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DIRECTORATE OF FISHERIES RESEARCH

AQUATIC ENVIRONMENT MONITORING REPORT

NUMBER 8

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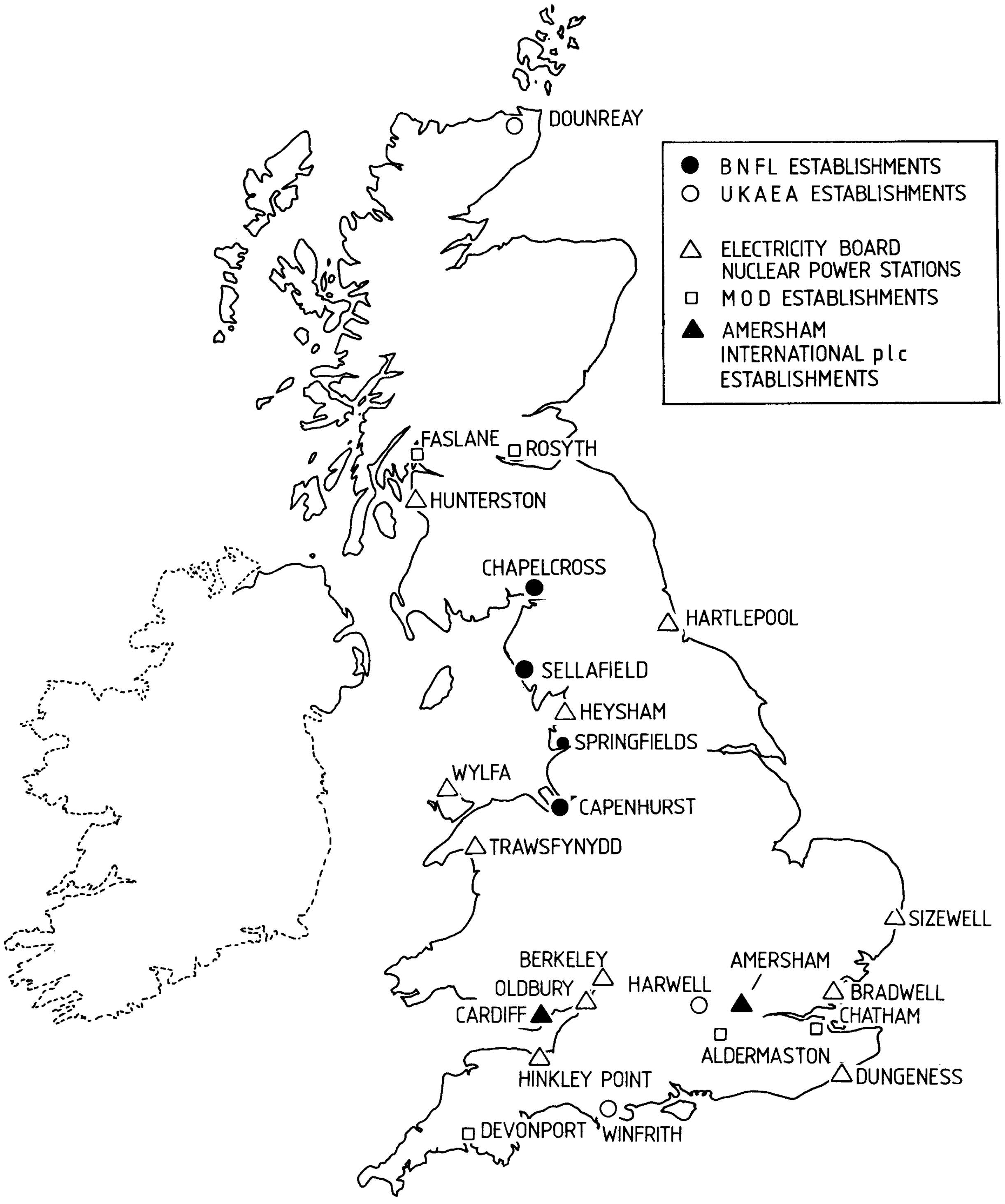

Figure 1. UK nuclear establishments giving rise to principal discharges of liquid radioactive waste.

1. Introduction

This report presents the results of the environmental monitoring programme carried out during 1980 by staff of the Aquatic Environment Protection Division Section 1, at the Fisheries Radiobiological Laboratory (FRL), a part 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). This 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 often 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 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 FRL's 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 1980 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 now published by the Environment Departments. The survey for 1980 has been published (DOE, Scottish Office & Welsh Office, 1981) but to enable the data on environmental levels presented in this report readily to be considered 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 1980. 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 only in curies since it is in these units that the limits are currently specified. 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 1980 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 1980 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 not disposed of 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 1980 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 1980 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 Department of the Environment (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 3,351 packages of 2,693 tonnes gross weight containing 66 TBq (1,791 Ci) of alpha activity and 3,925 TBq (106,079 Ci) of beta/gamma activity, including 1,486 TBq (40,169 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 *Coryphaenoides (Nematonurus) armatus* collected from near the sea bed in the disposal area. These

Table 1 Principal discharges of liquid radioactive waste from UK nuclear establishments, 1980

Establishment	Radioactivity	Discharge limit (annual equivalent), Ci	Discharges during 1980		
			TBq	Ci	% of limit utilised
BRITISH NUCLEAR FUELS LIMITED					
Sellafield					
Sea pipeline	Total beta	300 000	4 306	116 391	39
	Ruthenium-106	60 000	344	9 295	15
	Strontium-90	30 000	352	9 506	32
	Total alpha	6 000	39	1 045	17
Seaburn sewer	Total activity	4	0.0037	0.10	2.5
Springfields	Total alpha	360	0.93	25	7
	Total beta	12 000	131	3 534	29
Chapelcross	Total activity[1]	700	0.32	8.75	1.2
	Tritium	150	0.094	2.54	1.7
Capenhurst					
Rivacre Brook	Total activity[2]	0.04	0.00067	0.0181	45
Meols outfall	Technetium-99	4	0.0115	0.312	7.8
UNITED KINGDOM ATOMIC ENERGY AUTHORITY					
Winfrith	Total activity	30 000	63	1 702	5.7
	Ruthenium-106	9 000	0.29	7.75	<1
	Strontium-90	1 200	0.27	7.43	<1
	Total alpha	1 200	0.20	5.37	<1
Harwell	Total activity[1,3]	240	2.15	58	24
	Tritium	240	1.26	34	14
Dounreay	Total activity	24 000	63	1 715	7.1
	Strontium-90	2 400	13	350	15
	Total alpha	240	0.19	5	2.1
CENTRAL ELECTRICITY GENERATING BOARD					
Berkeley	Total activity[1]	200	2.1	57	28
	Tritium	1 500	2.8	76	5.1
Bradwell	Total activity[1]	200	1.4	39	20
	Zinc-65	5	0.0037	0.1	2.0
	Tritium	1 500	2.3	63	4.2
Dungeness	Total activity[1]	200	0.9	24	12
	Tritium	2 000	0.3	8	<1
Hinkley Point[4]					
"A" Station	Total activity[1]	200	5.1	138	69
	Tritium	2 000	2.0	53	2.7
"B" Station	Total activity[1,5]	100	0.15	4	4.0
	Sulphur-35	700	0.63	17	2.4
	Tritium	18 000	164	4 430	25
Oldbury	Total activity[1]	100	1.4	38	38
	Tritium	2 000	0.3	8	<1
Sizewell	Total activity[1]	200	1.9	52	26
	Tritium	3 000	1.0	28	<1
Trawsfynydd	Total activity[1]	40	0.52	14	35
	Caesium-137	7	0.06	1.6	23
	Tritium	2 000	1.0	27	1.4

Table 1 (continued)

Establishment	Radioactivity	Discharge limit (annual equivalent), Ci	Discharges during 1980		
			TBq	Ci	% of limit utilised
CENTRAL ELECTRICITY GENERATING BOARD (continued)					
Wylfa	Total activity[1]	65	0.07	2	3.1
	Tritium	4 000	11.3	306	7.7
SOUTH OF SCOTLAND ELECTRICITY BOARD					
Hunterston					
"A" Station	Total activity[1]	( )[6]	13.6	367	( )[6]
	Tritium	1 200	0.78	21	1.8
"B" Station	Total activity[1,5]	100	0.10	2.6	2.6
	Sulphur-35	700	1.55	42	6.0
	Tritium	40 000	110	2 969	7.4
MINISTRY OF DEFENCE (PROCUREMENT EXECUTIVE)					
Aldermaston	Total activity[1,3]	156	0.16	4.32	2.8
	Tritium	156	0.084	2.27	1.5
MINISTRY OF DEFENCE (NAVY DEPARTMENT)					
Chatham	Total activity[1]	20	0.00167	0.045	<1
	Cobalt-60	10	0.00167	0.045	<1
	Tritium	20	0.00381	0.103	<1
Devonport	Total activity[1]	4	0.00137	0.037	<1
	Cobalt-60	1	0.00137	0.037	3.7
	Tritium	10	0.00962	0.26	2.6
Faslane	Total activity[1]	1	0.000211	0.0057	<1
Rosyth	Total activity[1]	30	0.0163	0.44	1.5
AMERSHAM INTERNATIONAL plc					
Amersham	Total activity[1,3]	72	0.93	25.1	35
	Tritium	400	7.0	190	47
Cardiff	Beta/gamma activity[7]	2.4	0.0066	0.178	7.4
	Carbon-14	20	0.059	1.6	8.0
	Tritium	36 000	1.7	45.8	<1

[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 format above represents the way in which it has been agreed that the authorisation should be apportioned in practice.
[5]Excluding sulphur-35.
[6]For the 12 month period to the end of May 1980 the authorisation was 200 Ci. During this period, discharges were 7.2 TBq (194 Ci) or 97% of the authorised limit. For the 12 month period from June 1980 the authorisation was 432 Ci. From June to December 1980 the discharge was 9.9 TBq (267 Ci) or 62% of this new authorised limit.
[7]Excluding tritium, carbon-14 and radioisotopes of calcium and strontium.

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

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

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(T1) 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

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 = 100 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

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. The number of observations during the year is therefore 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 for each observation so as to allow for statistical variations. 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.

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

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

At many locations monitored by FRL the results for certain measurements, particularly total beta radioactivity concentrations and gamma dose rates, may be comparable with levels due to natural radioactivity. Further analysis of samples (usually by gamma spectrometry) can indicate the component of total beta radioactivity which may be 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 recom-

Table 3 Natural radioactivity concentrations of various environmental materials and natural background dose rates around the British Isles

Material	Total beta radioactivity concentration (wet)*	
	$Bq\ kg^{-1}$	Comments
Fish	40 to 100	Mostly ^{40}K
Shellfish	40 to 100	"
Seaweed	200 to 600	"
Sand	200 to 400	^{40}K and decay products of U and Th
Mud	700 to 1000	"

Gamma dose rates in air over intertidal sediments: $\mu Gy\ h^{-1}$

Sand, shingle	0.03 to 0.05
Mud	0.05 to 0.1

*Except sediments for which dry concentrations apply.

mendations 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, 1981). 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, 1981, 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. For the nuclides of main radiological importance in this report, the use of doses per unit intake for workers is unlikely to underestimate significantly doses to the public. It is to be noted, however, that the NRPB has recently published (Harrison, 1982) a review of gut uptake factors for transuranics. This review indicates that, for adult members of the public ingesting low concentrations of plutonium in food and water, an appropriate value of absorption factor by the gut would be a factor of 5 higher than that currently used in ICRP Publication 30 for appropriate forms of plutonium, except when a lower value can be justified. The effect of the consequent enhancement of doses from plutonium essentially by this factor has been considered in this report. Secondly, 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. Thirdly, 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 has been 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 FRL 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. FRL regularly monitors 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, the Calder Hall magnox-type nuclear power station and the Windscale Advanced Gas-cooled Reactor (AGR) development. 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 1980 are summarised in Table 1, and were within the limits set by the authorising Departments. Discharges of total beta activity, at 39% of the authorised limit, were slightly more than in 1979 (37%). Total beta discharges are substantially dependent upon releases of radiocaesium which mainly originate from the fuel element storage ponds. In 1980 caesium-137 pipeline discharges totalled 2966 TBq, a higher total than in 1979 (2562 TBq). Zeolite skips continued to be used in the ponds to absorb caesium, but for a short period adverse pond conditions caused some release of caesium previously absorbed on skips that were then operational. The optimised use of zeolite skips, so as to keep doses As Low As Reasonably Achievable (section 3.4) continued to be required by the authorising Departments. Largely for the same reason as for caesium, strontium-90 discharges in 1980 were more than in 1979. However, discharges of ruthenium-106, which does not derive mainly from the ponds, were less in 1980 than in 1979. This also applied for discharges of plutonium isotopes owing to the introduction of improved treatment of certain effluent streams, hence the total alpha activity released was less than in 1979.

A substantial monitoring effort was maintained by FRL during 1980. 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 1980, 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 the FRL 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, specific surveys are also carried out by FRL, 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; the Area averages about 5 km from the pipeline outlet. Table 4 includes the results of analyses by FRL of samples collected by authorities in Northern Ireland and the Irish Republic.

Table 4 Beta/gamma radioactivity in fish from the Irish Sea vicinity and further afield, 1980

Sampling area/landing point	Sample	No. of observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}		
			Total beta	^{134}Cs	^{137}Cs
Sellafield shoreline area[1,3]	Cod	13	2000	140	2000
	Pollack	1	1100	71	1100
Sellafield offshore area[1,3]	Plaice	4	650	35	580
	Dab	3	590	35	600
	Cod	3	750	43	630
	Whiting	2	760	37	610
	Flounder	2	720	38	670
	Ray	2	740	38	620
	Gurnard	1	340	17	220
Ravenglass[2]	Plaice	10	660	37	610
	Cod	12	990	61	850
	Salmon	1	220	2.0	8.2
Whitehaven[2]	Plaice	10	380	17	320
	Cod	11	430	21	330
Morecambe Bay[1]	Flounder	4	480	24	400
Fleetwood[2]	Plaice	3	260	11	160
	Cod	3	320	14	220
Cumbrian rivers[4]	Sea trout	4	380	19	300
Isle of Man[2]	Plaice	3	160	5.1	83
	Cod	4	250	8.0	130
	Herring	4	180	6.2	100
	Mixed fish	1	140	4.5	66
Solway[1]	Salmon	1	120	ND	2.6
	Flounder	4	350	16	300
North Anglesey[1]	Plaice	4	140	1.7	22
	Turbot	2	80	0.8	17
Northern Ireland[2]	Whiting	2	200	5.4	92
Republic of Ireland[2]	Plaice	4	140	0.4	38
	Cod	6	150	1.7	49
	Whiting	5	180	3.4	84
	Sprat	1	190	3.3	86
Minch[1]	Plaice	4	130	1.7	22
	Cod	4	160	2.5	35
	Herring	2	120	3.8	17
Northern North Sea[1]	Plaice	8	94	0.2	5.3
	Cod	10	120	0.3	8.7
	Haddock	4	NA	0.3	8.1
	Herring	2	130	0.2	4.6
Mid-North Sea[1]	Plaice	11	88	0.2	6.2
	Cod	11	120	0.5	13
	Haddock	5	NA	0.4	8.9
	Whiting	2	"	1.1	28
	Herring	1	100	0.6	16
Southern North Sea[1]	Plaice	4	110	0.1	3.3
	Cod	4	120	0.3	10
	Whiting	2	NA	0.2	5.8
Iceland area[1]	Plaice	2	65	ND	ND
	Cod	3	110	"	0.4
Barents Sea[1]	Cod	1	88	"	1.0

ND = not detected.
NA = not analysed.

[1]Sampling area.
[2]Landing point.
[3]See text 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, 1980

Sampling area/landing point	Sample	No. of observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}										
			Total beta	^{60}Co	^{95}Zr + ^{95}Nb	^{103}Ru	^{106}Ru	^{110m}Ag	^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu
Sellafield shoreline area[1,3]	Crabs	2	1000	ND	6.1	ND	300	5.1	40	600	44	ND	ND
	Winkles	5	5500	16	320	7.3	3200	32	31	470	160	"	3.6
St Bees[1]	Limpets	3	4500	2.5	250	14	1300	5.5	29	450	170	6.8	15
	Mussels	4	1900	2.5	910	14	4500	ND	28	320	190	11	11
	Winkles	4	4800	12	420	7.5	2200	15	28	380	150	3.9	14
Whitehaven[2]	*Nephrops*	3	470	ND	ND	ND	ND	ND	16	250	ND	ND	ND
	Queens	1	380	"	"		180	6.1	6.0	49	"	"	"
Morecambe Bay[1]	Shrimps	4	260	"	"	"	ND	ND	9.0	150	"	"	"
	Cockles	4	370	1.4	"	"	61	"	8.1	130	4.1	"	"
Isle of Man[2]	Scallops	4	99	ND	"	"	ND	"	0.9	14	ND	"	"
Kirkcudbright[2]	Scallops	4	87	"	"	"	1.7	"	1.4	17	"	"	"
	Queens	4	85	"	"	"	4.0	"	1.5	20	"	"	"
	Winkles	1	380	"	"	"	74	"	6.6	69	"	"	"
Solway[1]	Shrimps	3	210	"	"	"	2.9	"	7.0	130	"	"	"
Wirral[1]	Shrimps	2	270	"	"	"	ND	"	7.8	140	"	"	"
	Cockles	2	80	"	"	"	13	"	2.5	44	"	"	"
Conwy[2]	Mussels	2	91	"	"	"	"	"	1.4	17	"	"	"
North Anglesey[1]	Crabs	3	80	"	"	"	ND	"	ND	11	"	"	"
	Winkles	2	140	"	"	"	"	"	0.8	17	"	"	"
Northern Ireland[2]	*Nephrops*	2	140	"	"	"	"	"	"	25	"	"	"
Republic of Ireland[2]	*Nephrops*	4	170	"	"	"	"	"	2.2	39	"	"	"
	Prawns	1	180	"	"	"	"	"	ND	34	"	"	"

Table 6 Transuranic radioactivity in fish and shellfish from the Irish Sea vicinity and further afield, 1980

Sampling area/landing point	Sample	No. of 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	4	0.023	0.082	0.078	0.0013	0.00029
	Crabs	2	2.3	8.3	14	0.44	0.098
	Winkles	2	22	88	101	ND	0.39
Sellafield offshore area[1,3]	Plaice	4	0.020	0.083	0.084	0.00026	0.00043
	Rays	2	0.0095	0.040	0.036	ND	ND
St Bees[1]	Winkles	1	23	79	74	"	0.65
	Mussels	1	39	150	78	2.1	0.63
	Limpets	1	19	66	59	1.3	0.68
Ravenglass[2]	Plaice	1	0.030	0.12	0.11	0.0014	0.00057
	Cod	1	0.012	0.043	0.042	0.00062	0.00023
	Salmon	1	0.0072	0.028	0.024	ND	0.00017
Whitehaven[2]	Plaice	4	0.0086	0.034	0.033	ND	ND
	Cod	1	0.0045	0.019	0.016	"	"
	Nephrops	3	0.12	0.50	1.3	0.0070	0.0052
	Queens	1	1.4	6.3	5.9	0.013	0.019
Morecambe Bay[1]	Shrimps	1	0.14	0.57	0.60	ND	ND
	Cockles	1	1.4	6.5	8.0	"	0.029
Isle of Man[2]	Plaice	1	0.00060	0.0026	0.0036	"	ND
	Cod	1	0.00036	0.0015	0.0017	"	"
	Herring	1	0.00054	0.0027	0.0041	"	"
	Scallops	1	0.040	0.22	0.078	"	0.00035
Solway[1]	Salmon	1	0.00059	0.0033	0.0027	ND	ND
Kirkcudbright[2]	Scallops	4	0.13	0.55	0.24	0.00071	0.00079
	Queens	4	0.047	0.20	0.15	ND	0.00055
	Winkles	1	1.7	7.4	9.5	0.038	0.052
Conwy[2]	Mussels	1	0.062	0.29	0.38	ND	0.0021
Northern Ireland[2]	*Nephrops*	1	0.0066	0.029	0.063	"	ND
Republic of Ireland[2]	*Nephrops*	1	0.0079	0.038	0.020	"	0.00007
Minch[1]	Cod	1	0.00038	0.0015	0.0010	"	ND
Northern North Sea[1]	Cod	1	0.00068	0.0029	0.0019	"	"
Iceland area[1]	Cod	1	0.00033	0.0017	0.0014	"	"

ND = not detected.

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

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 fish from areas of the western Irish Sea, Scottish waters and the North Sea were generally less than in 1979. This is likely to be the effect of reduced radiocaesium discharges in 1979 as compared with 1978 (Hunt 1981). However, the radiocaesium concentrations in 1980 in fish from areas of the eastern Irish Sea, relatively close to Sellafield, were similar to concentrations in 1979. This is probably a reflection of the lower radiocaesium discharges for 1979 combined with the small increase for 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. 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.

Radiocaesium concentrations in Irish Sea shellfish in 1980 were generally similar to those in 1979. The concentrations of other beta/gamma emitting radionuclides in shellfish from the Irish Sea were also generally similar to those in 1979.

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, particularly, 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 1980 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 were in 1980 generally similar to those in 1979. These concentrations reflect discharges in earlier years and the effect of reduced plutonium discharges in 1980 is not yet apparent.

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 have been studied, and kept under review, by FRL. The other main variable is that of consumption rates. Surveys by FRL 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 kept under review by FRL, 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 re-assessed by FRL, and these are applicable for 1980. Techniques used in the collection of data have been improved and 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 and Shepherd, 1980) 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 to estimate doses it is not sufficient to determine only the total consumption rates of fish and shellfish together. FRL 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 these consumption rates were estimated to be 100 g d^{-1} fish, 18 g d^{-1} crustaceans and 18 g d^{-1} molluscs. These consumption rates, particularly for fish and molluscs, are different from those reported previously (Hunt, 1981). The recent survey revealed a reduction in consumption of local supplies of fish by some of the members of the previously-identified critical group. The diet of some of these people also included an increased proportion of fish from areas further afield than the Cumbrian coastal vicinity. For molluscs, an increase in the critical group consumption rate is attributed to the general effects of the economic recession, such that persons 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, the sub-groups are not independent; hence the maximising assumption is made that the consumption rate appropriate to the overall critical group is represented by these component consumption rates combined additively. 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 and 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 the Shoreline Area, whilst the exposure from consumption of molluscs is based upon an equal mix of mussels and winkles from the Shoreline Area.

Table 7 summarises doses in 1980. For each exposed population, the dose equivalent to each tissue from

Table 7 Individual radiation exposures due to consumption of Irish Sea fish and shellfish, 1980

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 18 g d^{-1} molluscs	^{90}Sr	0.4	0.4
		^{106}Ru	3.0	3.0
		^{134}Cs	0.8	0.8
		^{137}Cs	8.4	8.4
		^{238}Pu	0.5	2.3
		$^{239}Pu + ^{240}Pu$	1.9	9.5
		^{241}Pu	1.4	6.9
		^{241}Am	7.7	7.7
		Total	24	39
Consumers associated with commercial fisheries (Whitehaven, Fleetwood, Morecambe Bay)	360 g d^{-1} fish 70 g d^{-1} crustaceans 50 g d^{-1} molluscs	^{90}Sr	0.4	0.4
		^{106}Ru	0.1	0.1
		^{134}Cs	1.0	1.0
		^{137}Cs	11.0	11.0
		^{238}Pu	0.1	0.3
		$^{239}Pu + ^{240}Pu$	0.3	1.6
		^{241}Pu	0.2	1.2
		^{241}Am	2.0	2.0
		Total	15	18
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	1.0	1.0
		Total	1.1	1.1

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 are estimated from the discharges of these nuclides in 1980. 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 a higher gut uptake factor for plutonium, following NRPB's review (section 3.4), is shown in the last column of Table 7.

The effective dose to the critical group of local consumers in 1980, on the basis of dosimetric factors currently recommended by the ICRP, was at most 24% of the ICRP-recommended dose limit of 5 mSv year^{-1} for members of the public. For the purpose of comparison with results for 1979, data for 1980 have also been assessed on the basis of consumption rates used for 1979 (Hunt, 1981). On this basis, the effective dose to the critical group in 1980 would have been 20% of the ICRP-recommended dose limit for members of the public. This value would have represented a small reduction from 21% of the limit reported for 1979, mainly due to a slightly lower contribution from radiocaesium in fish. The increase to 24% of the limit for 1980 was therefore caused by the changes in consumption rates rather than by significant changes in radioactivity concentrations. The changes in consumption rates, a decrease for fish but an increase for molluscs, have the effect of increasing the contribution to the effective dose from the less conservative nuclides, particularly the transuranics. Thus the combined effect of the transuranics is now more important than the contribution from radiocaesium.

This effect becomes more pronounced if the dose is calculated on the basis of a higher gut uptake factor for plutonium (section 3.4). On this basis, the data would indicate a maximum effective dose to the critical group of local consumers of 39% of the ICRP-recommended limit for members of the public. For control purposes it is to be noted that, on this basis, 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). Consumption rates for molluscs have only recently attained the levels presently reported. Thus considerations of lifetime exposure apply more particularly to those members of the critical group who may have received doses from fish consumption for some years. Their effective dose equivalent has been around 1 mSv year^{-1} for only the last few years, not long enough for lifetime exposures to have exceeded, on average, 1 mSv year^{-1}. This consideration also applies at present when taking account of the mollusc consumers, even on the basis of a higher gut uptake factor. Nevertheless, the situation 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 combining these component consumption rates additively. 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. On the basis of dosimetric factors currently recommended by ICRP, these consumers in 1980 received 15% of the appropriate ICRP-recommended dose limit. This result is the same as that reported for 1979 (Hunt, 1981), and consistent with statements above on the generally similar radioactivity concentrations in fish and shellfish from the eastern Irish Sea during 1980 as compared with 1979. The result is increased by 3% as a result of enhancing the dose from plutonium nuclides by a factor of 5. This relatively small increase, as compared with that for the Cumbrian coastal consumers, reflects the lesser radiological importance of plutonium, as compared with the more conservative radiocaesium, at distance from Sellafield.

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 1980 was 1.1% of the ICRP-recommended dose limit for members of the public. This result is the same as that reported for 1979 (Hunt, 1981), due to similar radiocaesium concentrations in fish from the eastern Irish Sea in both years. The contribution to this result from plutonium is negligible because of its low concentration in fish.

Collective doses from fish and shellfish have been estimated for 1980 for the UK and other European countries. In general, the method used is 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 include the Irish Sea, Scottish waters, the North Sea, Baltic Sea, Norwegian Sea, Spitzbergen/ Bear Island area and Barents Sea. Corrections are made for the fraction of fish or shellfish consumed. The contribution of weapons-test fallout to the radioactivity concentrations is 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 1980. The results are presented in Table 8.

Table 8 Collective doses from fish and shellfish, 1980

Population	Size of population	Collective effective dose equivalent, man-Sv
UK	5.6×10^7	100
Other European countries	6.2×10^8	140

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 for the UK in 1980 represents a decrease in collective dose as compared with 130 man-Sv in 1979 (Hunt, 1981). This was mainly caused by the generally lower radiocaesium concentrations, noted above, in fish from the western Irish Sea and further afield. The collective dose to inhabitants of other countries in 1980 was also less than in 1979, when 170 man-Sv was reported. This decrease was due to the generally lower radiocaesium concentrations, as before, combined with reduced fish landings from the North Sea. Decreases in collective doses for both the UK and other countries are mainly the result, foreseen in the previous report (Hunt, 1981), of reduced radiocaesium discharges in 1979 as compared with 1978. These reductions were brought about by the optimised use, required by the authorising Departments, of zeolite skips in the magnox fuel storage ponds.

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 1980 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 1979 and 1980 results for both critical group and collective dose rates that an important factor determining exposures is the distribution of radioactivity in the marine environment. A continuing programme of research is maintained by FRL on marine behaviour and distributions (including budget assessments) of significant radionuclides. Data on the distribution of caesium-137 in sea water are regularly collected by research vessel cruises; the distribution observed in the Irish Sea in April 1980 is shown in Figure 2.

Comparison with the data for April 1979 (Hunt 1981) shows a generally similar distribution of caesium-137 in areas west of the Isle of Man. In the eastern Irish Sea, however, contours of given concentration were in April 1980 generally closer to Sellafield than in April 1979, indicating a reduced caesium-137 inventory in this part of the Irish Sea. This reflects the reduced radiocaesium discharges in 1979 as compared with 1978; the slightly increased discharges of 1980 were not then apparent. The distribution of caesium-137 observed in sea water in the North Sea during August and September 1980 is shown in Figure 3. Comparison with the data for May and June 1978 (Hunt, 1980) shows a generally similar distribution, and this is consistent with the similar caesium-137 concentrations observed in fish from the North Sea in 1978 and 1980 as compared with the generally higher concentrations of 1979 (Hunt, 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

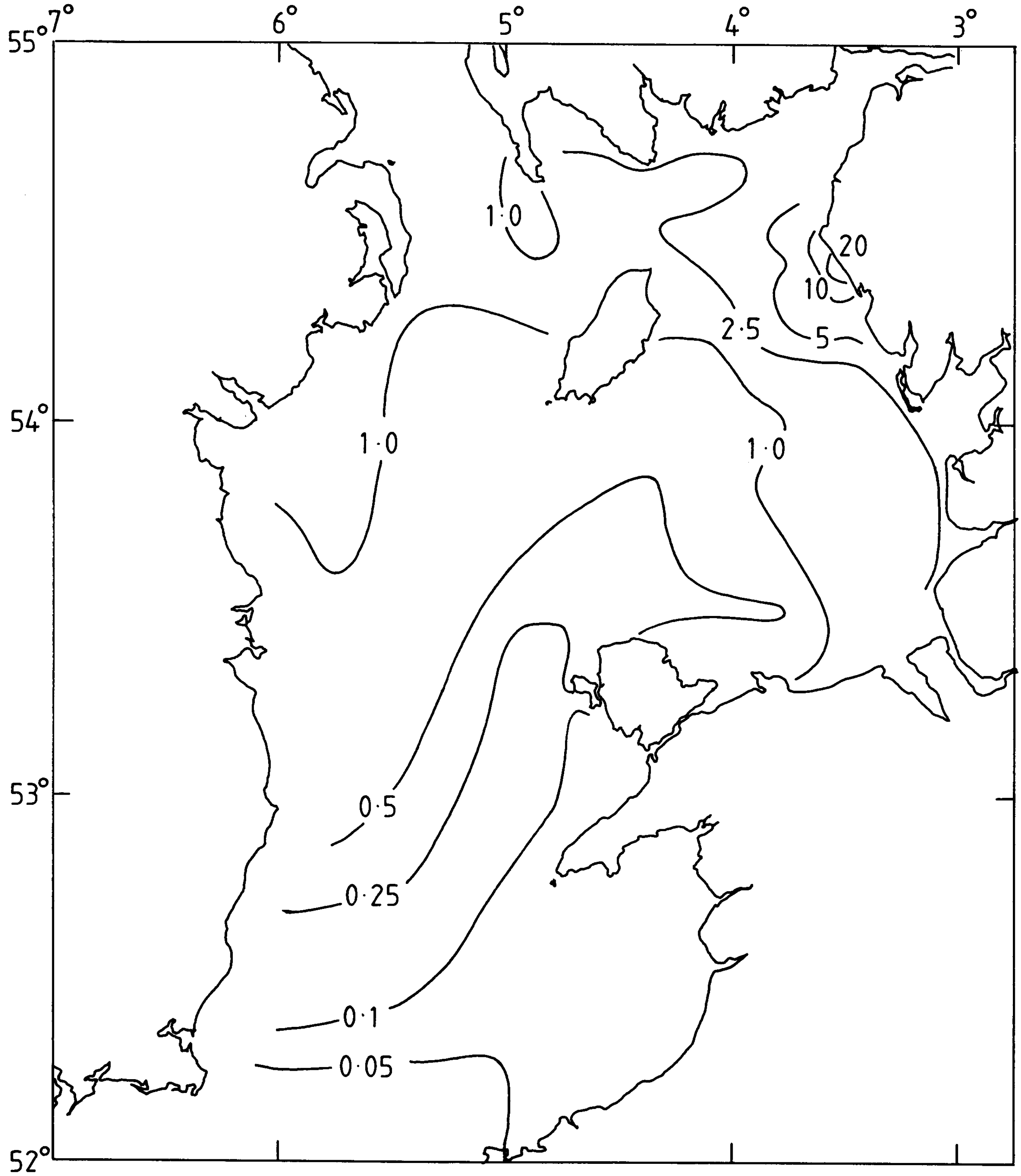

Figure 2. Concentration (Bq kg^{-1}) of caesium-137 in filtered water from the Irish Sea, April 1980.

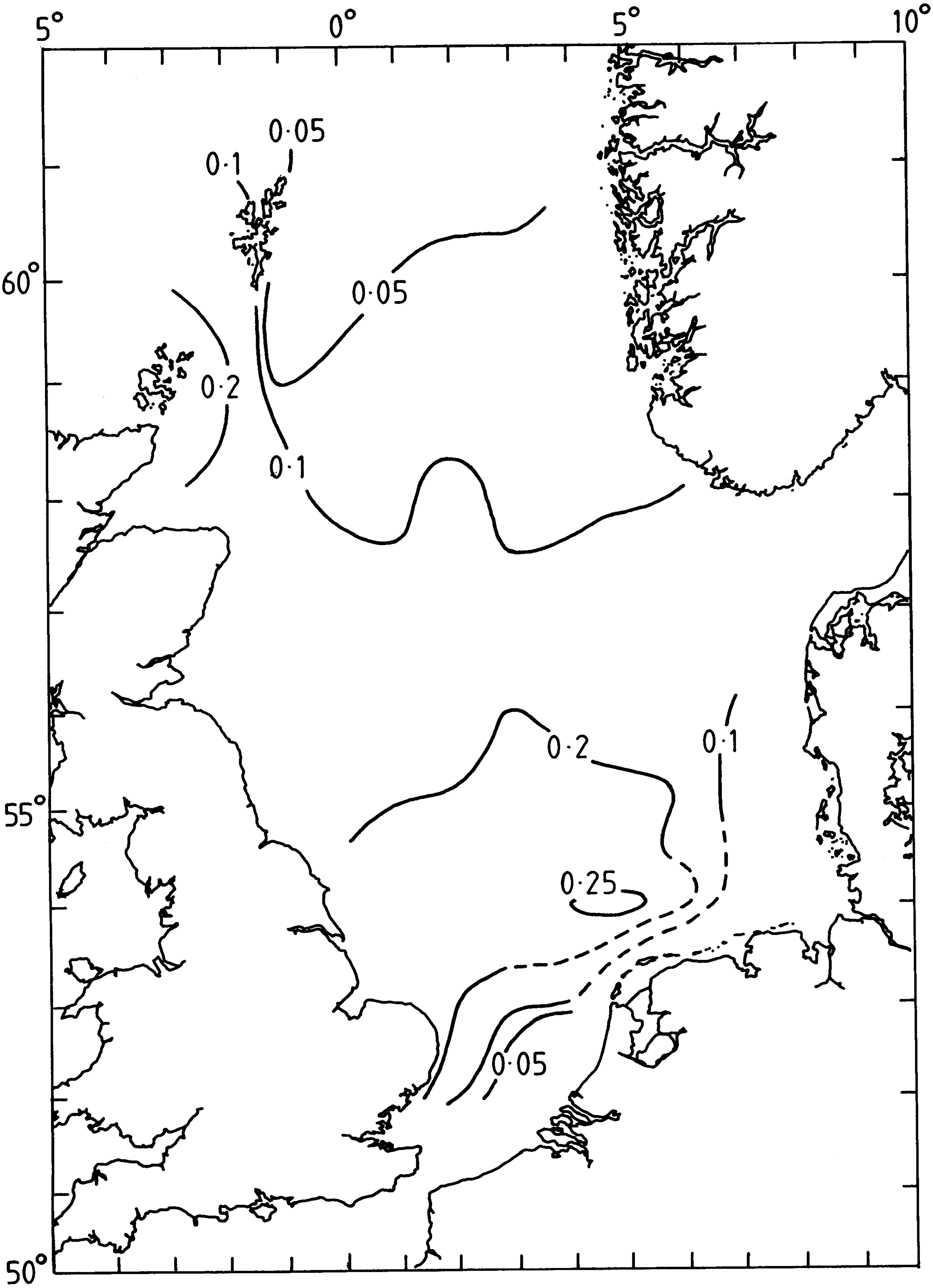

Figure 3. Concentration (Bq kg^{-1}) of caesium-137 in filtered water from the North Sea, August-September, 1980.

Table 9 Gamma radiation dose rates over intertidal areas of the Cumbrian coast and further afield, 1980

Location	Type of sediment	No. of observations†	Mean gamma dose rate in air at 1 m, $\mu Gy\ h^{-1}$
Maryport harbour	Silt	5	0.28
Workington harbour	"	5	0.32
Whitehaven harbour	"	24	0.68
St Bees	Sand	2	0.23
Braystones south	"	3	0.25
Sellafield	"	12	0.27
Seascale	"	4	0.23
Ravenglass Salmon Garth	Silt/mussel bed	12	0.45
Ravenglass small boats area	Sand	12	0.25
Newbiggin	Silt	12	0.95
Haverigg	"	4	0.54
Millom	Sand	4	0.15
Walney Island	Silt	20	0.28
Flookburgh	Sand	3	0.14
Fleetwood	"	4	0.11
Blackpool	"	4	0.11
Southport	"	4	0.10
New Brighton	"	4	0.10
Mersey (Rock Ferry)	Silt	4	0.14
Llandudno	Sand	4	0.10
Prestatyn	"	4	0.09
Kipford	Silt	4	0.32

Table 10 Radioactivity in sediment from the Cumbrian coast and further afield, 1980

Sampling point and sediment type	No. of 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	14 000	25	700	5 000	ND	350	5 700	990
Whitehaven (")	4	18 000	16	510	3 400	"	440	7 100	850
Newbiggin (")	12	37 000	68	3 000	11 000	330	490	7 700	3 500
Walney Island (")	4	7 100	17	340	2 200	ND	150	2 200	560
Heysham (")	4	3 400	5.6	34	790	ND	120	2 000	140
Sunderland Pt (")	4	4 400	10	ND	720	"	180	3 100	130
Fleetwood (sand)	4	350	ND	"	ND	"	10	150	ND
Blackpool (")	4	410	"	"	"	"	12	180	"
New Brighton (")	4	300	"	"	ND	"	2.3	90	"
Rock Ferry (silt)	4	2 700	2.2	"	220	"	80	1 800	50
Garlieston (")	4	1 900	ND	18	260	"	48	790	39
Kipford (")	5	6 100	14	150	1 800	"	170	2 800	260

Sampling point and sediment type	No. of 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	59	110	340	1 400	1 300	5.6	6.7
Whitehaven (")	4	70	130	330	1 500	1 200	ND	4.8
Newbiggin (")	12	280	350	960	4 200	2 800	48	17
Walney Island (")	4	53	72	NA	NA	800	NA	NA
Heysham (")	4	12	26	57	240	239	1.5	1.4
Sunderland Pt (")	4	17	7.6	66	290	284	ND	1.2
Blackpool (")	4	ND	ND	1.1	5.8	6.0	"	ND
Fleetwood (sand)	4	"	"	NA	NA	6.1	NA	NA
New Brighton (")	4	"	"	"	"	ND	"	"
Rock Ferry (silt)	4	"	7.4	30	134	150	ND	0.49
Garlieston (")	4	"	ND	25	120	140	"	0.26
Kipford (")	5	16	45	110	490	500	"	1.0

NA = not analysed.
ND = not detected.
†See text for definition.

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.

FRL regularly monitors 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 particularly in West Cumbria are generally lower than in 1979 (Hunt, 1981); this is mainly due to declining concentrations in sediments of short-lived fission products following reduced discharges in recent years.

FRL also regularly monitors radioactivity concentrations in sediments. This is both because of relevance to dose rates and in order to keep under review distributions of adsorbed radioactivity. Concentrations of beta/gamma radioactivity and transuranics, in most cases at the same locations as the dose rate measurements, are given in Table 10. Variations similar in cause to those of the dose rates are observed, and comparison with results for 1979 (Hunt, 1981) confirms the above comment on declining dose rates.

To identify those members of the public subject to the highest external exposures, occupancies of different locations need to be considered. FRL keeps 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 1980. Prior to this, the critical group for external exposure was represented by the salmon garth fisherman who worked in muddy areas of the Ravenglass Estuary. During 1980 the garth fell into disuse, being in a poor state of repair. It is now considered that, combining dose rates and occupancy times, the critical group for external exposure is represented by a fisherman who lives on board his boat in Whitehaven harbour. Taking account of the time the boat is shielded from the mud by tidal effects and the shielding afforded by the boat itself, his exposure is equivalent to that from spending 1050 h $year^{-1}$ over unshielded mud. From Table 9, making an allowance for natural background, his external exposure in 1980 was 11% 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). The fisherman also consumes 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 6% of the ICRP-recommended dose limit for members of the public, or 7% of this limit using the higher value for plutonium gut uptake derived from the recent NRPB studies (section 3.4). Total exposure of the externally exposed critical group is thus estimated to be 17-18% 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.

4.1.3 *Porphyra*/laverbread pathway

No harvesting of *Porphyra* in the Sellafield vicinity for ultimate consumption was reported in 1980; this pathway has therefore remained essentially dormant. However, in view of its potential importance and the value of *Porphyra* as an indicator, monitoring by FRL has continued. Samples of *Porphyra* are regularly collected from selected locations along the Cumbrian coast. Results of analyses for 1980 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 1980 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.

Table 11 Radioactivity in *Porphyra* from the Cumbrian coast, 1980

Sampling point	No. of observa- tions†	Mean radioactivity concentration (wet), Bq kg^{-1}							
		Total beta	$^{95}Zr + ^{95}Nb$	^{103}Ru	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
Braystones South	12	6100	410	38	4800	1.3	21	290	120
Seascale	12*	5000	210	27	4100	ND	22	280	89

Sampling point	No. of observa- tions†	Mean radioactivity concentration (wet), Bq kg^{-1}					
		^{155}Eu	^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm + ^{244}Cm$
Braystones South	12	2.3	31	113	74	0.97	0.40
Seascale	12*	ND	NA	NA	42	NA	NA

NA = not analysed.
ND = not detected.
†See text 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, 1980

Manufacturer	No. of observa- tions†	^{106}Ru concentration (wet) Bq kg^{-1}
A	12	< 6
B	3	< 14
C	12	< 5

†See text for definition.

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, FRL undertakes 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 1980 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).

Samples of seaweed are also collected by authorities in the Republic of Ireland and analysed by FRL on their behalf. These results are presented in Table 14. Again, the programme serves an indicator purpose only; the concentrations reported are of no radiological significance.

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 as a result of these discharges is very low. The critical pathway is by way of adsorption of the radioactivity on the muddy areas of river banks near the outfall; this gives rise to slightly increased dose rates in these areas, which are visited by members of the public. Dredgermen constitute the critical group. FRL regularly monitors dose rates and samples mud near the outfall. The mud is analysed for total beta radioactivity, beta/gamma emitting nuclides and transuranics. Results for 1980 are presented in Table 15. The only detectable radionuclide due to Springfields discharges is protactinium-234m; other radionuclides present are mainly

Table 13 Radioactivity in seaweeds from UK shorelines of the Irish Sea, 1980

Type of seaweed and sampling point	No. of observations†	Mean radioactivity concentration (wet), Bq kg^{-1}									
		Total beta	^{60}Co	^{95}Zr + ^{95}Nb	^{106}Ru	^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu	^{241}Am
Porphyra											
Larbrax	4	240	ND	ND	15	ND	9.7	ND	ND	ND	ND
Port William	4	250	"	"	32	1.5	17	"	"	"	0.5
Garlieston	4	260	"	"	50	1.9	30	"	"	"	1.1
Fucus vesiculosus											
Sellafield	12	8 100	15	380	530	120	1 600	69	0.7	1.4	35
Heysham	4	1 300	ND	2.9	23	25	360	ND	ND	ND	9.4
Port William	4	630	"	ND	3.7	5.8	81	"	"	"	1.2
Garlieston	4	770	"	ND	14	10	160	"	"	"	1.4
Auchencairn	4	810	0.3	1.9	12	11	170	"	"	"	2.5
Portrush	3	300	ND	ND	ND	1.3	13	"	"	"	ND
Millisle	1	520	4	"	"	3.7	53	"	"	"	"
Ascophyllum nodosum											
Millisle	2	450	"	"	"	1.9	38	"	"	"	"

Table 14 Radioactivity in seaweeds from the coast of the Republic of Ireland, 1980

Type of seaweed and sampling point	No. of observations†	Mean radioactivity concentration (dry), Bq kg^{-1}		
		Total beta	^{134}Cs	^{137}Cs
Porphyra				
Rosslare	1	470	ND	ND
Fucus vesiculosus				
Carlingford	1	2700	"	220
Skerries	1	2600	18	160
Dunmore	1	560	ND	ND
Rosslare	1	750	"	"
Laminaria				
Carlingford	1	2900	"	210
Skerries	1	3100	"	140
Rosslare	1	780	"	ND

Table 15(a) Radioactivity in sediment near the Springfields pipeline, 1980

Location	No. of observations†	Mean radioactivity concentration (dry), Bq kg^{-1}						
		Total beta	^{60}Co	^{106}Ru	^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu
Pipeline outlet	4	7 100	5.3	690	190	3 100	76	6.0	15

Location	No. of observations†	Mean radioactivity concentration (dry), Bq kg^{-1}					
		^{234m}Pa	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Pipeline outlet	4	39 000	69	330	320	0.64	1.2

ND = not detected.
†See text for definition.

Table 15(b) Gamma dose rates in air at 1 m over intertidal areas near the Springfields pipeline, 1980

Location	No. of observations†	μGy h^{-1}
Pipeline outlet	4	0.33
Upstream		
90 metres	4	0.30
460 metres	4	0.31
Downstream		
90 metres	4	0.29

†See text for definition.

from Sellafield. Exposure of critical individuals in 1980, including the Sellafield component, amounted to less than 1% of the ICRP-recommended dose limit; the contribution due to Springfields discharges would have been but a small fraction of this.

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; an authorisation was issued in September 1977 for their disposal to Liverpool Bay from the North Wirral outfall at Meols. Discharges commenced in August 1978. 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, FRL 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 1980 are presented in Table 16. The concentrations of artificial radioactivity are mainly due to Sellafield discharges and are consistent with values to be expected at this distance from Sellafield. Technetium-99 concentrations were less than in 1979 (Hunt, 1981) reflecting a reduction in discharges from Sellafield since 1978 when a greater volume of decay-stored liquors was released (Hunt, 1980). Exposure of critical shellfish consumers in the vicinity of the Wirral in 1980 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, which were within authorised limits, decreased in 1980 as compared with 1979, when cleaning operations were carried out in the fuel element storage ponds. 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 more significant, owing to occupancy rates. The second pathway is internal irradiation following consumption of locally-caught fish and shellfish, mainly shrimps. Monitoring by FRL, on behalf of departments

Table 16 Radioactivity in environmental materials in the vicinity of the Wirral, 1980

Material	Sampling point	No. of observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
			Total beta	^{99}Tc	^{106}Ru	^{134}Cs	^{137}Cs	^{241}Am
Shrimps	Wirral	2	270	5.3	ND	7.8	140	ND
Cockles	Hoylake	2	83	2.0	13	2.5	44	5.3
Fucus spiralis	Hoylake	4	490	170	ND	7.8	130	0.42
" "	Little Orme	4	420	210	"	3.5	47	ND
Sand	Hoylake	4	320	1.2	14	4.9	84	ND

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

Table 17(a) Radioactivity in environmental materials in the vicinity of Chapelcross, 1980

Material	Sampling point	No. of observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
			Total beta	$^{95}Zr + ^{95}Nb$	^{106}Ru	^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu
Flounder	Seafield	4	350	ND	ND	16	300	ND	ND
Salmon	"	1	120	"	"	ND	2.6	"	"
Shrimps	"	3	210	"	2.9	7.0	130	"	"
Fucus vesiculosus	Waterfoot	4	670	"	2.1	9.5	170	"	"
" "	Seafield	4	740	"	1.2	12	200	"	"
Sediment	"	4	3300	29	390	89	1500	84	3.1

Material	Sampling point	No. of 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	NA	NA	NA
Salmon	"	1	"	0.00059	0.0033	0.0027	ND	ND
Shrimps	"	3	"	NA	NA	NA	NA	NA
Fucus vesiculosus	Waterfoot	4	"	"	"	0.8	"	"
" "	Seafield	4	"	"	"	2.6	"	"
Sediment	"	4	2.8	31	145	135	1.3	0.53

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

Table 17(b) Gamma dose rates in air at 1 m over intertidal areas in the vicinity of Chapelcross, 1980

Location	No. of observations†	μGy h^{-1}
Seafield	8	0.17
Browhouses	8	0.14
Waterfoot	8	0.13
Torduff Point	4	0.10
Battle Hill	3	0.11

†See text for definition.

of the Scottish Office, reflects these pathways. Samples of *Fucus vesiculosus*, as a useful indicator, are also analysed. The results of monitoring in 1980 are presented in Table 17.

Concentrations of artificial radionuclides in the Chapelcross vicinity are mostly due to Sellafield discharges, and the general levels given in Table 17(a) are consistent with values to be expected at this distance from Sellafield. Concentrations in 1980 were generally similar to those in 1979, with negligible long-term effect following the pond cleaning operations. Exposure of the critical group in 1980, making the maximising assumption of additivity of the two pathways, amounted to less than 3% 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

FRL regularly monitors 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.

Table 18 Radioactivity in environmental materials from the vicinity of Winfrith, 1980

Material	Sampling point	No. of observa-tions†	Mean radioactivity concentration (wet), Bq kg^{-1}						
			Total beta	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn	^{137}Cs	^{238}Pu
Plaice	Weymouth Bay	1	95	ND	ND	ND	ND	0.8	NA
Crabs	Lulworth	2	100	"	"	16	70	ND	"
Oysters	Poole	3	56	"	"	2.9	150	"	"
Scallops	Lulworth	2	81	23	"	33	72	0.8	0.045
Limpets	Chapman's Pool	3	80	2.6	2.9	64	70	0.5	0.040
	Osmington Mills	3	73	ND	ND	20	26	ND	NA
Fucus serratus	Chapman's Pool	3	470	18	5.8	580	130	"	"
	Osmington Mills	3	390	15	2.1	360	70	"	"
	Weymouth	3	360	13	1.2	350	62	"	"
	Portland	3	320	11	ND	200	36	0.2	"
	Swanage	3	360	5.2	2.8	240	42	ND	"
	Hengistbury Head	3	260	3.0	2.6	86	15	0.2	"
	Bognor Regis	3	240	0.8	ND	15	0.6	ND	"
	St Catherine's Point	3	220	ND	"	37	ND	"	"
	Gurnard Bay	3	270	"	"	19	0.8	"	"

Material	Sampling point	No. of observa-tions†	Mean radioactivity concentration (wet), Bq kg^{-1}			
			$^{239}Pu + {}^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm + {}^{244}Cm$
Plaice	Weymouth Bay	1	NA	ND	NA	NA
Crabs	Lulworth	2	"	"	"	"
Oysters	Poole	3	"	"	"	"
Scallops	Lulworth	2	0.14	0.041	ND	0.0012
Limpets	Chapman's Pool	3	0.11	0.046	0.007	0.0009
	Osmington Mills	3	NA	ND	NA	NA
Fucus serratus	Chapman's Pool	3	"	"	"	"
	Osmington Mills	3	"	"	"	"
	Weymouth	3	"	"	"	"
	Portland	3	"	"	"	"
	Swanage	3	"	"	"	"
	Hengistbury Head	3	"	"	"	"
	Bognor Regis	3	"	"	"	"
	St Catherine's Point	3	"	"	"	"
	Gurnard Bay	3	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediments in Poole Harbour (2 observations): 0.055 μGy h^{-1}

ND = not detected.
NA = not analysed.
†See text for definition

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 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 the FRL monitoring programme. Monitoring of the indicator materials, limpets and *Fucus serratus*, provides additional information on the distribution of activation products. Data are presented in Table 18. The impact of Winfrith discharges was, as in previous years, mainly observed in the 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 1980 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 (HMS Vulcan) operated by the Ministry of Defence (Procurement Executive). Reprocessing of Prototype Fast Reactor (PFR) fuel took place for the first time in 1980. Monitoring by FRL near Dounreay is carried out on behalf of departments of the Scottish Office. There are two critical exposure pathways, both involving external radiation. The first pathway is due to radioactivity adsorbed mainly on fine 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. Regular measurements throughout the 1980 fishing season showed that their exposure 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 not carried out by FRL; the UKAEA have published the results of their surveys of these areas in their 1980 monitoring report (Flew, 1981). Public radiation exposure via this pathway was also low, at less than 1% of the ICRP-recommended dose limit.

FRL samples winkles from Sandside Bay to enable the sub-critical pathway of shellfish consumption to be kept under direct review. In addition, limpets and *Fucus vesiculosus*, as in previous years, were sampled as indicator materials. Results for 1980 are presented in Table 19. Radiocaesium concentrations are mostly due to discharges from Sellafield. Other radionuclides detected, including transuranics, mainly reflect Dounreay discharges. Slightly increased concentrations, as compared with 1979, of the short-lived fission products ruthenium-106 and cerium-144 were generally observed. These increases result from the slightly greater discharges of these nuclides in 1980 following the reprocessing operations mentioned above. However, the radiological significance of shellfish consumption was low;

Table 19 Radioactivity in environmental materials from the vicinity of Dounreay, 1980

Sampling point and material	No. of observations†	Mean radioactivity concentration (wet), Bq kg^{-1}								
		Total beta	^{54}Mn	^{60}Co	$^{95}Zr + ^{95}Nb$	^{106}Ru	^{124}Sb	^{125}Sb	^{134}Cs	^{137}Cs
Sandside Bay										
Winkles	4	190	ND	1.8	ND	15	ND	4.8	ND	6.0
Limpets	12	400	"	1.3	0.4	44	"	13	0.08	9.4
Fucus vesiculosus	12	580	1.1	4.5	0.9	9.7	0.3	1.4	1.5	21

Sampling point and material	No. of observations†	Mean radioactivity concentration (wet), Bq kg^{-1}						
		^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am	$^{243}Cm + ^{244}Cm$
Sandside Bay								
Winkles	4	43	ND	0.3	0.25	0.93	0.45	0.011
Limpets	12	91	0.7	1.5	0.56	2.2	1.1	0.010
Fucus vesiculosus	12	67	1.3	1.7	NA	NA	0.48	NA

ND = not detected.
NA = not analysed.
†See text for definition.

Table 20 Radioactivity in environmental materials and gamma dose rates near Berkeley and Oldbury nuclear power stations, 1980

Material	No. of observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}		
		Total beta	^{134}Cs	^{137}Cs
Flounders	4	110	ND	3.5
Eels	1	39	"	ND
Shrimps	4	76	0.29	2.9
Fucus vesiculosus	2	290	ND	7.0
Mud: area of outfalls	4	730	ND	62
area upstream	2	550	"	14

Mean gamma dose rate in air at 1 m over intertidal mud (5 observations†): 0.087 μGy h^{-1}

Table 21 Radioactivity in environmental materials and gamma dose rates near Bradwell nuclear power station, 1980

Material	No. of observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta	^{60}Co	^{65}Zn	^{106}Ru	^{134}Cs	^{137}Cs	^{238}Pu
Whiting	1	130	ND	ND	ND	ND	7.7	NA
Oysters	2	62	"	8.9	"	"	2.2	0.0021
Whelks	1	NA	"	ND	"	"	2.3	NA
Fucus vesiculosus	2	240	"	"	"	"	6.9	"
Mud	4	820	9.9	"	1.7	4.9	69	"

Material	No. of observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}			
		$^{239}Pu + ^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm + ^{244}Cm$
Whiting	1	NA	NA	NA	NA
Oysters	2	0.0099	0.030	0.0025	0.0015
Whelks	1	NA	NA	NA	NA
Fucus vesiculosus	2	"	"	"	"
Mud	4	"	"	"	"

Mean gamma dose rate in air at 1 m over intertidal mud (4 observations†): 0.082 μGy h^{-1}

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

for high-rate winkle consumers the radiation dose was less than 0.2% of the ICRP-recommended dose limit. This pathway therefore remained of sub-critical importance in 1980.

6. Nuclear power stations operated by the electricity boards

All but one of these power stations are in England and Wales and are, or will be, operated by the Central Electricity Generating Board. The Scottish power station at Hunterston is operated by the South of Scotland Electricity Board. Results are presented for two power stations not yet operational, namely Hartlepool and Heysham, where monitoring by FRL has 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 environmental monitoring by FRL. 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. FRL therefore analyses samples of fish and shellfish and monitors 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 1980 are presented in Table 20. The only artificial radioactivity detected 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. 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. Radiological exposure pathways from these discharges were reviewed in 1980. 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. Environmental monitoring by FRL 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 1980 are summarised in Table 21.

In fish, the only artificial radioactivity detected was due to radiocaesium, for which concentrations represent the combined effects of discharges from the station, of Sellafield discharges, and of fallout. Apportionment is difficult because of the low levels detected. The dose to members of the critical group of fish and shellfish consumers, however, was low, totalling less than 0.4% of the ICRP-recommended dose limit for members of the public. The concentration of zinc-65 in oysters remained low in 1980 such that the contribution of this nuclide remained of small importance. The concentrations in oysters of transuranic nuclides, from local discharges and from Sellafield, 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. The FRL monitoring programme therefore includes analyses of fish and gamma dose rate surveys of the generally sandy beach. Samples of sand are also collected and analysed. Local whelks have been analysed mainly for their value as an indicator material. The results for 1980 are given in Table 22.

Table 22 Radioactivity in environmental materials and gamma dose rates near Dungeness nuclear power station, 1980

Material	No. of observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}		
		Total beta	^{60}Co	^{137}Cs
Plaice	2	110	ND	1.5
Flounder	1	130	"	ND
Whelks	1	140	3.0	"
Sand	2	300	5.2	3.6

Mean gamma dose rate at 1 m over intertidal sand (10 observations†): 0.059 μGy h^{-1}

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

Concentrations of caesium-137 in fish, when detectable, were not significantly above the levels to be expected as a result of fallout. The radiation dose to members of the critical group of fish consumers was very low, at less than 0.1% of the ICRP-recommended dose limit. Gamma dose rates over sand were indistinguishable from natural background levels. Both whelks and sand samples, as in previous recent years, appeared to show 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; however, the concentrations here continued to be of negligible radiological significance.

6.4 Hartlepool, Cleveland

This station is not yet operational; its two Advanced Gas-cooled Reactors (AGRs) were under construction in 1980. However, monitoring by FRL had already begun in order to investigate background levels and to establish reliable sources of environmental materials. Potential critical pathways for radiation exposure of the public near this station likely to be associated with future 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. Results of the FRL monitoring programme carried out in 1980 are shown in Table 23. Concentrations of radocaesium 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.

Table 23 Radioactivity in environmental materials and gamma dose rates near Hartlepool nuclear power station, 1980

Material	No. of observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}		
		Total beta	^{134}Cs	^{137}Cs
Cod	4	150	0.56	25
Crabs	4	66	ND	3.4
Fucus vesiculosus	4	290	"	6.3
Sand	4	170	"	5.7
Mud	1	960	"	178

Mean gamma dose rate in air at 1 m over intertidal sand (8 observations†): 0.083 µGy h^{-1}

ND = not detected.
*Except for sediments where dry concentrations apply.
†See text for definition.

6.5 Heysham, Lancashire

This establishment, which will comprise two, essentially separate, nuclear power stations both powered by AGRs, was under construction in 1980. Monitoring by FRL 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 future 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. The FRL 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 1980 are given in Table 24. 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 1980 of members of the critical group of fish and shellfish consumers associated with commercial fisheries (which include the Morecambe Bay area) were 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 the "B" station, which has been operational since 1976, by AGRs. Liquid radioactive discharges are made via the same outfall and for the purposes of FRL 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. The FRL 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 1980, presented in Table 25, 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.

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. There are two critical radiation exposure pathways: fish and shellfish consumption leading to internal irradiation, and occupancy

Table 24 Radioactivity in environmental materials and gamma dose rates near Heysham nuclear power station, 1980

Material	No. of observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{60}Co	^{95}Zr + ^{95}Nb	^{106}Ru	^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu
Flounders	4	480	0.15	ND	ND	24	400	ND	ND
Shrimps	4	260	ND	"	"	9.0	150	"	"
Cockles	4	370	1.4	"	61	8.1	130	4.1	"
Fucus vesiculosus	4	1300	ND	"	23	25	360	ND	"
Sediment:									
Sunderland Point	4	4400	5.0	"	720	180	3100	88	8.6
Half Moon Bay	4	3400	2.8	17	790	120	2500	140	6.1

Material	No. of observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
		^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm + ^{244}Cm
Flounders	4	ND	NA	NA	ND	NA	NA
Shrimps	4	"	0.14	0.57	0.60	ND	ND
Cockles	4	"	1.4	6.5	8.0	"	0.03
Fucus vesiculosus	4	"	NA	NA	9.4	NA	NA
Sediment:							
Sunderland Point	4	3.8	66	290	280	ND	1.2
Half Moon Bay	4	13	57	240	240	1.5	1.4

Mean gamma dose rate in air at 1 m over intertidal sediment:
Heysham vicinity (23 observations†): 0.15 μGy h^{-1}
Sunderland Point (12 observations†): 0.14 μGy h^{-1}

Table 25 Radioactivity in environmental materials and gamma dose rates near Hinkley Point nuclear power station, 1980

Material	No. of observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta	^{60}Co	^{134}Cs	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am
Flounders	4	120	ND	ND	3.5	NA	NA	ND
Eels	1	170	"	"	4.2	"	"	"
Shrimps	4	100	"	0.60	3.5	0.0039	0.019	0.011
Fucus vesiculosus	2	370	7.1	ND	7.6	NA	NA	ND
Sediment	2	590	ND	"	36	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sediment (3 observations†): 0.098 μGy h^{-1}

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

Table 26 Radioactivity in environmental materials and gamma dose rates near Hunterston nuclear power station, 1980

Material	No. of observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{95}Zr + ^{95}Nb	^{106}Ru	^{110m}Ag
Mixed fish	4	250	ND	ND	ND	ND	ND	ND
Cockles	4	110	"	5.1	"	3.1	17	"
Winkles	5	260	"	9.7	2.6	ND	78	5.4
Limpets	4	270	"	20	4.7	19	63	ND
Fucus spiralis	4	690	2.8	19	3.0	33	42	"
Sand	4	380	ND	6.5	ND	ND	ND	"

Material	No. of observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		^{134}Cs	^{137}Cs	^{144}Ce	^{155}Eu	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am
Mixed fish	4	6.8	120	ND	ND	0.0007	0.0029	0.0023
Cockles	4	4.9	23	13	"	NA	NA	ND
Winkles	5	7.5	28	16	"	"	"	0.24
Limpets	4	11	45	45	"	"	"	ND
Fucus spiralis	4	26	100	53	0.52	"	"	"
Sand	4	11	76	12	ND	"	"	"

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

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

of intertidal areas leading to external exposure. FRL regularly monitors, on behalf of departments of the Scottish Office, samples of fish and shellfish and carries out gamma dose rate measurements on the foreshore. Samples of sand are analysed together with limpets and *Fucus spiralis* as indicators. The results of monitoring in 1980 are shown in Table 26.

The concentrations of artificial radioactivity in this area are predominantly due to Sellafield discharges, the general values being consistent with those to be expected at this distance from Sellafield. However, the resulting 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. No effects were detectable due to the increased 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

FRL monitoring near this station reflects the two critical radiation exposure pathways of fish and shellfish consumption leading to internal irradiation, and of occupancy of intertidal areas giving rise to external exposure. Gamma dose rates are measured over sandy intertidal areas, where dose rates may be expected to be higher than on the rest of the beach which is mainly shingle. Results for 1980 are shown in Table 27.

Table 27 Radioactivity in environmental materials and gamma dose rates near Sizewell nuclear power station, 1980

Material	No. of observations†	Mean radioactivity concentration (wet), Bq kg^{-1}	
		Total beta	^{137}Cs
Mixed fish	2	97	10
Crabs	2	77	2.4

Mean gamma dose rate in air at 1 m over intertidal sand (10 observations†): 0.054 μGy h^{-1}

†See text for definition.

The radiocaesium concentrations in fish represent the combined effect of discharges from the station and from Sellafield, as well as of fallout. Apportionment is difficult in view of the low levels detected. The total radiation

Table 28 Radioactivity in environmental materials near Trawsfynydd nuclear power station, 1980

Material	No. of observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{90}Sr	^{106}Ru	^{125}Sb	^{134}Cs
Rainbow trout	7	270	ND	0.1	ND	NA	1.0	ND	22
Brown trout	4	750	"	ND	"	"	ND	"	85
Perch	4	1400	"	"	"	"	"	"	150
Mud	4	1900	"	5.2	"	"	"	210	40
Peat	4	4200	"	24	"	"	"	640	7.5
Fontinalis									
Afon Prysor	4	220	0.23	0.4	"	"	"	ND	2.2
Gwylan Stream	4	1400	0.80	27	3.9	"	79	136	23
Water									
Hot Lagoon	4	NA	NA	NA	NA	0.29	NA	NA	0.024
Cold Lagoon	4	"	"	"	"	0.30	"	"	0.029

Material	No. of observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
		^{137}Cs	^{144}Ce	^{155}Eu	^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am
Rainbow trout	7	170	ND	ND	0.0004	0.0017	0.0060
Brown trout	4	800	"	"	0.0004	0.0019	0.0042
Perch	4	1400	"	"	0.0007	0.0025	0.0035
Mud	4	1000	"	5.2	NA	NA	1.4
Peat	4	1400	"	ND	"	"	ND
Fontinalis							
Afon Prysor	4	8.0	"	"	"	"	"
Gwylan Stream	4	280	34	4.12	"	"	1.3
Water							
Hot Lagoon	4	0.23	NA	NA	"	"	NA
Cold Lagoon	4	0.25	"	"	"	"	"

Table 29 Radioactivity in environmental materials and gamma dose rates near Wylfa nuclear power station, 1980

Material	No. of observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{60}Co	^{106}Ru	^{134}Cs	^{137}Cs	^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am	$^{243}Cm + ^{244}Cm$
Plaice	4	140	ND	ND	1.7	22	NA	NA	ND	NA
Turbot (Fish Farm)	2	79	"	"	0.8	17	"	"	"	"
Crabs	3	80	"	"	ND	11	"	"	"	"
Winkles	2	140	"	"	0.8	17	"	"	"	"
Mussels	2	91	"	"	1.4	17	0.062	0.29	0.38	0.0021
Fucus vesiculosus	6	460	"	"	1.6	33	NA	NA	ND	NA
Mud	3	1900	1.0	39	54	1000	11	56	64	ND

Mean gamma dose rate in air at 1 m over intertidal mud (13 observations†): 0.10 μGy h^{-1}

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

exposure to local fish consumers was low, at less than 0.4% of the ICRP-recommended dose limit. Gamma dose rates continued to be indistinguishable above the natural background.

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. The critical radiation exposure pathway here is due to consumption of fish caught in the lake, leading to internal irradiation; the important radionuclides are those of caesium and, to a lesser extent, strontium-90. Species of fish in the lake include the indigenous brown trout, perch and, more recently, rudd. The lake is also regularly stocked with rainbow trout reared in hatcheries containing lake water. Rainbow trout now account for the highest consumption rates but, because radiocaesium concentrations in rainbow trout are considerably lower than in indigenous fish as a result of the limited time spent in the lake, consumption of brown trout still accounts for a large proportion of the radiation exposure. Perch are also consumed, but at still lower rates; rudd are rarely eaten, if at all. FRL regularly analyses samples of rainbow trout, brown trout and perch. As part of FRL's 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 1980 are shown in Table 28.

Radiocaesium concentrations in fish in 1980 were slightly higher than in 1979. 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 1980 members of the critical group of fish consumers received less than 3% of the ICRP-recommended dose limit. This result reflects the present low consumption rate of brown trout compared with rainbow trout. Consumption rate data will continue to be kept under review, however, in case the rates for indigenous fish should return to their former levels.

6.10 Wylfa, Gwynedd

Liquid radioactive wastes from this station are discharged to the Irish Sea under authorisation of the Welsh Office. Monitoring is carried out by FRL in respect of the two critical pathways, of local fish and shellfish consumption leading to internal irradiation and of occupancy of intertidal areas resulting in external exposure. Locally-caught fish and shellfish are sampled. Gamma dose rate measurements over intertidal mud are carried out and, in support, samples of mud are analysed. The indicator seaweed *Fucus vesiculosus* is also sampled. The results of monitoring in 1980 are presented in Table 29.

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 total radiation exposure of members of the critical group in 1980 was less than 0.3% of the ICRP-recommended dose limit. The magnitude of discharges from the station indicate that the local contribution will have been a small fraction of this.

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. Monitoring of the effects of all these discharges is carried out by FRL, 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. FRL therefore regularly carries out measurements of gamma dose rates; these are supported by analyses of sediments. Indicator seaweeds are also analysed. Results of monitoring in 1980 are presented in Table 30. 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 Department of the Environment. Due to an increased demand for radiopharmaceuticals, the company has built

Table 30 Radioactivity in environmental materials and gamma dose rates near naval establishments, 1980

Establishment	Material	No. of 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	No. of observations†	μGy h^{-1}
Chatham	Sediment	6	780	2.5	9.3	0.65	40	16	0.074
Devonport	Winkles	2	89	ND	ND	ND	0.3	NP	NP
	Fucus vesiculosus	2	220	"	0.7	"	ND	"	"
	Sediment	6	910	0.9	4.3	"	12	12	0.089
Faslane	Sediment	4	890	ND	3.5	11	200	20	0.096
Rosyth	Sediment	2	600	2.3	3.9	24	71	7	0.088
Holy Loch	*Fucus spiralis*	4	260	ND	ND	1.7	25	NP	NP
	Sediment	1	470	"	49	11	140	32	0.095

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

Table 31 Radioactivity in environmental materials and gamma dose rates near the outfall of the sewer serving Amersham International plc, Cardiff, 1980

Material	No. of observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}					
		Total beta	^{60}Co	^{131}I	^{134}Cs	^{137}Cs	^{144}Ce
Flounders	3	98	ND	ND	ND	2.4	ND
Winkles	4	150	0.3	"	0.2	2.8	"
Fucus spiralis	5	180	ND	21	ND	0.9	"
Fucus vesiculosus	3	290	"	3.6	"	1.2	"
Sediment	8	970	"	ND	"	62	1.9

Mean gamma dose rate in air at 1 m over intertidal sediment (8 observations): 0.080 μGy h^{-1}

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

a new laboratory to manufacture these near Cardiff. An authorisation issued by the Welsh Office, to dispose of liquid radioactive wastes from this establishment to a sewer discharging into the Severn Estuary, came into force in October 1979. The FRL 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 1980 are presented in Table 31. Artificial radioactivity detected was due to radiocaesium and other nuclides. However, none of these nuclides was discharged by this establishment in 1980; the results were therefore due to the combined background effects noted above. Small amounts of iodine-131 detected in seaweed are likely to have been due to discharges from a local hospital. The exposure of the critical group of fish and shellfish consumers due to these effects in 1980 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.

Table 32 Radioactivity in marine environmental materials from the Channel Islands, 1980

Material	Sampling area	No. of observations†	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			Total beta	^{60}Co	^{106}Ru	^{137}Cs	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am	^{243}Cm + ^{244}Cm
Ray	Guernsey	1	110	ND	ND	3.1	0.00006	0.00024	0.00028	ND
Crabs	Guernsey	1	92	"	"	0.9	0.00034	0.0014	0.0022	"
	Jersey	1	73	"	"	ND	0.0019	0.0053	0.0050	0.0011
Mussels	Jersey	1	67	"	33	0.4	0.034	0.11	0.074	0.0097
Oysters	Jersey	1	69	"	13	1.9	0.014	0.044	0.022	0.0027
Limpets	Jersey	1	58	"	13	0.4	0.012	0.042	0.025	0.0032
	Guernsey	1	120	"	ND	1.3	0.0048	0.026	0.013	0.0019
	Alderney	1	85	"	11	0.7	0.012	0.019	0.025	0.0075
Porphyra	Jersey									
	Greve de Lecq	4	260	"	4.3	ND	NA	NA	ND	NA
	La Rozel	3	200	"	8.2	"	"	"	"	"
	Guernsey									
	Fort Doyle	4	200	"	4.7	"	"	"	"	"
	Fermain Bay	4	220	"	5.0	"	"	"	"	"
	Alderney									
	Telegraph Bay	2	240	"	17	"	"	"	"	"
	Quenard Point	1	240	"	41	"	"	"	"	"
Fucus serratus	Jersey									
	La Rozel	4	320	"	1.4	"	0.041	0.125	0.026	0.0026
	Guernsey									
	Fermain Bay	4	250	"	1.6	0.13	0.020	0.070	0.014	0.0018
	Alderney									
	Quenard Point	4	300	0.70	2.0	ND	0.028	0.074	0.025	0.0056
Sediment	Jersey									
	St Helier Harbour	1	650	ND	69	5.9	0.40	1.6	0.93	0.12
	Guernsey									
	Bordeaux Harbour	1	520	"	ND	3.0	0.052	0.39	0.12	ND
	Alderney									
	Crabbe Harbour	1	950	"	21	5.8	0.27	1.2	0.61	0.071

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

9. Channel Islands monitoring

FRL has 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 1980 are given in Table 32. Concentrations of caesium-137 in fish and shellfish were not significantly in excess of those to be expected from 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 may also be attributed to this plant. However, the concentrations of artificial radionuclides in each of these materials were of negligible radiological significance.

10. Summary and Conclusions

A summary of estimated public radiation exposures in 1980 resulting from liquid radioactive waste discharges from nuclear establishments monitored by FRL is presented in Table 33. 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. Consideration has been given to the implications of a higher gut uptake factor for plutonium (section 3.4). For the more significant exposures, results using this factor are presented in parentheses after the results calculated using the factor given in ICRP Publication 30 (1979a, b; 1980; 1981; 1982a, b). Where exposures are of less significance, no value is given in parentheses; if there is a contribution from plutonium, these results are calculated using the higher uptake factor. This procedure has been followed as these results are presented using a "less than" sign. In most of these cases, the contribution from plutonium is in any case very small and the results would not be changed significantly by the use of a higher uptake factor.

All exposures were well 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

Table 33 Summarised estimates of public radiation exposure from discharges of liquid radioactive waste in the UK, 1980

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* (39) 15* (18)
	External	Whitehaven fishermen	17* (18)
	Porphyra/laverbread consumption	Consumers in South Wales	0.1
Springfields	External	Dredgermen	1[a]
Capenhurst (Meols outfall)	Shellfish consumption	Local fishing community	4[a]
Chapelcross	External Fish and shellfish consumption	Local fishermen	3[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] 0.2[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	0.1
Hartlepool[c]	Fish and shellfish consumption External	Local fishing community Coal collectors	1[a]
Heysham[c]	Fish and shellfish consumption External	Local fishing community	15 (18)[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[b]
Sizewell	Fish and shellfish consumption External	Local fishing community	0.4[b]
Trawsfynydd	Fish consumption	Local fishing community	3
Wylfa	Fish and shellfish consumption External	Local fishing community	0.3[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	General public	0.1[b]
AMERSHAM INTERNATIONAL plc			
Cardiff	Fish and shellfish consumption External	Local fishing community	0.1[a]

*On the basis of the unmodified plutonium gut uptake factor as in ICRP Publication 30; the result using the enhanced gut uptake factor follows in parentheses (see text).
[a]Mainly due to discharges from Sellafield.
[b]Partly due to discharges from Sellafield.
[c]No radioactive discharges made in 1980. Potential critical pathways given; exposures are due to other sources of artificial radioactivity.

reprocessing operations; the next most important contribution was from radiocaesium which is discharged mainly from the fuel element storage ponds. The increases as compared with the results reported for 1979 (Hunt, 1981) are due to changes in habits survey data and to consideration of a higher plutonium gut uptake factor rather than to increases in radioactivity concentrations. Contributions to exposures near many other nuclear establishments were also caused by radioactivity from Sellafield. Since apportionment of exposure to radioactivity of local origin is often difficult, the exposure from all sources (including the small contribution due to fallout) is quoted in Table 33, with an appropriate footnote.

As in previous years, collective doses from UK liquid radioactive discharges have also been considered. The most significant discharges giving rise to collective dose, compared with which all other discharges may be disregarded, were those from Sellafield, radiocaesium being the most significant component. Details are given in section 4.1.1. The collective effective dose equivalent to the UK population in 1980 was 100 man-Sv, a reduction from 130 man-Sv reported for 1979. For the population of other European countries the collective effective dose equivalent was 140 man-Sv in 1980, representing a decrease from 170 man-Sv for 1979. These reductions, predicted in the previous report (Hunt, 1981), are due to generally lower radiocaesium concentrations in fish from the western Irish Sea and further afield following reductions in radiocaesium discharges from Sellafield in 1979 as compared with 1978. These reductions were brought about by the optimised use, as required by the authorising Departments, of zeolite skips in the magnox fuel storage ponds.

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