effective dose would have been 46% of this limit. In addition, as indicated earlier, doses have also been assessed using the consumption rate data available in 1981; this also facilitates comparison with results for 1980 (Hunt, 1982). Table 7 shows that the effective dose to the critical group using these consumption rates would have been 34% of the ICRP-recommended dose limit on the basis of the enhanced plutonium gut uptake factor. The reduction to 34% from 39% reported for 1980 (Hunt, 1982) is explained by a lower contribution from plutonium in shellfish. No reduction is apparent on the alternative dosimetric basis (24% in 1981 and 1980) because of a small increase for 1981 in the dose contribution due to ruthenium-106 and americium-241 which is balanced, but not outweighed as in the previous case, by the reduction in the plutonium contribution. For control purposes it is to be noted that for this critical group the appropriate ICRP-recommended limit for non-stochastic (threshold) effects is more restrictive than the limit for stochastic effects.

The dose to the critical group has also been considered in the context of the ICRP's advice on lifetime exposure (section 3.4). Effective dose equivalent rates to the critical group in excess of 1 mSv $year^{-1}$ (20% of the ICRP-recommended dose limit for members of the public) have only been reported for the last few years. This is not long enough for lifetime exposures to have exceeded, on average, 1 mSv $year^{-1}$. As a result of measures already implemented by BNFL, discharges of radiocaesium and actinides are

Table 7 Individual radiation exposures due to consumption of Irish Sea fish and shellfish, 1981

Exposed population	Consumption rate used in assessment (see text)	Nuclide	Effective dose equivalent (as % of ICRP-recommended dose limit of 5 mSv year^{-1} for members of the public)	
			On basis of current ICRP recommendations	Effect of Pu enhanced by a factor of 5 (see text)
Consumers in local fishing community	100 g d^{-1} fish 18 g d^{-1} crustaceans 45 g d^{-1} molluscs	^{90}Sr	0.3	0.3
		^{106}Ru	9.6	9.6
		^{134}Cs	0.7	0.7
		^{137}Cs	8.6	8.6
		^{238}Pu	0.7	3.4
		^{239}Pu + ^{240}Pu	2.9	14.5
		^{241}Pu	2.3	11.5
		^{241}Am	20.2	20.2
		Total	46	69
Consumers in local fishing community	100 g d^{-1} fish 18 g d^{-1} crustaceans 18 g d^{-1} molluscs	^{90}Sr	0.3	0.3
		^{106}Ru	3.9	3.9
		^{134}Cs	0.7	0.7
		^{137}Cs	7.7	7.7
		^{238}Pu	0.3	1.4
		^{239}Pu + ^{240}Pu	1.2	6.0
		^{241}Pu	1.0	4.8
		^{241}Am	8.7	8.7
		Total	24	34
Consumers associated with commercial fisheries (Whitehaven, Fleetwood, Morecambe Bay)	360 g d^{-1} fish 70 g d^{-1} crustaceans 50 g d^{-1} molluscs	^{134}Cs	0.3	0.3
		^{106}Ru	0.1	0.1
		^{134}Cs	1.0	1.0
		^{137}Cs	11.7	11.7
		^{238}Pu	0.1	0.3
		^{239}Pu + ^{240}Pu	0.4	1.8
		^{241}Pu	0.3	1.3
		^{241}Am	2.0	2.0
		Total	16	19
Typical member of the fish-eating public consuming fish landed at Whitehaven/Fleetwood	40 g d^{-1} fish	^{134}Cs	0.1	0.1
		^{137}Cs	1.1	1.1
		Total	1.2	1.2

declining, and further measures to reduce these discharges are planned. Nevertheless, the dose to the critical group in the context of lifetime exposure is being kept under review.

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 360 g d^{-1}, 70 g d^{-1} and 50 g d^{-1} respectively. As for the Cumbrian coastal community, the overall critical group has been defined by the maximising procedure of summing exposures due to these component consumption rates. The dose rate due to intake of fish has been assessed using activity concentrations of an equal mix of plaice and cod landed at Whitehaven and Fleetwood. Consumption of crustaceans has been based on shrimps from Morecambe Bay, and consumption of molluscs has been based on Morecambe Bay cockles. The effective dose equivalent to members of this critical group in 1981 is given in Table 7. The total of 19% of the ICRP-recommended dose limit for members of the public, on the basis of the enhanced gut uptake factor for plutonium, represents a slight increase on 18% of this limit reported for 1980 (Hunt, 1982). The main reason for this increase was the greater concentration during 1981 of radiocaesium in fish from the western Irish Sea reported earlier in this section.

The effective dose appropriate to a consumption rate of 40 g d^{-1} 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 1981 was 1.2% of the ICRP-recommended dose limit for members of the public, which represents a

slight increase on the 1.1% reported for 1980 (Hunt, 1982). This increase was also due to the greater concentration during 1981 of radiocaesium in fish from the western Irish Sea.

Collective doses from fish and shellfish have been estimated for 1981 for the UK and other European countries. In general, the method used has been to combine data on fish and shellfish landings from relevant sea areas with average radioactivity concentrations in fish and shellfish caught in these areas. Sea areas considered included the Irish Sea, Scottish waters, the North Sea, Baltic Sea, Norwegian Sea, Spitzbergen/Bear Island area and Barents Sea. Corrections were made for the fraction of fish or shellfish consumed. The contribution of weapons-test fallout to the radioactivity concentrations was subtracted. Consideration has been given to the pathway due to fish offal and industrial fisheries, the product of both of which is fish meal which is fed to pigs and poultry. Consumption of food products from these animals gives rise to a small contribution to the collective dose, and this has been included for 1981. The results are presented in Table 8.

Table 8 Collective doses from fish and shellfish, 1981

Population	Size of population	Collective effective dose equivalent, man-Sv
UK	5.6×10^7	130
Other European countries	6.2×10^8	150

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 relatively 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 result of 130 man-Sv for the UK in 1981 represents an increase in collective dose as compared with 100 man-Sv in 1980 (Hunt, 1982). This increase was mainly caused by the higher radiocaesium concentrations, noted above, in fish from the western Irish Sea and Scottish waters. There were also increased catches of fish, particularly herring, from Scottish waters. The collective dose to inhabitants of other countries in 1981 was also greater than in 1980, when 140 man-Sv was reported. This increase was mainly due to the higher radiocaesium concentrations in fish from the Irish Sea and Scottish waters; also, other European countries as well as the UK took a greater herring catch from Scottish waters during 1981. However, the increase in collective dose for European countries in 1981 was not as great as for the UK because of the general reductions in radiocaesium concentrations in fish from the North Sea. The increases in collective dose for 1981 for the UK and other countries were most likely caused by increased fishing and by the probable reduction in water flow through the Irish Sea; the doses themselves were, for the UK, similar to those in 1979 and, for European countries, less than in 1979 (Hunt, 1981).

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 1981 the UK collective doses through the fish and shellfish pathways as a result of liquid radioactive waste disposal operations amounted to less than 5% of this value.

It is clear from the statements above which compare the 1980 and 1981 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 distributions (including budget assessments) of significant radionuclides. Data on the distribution of caesium-137 in sea water are regularly collected by research vessel cruises; the distribution observed in the Irish Sea in March 1981 is shown in Figure 2. Comparison with the data for April 1980 (Hunt, 1982) shows that concentrations of caesium-137 in sea water of the Irish Sea generally increased in 1981. Radiocaesium discharges from Sellafield reduced during 1981, thus the increased concentrations were probably due to a lower rate of flow of water through the Irish Sea than in 1980. The distribution of caesium-137 in sea water in the North Sea during August and September 1981 is shown in Figure 3. Comparison with the data for August and September 1980 (Hunt, 1982) shows generally lower caesium-137 concentrations for 1981, consistent with observations on concentrations in fish. A reduction in radiocaesium concentrations in the North Sea has been observed since 1979 (Hunt, 1981), reflecting the general reductions in radiocaesium discharges from Sellafield since 1977 achieved by the use of zeolite skips in the magnox fuel storage ponds.

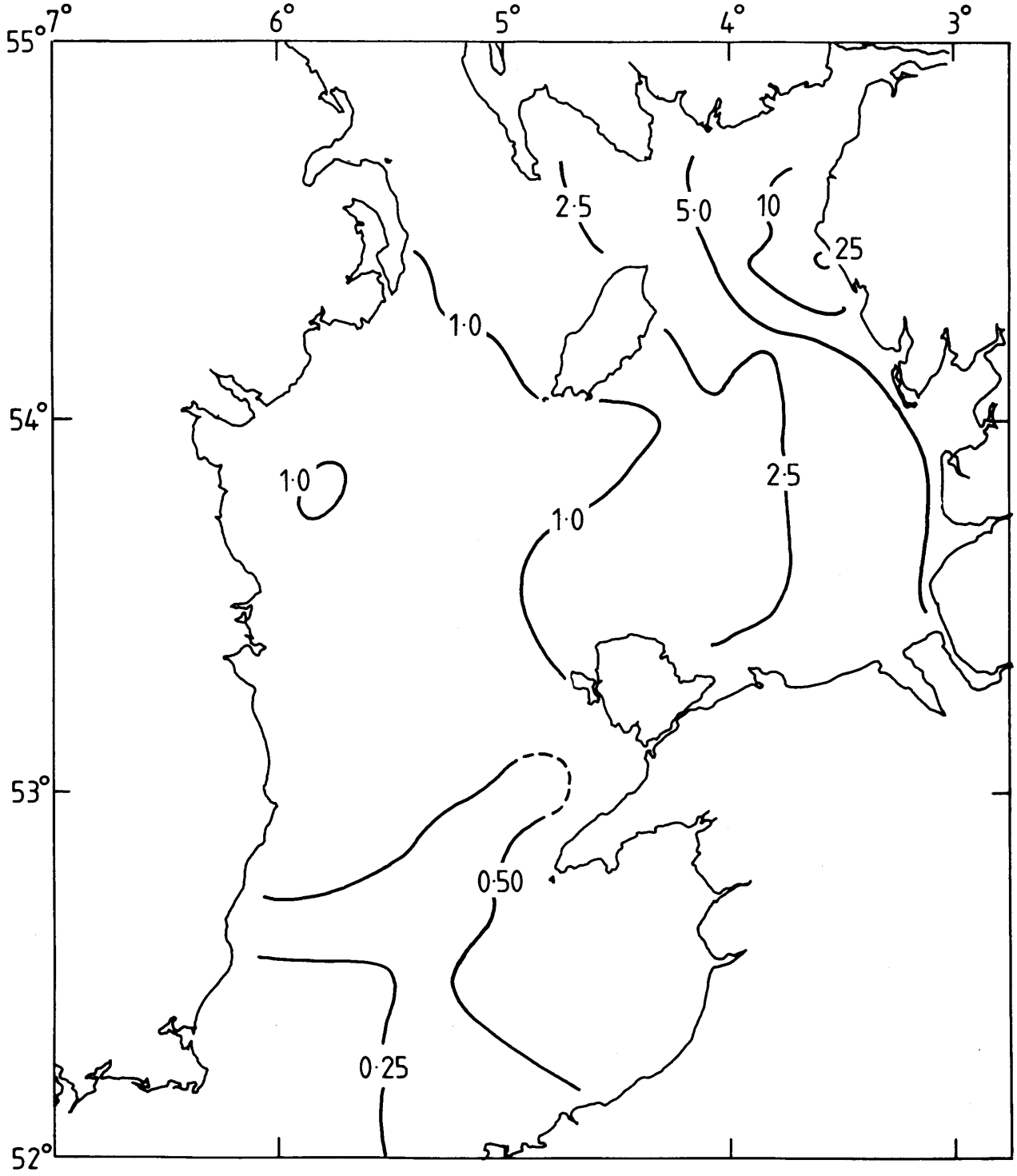

Figure 2. Concentration (Bq kg^{-1}) of caesium-137 in filtered water from the Irish Sea, March 1981.

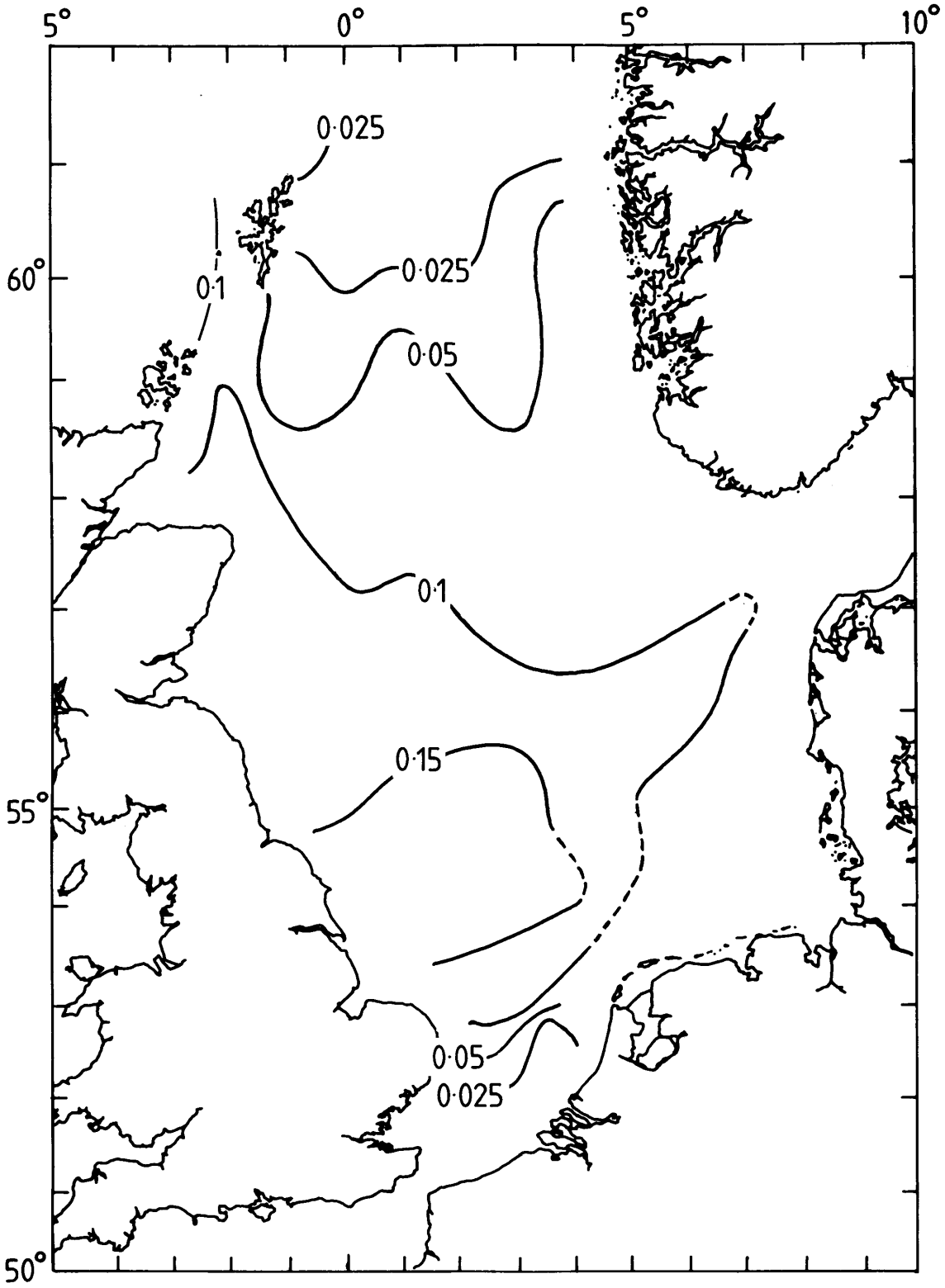

Figure 3. Concentration (Bq kg^{-1}) of caesium-137 in filtered surface water from the North Sea, August-September, 1981.

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 1m above ground level. Monitoring in Scotland is carried out on behalf of 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, 6.10). 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 1981 were generally similar to those in 1980 (Hunt, 1982).

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

Table 9 Gamma radiation dose rates over intertidal areas of the Cumbrian coast and further afield, 1981

Location	Ground type	No. of sampling observations†	Mean gamma dose rate in air at 1 m, $\mu Gy\ h^{-1}$
Maryport harbour	Silt	4	0.35
Workington harbour	"	4	0.37
Whitehaven outer harbour	"	12	0.51
" " "	Sand	12	0.30
Whitehaven yacht basin	Silt	12	0.82
St Bees	Sand	4	0.16
Seamill winkle beds	Rock	4	0.20
Braystones south	Sand	5	0.21
" " winkle beds	Rock	2	0.25
Drigg	Sand	2	0.16
" winkle beds	Rock	4	0.25
Seascale	Sand	5	0.17
Sellafield	"	12	0.23
Ravenglass - Salmon Garth	"	12	0.19
" "	Silt	12	0.51
" "	Mussel beds	12	0.47
Ravenglass - boats area	Sand	12	0.20
" "	Silt	12	0.46
Ravenglass - ford area north	"	12	0.61
" " south	"	12	0.55
Newbiggin	"	12	0.92
Newbiggin - west of bridge	Sand/silt	12	0.54
" east " "	Salt marsh	12	0.90
Haverigg	Sand	3	0.23
"	Silt	4	0.40
Millom	Sand	3	0.13
"	Silt	3	0.36
Walney Island	Sand/silt	20	0.24
Flookburgh	Sand	4	0.13
Fleetwood	"	4	0.097
Blackpool	"	4	0.084
Southport	"	4	0.081
New Brighton	"	4	0.088
Mersey (Rock Ferry)	Silt	4	0.18
Llandudno	Sand	4	0.093
Prestatyn	"	4	0.072
Kipford - slipway	Silt	3	0.21
" - stone jetty	"	3	0.16
" - flooded pasture	"	3	0.28
Auchencairn	Sand/silt	3	0.14

†See section 3.3 for definition.

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 1980 (Hunt, 1982) shows generally similar concentrations, in line with the behaviour of dose rates. It is to be noted that these levels of radionuclide concentrations give rise to negligible exposure following inhalation of resuspended sediment (Pattenden *et al.*, 1981).

To identify those members of the public subject to the highest external exposures, occupancies of different locations need to be considered. We keep under review the amounts of time spent by members of the public on intertidal areas of coastline bordering the north-east Irish Sea, and, together with the consumption rates as described in section 4.1.1, these habits have been recently re-surveyed. The results are applicable for 1981. It is 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 710 h year^{-1} over unshielded mud. From Table 9, making an allowance for natural background, their external exposure in 1981 was 9% of the ICRP-recommended limit 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. This addition is estimated to be 5% of the ICRP-recommended dose limit for members of the public, on the basis of both values of gut uptake factor for plutonium described in section 3.4. Total exposure of the externally exposed critical group is thus estimated to be 14% of the appropriate ICRP-recommended 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.

Table 10 Radioactivity in sediment from the Cumbrian coast and further afield, 1981

Sampling point and sediment type	No. of sampling observations†	Mean radioactivity concentration (dry), Bq kg^{-1}							
		Total beta	^{60}Co	^{95}Zr + ^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
Maryport (silt)	4	11 000	23	590	4 500	36	250	4 800	470
Whitehaven (")	4	14 000	22	1 100	4 700	ND	370	6 800	500
Newbiggin (")	12	24 000	52	5 500	11 000	270	320	6 100	1 600
Walney Island (")	4	6 600	15	1 000	3 000	53	170	2 900	500
Heysham (")	4	4 900	11	100	2 200	38	160	2 600	290
Sunderland Pt (")	4	1 900	ND	ND	260	ND	65	1 400	ND
Fleetwood (sand)	4	360	"	"	ND	"	11	170	"
Blackpool (")	3	350	"	"	"	"	12	160	"
New Brighton (")	4	380	"	"	"	"	5.3	120	"
Rock Ferry (silt)	4	3 600	5.3	"	360	"	140	2 800	63
Garlieston (")	4	2 700	1.1	30	390	2.1	45	900	34
Kipford slipway (")	4	3 300	2.9	130	1 100	ND	110	2 100	100
" marsh (")	3	4 100	6.1	98	960	"	110	2 500	83
" jetty (")	3	2 000	2.7	39	390	"	60	1 200	32

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	70	91	NA	NA	1 200	NA	NA
Whitehaven (")	4	99	91	270	1 100	1 100	ND	6.0
Newbiggin (")	12	230	240	650	2 500	2 300	"	14
Walney Island (")	4	62	71	NA	NA	780	NA	NA
Heysham (")	4	40	21	"	"	460	"	"
Sunderland Pt (")	4	ND	ND	"	"	120	"	"
Blackpool (")	3	"	"	"	"	4.6	"	"
Fleetwood (sand)	4	"	"	3.9	18	7.5	ND	0.012
New Brighton (")	4	"	"	NA	NA	1.3	NA	NA
Rock Ferry (silt)	4	5.8	19	"	"	240	"	"
Garlieston (")	4	6.5	10	"	"	150	"	"
Kipford slipway (")	4	9.9	13	"	"	350	"	"
" marsh (")	3	21	16	84	390	420	ND	0.72
" jetty (")	3	ND	ND	32	150	170	"	0.12

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

Table 11 Radioactivity in *Porphyra* from the Cumbrian coast, 1981

Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}						
		Total beta	^{95}Zr + ^{95}Nb	^{103}Ru	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs
Braystones South	11	10 000	700	110	9 100	36	14	210
Seascale	12*	7 100	400	94	5 900	8.2	10	170

Sampling point	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
Braystones South	12	30	15	55	53	ND	0.11
Seascale	12*	21	NA	NA	51	NA	NA

NA = not analysed.
ND = not detected.
†See section 3.3 for definition.
*These samples are taken weekly and counted wet to provide a rapid indication; they are later bulked for analysis on a monthly basis.

Table 12 Radioactivity in laverbread from South Wales, 1981

Manufacturer	No. of sampling observations†	^{106}Ru concentration (wet)
		Bq kg^{-1}
A	9	< 9
C	9	< 5

†See section 3.3 for definition.

4.1.3 *Porphyra*/laverbread pathway

No harvesting of *Porphyra* in the Sellafield vicinity for ultimate consumption was reported in 1981; 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 1981 are presented in Table 11. Samples of laverbread from the product of the major manufacturers are regularly collected from markets in South Wales and analysed for ruthenium-106. Results for 1981 are presented in Table 12. Because of the low concentrations, results are given as limits of detection. The exposure of critical individuals was less than 0.1% of the ICRP-recommended dose limit, confirming the virtual abeyance of this pathway.

4.1.4 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 13 presents the results of measurements in 1981 on seaweeds from UK shorelines of the Irish Sea. Radioactivity concentrations in *Porphyra* are reported in this section for areas relatively remote from Sellafield because of the value of this seaweed as an indicator, particularly for ruthenium-106. Although small quantities of *Porphyra* and *Ascophyllum nodosum* from these locations may be eaten, radioactivity concentrations are of negligible radiological significance. *Fucus* seaweeds are also 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 DOE(NI).

Table 13 Radioactivity in seaweeds from UK shorelines of the Irish Sea, 1981

Type of seaweed and sampling point	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}									
		Total beta	^{60}Co	^{95}Zr + ^{95}Nb	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{241}Am
Porphyra											
Larbrax	4	270	ND	ND	21	ND	ND	ND	9.1	ND	ND
Port William	4	270	"	"	60	"	"	1.0	21	"	"
Garlieston	4	340	"	"	83	"	23	2.7	42	"	3.9
Kirkcudbright	1	180	"	"	18	"	ND	1.8	15	"	1.9
Fucus vesiculosus											
Sellafield	12	11 000	21	790	910	15	"	78	1 200	19	46
Heysham	4	2 800	0.4	ND	19	ND	"	22	380	ND	6.5
Port William	4	920	ND	"	13	"	"	6.4	100	"	0.5
Garlieston	4	1 100	"	"	31	"	"	9.4	170	"	4.7
Auchencairn	4	1 600	"	"	26	"	"	16	260	"	2.1
Portrush	4	410	"	"	ND	"	"	0.5	12	"	ND
Millisle	1	420	"	"	"	"	"	1.9	38	"	"
Rhodymenia palmata											
Millisle	1	990	"	"	"	"	"	4.6	55	"	"
Ascophyllum nodosum											
Millisle	1	580	"	"	"	"	"	4.6	55	"	"
Fucus spiralis											
Millisle	1	320	"	"	"	"	"	2.4	34	"	"

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

4.2 Springfields, Lancashire

This establishment is mainly concerned with manufacture of fuel elements for nuclear reactors and production of uranium hexafluoride. Radioactive waste arisings are small and consist mainly of uranium and its daughter products; liquid discharges are made by pipeline to the Ribble Estuary. Public radiation exposure in this vicinity as a result of these discharges is very low; there is, however, a greater contribution due to Sellafield discharges. The critical pathway is external exposure, due to adsorption of radioactivity on the muddy areas of river banks. The amounts of time for which members of the public are subject to such exposure is kept under review. In 1981, the critical group consisted 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 mud.

Table 14(a) Radioactivity in sediment near the Springfields pipeline, 1981

Location	No. of sampling observations†	Mean radioactivity concentration (dry), Bq kg^{-1}							
		Total beta	^{60}Co	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu
Pipeline outlet	4	7 700	16	1 200	22	280	5 300	150	43

Location	No. of sampling observations†	Mean radioactivity concentration (dry), Bq kg^{-1}					
		^{155}Eu	^{234m}Pa	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{243}Cm + ^{244}Cm
Pipeline outlet	4	21	27 000	81	360	400	1.4

†See section 3.3 for definition.

Table 14(b) Gamma dose rates in air at 1 m over intertidal areas near the Springfields pipeline, 1981

Location	No. of sampling observations†	μGy h^{-1}
Pipeline outlet	4	0.31
460 m upstream	4	0.31
Freckleton boatyard	3	0.25

†See section 3.3 for definition.

Results for 1981 are shown in Table 14. 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 1981, including the Sellafield component, was about 7% of the ICRP-recommended dose limit. The increase in external exposure compared with results reported for 1980 (Hunt, 1982) is due to the longer times spent over muddy areas by houseboat dwellers than by the previously-reported critical group which consisted of dredgermen. The exposure is still mainly due to Sellafield discharges; the contribution due to Springfields would have been a small fraction of the total.

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. Recently, uranium recovered from irradiated fuel has been recycled; this may contain small quantities of fission products, of which technetium-99 is the only component of potential significance. Waste arisings in this second category are again very low; their disposal to Liverpool Bay from the North Wirral outfall at Meols is regulated by authorisation. It is not expected that the environmental consequences of these small disposals would be detectable above background levels due both to natural sources of radioactivity and to Sellafield discharges. However, we have established an environmental monitoring programme 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 1981 are presented in Table 15. 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 were higher than in 1980 (Hunt, 1982), reflecting discharges of decay-stored liquors from Sellafield during the latter part of 1980. Discharges of technetium-99 from Capenhurst were reduced in 1981 as compared with 1980. Exposure of critical shellfish consumers in the vicinity of the Wirral in 1981 amounted to less than 4% of the ICRP-recommended dose limit; 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. Discharges increased in 1981 as compared with 1980 due to emptying of a fuel element storage pond, but were still well within authorised limits. There are two pathways of potential importance leading to public radiation exposure. Of these, external exposure from use of intertidal areas by fishermen is likely to be the

Table 15 Radioactivity in environmental materials in the vicinity of the Wirral, 1981

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
			Total beta	^{99}Tc	^{106}Ru	^{134}Cs	^{137}Cs	^{241}Am
Shrimps	Wirral	4	260	12	12	6.9	130	ND
Cockles	Hoylake	4	120	5.8	12	2.7	51	4.0
Fucus spiralis	Hoylake	3	600	390	2.2	6.7	130	1.8
" "	Little Orme	4	640	540	ND	3.7	66	ND
Sand	Hoylake	4	320	1.3	"	5.3	92	0.5

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

Table 16(a) Radioactivity in environmental materials in the vicinity of Chapelcross, 1981

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
Flounder	Seafield	4	380	ND	ND	ND	13	340	ND
Salmon	"	1	88	"	"	"	ND	2.6	"
Shrimps	"	4	200	"	"	"	8.4	150	"
Fucus vesiculosus	Waterfoot	4	1000	"	"	6.7	10	190	"
" "	Seafield	4	960	"	"	22	12	230	"
Sediment	"	4	2100	1.5	100	490	80	1600	46

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	"	0.00055	0.0025	0.0029	ND	ND
Shrimps	"	4	"	NA	NA	ND	NA	NA
Fucus vesiculosus	Waterfoot	4	"	"	"	2.0	"	"
" "	Seafield	4	"	"	"	8.5	"	"
Sediment	"	4	9.7	"	"	120	"	"

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

Table 16(b) Gamma dose rates in air at 1 m over intertidal areas in the vicinity of Chapelcross, 1981

Location	No. of sampling observations†	μGy h^{-1}
Seafield	7	0.18
Browhouses	5	0.15
Waterfoot	5	0.13
Torduff Point	4	0.13
Battle Hill	4	0.12

†See section 3.3 for definition.

more significant, owing to occupancy rates. The second pathway is internal irradiation following consumption of locally-caught fish and shellfish, mainly shrimps. Our monitoring, which is carried out on behalf of departments of the Scottish Office, reflects these pathways. Samples of *Fucus vesiculosus*, as a useful indicator, are also analysed. The results of monitoring in 1981 are presented in Table 16.

Concentrations of artificial radionuclides in the Chapelcross vicinity are mostly due to Sellafield discharges, and the general levels given in Table 16(a) are consistent with values to be expected at this distance from Sellafield. Radiocaesium concentrations in 1981 were generally higher than in 1980, reflecting concentrations in the Irish Sea as a whole (section 4.1.1). Exposure of the critical group in 1981, making the maximising assumption of additivity of the two pathways, amounted to less than 4% of the ICRP-recommended dose limit. 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 Department of the Environment rather than this Ministry.

5.1 Atomic Energy Establishment, Winfrith, Dorset

The principal installation at which liquid radioactive wastes arise at this establishment is the Steam Generating Heavy Water Reactor. Most of the activity is due to tritium from

Table 17 Radioactivity in environmental materials from the vicinity of Winfrith, 1981

Material	Sampling point	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
			Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{137}Cs	^{144}Ce	^{238}Pu
Mackerel	Weymouth Bay	2	120	ND	ND	5.1	3.4	ND	NA
Crabs	" "	2	72	"	44	85	ND	"	"
Oysters	Poole	2	55	"	3.3	130	"	"	"
Scallops	Weymouth Bay	1	120	11	20	30	"	"	0.041
Fucus serratus	Kimmeridge	2	610	63	900	96	"	"	NA
	Chapman's Pool	2	450	27	530	85	"	"	"
	Osmington Mills	2	450	7.6	430	45	"	"	"
	Weymouth	2	330	9.8	350	12	0.4	"	"
	Portland	2	350	12	190	19	ND	"	"
	Swanage	2	530	22	500	65	"	"	"
	Hengistbury Head	2	390	6.5	340	29	"	"	"
	Bognor Regis	2	320	ND	51	2.2	"	"	"
	St Catherine's Point	2	310	"	120	17	0.4	"	"
	Gurnard Bay	2	330	0.2	70	11	1.0	"	"
	Sandgate	1	340	ND	8.5	ND	1.8	"	"
Mud	Poole	2	583	19	147	22	13	32	"
	Calshot	2	650	15	55	ND	11	24	"
	Hythe	1	450	ND	21	"	7.1	ND	"

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 Bay	2	NA	ND	NA	NA
Crabs	" "	2	"	"	"	"
Oysters	Poole	2	"	"	"	"
Scallops	Weymouth Bay	1	0.14	0.047	ND	0.00034
Fucus serratus	Kimmeridge	2	NA	ND	NA	NA
	Chapman's Pool	2	"	"	"	"
	Osmington Mills	2	"	"	"	"
	Weymouth	2	"	"	"	"
	Portland	2	"	"	"	"
	Swanage	2	"	"	"	"
	Hengistbury Head	2	"	"	"	"
	Bognor Regis	2	"	"	"	"
	St Catherine's Point	2	"	"	"	"
	Gurnard Bay	2	"	"	"	"
	Sandgate	1	"	"	"	"
Mud	Poole	2	"	"	"	"
	Calshot	2	"	"	"	"
	Hythe	1	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediments in Poole Harbour (4 sampling observations†): 0.062 μGy h^{-1}

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

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. Monitoring of the indicator material, *Fucus serratus*, provides additional information on the distribution of activation products. Data are presented in Table 17.

The impact of Winfrith discharges was, as in previous years, mainly observed in the activation product concentrations. Radiocaesium concentrations were similar to those to be expected from fallout; local discharges were likely to give rise to a negligible contribution. In 1981 the total radiation dose to critical consumers near this establishment was low, at less than 1% of the ICRP-recommended dose limit.

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. 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 absorbed mainly on fine sediments 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 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, unless discharges should increase significantly, dose rates on nets will be low, such that monitoring by the UKAEA is sufficient. Its surveys (Flew, 1982) have confirmed that the exposure of these fishermen was low, at less than 1% of the ICRP-recommended dose limit.

The second critical pathway is due to adsorption of radioactivity on fine particulates which become stranded in rocky clefts on the foreshore. This leads to exposure mainly to gamma radiation of those who frequent these areas; winkle picking accounts for the highest occupancies. Monitoring of foreshore dose rates is also carried out by the UKAEA (Flew, 1982). Public radiation exposure via this pathway was low, at less than 1% of the ICRP-recommended dose limit.

We sample winkles from Sandside Bay to enable the sub-critical pathway of shellfish consumption to be kept under direct review. Additionally, in 1981 as in previous years, limpets and *Fucus vesiculosus* were sampled as indicator materials. Results are presented in Table 18. Radiocaesium concentrations are mostly due to discharges from Sellafield. Other radionuclides detected, including transuranics, mainly reflect Dounreay discharges. Concentrations were

Table 18 Radioactivity in environmental materials from the vicinity of Dounreay, 1981

Sampling point and material	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}								
		Total beta	^{54}Mn	^{60}Co	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
Sandside Bay										
Winkles	4	190	ND	3.7	19	0.7	1.1	ND	5.4	59
Limpets	12	310	"	2.2	33	0.1	8.2	0.2	8.0	95
Fucus vesiculosus	12	420	2.2	11	7.9	ND	0.3	0.4	13	49

Sampling point and material	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}						
		^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Sandside Bay								
Winkles	4	ND	ND	0.24	0.70	2.8	0.056	0.0067
Limpets	12	0.24	1.0	0.70	1.8	6.3	ND	0.017
Fucus vesiculosus	12	ND	0.3	NA	NA	13	NA	NA

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

generally similar to those in 1980, except for americium-241 of which higher concentrations were observed due to increased discharges in 1981. However, the radiological significance of shellfish consumption was low; for high-rate winkle consumers the radiation dose was less than 0.3% of the ICRP-recommended dose limit. This pathway therefore remained of sub-critical importance in 1981.

6. Nuclear power stations operated by the electricity boards

All but one of these power stations are in England and Wales and are operated by the Central Electricity Generating Board. The Scottish power station at Hunterston is operated by the South of Scotland Electricity Board. Results are also presented for two power stations not operational in 1981, namely Hartlepool and Heysham, where our monitoring had already commenced.

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 1981 are presented in Table 19. 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. Public radiation exposure, however, was very low, at less than 0.1% of the ICRP- recommended limit to the critical group of fish and shellfish consumers. Very small concentrations of other artificial radionuclides, in addition to radiocaesium, were detected in mud and seaweed but taken together were of negligible radiological significance. Directly-measured gamma dose rates over intertidal mud continued to be indistinguishable from the natural background.

6.2 Bradwell, Essex

Radioactive liquid effluent from this power station is discharged to the estuary of the River Blackwater. There are two critical pathways, via consumption of locally-caught fish and shellfish, and external exposure of people who live in houseboats moored in muddy areas of the estuary. Our environmental monitoring reflects these pathways. Gamma dose rate measurements are supported by analyses of intertidal mud, and *Fucus vesiculosus* is analysed as an indicator material.

Measurements for 1981 are summarised in Table 20. In fish and shellfish, 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

Table 19 Radioactivity in environmental materials and gamma dose rates near Berkeley and Oldbury nuclear power stations, 1981

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
		Total beta	^{60}Co	^{134}Cs	^{137}Cs	^{144}Ce	^{155}Eu
Flounders	2	97	ND	ND	3.0	ND	ND
Eels	1	86	"	"	4.2	"	"
Shrimps	3	98	"	"	3.1	"	"
Fucus vesiculosus	2	260	1.1	6.6	65	"	"
Mud: area of outfalls	4	830	ND	7.7	84	4.3	1.5
area upstream	4	710	"	5.0	65	ND	ND

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

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

Table 20 Radioactivity in environmental materials and gamma dose rates near Bradwell nuclear power station, 1981

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta	^{60}Co	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
Mixed fish	5	120	ND	ND	ND	0.2	7.4	ND
Oysters	2	96	"	"	"	0.6	4.0	"
Fucus vesiculosus	2	330	0.7	"	0.4	4.6	23	"
Mud	5	970	7.1	6.3	ND	29	190	16

Mean gamma dose rate in air at 1 m over intertidal mud (8 sampling observations†): 0.070 μGy h^{-1}

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

members of the critical group of fish and shellfish consumers, however, was low, totalling less than 0.4% of the ICRP-recommended dose limit for members of the public. The presence of zinc-65 in oysters was not detectable in our 1981 samples. The small concentrations of artificial radionuclides detected in mud and seaweed were of negligible radiological significance. Gamma dose rates, as directly measured, were indistinguishable from the natural background.

6.3 Dungeness, Kent

The two critical radiation exposure pathways as a result of liquid radioactive waste discharges from this station are 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 1981 are given in Table 21.

Table 21 Radioactivity in environmental materials and gamma dose rates near Dungeness nuclear power station, 1981

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}			
		Total beta	^{60}Co	^{106}Ru	^{137}Cs
Plaice	3	180	ND	ND	2.3
Whiting	1	390	"	"	7.9
Whelks	1	130	2.7	10	ND
Fucus serratus	1	340	8.5	ND	1.8
Sand	2	350	7.0	"	4.3

Mean gamma dose rate in air at 1 m over intertidal sand (9 sampling observations†): 0.057 μGy h^{-1}

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

Concentrations of caesium-137 in plaice are attributable to discharges from the station and from Sellafield, with a small contribution due to fallout. Apportionment is difficult at these low levels. Concentrations of caesium-137 in whiting are similar to those in the southern North Sea (Table 4) and are likely to be the result of fish migration. The radiation dose to members of the critical group of fish consumers was very low, at less than 0.2% of the ICRP-recommended dose limit. Gamma dose rates over sand were indistinguishable from natural background. Whelks, seaweed and sand all showed trace levels of cobalt-60. The indicator sampling programme described in section 5.1 shows that AEE Winfrith rather than Dungeness may be the source of this nuclide. 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 both cobalt-60 and ruthenium-106 were, however, of negligible radiological significance.

6.4 Hartlepool, Cleveland

This station, with its two AGRs, was not yet operational in 1981. However, our monitoring had already begun in order to investigate background levels and to establish reliable sources of environmental materials. Potential critical pathways for radiation exposure for the public near this station likely to be associated with liquid 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.

Table 22 Radioactivity in environmental materials and gamma dose rates near Hartlepool nuclear power station, 1981

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
		Total beta	^{134}Cs	^{137}Cs	^{238}Pu	^{239}Pu+^{240}Pu	^{241}Am
Cod	4	120	0.5	16	NA	NA	ND
Shrimps	2	64	ND	4.4	0.0014	0.0066	0.0025
Crabs	4	57	"	3.0	0.00081	0.0047	0.0035
Fucus vesiculosus	3	250	"	6.7	NA	NA	ND
Sand	3	150	"	6.2	"	"	"
Mud	3	650	6.9	98	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediment (6 sampling observations†): 0.072 μGy h^{-1}

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

Results of our monitoring programme carried out in 1981 are shown in Table 22. Concentrations of radiocaesium and transuranics were due to discharges from Sellafield and to fallout; the radiation exposure of the potentially critical group of local fish and shellfish consumers from these existing sources was low, at less than 1% of the ICRP-recommended dose limit for members of the public.

6.5 Heysham, Lancashire

This establishment, which will comprise two, essentially separate, nuclear power stations both powered by AGRs, was under construction in 1981. Our monitoring had begun for similar reasons as for the station at Hartlepool; in addition, information on radiation exposures and on the distribution of a range of radionuclides as a result of Sellafield discharges is to be gained. The potential critical radiation exposure pathways from liquid radioactive discharges from Heysham are likely to be internal irradiation following consumption of locally-caught fish and shellfish (mainly shrimps and cockles), 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 1981 are given in Table 23. These mainly reflect discharges from Sellafield; it is unlikely that the effect of future discharges from Heysham will be detectable above the Sellafield-derived background. Estimates of the radiation exposure in 1981 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.

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 "B" station by AGRs. Liquid radioactive discharges are made via the same outfall and for the purposes of our environmental monitoring are considered together. There are two critical radiation exposure pathways associated with liquid radioactive waste 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 1981 presented in Table 24, indicate concentrations of radiocaesium representing the combined effect of discharges from the station and from Sellafield, in addition to fallout. Apportionment is difficult in view of the low levels detected. The total radiation exposure of members of the critical group through the fish and shellfish pathway was low, at less than 0.2% of the ICRP-recommended dose limit. The concentrations in shrimps of transuranic nuclides from the station and from Sellafield were of negligible radiological significance. Gamma radiation dose rates over intertidal sediment close to the station were indistinguishable from the natural background.

Table 23 Radioactivity in environmental materials and gamma dose rates near Heysham nuclear power station, 1981

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{60}Co	^{95}Zr + ^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
Flounders	4	420	ND	ND	ND	ND	22	420	ND
Shrimps	4	270	"	"	"	"	8.8	170	"
Cockles	4	590	1.1	8.9	58	"	4.9	96	4.7
Fucus vesiculosus	4	2800	0.4	ND	19	"	22	380	ND
Sediment:									
Sunderland Point	4	1900	ND	"	260	"	65	1400	"
Half Moon Bay	4	4900	11	101	2200	38	160	2600	290

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
		^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{243}Cm + ^{244}Cm
Flounders	4	ND	ND	NA	NA	ND	NA
Shrimps	4	"	"	0.014	0.066	0.075	ND
Cockles	4	"	0.7	1.7	8.1	9.1	0.036
Fucus vesiculosus	4	"	ND	NA	NA	6.5	NA
Sediment:							
Sunderland Point	4	"	"	"	"	120	"
Half Moon Bay	4	40	21	"	"	460	"

Mean gamma dose rate in air at 1 m over intertidal sediment:
Heysham vicinity (19 sampling observations†): 0.15 μGy h^{-1}
Sunderland Point (9 sampling observations†): 0.14 μGy h^{-1}

Table 24 Radioactivity in environmental materials and gamma dose rates near Hinkley Point nuclear power station, 1981

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}				
		Total beta	^{60}Co	^{134}Cs	^{137}Cs	^{238}Pu
Flounders	3	120	ND	ND	4.3	NA
Eels	1	60	"	"	4.3	"
Shrimps	3	95	"	0.1	3.6	0.011
Fucus vesiculosus	3	260	2.6	0.7	6.9	NA
Sediment	2	520	ND	2.5	32	"

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	3	NA	ND	NA	NA
Eels	1	"	"	"	"
Shrimps	3	0.032	0.023	0.053	0.0022
Fucus vesiculosus	3	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 25 Radioactivity in environmental materials and gamma dose rates near Hunterston nuclear power station, 1981

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{106}Ru	^{110m}Ag	^{134}Cs	^{137}Cs
Cod	4	190	ND	ND	ND	ND	ND	4.6	90
Eel (fish farm A)	1	71	"	"	"	"	"	1.0	15
Turbot (fish farm B)	1	110	"	"	"	"	"	1.2	33
Cockles	4	200	"	7.3	"	69	"	6.8	28
Winkles	4	400	1.3	19	1.0	160	17	10	37
Fucus spiralis	3	1200	8.9	62	10	98	ND	24	100
Fucus vesiculosus	1	860	6.2	32	8.0	65	"	14	90
Sand	4	360	ND	4.7	ND	16	"	12	97

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		^{144}Ce	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Cod	4	ND	ND	NA	NA	ND	NA	NA
Eel (fish farm A)	1	"	"	"	"	"	"	"
Turbot (fish farm B)	1	"	"	"	"	"	"	"
Cockles	4	39	0.6	0.23	0.42	0.29	1.8	0.084
Winkles	4	40	ND	NA	NA	ND	NA	NA
Fucus spiralis	3	170	1.9	"	"	19	"	"
Fucus vesiculosus	1	84	1.6	"	"	ND	"	"
Sand	4	47	3.2	"	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sand (10 sampling observations†): 0.11 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, of which the latter is powered by AGRs. Liquid radioactive waste discharges are made under authorisation of the Scottish Development Department to the Firth of Clyde. 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 (see Table 1) to allow increased discharges of these radionuclides, and this authorisation was renewed in 1981 for a further year. 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 1981 are shown in Table 25.

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 public radiation exposure in 1980 was low, at less than 2% of the ICRP-recommended dose limit to members of the critical group of fish and shellfish consumers. 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 likely to be fed on manufactured food brought from further afield. No effects were detectable due to the continued increased level of radiocaesium discharges. The concentrations of cobalt-60 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

Radiation exposure pathways due to liquid radioactive waste disposals from this station were reviewed in 1981 (Leonard and Smith, 1982). The two critical pathways continue to be due to fish and shellfish consumption

leading to internal irradiation, and to occupancy of intertidal areas giving rise to external exposure. Our monitoring in 1981 reflected these pathways; the results are shown in Table 26.

The radiocaesium concentrations in fish and shellfish represent the combined effect of discharges from the station and from Sellafield, as well as of fallout. Apportionment is difficult at the low levels measured. Trace levels of cobalt-60 detected in mussels are likely to be 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 0.3% of the ICRP-recommended dose limit. Gamma dose rates, as in previous years, were indistinguishable from the natural background.

Table 26 Radioactivity in environmental materials and gamma dose rates near Sizewell nuclear power station, 1981

Material	No. of sampling observations†	Mean radioactivity concentration (wet), Bq kg^{-1}			
		Total beta	^{60}Co	^{134}Cs	^{137}Cs
Mixed fish	4	140	ND	0.8	16
Crabs	1	68	"	ND	2.7
Mussels	2	41	0.2	"	1.4
Oysters	1	28	ND	"	0.5

Mean gamma dose rate in air at 1 m over intertidal sand/shingle (15 sampling observations†): 0.051 μGy h^{-1}

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

Table 27 Radioactivity in environmental materials near Trawsfynydd nuclear power station, 1981

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{54}Mn	^{60}Co	^{90}Sr	^{95}Zr+^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs
Rainbow trout	9	190	ND	ND	11	ND	ND	ND	7.2	68
Brown trout	6	640	"	"	14	"	"	"	82	610
Perch	8	1300	"	"	140	"	"	"	150	1300
Mud	10	4400	"	13	NA	"	"	900	80	3500
Peat	5	3000	"	9.6	"	"	59	360	47	1200
Fontinalis										
Afon Prysor	5	310	2.5	ND	"	50	15	0.25	0.40	9.7
Gwylan Stream	5	790	4.0	32	"	ND	46	63	13	150
Water										
Hot Lagoon	5	NA	NA	NA	0.31	NA	NA	NA	0.017	0.19
Cold Lagoon	2	"	"	"	0.30	"	"	"	0.036	0.31

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	^{242}Cm+^{244}Cm
Rainbow trout	9	ND	ND	0.00018	0.00086	0.00086	ND	0.00002
Brown trout	6	"	"	0.00024	0.0012	0.0013	0.00011	0.000033
Perch	8	"	"	0.00031	0.0013	0.0017	0.00016	0.00005
Mud	6	"	"	NA	NA	5	NA	NA
Peat	5	"	5.5	"	"	10	"	"
Fontinalis								
Afon Prysor	5	27	1.2	"	"	NA	"	"
Gwylan Stream	5	36	0.44	"	"	"	"	"
Water								
Hot Lagoon	5	NA	NA	"	"	"	"	"
Cold Lagoon	2	"	"	"	"	"	"	"

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

6.9 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 the other UK nuclear power stations which discharge to estuarine or coastal waters. A review of exposure pathways was carried out in 1981. The critical pathway continues to be 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. During 1981 a small proportion of brown trout were also introduced in this way. Because of the limited period they spend in the lake, these fish generally exhibit lower radiocaesium concentrations than indigenous fish. The 1981 review of pathways showed that consumption rates of brown and rainbow trout by the critical group were higher than in previous surveys, with a nearly equal preference between the two species. Thus exposures were likely to be higher than in previous years and to depend more heavily on radionuclide concentrations in brown trout.

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 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 1981 are shown in Table 27.

Radiocaesium concentrations in fish in 1981 were lower than in 1980, reflecting reduced discharges. As in previous years, low concentrations of transuranic nuclides from station operations were also observed in fish. In contrast with the behaviour of radiocaesium, concentrations of transuranics tend to be similar in both brown trout and rainbow trout. Transuranics would therefore appear to be taken up into fish mainly via water, whilst caesium is taken up mainly via food. The concentrations of transuranics in fish continued to be of negligible radiological significance.

It is estimated that in 1981 members of the critical group of fish consumers received about 11% of the ICRP-recommended dose limit. This increased exposure as compared with 1980 (Hunt, 1982) reflects the higher fish consumption rates noted above. These rates will continue to be kept under review.

6.10 Wylfa, Gwynedd

Liquid radioactive wastes from this station are discharged to the Irish Sea under authorisation of the Welsh Office. We carried out a review of exposure pathways in 1981. The two critical pathways continue to be due to consumption of local fish and shellfish and to occupancy of intertidal areas; consumption rates were found to be higher than in previous surveys. Monitoring is carried out in respect of the two critical 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 1981 are presented in Table 28.

The 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 generally increased concentrations of radiocaesium in fish and shellfish as compared with 1980 are consistent with those in the Irish Sea and noted in section 4.1.1. The total radiation exposure of members of the critical group in 1981 was less than 3% of the ICRP-recommended dose limit. The increase from the result reported for 1980 (Hunt, 1982) is due to the higher consumption rates and the increased radiocaesium concentrations; however, the exposure is still small. 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 are operated by the Ministry of Defence (Navy Department). The US naval base at Holy 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 analyses of sediments. Indicator shellfish and seaweed are also analysed.

Results of monitoring in 1981 are presented in Table 29.

Table 28 Radioactivity in environmental materials and gamma dose rates near Wylfa nuclear power station, 1981

Material	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
Plaice	4	120	ND	ND	ND	1.1	31	ND
Crab	3	110	0.4	"	"	0.6	22	"
Winkles	2	130	ND	"	8.3	0.4	16	"
Mussels	3	130	"	"	8.8	0.8	25	"
Fucus vesiculosus	4	630	"	"	3.2	2.5	42	"
Mud	2	2300	2.8	76	130	65	1500	60

Material	No. of sampling observations	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
		^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Plaice	4	ND	NA	NA	ND	NA	NA
Crabs	3	"	"	"	"	"	"
Winkles	2	"	"	"	1.2	"	"
Mussels	3	"	0.056	0.28	0.36	ND	0.0013
Fucus vesiculosus	4	"	NA	NA	ND	NA	NA
Mud	2	15	"	"	92	"	"

Mean gamma dose rate in air at 1 m over intertidal mud (12 sampling observations†): 0.087 μGy h^{-1}

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

Table 29 Radioactivity in environmental materials and gamma dose rates near naval establishments, 1981

Establishment	Material	No. of sampling observations†	Mean radioactivity concentration, (wet)*, Bq kg^{-1}						Mean gamma dose rate in air at 1 m	
			Total beta	^{54}Mn	^{60}Co	^{134}Cs	^{137}Cs	^{144}Ce	No. of sampling observations†	μGy h^{-1}
Chatham	Sediment	6	880	ND	9.2	4.2	68	ND	16	0.066
Devonport	Winkles	2	97	"	0.2	ND	0.3	4.8	NP	NP
	Fucus vesiculosus	2	200	"	ND	"	0.2	ND	"	"
	Sediment	6	920	0.3	0.2	1.4	11	25	12	0.083
Faslane	Sediment	4	630	ND	15	10	210	9.5	20	0.086
Rosyth	Sediment	2	510	"	2.8	4	66	ND	7	0.077
Holy Loch	*Fucus spiralis*	4	280	"	0.3	2.0	34	4.2	NP	NP
	Sediment	2	230	"	46	1.6	44	ND	32	0.085

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

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.

8. Amersham International plc

Amersham International plc (until 1981 known as The Radiochemical Centre Limited) is engaged in the manufacture of radioactive materials for use in industry, research and medicine. 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. Due to an increased demand for the company's products, a laboratory was built at a site near Cardiff. This laboratory has been engaged since 1980 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. The authorisation was changed in September 1981 to allow increased discharges of carbon-14. These increased discharges are of negligible radiological significance.

Our monitoring programme 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. It is expected that the environmental consequences of discharges from this establishment will be very small and difficult to detect above the background levels due to fallout, adjacent nuclear facilities, and possibly Sellafield.

The results of monitoring in 1981 are presented in Table 30. Artificial radioactivity detected was due to radiocaesium and other nuclides. However, none of these nuclides was processed or discharged by this establishment in 1981; the results were therefore due to the combined background effects noted above. The exposure of the critical group of fish and shellfish consumers due to these effects in 1981 was less than 0.1% of the ICRP-recommended dose limit for members of the public. Gamma dose rates over sediment were indistinguishable from those to be expected from natural background.

9. Channel Islands monitoring

We have continued to analyse marine environmental samples provided by the Channel Islands States in surveillance of the effects of radioactive liquid discharges from the French reprocessing plant at Cap de la Hague. Fish and shellfish are monitored in relation to the internal irradiation pathway; sediment is analysed with relevance to external exposures. Seaweeds are sampled as indicator materials.

The results for 1981 are given in Table 31. Concentrations of caesium-137 in fish and shellfish were not significantly in excess of those to be expected from other sources, including fallout. However, the presence of transuranics in fish and shellfish may be attributed to discharges from the plant at Cap de la Hague. The presence of ruthenium-106 in environmental materials, in increased concentrations in 1981, may also be attributed to this plant. However, the concentrations of artificial radionuclides in each of these materials were still of negligible radiological significance.

Table 30 Radioactivity in environmental materials and gamma dose rates near the outfall of the sewer serving Amersham International plc, Cardiff, 1981

Material	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{54}Mn	^{60}Co	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{155}Eu
Flounders	4	170	ND	ND	ND	ND	1.8	ND	ND
Winkles	4	130	"	"	"	"	2.2	"	"
Fucus spiralis	3	200	"	"	"	0.04	1.2	"	"
Fucus vesiculosus	4	230	"	"		0.08	2.2	"	"
Sediment	8	1000	0.8	0.8	1.7	6.3	79	14	2.3

Mean gamma dose rate in air at 1 m over intertidal sediment (8 sampling observations†): 0.081 μGy h^{-1}

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

Table 31 Radioactivity in marine environmental materials from the Channel Islands, 1981

Material	Sampling area	No. of sampling observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
			Total beta	^{60}Co	^{106}Ru	^{137}Cs	^{144}Ce	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{243}Cm + ^{244}Cm
Ray	Guernsey	1	150	ND	ND	7.6	ND	0.00008	0.00034	0.00046	ND
Crabs	Guernsey	1	120	"	"	ND	"	0.00083	0.0018	0.010	0.0028
	Jersey	1	68	"	2.9	"	"	0.0032	0.0074	0.0089	0.0015
Oysters	Jersey	1	89	"	47	"	"	0.016	0.040	0.027	0.0030
Limpets	Jersey	1	77	"	24	"	"	0.0090	0.009	0.023	0.012
	Guernsey	1	35	"	7.9	"	"	0.0054	0.015	0.0066	0.0010
	Alderney	1	130	"	23	"	"	0.012	0.022	0.030	0.0046
Porphyra	Jersey										
	Greve de Lecq	4	230	"	67	"	"	NA	NA	ND	NA
	La Rozel	4	220	0.2	52	0.4	"	"	"	"	"
	Guernsey										
	Fort Doyle	4	180	ND	47	ND	"	"	"	"	"
	Fermain Bay	4	180	"	23	"	"	"	"	"	"
	Alderney										
	Telegraph Bay	3	190	"	56	"	"	"	"	"	"
	Quenard Point	4	240	"	97	"	4.7	"	"	"	"
	Braye Harbour	1	160	"	26		ND				
Fucus serratus	Jersey										
	La Rozel	4	350	1.5	23	0.4	"	0.040	0.090	0.027	0.0038
	Guernsey										
	Fermain Bay	4	240	1.0	20	0.5	"	0.025	0.064	0.019	0.0027
	Alderney										
	Quenard Point	3	470	5.7	62	0.4	6.1	0.059	0.13	0.065	0.011
	Braye Harbour	1	280	1.1	15	ND	ND				
Sediment	Jersey										
	St Helier Harbour	1	800	1.3	190	10	25	1.0	2.9	1.8	0.22
	Guernsey										
	Bordeaux Harbour	1	380	ND	ND	4.3	ND	0.051	0.17	0.054	0.0012
	Alderney										
	Braye Harbour	1	520	"	"	5.1	"	0.12	0.53	0.24	0.025

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

10. Summary and Conclusions

A summary of estimated public radiation exposures in 1981 resulting from liquid radioactive waste discharges from nuclear establishments which we monitor is presented in Table 32. The exposures are expressed in terms of the effective dose equivalent to members of the critical group as percentages of the ICRP-recommended dose equivalent limit for members of the public, and incorporate the higher gut uptake factor for plutonium (section 3.4), except where otherwise indicated.

All exposures remained within the ICRP-recommended limit for members of the public. 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 important contribution was from radiocaesium which is discharged mainly from the fuel element storage ponds. The increases as compared with the results reported for 1980 (Hunt, 1982) are due to changes in consumption rates of molluscs rather than to increases in radioactivity concentrations. 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 32, 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 signficant component. Details are given in section 4.1.1. The collective effective dose equivalent to the UK population in 1981 was 130 man-Sv, an increase from 100 man-Sv reported for 1980. For the population of other European countries the collective effective dose equivalent was 150 man-Sv in 1981, representing an increase from 140 man-Sv for 1980. A probable reduced flow through the Irish Sea and Scottish waters in 1981 caused radiocaesium concentrations in sea water, and hence in fish, to rise. Greater herring catches by the UK and other European countries in Scottish waters contributed to the increased collective doses. These increases occurred despite reductions in radiocaesium discharged from Sellafield in 1981.

Table 32 Summarised estimates of public radiation exposure from discharges of liquid radioactive waste in the UK, 1981

Establishment	Radiation exposure pathway	Critical group	Effective dose equivalent (as % of ICRP-recommended dose limit of 5 mSv year^{-1} for members of the public)
BRITISH NUCLEAR FUELS LIMITED			
Sellafield	Fish and shellfish consumption	Local fishing community Commercial fishing community	24-69* 16-19*
	External	Whitehaven boat dwellers	14
	Porphyra/laverbread consumption	Consumers in South Wales	<0.1
Springfields	External	Houseboat dwellers	7[a]
Capenhurst (Meols outfall)	Shellfish consumption	Local fishing community	<4[a]
Chapelcross	External Fish and shellfish consumption	Local fishermen	<4[a]
UNITED KINGDOM ATOMIC ENERGY AUTHORITY			
Winfrith	Fish and shellfish consumption	Local fishing community	<1
Dounreay	External to hands: fishing gear External Shellfish consumption	Local fishermen Winkle pickers Local fishing community	<1[b] <1[b] <0.3[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 External	Local fishing community Houseboat dwellers	<0.4[b]
Dungeness	Fish consumption External	Local fishing community	<0.2
Hartlepool[c]	Fish and shellfish consumption External	Local fishing community Coal collectors	<1[a]
Heysham[c]	Fish and shellfish consumption External	Local fishing community	19[a] <1[a]
Hinkley Point	Fish and shellfish consumption External	Local fishing community	<0.2[b]
Hunterston	Fish and shellfish consumption External	Local fishing community	<2[a]
Sizewell	Fish and shellfish consumption External	Local fishing community	<0.3[b]
Trawsfynydd	Fish consumption	Local fishing community	11
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]

*See section 4.1.1. The upper value in each case is based on revised consumption rates and the enhanced gut uptake factor for plutonium, which is still under review by ICRP.
[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.

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