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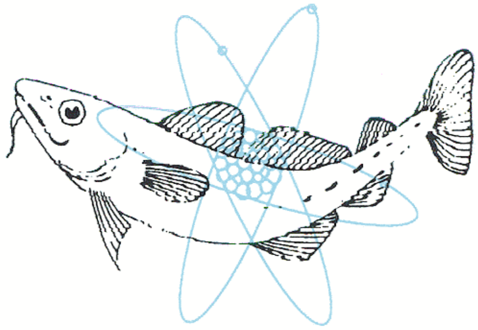

Radioactivity in Surface and Coastal Waters of the British Isles, 1990

MAFF

Directorate of Fisheries Research

Lowestoft, 1992

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD
DIRECTORATE OF FISHERIES RESEARCH

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Radioactivity in Surface and Coastal Waters of the British Isles, 1990

LOWESTOFT

1992

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1. INTRODUCTION

This report presents the results of the environmental monitoring programme carried out during 1990 by staff of the Ministry of Agriculture, Fisheries and Food's (MAFF's) Directorate of Fisheries Research (DFR), Lowestoft. This programme, together with the Terrestrial Radioactivity Monitoring Programme (TRAMP) (MAFF, 1990) and the programme operated by Her Majesty's Inspectorate of Pollution (HMIP, 1991) supports statutory functions under the Radioactive Substances Act, 1960 (Great Britain - Parliament, 1960). The DFR programme is set up to verify the satisfactory control of liquid radioactive waste discharges to the aquatic environment, and to ensure that the resulting public radiation exposure is within nationally-accepted limits. The monitoring is independent of similar programmes carried out by nuclear site operators as a condition of their authorisations to discharge radioactive wastes. This report includes results of monitoring carried out on behalf of departments of the Scottish Office, the Welsh Office, the Department of the Environment for Northern Ireland, and the Channel Islands States. Where appropriate, the monitoring data are supplemented by results from our extensive programme of research into the behaviour of radioactivity in the aquatic environment. The special programme of monitoring of the freshwater environment, in connection with the accident at Chernobyl, USSR on 26 April 1986, was continued during 1990, and the results are presented in this report.

To set the monitoring results from our regular programme in context, liquid radioactive discharges from UK nuclear establishments to the aquatic environment in 1990 are first summarised. Before the results are presented, an explanatory section gives details of methods of analysis and presentation and a sub-section explains how results are interpreted in terms of public radiation exposures.

2. DISCHARGES OF RADIOACTIVE WASTE

Data on radioactive waste discharges are published annually by the Environment Departments (Department of the Environment, 1990, 1991; Scottish Development Department, 1990(a)(b)), the latest available data being for the year 1989. Details of the 1990 discharges are not yet available, but a summary is included here. This enables the results of environmental monitoring presented in this report to be considered in the context of the relevant discharges.

2.1 Liquid radioactive waste

Table 1 lists the principal discharges of liquid radioactive waste from UK nuclear establishments during 1990. The locations of these establishments are shown in Figure 1. Table 1 also lists the discharge limits which are authorised or, in the case of Crown operators, administratively agreed. In some cases, the authorisations specify limits in greater detail than can be summarised in a single table: in particular, where periods shorter than one year are specified, the annual equivalent has been used. The authorised limits are usually very much lower than the levels of activities which could be released without exceeding the dose limits which are recommended by the International Commission on Radiological Protection (ICRP), and embodied in national policy (Great Britain - Parliament, 1986). The percentages of the authorised (or agreed) limits taken up in 1990 are also stated in Table 1.

For completeness, it should be noted that radiological safety for US Navy operations in the Holy Loch is the responsibility of the US Navy in association with the Ministry of Defence who publish information annually (Fuller and Casey, in press).

2.2 Solid radioactive waste

In addition to receiving most of the above liquid discharges, the marine environment has also received packaged solid waste of low specific activity, mainly disposed of in an area of the deep Atlantic Ocean. The most recent such disposal was in 1982; none was carried out in 1990, and it was announced by the Secretary of State for Energy (Great Britain - Parliament, 1988) that sea disposal of drummed radioactive wastes would not be resumed. Instead, such wastes will be prepared for eventual disposal in the National Radioactive Waste Centre to be developed by UK Nirex Ltd for both low- and intermediate-level radioactive wastes. The UK Government has not ruled out sea disposal for large items such as boilers from decommissioned power stations, but will keep under review whether this disposal option needs to be maintained.

Routine environmental monitoring does not provide an effective means of assessing radiation exposure from deep-sea disposal, as radionuclides from this practice are largely undetectable in environmental samples (OECD [NEA], 1990). International surveillance of the effects of these disposals is coordinated by the Nuclear Energy Agency of the Organisation for Economic Cooperation and Development by means of a Coordinated Research and Environmental Surveillance Programme (CRESP) (OECD [NEA], 1981). This Programme is continuing (OECD [NEA], 1990). In the absence of readily detectable radioactivity from the disposal practice, radiation exposure is assessed mainly by the use of mathematical modelling. The emphasis of surveillance within CRESP has been to improve, by means of appropriate research, the data for modelling assessments. These assessments indicate that the environmental impact of these disposals is negligible (OECD [NEA], 1985).

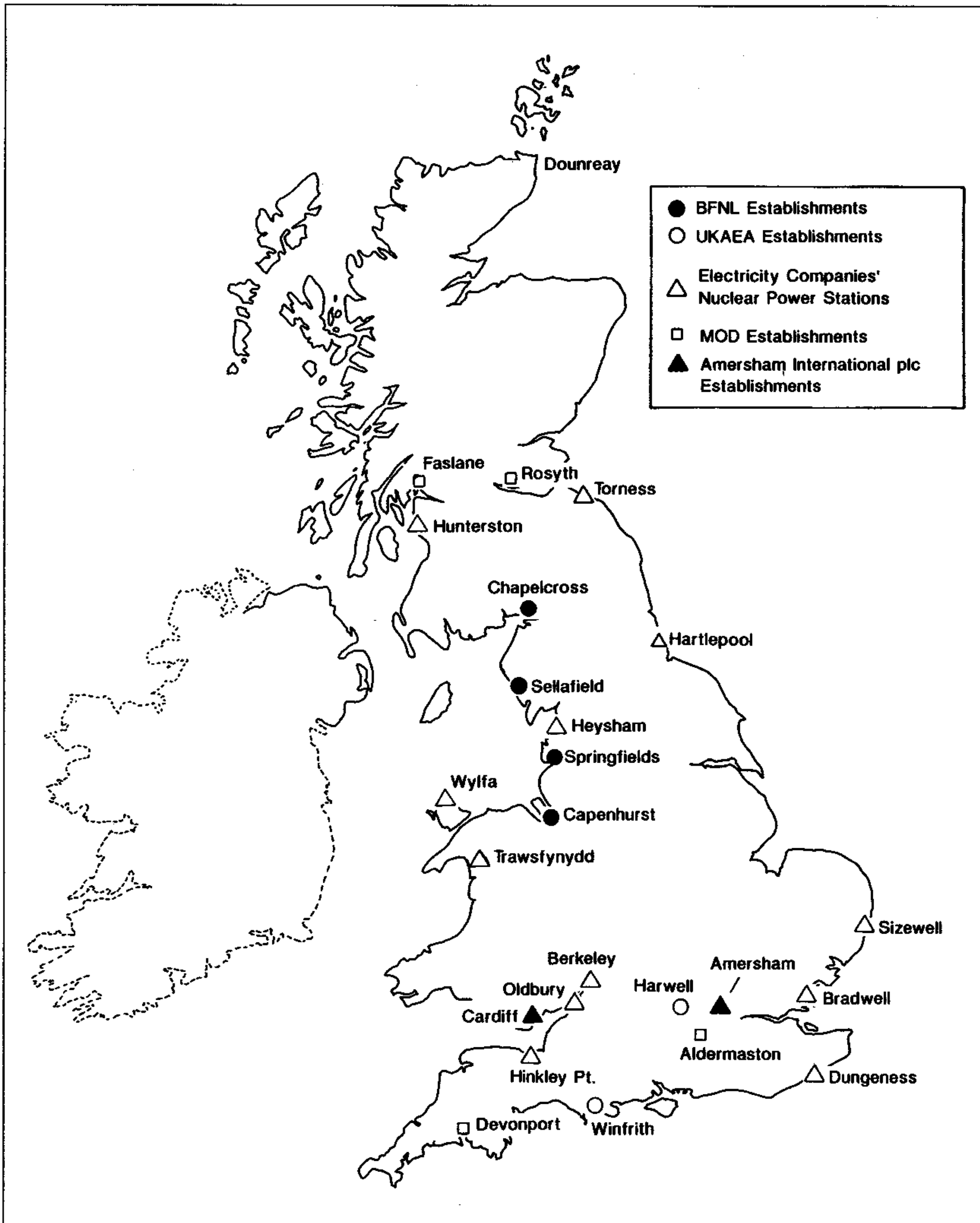

Figure 1. UK nuclear establishments giving rise to principal discharges of liquid radioactive waste

Table 1. Principal discharges of liquid radioactive waste from UK nuclear establishments 1990

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1990	
			TBq [12]	% of limit
British Nuclear Fuels plc				
Sellafield	Total alpha	10	2.16	22
Sea pipelines[2]	Total beta	500	70.93	14
	Tritium	3500	1698.62	49
	Carbon-14	4	1.97	49
	Cobalt-60	8	0.17	2.1
	Strontium-90	35	4.22	12
	Zirconium-95+Niobium-95	180	6.82	3.8
	Technetium-99	10	3.82	38
	Ruthenium-106	170	16.54	9.7
	Iodine-129	0.4	0.11	28
	Caesium-134	10	1.15	12
	Caesium-137	110	23.46	21
	Cerium-144	22	2.01	9.1
	Plutonium alpha	7	1.14	16
	Plutonium-241	170	31.61	19
	Americium-241	3	0.75	25
Seaburn sewer	Total activity	0.148	0.0013	0.9
Springfields	Total alpha	13.32	0.20	1.5
	Total beta	444	92	21
Chapelcross	Total alpha	0.1	0.0005	0.5
	Total beta[1]	25	0.11	< 1
	Tritium	5.5	0.28	5.1
Capenhurst				
Rivacre Brook	Uranium	0.02	0.0030	15
	Uranium daughters	0.02	0.010	50
	Non-uranic alpha	0.003	0.00013	4.3
	Technetium-99	0.1	0.0066	6.6
Meols outfall	Technetium-99	0.148	NIL	NIL
United Kingdom Atomic Energy Authority				
Winfrith	Tritium	650	39.2	6.0
	Cobalt-60	10	1.2	12
	Zinc-65	6	0.19	3.2
	Total alpha	0.3	0.004	1.3
	Other radionuclides	80	2.6	3.3
Harwell	Total activity[1,3]	8.88	0.17	1.9
	Tritium	8.88	1.0	12
Dounreay	Total alpha[4]	0.75	0.022	2.9
	Total beta	110	4.3	3.9
	Tritium	130	0.30	< 1
	Cobalt-60	1.0	0.023	2.3
	Strontium-90	12	1.3	11
	Zirconium-95 +Niobium-95	6.0	0.01	< 1
	Ruthenium-106	12	0.34	2.8
	Silver-110m	0.4	0.01	< 2.5
	Caesium-137	50	2.2	4.4
	Cerium-144	12	0.038	< 1
	Plutonium-241	15	0.72	4.8
	Curium-242	1.0	0.019	1.9
Nuclear Electric plc				
Berkeley	Total activity[1]	7.4	0.33	4.4
	Tritium	55.5	1.35	2.4
Bradwell	Total activity[1]	7.4	0.32	4.4
	Zinc-65	0.185	0.00097	< 1
	Tritium	55.5	1.4	2.5
Dungeness				
'A' Station	Total activity[1]	7.4	0.39	5.3
	Tritium	74	0.71	< 1
'B' Station	Total activity[1,5]	4	0.0091	< 1
	Sulphur-35	25	0.05	< 1
	Tritium	650	7.2	1.1
Hartlepool	Total activity[1,5]	4	0.020	< 1
	Sulphur-35	7.5	0.92	12
	Tritium	1850	166	9.0

Table 1. Continued

Establishment	Radioactivity	Discharge limit (annual equiv-alent), TBq	Discharges during 1990 TBq[12]	Discharges during 1990 % of limit
Heysham Station 1	Total activity[1,5]	4	0.058	1.4
	Sulphur-35	7.5	0.40	5.3
	Tritium	1850	157	8.5
Station 2	Tritium	1200	45.2	3.8
	Sulphur-35	7	0.073	1.0
	Cobalt-60	0.036	0.000007	< 1
	Other radionuclides	0.45	0.011	2.4
Hinkley Point[6] 'A' Station	Total activity[1,5]	7.4	0.39	6.2
	Sulphur-35	3.7	0.23	7.4
	Tritium	74	0.74	1.2
	Total activity[1,7]	1.0	0.053	-
	Caesium-137	1.5	0.084	-
	Tritium	25	0.17	-
'B' Station	Total activity[1,5]	3.7	0.030	< 1
	Sulphur-35	22.2	1.2	6.6
	Tritium	666	231	42
	Total activity[1,5,8]	0.25	0.0075	18
	Sulphur-35	2.0	0.39	-
	Cobalt-60	0.035	0.00026	-
	Tritium	650	64	-
Oldbury	Total activity[1]	3.7	0.43	12
	Tritium	74	1.7	2.3
Sizewell	Total activity[1]	7.4	0.43	5.8
	Tritium	111	5.0	4.5
Trawsfynydd	Total activity[1]	1.48	0.33	22
	Caesium-137	0.259	0.041	16
	Tritium	74	2.5	3.4
Wylfa	Total activity[1]	2.405	0.072	3.0
	Tritium	148	5.4	3.6
Scottish Nuclear Ltd				
Hunterston 'A' Station	Total activity[1]	7.5	0.32	4.3
	Tritium	48	0.52	1.1
'B' Station	Total activity[1,5]	3.7	0.05	1.4
	Sulphur-35	26	2.5	9.6
	Tritium	1480	353	24
Torness	Tritium	1200	82	6.8
	Sulphur-35	10	0.081	< 1
	Cobalt-60	0.05	0.000029	< 1
	Beta activity[1,5,8]	0.45	0.0018	< 1
	Total alpha	0.0045	0.000008	< 1
Ministry of Defence (Procurement Executive)				
Aldermaston	Total activity[1,3]	5.8	0.045	< 1
	Tritium	5.8	0.60	10
Ministry of Defence (Navy Department)				
Devonport[9]	Total activity[1,8]	0.002	0.000009	< 1
	Cobalt-60	0.016	0.0014	8.8
	Tritium	0.12	0.049	41
Faslane	Total activity[1]	0.037	0.000084	< 1
Rosyth[10]	Beta activity[1,8]	0.01	0.0002	2.0
	Cobalt-60	0.055	0.0005	< 1
	Tritium	0.01	0.00056	5.6
	Total alpha	1×10^{-6}	6×10^{-7}	60
Amersham International plc				
Amersham	Total activity[1,3]	2.7	1.07	40
	Tritium	14.8	0.032	< 1
Cardiff	Beta/gamma activity[11]	0.096	0.022	23
	Carbon-14	2	1.57	79
	Tritium	1400	609	44

1. *Excluding tritium*
2. *Authorisation was varied with effect from 1 January 1990*
3. *Authorisation of agreement specifies a control formula in which the total effective activity is calculated to allow for the relative radiotoxicities of different nuclides. The sums of the actual discharges were lower than the values indicated*
4. *Excluding curium-242*
5. *Excluding sulphur-35*
6. *Authorisation was revised with effect from 1 November 1990. For each station the first block of data relates to the period 1 January to 31 October 1990; the second block of data relates to the period 1 November to 31 December 1990. '% of limit' refers to discharges during the first ten months of the year as a percentage of the equivalent limit for ten months of a year*
7. *Excluding caesium-137*
8. *Excluding cobalt-60*
9. *The operator of this site is Devonport Management Ltd*
10. *The operator of this site is Babcock Thorn Ltd*
11. *Excluding tritium, carbon-14 and radioisotopes of calcium and strontium*
12. *Some discharges are upper estimates because they include "less than" data derived from analyses of effluents at limits of detection*

3. METHODS OF ANALYSIS AND OF PRESENTATION AND INTERPRETATION OF RESULTS

3.1 SI units

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

3.2 Summary of analytical methods

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

Total beta radioactivity is measured using thin sources with a potassium-40 standard (Dutton, 1968). The efficiency of the method is nearly constant over a wide range of beta energies and the result gives a measure of the total radioactivity of the beta emitters present, including natural radioactivity. However, agreement with the total as derived from isotopic analysis is not expected to be exact. The main advantage of total beta measurements is that they can be carried out quickly to give an early warning of any change in radioactivity concentrations which might require further investigation; they also provide reassurance that no beta-emitting radionuclides of significance have been neglected.

Gamma-emitting nuclides are analysed by gamma spectrometry. This is carried out using both NaI(Tl) and Ge detectors, calibrated using suitable reference sources. The spectra are reduced by computer-aided techniques to give radioactivity concentrations of detected nuclides. For samples of biota and sediments, searches are routinely made for, amongst others, the artificial gamma emitters listed in Table 3. In the tables of results for these samples, the absence of a column for any of these nuclides indicates non-detectability in each sample in that table. Otherwise, non-detectability is indicated by 'ND'. Approximate detection limits for these nuclides under typical conditions are listed in Table 3; however, these conditions may vary, sometimes significantly.

Pure beta emitters, such as carbon-14, sulphur-35, strontium-90, technetium-99, promethium-147 and plutonium-241, are chemically separated from samples before beta counting (Harvey *et al.*, 1989, 1991). Alpha-emitting thorium, uranium and transuranic nuclides are chemically separated and analysed by alpha spectrometry using silicon surface-barrier detectors (Harvey and Thurston, 1988; Lovett *et al.*, 1990). Thorium-234 is analysed by reference to the activity of protactinium-234m using gamma spectrometry. Radiochemical procedures are generally labour-intensive and are carried out on samples in which these nuclides are of particular relevance, often on an annual bulk (sub-section 3.3). Detection limits are usually much lower for radionuclides analysed using these procedures than for gamma-emitting radionuclides.

Table 2. Radiological units used in this report

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

Table 3. Artificial gamma-emitting radionuclides routinely analysed and approximate limits of detection

Radionuclide	Approximate limit of detection*, Bq kg^{-1}
Manganese-54	0.2
Cobalt-58	0.3
Iron-59	0.5
Cobalt-60	0.2
Zinc-65	0.4
Zirconium-95 plus Niobium-95	1.0
Ruthenium-106	1.0
Silver-110m	0.5
Antimony-125	0.4
Caesium-134	0.1
Caesium-137	0.1
Cerium-144	1.0
Europium-154	1.0
Europium-155	1.0
Americium-241	1.0#

* *Under typical conditions of counting; these may vary in practice*
\# *When analysed by alpha spectrometry, much lower limits are achieved*

Measurements of gamma dose in air over intertidal areas are made at 1 m above the ground using Mini Instruments* environmental radiation meters type 6-80 with compensated G-M tubes type MC-71. Thermoluminescent dosemeters are also used to measure integrated doses over a period of time in some situations. External beta doses are measured on contact with the source, for example, fishing nets, using Berthold* LB 1210B contamination monitors. These portable instruments are calibrated against recognised reference standards.

3.3 Methods of presentation of measurements

The tables of monitoring results generally contain summarised values of observations obtained during the year under review. Observations of a given quantity may vary throughout the year; in general, any variations are larger than the analytical errors inherent in the observations. The variations may, for example, be due to changes in rates of discharge or to different conditions in the receiving environment. The presentation of the summarised results reflects the purpose of this monitoring which is interpretation in terms of public radiation exposures. The method of interpretation is described more fully in sub-section 3.4. The appropriate integration period for comparison with recommended limits is at least one year; standard practice is to combine annual rates of consumption or occupancy of the more highly exposed members of the public (the critical group) with the arithmetic means of observed radioactivity concentrations or dose rates, respectively, during the year. The use of, for example, the highest observed (but unsustained) radioactivity concentration with an annual consumption rate would not provide a realistic basis for comparison with the recommended limits. Therefore, the tables present the arithmetic means of observations made during the year. This procedure takes account of corrections for radioactive decay which are made to the time of sampling.

* *The reference to proprietary products in this report should not be construed as an official endorsement of these products, nor is any criticism implied of similar products which have not been mentioned.*

The frequency of sampling reflects the resolution (which affects the accuracy) judged to be necessary in the assessment of dose and is largely governed by the radiological importance. The tables indicate the number of sampling observations carried out during the year. Observations on biota consist of the results of analysing suitably large samples of material; for fish and shellfish, a sufficient number of individual animals is sampled and analysed for each observation so as to allow for statistical variations. The number of individuals sampled also reflects the radiological importance. Thus, as in previous years, the number of individual animals in a sample varied – by up to several hundred for fish and molluscs from near Sellafield. For external beta and gamma dose rates, each observation consists of the mean of a number of individual readings at a given location. This number again depends upon the radiological importance of the observation; the locations or materials chosen are generally those where there is likely to be occupancy or handling by persons as determined by habits surveys (see sub-section 3.4).

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

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

The results for certain measurements, particularly total beta and carbon-14 radioactivity concentrations and beta and gamma dose rates, include a contribution due to natural radioactivity. Further analysis of samples

Table 4. Concentrations of natural radioactivity in various environmental materials and dose rates for natural background 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: 0.03 - 0.1 $\mu Gy\ h^{-1}$

**Except sediments for which dry concentrations apply*

(usually by gamma spectrometry) indicates the component of total beta radioactivity which is due to artificial sources and the component due to natural radionuclides (mainly potassium-40 and the decay products of uranium and thorium). In the case of gamma dose rates, an indication of the natural background component can be gained from measurements at similar locations which are remote from nuclear activities or from experience before these activities began. Table 4 lists representative values to be expected from natural sources of radioactivity. It should be noted that concentrations of alpha-emitting radioactivity can also be due to natural radionuclides. Typical levels of total alpha radioactivity are approximately 2 and 40 Bq kg^{-1} (wet) in fish and shellfish respectively (Pentreath *et al.*, 1989 (a)). These are mostly due to polonium-210. Near Whitehaven in Cumbria, concentrations of polonium-210 of a few hundred Bq kg^{-1} (wet) can be detected in shellfish. These are due to discharges from a phosphogypsum plant. The radiation dose to high-rate seafood consumers due to discharges from this plant is estimated to be approximately 0.3 mSv $year^{-1}$ (Rollo *et al.*, in press).

Radiation exposures from unenhanced sources of natural radioactivity are in most cases greater than those from artificial radioactivity.

3.4 Method of interpretation of results

The monitoring results in this report are interpreted in terms of radiation exposures of the public. The standards against which these exposures are judged are embodied in national policy on radioactive waste (Great Britain - Parliament, 1986). The National Radiological Protection Board (NRPB) advises the UK Government on appropriate standards, including the recommendations of the ICRP. Current UK practice relevant to the general public is mainly based on the recommendations of the ICRP as set out in ICRP Publication 26 (ICRP, 1977). The Euratom Directive on basic radiation safety standards (Commission of the European Communities, 1980), with which UK legislation complies, is based on the recommendations of ICRP-26, as are the Basic Safety Standards for Radiation Protection promulgated by the International Atomic Energy Agency (IAEA, 1982). In this report, results have been interpreted also on the basis of the recommendations of ICRP-26, taking account of recent explanatory statements by the ICRP (ICRP, 1987) and advice from the NRPB (NRPB, 1987).

The ICRP has recently published a comprehensive revision of its recommendations, in ICRP Publication 60 (ICRP, 1991). These recommendations have not yet been adopted by the UK Government, but are being considered, with advice from the NRPB. To assist in this process of consideration, and in keeping with our practice of providing up-to-date information, some of the relevant implications of ICRP-60 are addressed in this report.

In addition to reviewing radiation risks and other key factors, ICRP-60 includes new recommendations on the conceptual framework of radiological protection. The ICRP now recommends separate systems of radiological protection for 'practices', which are those activities which increase exposures, and 'interventions', which may be necessary in existing situations, to reduce exposures which might otherwise occur. ICRP-60 recommends that practices should be subject to a dose/risk limitation system which contains the three elements of justification, optimisation, and compliance with limits, with the additional proviso that optimisation should be subject to appropriate constraints which apply within the overall limits. The setting of constraints is left to National Authorities, and is being considered by the UK Government. The dose limit for individual members of the public, recommended in ICRP-60, is an effective dose of 1 mSv in a year. However, in special circumstances, a higher value of effective dose could be allowed in a single year, provided that the average over 5 years does not exceed 1 mSv per year. The term 'effective dose' replaces 'effective dose equivalent' of ICRP-26; in addition, different tissue weighting factors apply to effective dose and, in this report, the appropriate use of the two terms denotes which system (i.e. ICRP-26 or ICRP-60) is being referred to.

The separate dose limitation system of ICRP-60 which applies for interventions involves, firstly, justification in terms of positive net benefit and, secondly, that the net benefit should be maximised through a process of optimisation. The ICRP does not recommend dose limits which are applicable for intervention purposes because measures might be indicated which would be out of proportion to the benefit to be gained, thus conflicting with the two elements of the system of protection. Some important examples related to intervention are given in this report where there is significant radioactivity already in the environment because of the effects of discharges made in the past. Noting the reservations of ICRP in applying dose limits in such a situation, we are currently considering whether it would be appropriate to compare the combined effects of current and past discharges calculated using ICRP-60 dose coefficients with a level of 1 mSv in a year. If this level were exceeded then intervention might need to be considered. In addition, to provide further information to help with the process of interpreting the ICRP-60 recommendations, we have also calculated the effects of current discharges from Sellafield and Springfields separately.

Both the ICRP-26 and ICRP-60 dose limitation systems for practices include, within appropriate dose limits to individuals, the requirement that 'all exposures shall be kept as low as reasonably achievable...' (ALARA). This requirement involves consideration of collective, as well as individual, doses in radiological control procedures. As in previous reports in this series, collective doses from liquid radioactive waste discharges continue to be kept under review. The ICRP and the NRPB do not recommend a dose limit for populations; such a limit might be regarded as suggesting the acceptability of a higher population exposure than is either necessary or probable. For reference purposes, in this report, collective doses averaged over the UK population are compared with the average natural background level of approximately 2.2 mSv (NRPB, 1989).

For practices, both ICRP-26 and ICRP-60 recommend that doses should meet the ALARA objective, subject to compliance with appropriate individual dose limits. Control of individual exposures is intended to limit stochastic effects (i.e. those whose probability depends on the dose) to an acceptable level and to prevent non-stochastic or deterministic (threshold) effects. For stochastic effects, it is recommended that the risk should be equal whether the whole body is irradiated uniformly or non-uniformly; weighting factors proportional to the risk are defined for different organs. The weighted sum of organ doses is called the effective dose equivalent in ICRP-26, or effective dose in ICRP-60. Exposures from intakes of radioactivity can continue for a number of years, depending upon body retention time. The ICRP-26 committed effective dose equivalent (or committed effective dose in ICRP-60) represents the integrated exposure over 50 years following an intake. The ICRP-26 principal limit for the committed effective dose equivalent received by a member of the public is 1 mSv in a year (ICRP, 1985); however, it is permissible to use a subsidiary dose limit of 5 mSv in a year for some years, provided that the average annual committed effective dose equivalent over a lifetime does not exceed 1 mSv $year^{-1}$. These dose limits apply to the sum of the effective dose equivalent resulting from external exposure during one year and the committed effective dose equivalent incurred from that year's intake of radionuclides. ICRP-60's dose limits were given earlier, and a parallel additive rule applies. For members of the public, the dose limitation criteria for both methodologies apply at each site to the mean dose of the appropriate 'critical group', which is that small group of people who, because of their habits and other aspects of behaviour which affect the doses received, are likely to be the most exposed.

In this report, the committed effective dose equivalents to the critical groups presented are compared with the principal ICRP-recommended dose limit of 1 mSv $year^{-1}$ and, where examples are given of the implications of ICRP-60, effective doses are compared with the dose limits of 1 mSv $year^{-1}$. As regards non-stochastic (deterministic) effects due to intakes of radionuclides, the ICRP has indicated (ICRP, 1984a, 1991) that because of the limitation on lifetime exposure, described above, these effects in members of the public will be avoided. For external exposures, specific non-stochastic (deterministic) limits are appropriate. For example, the ICRP continues to recommend (ICRP, 1991) the limit for skin of 50 mSv $year^{-1}$; this limit is applicable in the case of handling of fishing gear.

For the calculations based on ICRP-26, values for committed effective dose equivalents, following intakes by members of the public, have been taken from three sources:

(i) NRPB Documents (NRPB, 1990);

(ii) ICRP Publication 56 (ICRP, 1989); and

(iii) the NRPB 'RAPID' database (Greenhalgh *et al.*, 1986) as amended by changes in dosimetric factors outlined in Kendall *et al.* (1987).

Where there is a choice, the most recent information is adopted. ICRP-60's dose calculations are based on data taken from Phipps *et al.* (1991). For reference, data on dose per unit intake are provided in Appendix 2 of this report.

Our dose assessments include consideration of children, where they are known to be members of critical groups, and the use of appropriate gut transfer factors. The NRPB has recently made recommendations on gut transfer factors for a range of radionuclides (NRPB, 1990). These recommendations include endorsement of the results of recent work at this Laboratory, using adult, human volunteers, which has suggested a gut transfer factor of 0.0002 in connection with the consumption of plutonium and americium in winkles from near Sellafield (Hunt *et al.*, 1986, 1990). For these and other actinides in food in general, the NRPB considers a gut transfer factor of 0.0005 to be a reasonable best estimate (NRPB, 1990). In this report, when estimating doses to consumers of winkles from the Irish Sea, a gut transfer factor of 0.0002 is used for plutonium and americium. For other foods and for winkles from outside the Irish Sea, the factor of 0.0005 is used for these radioelements.

In the case of external exposure to penetrating radiation, uniform whole body exposure has been assumed. The measured quantity is absorbed dose rate in air. When interpreting this in terms of radiological effect, an absorbed dose rate in air of 1 mGy h^{-1} has been taken as producing an effective dose equivalent rate of 0.87 mSv h^{-1} (Spiers *et al.*, 1981). This factor does not change significantly for effective dose under ICRP-60. For external exposure of skin, the measured quantity is contamination in Bq cm^{-2}. In this case, dose rate factors in Sv $year^{-1}$ per Bq cm^{-2} are used which are calculated for a depth in tissue of 7 mg cm^{-2} (Kocher and Eckerman, 1987). When assessing external exposures to gamma radiation and internal exposures due to ingestion of carbon-14, estimates of dose rates and concentrations, as appropriate, due to natural background levels are subtracted.

In order to interpret monitoring results in terms of committed effective dose equivalents to critical groups, the remaining data required are, as appropriate, rates of food consumption and/or occupancy of areas relevant to external exposure. These are obtained by habits surveys specific to, and generally near, each nuclear establishment of interest. The results are kept under review and the surveys are repeated at intervals. The main purpose of the surveys is to identify, and to quantify, the relevant habits of the critical group of persons most highly exposed through a particular pathway or pathways. In this report, critical group habits data relevant to a given establishment are combined with the results of environmental monitoring and appropriate dosimetric data as above to estimate the committed effective dose equivalent to the critical group, which may then be compared with the appropriate dose limitation criteria.

It has been generally assumed, in radiological protection, that controls applied to radioactive waste disposal to provide adequate protection for man will result in sufficiently low concentrations of radionuclides in the environment that the fauna and flora are also likely to be protected (ICRP, 1977, 1990). This assumption has been specifically addressed in the case of the aquatic environment of the British Isles, and our research programmes include a continuing study of potential radiological effects on aquatic populations. Studies of such effects on fish and shellfish (e.g. Woodhead and Pentreath, 1989) and on seabirds (Woodhead, 1986) have confirmed the applicability of the general assumption in these cases. In addition, the wider context of the work of DFR (MAFF, 1989) includes research programmes which are designed to keep the health of fish and shellfish stocks under close scrutiny.

4. BRITISH NUCLEAR FUELS PLC (BNFL)

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

4.1 Sellafield, Cumbria

Operations and facilities at this establishment include fuel element storage and decanning, the Windscale nuclear fuel reprocessing plant and the Calder Hall magnox-type nuclear power station. Liquid radioactive waste discharges include a very minor contribution from the adjoining UKAEA Windscale Laboratories. The most significant discharges are from the BNFL fuel element storage ponds and the reprocessing plant, through which pass all of the irradiated Magnox fuel from the UK nuclear power programme, and some fuel from abroad. Most of the radioactive waste separated from the fuel is presently stored on site; relatively small quantities of radioactivity are discharged to the north-eastern Irish Sea through pipelines which terminate 2.1 km beyond low-water mark. On 1 January 1990, the authorisation to discharge these wastes was varied, specifying lower limits to radioactivity in discharges than previously. The condition requiring BNFL to use the 'best practicable means' (BPM) to control discharges is unchanged. This condition reflects, *inter alia*, the objective of keeping radiation exposures 'as low as reasonably achievable' (ALARA), to comply with the ICRP principles, as described in sub-section 3.4. This condition also has the effect of requiring the use of the 'best available technology' as described in the recommendations of the Paris Commission (PARCOM, 1989).

Discharges from the Sellafield pipelines during 1990 are summarised in Table 1, and were within the new, more stringent limits set by the Authorising Departments. The site ion-exchange effluent plant (SIXEP) and the salt evaporator operated during 1990. Discharges of most radionuclides were slightly lower than those in 1989 because of a period of shutdown of reprocessing in mid-1990 for plant refurbishment. Transfers to SIXEP of some sludges from the older fuel storage ponds continued as part of pre-decommissioning operations. These transfers resulted in slightly greater discharges of radiocaesium from SIXEP than would have otherwise occurred, but overall discharges of radiocaesium, at 23.5 TBq in 1990, were still less than those in 1989 (28.6 TBq). Discharges of total beta activity were 71 TBq (1989: 101 TBq). Discharges of alpha-emitting radionuclides in 1990 totalled 2.2 TBq (1989: 2.7 TBq).

Our regular monitoring continued during 1990. Important radiation exposure pathways were still from consumption of fish and shellfish and from external exposure to gamma rays from occupancy over sediments, with other pathways being kept under review. Following established practice, the largest monitoring effort was expended on these more important pathways. In 1990, as in previous recent years, there was no harvesting of *Porphyra* in the immediate vicinity of Sellafield for manufacture of laverbread, but monitoring continued because the pathway remains potentially important. An extensive research programme also continued. The aims of this programme are to improve our knowledge of the distribution and behaviour of radionuclides in the marine environment, especially in relation to the critical exposure pathways, and also to provide a means of assessing other pathways of lower current importance, thereby assisting in keeping all exposure pathways under review. Results from our research programme are included where relevant.

4.1.1 The fish and shellfish consumption pathway

Public radiation exposure from Sellafield discharges by consumption of fish is still predominantly due to radiocaesium. Concentrations of total beta activity and caesium-134 and -137 in fish from the vicinity of the Irish Sea and from further afield are given in Table 5(a). Data are listed by location of sampling or landing point, in approximate order of increasing distance from Sellafield. So as to be representative of consumption by the public, samples are generally obtained from commercial sources. However, to minimise the risk of underestimating exposures, and as certain species of fish or shellfish may not be available commercially, we also carry out specific surveys. The 'Sellafield Coastal Area' extends 15 km north and south of Sellafield from St Bees Head to Selker and 11 km offshore; most of the local fish and shellfish consumed by the critical group is taken from this Area (Leonard and Hunt, 1985). Our specific surveys are carried out in the smaller 'Sellafield Offshore Area' where experience has shown that good catch rates may be obtained. This Area consists of a rectangle, one nautical mile wide by two nautical miles long, situated south of the pipeline with the long side parallel to the shoreline; it averages about 5 km from the pipeline outlet.

The results reflect the progressive dilution of radiocaesium with increasing distance from Sellafield, but the rate of decline of radiocaesium concentrations with distance is not as marked as was the case some years ago, because of the significant reductions in discharges since that time. The ratios of caesium-137 to caesium-134 (half-lives 30 years and 2 years respectively) reflect the age of the radioactivity; up to 1985, these ratios increased with distance from Sellafield, but in 1986 they were perturbed by the addition of radiocaesium from Chernobyl which was relatively rich in caesium-134. This perturbation persisted in fish from Scottish waters and the North Sea until 1988 (Hunt, 1989) but was difficult to detect in these areas in 1989 or 1990 due to decreasing concentrations of caesium-134. However, radiocaesium in fish from the Baltic Sea is substantially from the Chernobyl accident. Concentrations of radiocaesium in fish known to have been caught in Icelandic waters remained typical of those from weapons-test fallout, at a value of about 0.3 Bq kg^{-1} for caesium-137 in cod. In the Irish Sea, the ratios of caesium-137 to caesium-134 were generally higher than those in recent discharges from Sellafield, even allowing for residence time in the water and uptake into fish; this suggests that a significant contribution from aged radiocaesium is present, due to remobilisation from the sediment of the Irish Sea (Hunt and Kershaw, 1990).

Variations between fish species for a given area, while not large, are mainly to be explained in terms of residence time in the area as well as in terms of feeding habits. To obtain representative results for dose estimation, samples include large numbers of individual fish (sub-section 3.3).

Concentrations of radiocaesium in fish from the eastern Irish Sea in 1990 were generally similar to those in 1989. This is consistent with the observation that much of the radiocaesium in fish in this area is due to remobilisation of aged deposits. Further afield, concentrations of radiocaesium in fish were lower than those in 1989, continuing the downward trend due to reductions in discharges during the 1980s.

Specific radionuclides, other than caesium-134 and -137, which were detected in fish in 1990, are listed in Table 5(b). Analyses of samples of fish for carbon-14, strontium-90, technetium-99 and promethium-147

Table 5(a). Beta/gamma radioactivity in fish from the Irish Sea vicinity and further afield, 1990

Sampling area/ landing point	Sample	No. of sampling observa-tions[3]	Mean radioactivity concentration (wet), Bq kg^{-1}		
			Total beta	^{134}Cs	^{137}Cs
Sellafield coastal area[1]	Cod	6	190	0.8	37
	Plaice	2	190	1.0	37
Sellafield offshore area[1]	Cod	3	190	0.5	27
	Plaice	4	130	0.2	14
	Flounder	1	150	0.9	69
	Dab	3	160	0.4	24
	Whiting	2	170	0.6	40
Ravenglass[2]	Cod	16	160	0.5	29
	Plaice	8	150	0.3	24
	Whiting	2	120	0.3	23
	Flounder	1	180	0.8	45
	Hake	1	140	0.8	21
	Whitebait	1	99	ND	13
	Sea trout	1	160	0.7	31
	Salmon	1	100	ND	2.9
Whitehaven[2]	Cod	4	160	0.4	21
	Plaice	4	130	0.1	14
	Rays	3	150	0.6	37
	Whiting	1	160	0.5	35
	Herring	3	110	ND	10
	Hake	1	140	0.5	20
Morecambe Bay[1]	Flounder	4	160	0.4	54
	Plaice	3	130	0.07	25
	Bass	2	170	0.6	50
	Whitebait	1	94	0.3	20
Cumbrian rivers[4]	Brown trout	2	120	ND	ND
	Sea trout	5	130	"	19
Fleetwood[2]	Cod	4	140	0.2	17
	Plaice	4	120	0.2	14
	Fish meal[5]	2	240	0.2	3.7
Isle of Man[2]	Cod	4	150	0.1	11
	Plaice	3	100	ND	6.0
	Herring	2	170	0.1	7.5
	Whiting	1	120	0.3	14
Inner Solway[1]	Salmon	1	160	ND	1.1
	Sea trout	2	140	"	15
	Flounder	4	180	0.6	65
Kirkcudbright[2]	Plaice	3	100	0.2	9.7
North Anglesey[1]	Plaice	2	100	ND	2.5
	Spurdog	2	110	0.2	12
Northern Ireland[2]	Cod	6	130	0.07	7.5
	Whiting	8	120	ND	8.8
	Herring	4	120	0.3	7.2
	Dogfish	5	90	0.1	7.4
	Saithe	1	100	ND	5.0
Ayr[2]	Cod	4	140	0.2	8.9
	Plaice	3	100	0.06	5.8
	Whiting	1	130	ND	2.6
Loch Leven[1]	Salmon	1	130	"	1.1
Minch[1]	Cod	4	150	ND	2.0
	Plaice	4	100	0.03	1.3
	Haddock	4	120	ND	1.0
	Herring	2	120	"	1.5
	Mackerel	7	110	"	0.7
Shetland[1]	Fish meal[5]	1	500	ND	2.1
Northern North Sea[1]	Plaice	4	100	"	1.4
	Cod	6	130	"	1.3
	Haddock	8	120	"	1.0
	Saithe	4	NA	"	1.4
	Herring	6	120	"	0.8
	Mackerel	2	NA	"	0.4
	Whiting	1	"	"	1.4
Mid North Sea[1]	Plaice	8	96	0.02	1.1
	Cod	8	130	0.04	1.9
	Haddock	5	NA	ND	0.9
	Herring	8	110	"	1.1
	Mackerel	1	NA	"	1.0
	Whiting	2	"	"	1.1
Southern North Sea[1]	Plaice	3	91	"	1.0
	Cod	3	130	"	1.0
	Herring	3	110	"	0.7
	Mackerel	1	NA	"	0.6
	Whiting	1	NA	"	1.0
Norwegian Sea[1]	Cod	2	110	ND	1.1
Baltic Sea[1]	Cod	3	110	2.1	16
	Herring	2	110	1.1	7.9
English Channel[1]	Plaice	2	110	ND	0.3
	Cod	2	130	"	0.6
	Whiting	1	98	"	ND
	Mackerel	1	100	"	0.5
Iceland area[1]	Cod	2	110	"	0.3
Icelandic processed	Cod	2	110	"	0.8
	Haddock	1	110	"	0.1

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

Table 5(b). Other beta/gamma radioactivity in fish from the Irish Sea vicinity, 1990

Sampling area/ landing point	Sample	No. of sampling observa-tions[3]	Mean radioactivity concentration(wet), Bq kg^{-1}					
			^{14}C	^{60}Co	^{65}Zn	^{90}Sr	^{99}Tc	^{147}Pm
Sellafield offshore area[1]	Plaice	1	82	ND	ND	0.065	0.68	0.0074
	Cod	1	95	"	"	0.12	0.39	0.013
Ravenglass[2]	Whitebait	1	NA	0.5	"	0.38	NA	NA
Whitehaven[2]	Plaice	1	43	ND	"	0.070	"	"
	Cod	1	43	"	"	0.051	"	"
Morecambe Bay[1]	Plaice	1	35	"	"	NA	"	"
	Flounder	1	46	"	"	"	"	"
Fleetwood[2]	Plaice	1	34	"	"	"	"	"
	Cod	1	23	"	"	"	"	"
	Fish meal[4]	1	NA	"	"	0.50	"	"
Isle of Man[2]	Plaice	1	30	"	"	NA	"	"
Inner Solway[1]	Flounder	1	22	"	"	"	"	"
North Anglesey[2]	Dogfish	1	20	"	"	"	"	"
Minch[1]	Mackerel	1	64	"	"	"	"	"
Shetland[2]	Fish meal[4]	1	NA	"	"	0.042	"	"
Northern North Sea[1]	Cod	2	"	0.1	"	NA	"	"
	Haddock	1	12	ND	"	"	"	"
	Herring	2	NA	0.3	"	"	"	"
	Mackerel	2	"	0.9	"	"	"	"
Mid North Sea[1]	Cod	1	7.8	ND	"	"	"	"
Iceland area[1]	Cod	1	19	"	"	"	"	"
Icelandic processed	Cod	1	15	"	"	"	"	"
English Channel[1]	Plaice	2	NA	0.06	0.24	"	"	"

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

continued to be included in our monitoring programme to enable the effects of discharges of these nuclides from Sellafield to be assessed, and for results based on measurements to be included later in consideration of critical group and collective dose. Analyses for these radionuclides are labour-intensive; thus a selection of samples was made based on potential radiological significance. The data for 1990 confirm that the radiological significance of these radionuclides remained low.

For shellfish, a wide range of radionuclides contributes to radiation exposure of consumers owing to generally greater uptake in these organisms than in fish. Table 6 lists concentrations of total beta activity and beta/gamma-emitting nuclides in shellfish from the Irish Sea and further afield. Results for carbon-14, strontium-90, technetium-99 and promethium-147 are included. Winkles are of particular radiological importance to the critical group near to Sellafield, as described later in this section. In addition to our own samples, supplies of winkles, mussels and limpets were obtained from consumers who collected them in the Sellafield Coastal Area exploited by this critical group.

Concentrations of artificial radionuclides in shellfish, as with fish, diminish with increasing distance from Sellafield; the rate of reduction is least for nuclides which are relatively mobile in sea water, such as isotopes of caesium. There are substantial variations between species: in general, molluscs tend to concentrate the less mobile nuclides to a greater extent than crustaceans, which in turn tend to concentrate them more than fish; the reverse behaviour is generally observed for mobile nuclides. Concentrations of beta/gamma-emitting radionuclides in shellfish in 1990 were generally similar to those in 1989, with some evidence of reductions (e.g. for ruthenium-106) in line with decreases in discharges.

Table 6. Beta/gamma radioactivity in shellfish from the Irish Sea vicinity and further afield, 1990

Sampling area/ landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
			Total beta	^{14}C	^{54}Mn	^{60}Co	^{65}Zn	^{90}Sr	^{95}Zr	^{95}Nb	^{99}Tc
Sellafield coastal area[1]	Crab	5	150	100	ND	3.4	ND	1.2	ND	ND	5.8
	Lobster	5	420	160	"	2.0	"	0.65	"	"	630
	Winkles[4]	12	380	72	"	5.6	"	17	0.8	0.4	76
	Winkles[5]	4	360	NA	"	6.4	"	NA	2.5	3.7	NA
	Winkles[6]	3	240	"	"	3.4	"	"	ND	ND	"
	Mussels[4]	5	220	"	"	3.3	"	"	0.6	0.5	"
	Limpets[4]	3	410	"	"	6.0	"	"	0.5	0.8	"
Sellafield offshore area[1]	Whelks	2	230	"	"	5.3	"	"	ND	ND	"
St Bees[1]	Winkles	4	290	32	"	4.8	"	9.4	1.1	0.7	45
	Mussels	4	260	NA	"	4.0	"		4.1	1.1	NA
	Limpets	4	430	"	"	5.0	"	"	1.8	2.9	"
Nethertown[1]	Winkles	12	350	65	"	5.6	"	13	2.7	3.2	72
Drigg[1]	Winkles	4	430	59	"	8.5	"	7.5	1.9	1.6	150
Ravenglass[1]	Cockles	4	230	NA	"	9.6	"	NA	1.6	2.6	NA
	Mussels	4	230	"	"	4.6	"	"	1.3	ND	"
Ravenglass[2]	Crabs	3	110	"	"	1.6	"	"	ND	"	"
	Lobsters	3	240	"	"	0.5	"	"	"	"	"
	Whelks	3	160	"	"	3.4	0.1	"	"	"	"
Tarn Bay[1]	Winkles	4	350	"	"	5.1	ND	"	3.1	4.7	"
Whitehaven[2]	*Nephrops*	4	120	"	"	1.3	"	"	ND	ND	"
	Whelks	4	120	"	"	0.6	"	"	"	"	"
Parton[1]	Winkles	12	240	"	"	2.7	"	"	0.7	0.4	"
Roosebeck[1]	Oysters	4	75	"	"	0.7	"	"	ND	ND	"
Haverigg[1]	Cockles	2	140	"	"	3.5	"	"	0.7	0.7	"
Millom[1]	Mussels	2	170	"	"	1.1	"	"	ND	ND	"
Whitrigg scar[1]	Shrimps	1	120	"	"	0.9	"	"	"	"	"
Morecambe Bay[1]	Shrimps	4	96	"	"	ND	"	0.15	"	"	"
	Cockles	4	100	"	"	1.6	"	1.0	"	"	"
Heysham[1]	Cockles	4	85	"	"	1.4	"	NA	"	"	"
	Mussels	4	71	"	"	0.3	"	"	"	"	"
Fleetwood[2]	Squid	1	86	"	"	ND	"	"	"	"	"
	Whelks	3	110	"	"	0.5	"	"	"	"	"
Isle of Man[2]	Scallops	4	86	"	"	ND	"	"	"	"	"
Inner Solway[1]	Shrimps	4	100	"	"	"	"	"	"	"	"
Southerness[1]	Winkles	4	230	"	"	1.0	"	"	0.1	ND	"
Kirkcudbright[2]	Scallops	4	49	"	"	ND	"	"	ND	"	"
	Queens	4	64	"	"	0.09	"	"	"	"	"
North Solway coast[1]	Cockles	3	110	"	"	2.0	"	"	0.3	0.2	"
	Winkles	4	110	"	"	1.0	"	"	ND	ND	"
Wirral[1]	Shrimps	2	72	"	"	0.3	"	"	"	"	0.72
	Cockles	2	69	"	"	0.4	"	"	"	"	1.1
Conwy[2]	Mussels	2	38	"	"	ND	"	"	"	"	NA
North Anglesey[1]	Crabs	2	89	"	"	"	"	"	"	"	"
	Winkles	2	88	"	"	0.4	"	"	"	"	"
Northern Ireland[2]	*Nephrops*	8	110	"	"	0.2	"	"	"	"	"
	Winkles	4	85	"	"	0.1	"	"	"	"	"
Minch[1]	*Nephrops*	4	89	"	"	ND	"	"	"	"	"
Northern North Sea[1]	*Nephrops*	5	93	"	"	"	"	"	"	"	"
Mid North Sea[1]	Queens	1	NA	"	"	"	"	"	"	"	"
	Mussels	1	54	"	"	"	"	"	"	"	"
	Mussels[7]	2	29	"	"	"	"	"	"	"	"
Southern North Sea[1]	Cockles	2	21	"	"	1.7	"	"	"	"	"
	Cockles[8]	2	45	"	"	0.4	"	"	"	"	"
	Mussels	5	36	"	"	ND	"	"	"	"	"

Table 6. Continued

Sampling area/ landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet)*, Bq kg^{-1}									
			^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{147}Pm	^{154}Eu	^{155}Eu
Sellafield coastal area[1]	Crab	5	ND	11	4.4	0.7	ND	10	ND	2.7	ND	ND
	Lobster	5	"	8.9	6.7	0.2	0.2	14	0.6	4.8	0.08	0.06
	Winkles[4]	12	"	65	6.5	3.3	0.06	25	1.4	12	ND	0.3
	Winkles[5]	4	0.2	90	9.0	4.3	0.1	23	3.1	NA	1.2	0.5
	Winkles[6]	3	ND	33	5.5	3.1	ND	15	ND	"	ND	ND
	Mussels[4]	5	0.09	44	ND	2.1	0.1	8.5	0.5	"	1.0	0.6
	Limpets[4]	3	ND	37	2.9	3.7	ND	13	0.6	"	0.7	0.6
Sellafield offshore area[1]	Whelks	2	"	57	9.2	2.2	"	6.4	1.5	"	0.6	0.4
St Bees[1]	Winkles	4	"	60	6.6	4.5	0.2	24	1.7	8.0	0.6	0.3
	Mussels	4	"	86	3.0	2.5	ND	11	2.4	NA	0.2	0.3
	Limpets	4	"	47	3.3	6.0	0.2	26	2.7	"	1.5	0.9
Nethertown[1]	Winkles	12	0.2	87	8.0	5.5	0.4	31	4.0	14	1.3	0.7
Drigg[1]	Winkles	4	0.4	130	8.7	5.9	ND	23	4.3	16	0.5	0.5
Ravenglass[1]	Cockles	4	ND	61	1.1	0.9	"	15	3.4	NA	2.0	1.4
	Mussels	4	"	71	ND	3.7	"	7.6	ND	"	ND	0.6
Ravenglass[2]	Crabs	3	"	5.5	2.2	0.4	"	6.6	"	"	"	ND
	Lobsters	3	"	ND	3.3	ND	"	7.8	"	"	"	0.2
	Whelks	3	"	30	6.2	1.3	"	5.1	"	"	"	ND
Tarn Bay[1]	Winkles	4	0.5	92	5.8	3.9	0.2	26	3.4	"	0.9	0.6
Whitehaven[2]	*Nephrops*	4	ND	ND	ND	ND	0.09	12	ND	"	ND	ND
	Whelks	4	"	4.1	1.3	"	ND	3.5	"	"	"	"
Parton[1]	Winkles	12	0.1	37	2.2	3.4	0.2	26	0.09	"	0.03	0.1
Roosebeck[1]	Oysters	4	ND	3.5	2.1	ND	ND	5.0	ND	"	ND	ND
Haverigg[1]	Cockles	2	"	20	ND	1.0	0.2	18	1.6	"	1.1	0.5
Millom[1]	Mussels	2	0.2	21	"	0.7	0.09	8.4	0.9	"	ND	0.1
Whitrigg scar[1]	Shrimps	1	ND	ND	"	ND	0.7	20	ND	"	"	ND
Morecambe Bay[1]	Shrimps	4	"	"	"	"	0.2	20	"	"	"	"
	Cockles	4	"	4.4	"	0.4	0.2	15	"	"	"	"
Heysham[1]	Cockles	4	"	3.7	"	0.5	0.06	8.7	"	"	0.07	0.1
	Mussels	4	"	2.1	"	0.2	0.1	4.5	"	"	ND	ND
Fleetwood[2]	Squid	1	"	ND	"	ND	ND	4.7	"	"	"	"
	Whelks	3	"	2.3	0.5	"	"	3.1	"	"	"	"
Isle of Man[2]	Scallops	4	"	ND	ND	"	"	1.1	"	"	"	"
Inner Solway[1]	Shrimps	4	"	ND	"	"	0.2	21	"	"	"	"
Southerness[1]	Winkles	4	"	8.6	1.6	0.9	0.1	24	"	"	0.1	"
Kirkcudbright[2]	Scallops	4	"	ND	ND	ND	ND	0.4	"	"	ND	"
	Queens	4	"	"	0.3	"	"	1.2	"	"	"	"
North Solway coast[1]	Cockles	3	"	3.0	ND	"	"	13	"	"	"	"
	Winkles	4	"	3.8	2.0	0.5	"	4.8	"	"	"	"
Wirral[1]	Shrimps	2	"	ND	ND	ND	"	7.1	"	"	"	"
	Cockles	2	"	"	"	"	"	7.0	"	"	"	"
Conwy[2]	Mussels	2	"	"	"	"	"	1.1	"	"	"	"
North Anglesey[1]	Crabs	2	"	"	0.07	"	"	1.7	"	"	"	"
	Winkles	2	"	0.7	0.2	"	"	3.7	"	"	"	"
Northern Ireland[2]	*Nephrops*	8	"	ND	ND	"	"	3.7	"	"	"	"
	Winkles	4	"	"	0.08	"	"	1.1	"	"	"	"
Minch[1]	*Nephrops*	4	"	"	0.08	"	"	0.7	"	"	"	"
Northern North Sea[1]	*Nephrops*	5	"	"	ND	"	"	0.7	"	"	"	"
Mid North Sea[1]	Queens	1	"	"	"	"	"	ND	"	"	"	"
	Mussels	1	"	"	"	"	"	0.5	"	"	"	"
	Mussels[7]	2	"	"	"	"	"	0.08	"	"	"	"
Southern North Sea[1]	Cockles	2	"	"	"	"	"	0.1	"	"	"	"
	Cockles[8]	2	"	"	"	"	"	0.2	"	"	"	"
	Mussels	5	"	"	"	"	"	0.4	0.1	"	"	"

NA = not analysed; ND = not detected; [1]Sampling area; [2]Landing point; [3]See sub-section 3.3 for defintion; [4]Samples collected by Consumer 116; [5]Samples collected by Consumer 460; [6]Samples collected by Consumer 311; [7]Landed in Denmark; [8]Landed in The Netherlands

Analyses for transuranics are labour-intensive; as in previous years, a selection of samples of fish and shellfish chosen mainly on the basis of potential radiological significance was analysed for transuranic nuclides. Analyses were often carried out on bulked samples (sub-section 3.3). The data for 1990 are presented in Table 7. Transuranics are less mobile than radiocaesium in sea water; this is reflected in higher concentrations of transuranics in shellfish as compared with fish, and a rapid reduction with distance from Sellafield in concentrations of transuranics, particularly in shellfish.

Over the past decade, discharges of transuranic nuclides from Sellafield have reduced significantly, resulting in overall decreases in concentrations of these nuclides in fish and shellfish. However, the non-mobile nature of these nuclides causes a delayed effect in the environment (Hunt, 1985) such that a contribution to present concentrations is provided by discharges in earlier years. In 1990, when compared with 1989, concentrations of transuranic nuclides in fish and shellfish showed general decreases, in line with the expected trend. However, our model predictions (Hunt, 1986; Pentreath *et al.*, 1989(b)) suggest that there is likely to be a gradual slowing down in the rate of decrease in these concentrations.

The radiation dose to consumers of fish and shellfish depends upon the product of the mass of foodstuff consumed and its radioactivity concentration. Because of variations in these two quantities between individual consumers, a wide range of annual doses is to be expected. The critical group approach, which is well established in the UK and recommended by the ICRP for control purposes, is based on identifying groups of individuals in exposed populations who are subject to the highest radiation exposures. Of the two main variables, radioactivity concentrations in fish and shellfish are highest in the Coastal Area as defined above. Hence, eaters of fish and shellfish within the local community represent one exposed population whose consumption rates we have studied and kept under review. As regards the other main variable, consumption rates, surveys have shown that, in addition to the local fishing community, the larger population in Cumbria and north Lancashire, including those associated with commercial fisheries based primarily at Whitehaven, Fleetwood and in the Morecambe Bay area, contains consumers of large quantities of fish and shellfish. These additional populations are kept under review, even though, in general, the relevant fishing grounds are further afield than the Cumbrian Coastal Area and concentrations of radioactivity in fish landed are lower.

The consumption rates of the local fishing community described above were kept under review in 1990. Techniques used in the collection of data have continued to include the use of 'consumption logging sheets', particularly by members of critical groups (Leonard *et al.*, 1982; Leonard, 1984). Consumption rate data have been interpreted using techniques based upon ICRP recommendations (Hunt *et al.*, 1982) to select appropriate critical groups of higher-rate consumers. We have included consideration of children's consumption rates in this selection process (Leonard and Hunt, 1985).

Radioactivity concentrations in fish and shellfish vary with the species involved, so in estimation of doses to consumers it is not sufficient to determine only the total consumption rates of fish and shellfish together. Our experience (illustrated by Tables 5-7) has shown, however, that for a given area within each of the classes fish, crustaceans and molluscs, the concentrations of given nuclides in representative samples are relatively constant. For each of the exposed populations, therefore, sub-groups of persons were identified who were likely to have received the greatest exposures from eating each class of foodstuff, and mean consumption rates for the sub-groups were determined. For the local fishing community, these sub-groups' consumption rates of fish and shellfish in 1990 were not significantly different from those in 1989 (Hunt, 1990), and the rates of 37 kg year^{-1} fish, 6.0 kg year^{-1} crustaceans, and 8.3 kg year^{-1} molluscs have been used in the assessment of doses to the critical group of fish and shellfish consumers.

The habits survey data show that above-average consumers in each of the component sub-groups are not generally members of another component sub-group. However, members of more than one sub-group do exist, so to avoid underestimating the exposure of the overall critical group, this exposure is derived by adding together the exposures of each sub-group. Comparison based on individual critical group members' exposures shows that this procedure is not excessively conservative (Leonard and Hunt, 1985). Plaice and cod are overwhelmingly the most popular fish eaten by the high-rate consumers, and the assessment of exposure of the critical group of local consumers was based upon an equal mix of these species taken from the Sellafield Offshore Area and from landings at Ravenglass, typical sources of most of the local commercial supplies. The exposure due to consumption of crustaceans, following the 1990 review of consumption rates, was calculated on the basis of a mix of two-thirds crabs and one-third lobsters from the Coastal Area and landings at Ravenglass, combined equally. The exposure from consumption of molluscs was calculated on the basis of averaged radionuclide concentrations in winkles from the Coastal Area, including data from both our own sampling at specific locations within this Area and from samples collected by local consumers.

Table 7. ***Transuranic radioactivity in fish and shellfish from the Irish Sea vicinity and further afield, 1990***

Sampling area/ landing point	Sample	No. of sampling observations[3]	Mean radioactivity concentration (wet), Bq kg^{-1}						
			^{237}Np	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Sellafield coastal area[1]	Plaice	1	NA	0.012	0.049	NA	0.068	ND	0.00019
	Cod	2	"	0.0088	0.036	"	0.049	0.00029	0.00016
	Crab	3	0.060	0.25	1.0	29	3.6	0.0045	0.011
	Lobster	3	0.12	0.16	0.67	21	7.4	ND	0.029
	Winkles[4]	4	0.16	4.9	22	370	37	0.038	0.098
	Winkles[5]	2	NA	4.7	21	360	38	0.13	0.080
	Winkles[6]	3	"	2.0	8.8	150	15	ND	0.043
	Mussels[4]	1	"	3.5	16	NA	28	0.083	0.082
	Limpets[4]	1	"	4.1	19	"	33	0.090	0.14
Sellafield offshore area[1]	Plaice	1	0.0007	0.0022	0.0098	0.18	0.018	ND	0.00004
	Cod	1	0.0004	0.0028	0.012	NA	0.022	0.00012	0.00008
	Whelks	1	NA	1.0	4.4	"	15	0.056	0.043
St Bees[1]	Winkles	4	0.12	3.8	17	280	29	0.043	0.064
	Mussels	2	NA	3.7	16	280	26	0.061	0.077
	Limpets	1	"	5.3	24	NA	39	ND	0.11
Nethertown[1]	Winkles	4	0.32	5.6	25	430	41	0.11	0.10
Drigg[1]	Winkles	4	0.31	6.3	27	470	54	0.11	0.16
Ravenglass[1]	Whitebait	1	NA	0.11	0.49	7.8	0.64	ND	0.0020
	Cockles	1	"	4.5	19	330	49	0.12	0.21
	Mussels	1	"	4.1	17	310	29	0.078	0.12
Ravenglass[2]	Plaice[7]	1	"	0.0027	0.012	NA	0.024	ND	0.00009
	Cod[7]	1	"	0.0029	0.013	"	0.019	"	0.00005
	Crab[8]	1	"	0.14	0.63	"	2.7	"	0.010
	Lobster[8]	1	"	0.11	0.48	"	9.4	"	0.026
	Whelks[8]	1	"	0.48	2.1	36	4.6	0.018	0.019
Tarn Bay[1]	Winkles	1	"	5.1	22	390	37	0.084	0.11
Whitehaven[2]	Plaice	1	"	0.0015	0.0063	NA	0.011	0.00004	0.00005
	Cod	1	"	0.00060	0.0027	"	0.0060	ND	0.00002
	Herring	1	"	0.0045	0.022	"	0.031	"	0.00007
	Rays	1	"	0.00093	0.0045	"	0.0068	"	0.00002
	Nephrops	1	"	0.052	0.26	"	0.67	"	0.0020
	Whelks	1	"	0.20	0.99	15	1.4	"	0.0036
Parton[1]	Winkles	1	"	2.7	13	210	20	"	0.058
Roosebeck[1]	Oysters	1	"	0.29	1.4	NA	1.2	0.0031	0.0028
Haverigg[1]	Cockles	1	"	2.7	12	"	28	0.061	0.076
Millom[1]	Mussels	1	"	0.98	4.6	"	8.0	0.024	0.020
Morecambe Bay[1]	Shrimps	1	"	0.011	0.052	0.79	0.077	ND	0.00029
	Cockles	1	"	0.77	3.4	54	8.5	"	0.024
Heysham[1]	Mussels	1	"	0.23	1.1	NA	1.8	ND	0.0054
	Cockles	1	"	0.68	3.4	"	8.4	0.033	0.011
Fleetwood[2]	Cod	1	"	0.00029	0.0013	"	0.0025	ND	ND
	Plaice	1	"	0.00060	0.0030	"	0.0062	"	0.00002
	Fish meal[9]	1	"	0.0034	0.019	"	0.023	"	ND
	Whelks	1	"	0.10	0.55	7.9	0.83	"	0.0023

Table 7. Continued

Sampling area/ landing point	Sample	No. of sampling observa-tions[3]	Mean radioactivity concentration (wet), Bq kg^{-1}						
			^{237}Np	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Isle of Man[2]	Cod	1	NA	0.00016	0.00079	NA	0.0014	ND	ND
	Plaice	1	"	0.00047	0.0023	"	0.0030	"	0.00001
	Herring	1	"	0.00028	0.0013	"	0.0016	"	ND
	Scallops	1	"	0.029	0.14	"	0.045	"	"
Inner Solway[1]	Sea trout	1	"	0.00060	0.0030	"	0.0042	"	0.00001
Southerness[1]	Winkles	1	"	1.1	5.3	"	8.7	"	0.034
Kirkcudbright[2]	Plaice	1	"	0.00060	0.0031	"	0.0059	"	ND
	Scallops	1	"	0.018	0.088	"	0.034	"	"
	Queens	1	"	0.019	0.097	"	0.11	"	0.00024
North Solway coast[1]	Cockles	1	"	1.2	5.6	"	13	"	0.046
	Winkles	1	"	0.43	2.0	"	3.3	"	0.0080
Ayr[2]	Cod	1	"	0.00012	0.00059	"	0.00087	"	ND
	Plaice	1	"	0.00020	0.00096	"	0.0017	"	0.00001
Wirral[1]	Cockles	1	"	0.33	1.7	"	3.0	"	0.011
Conwy[2]	Mussels	1	"	0.046	0.22	"	0.35	"	0.00086
North Anglesey[1]	Spurdog	1	"	0.00009	0.00042	"	0.00074	"	ND
	Winkles	1	"	0.20	0.98	"	1.3	"	0.0030
Northern Ireland[2]	Whiting	1	"	0.0011	0.0058	"	0.0079	"	0.00002
	Nephrops	1	"	0.014	0.069	"	0.17	"	0.00034
	Winkles	1	"	0.052	0.25	"	0.15	"	ND
Minch[1]	Cod	1	"	0.00006	0.00035	"	0.00061	"	"
	Haddock	1	"	0.00011	0.00067	"	0.00057	"	"
	Mackerel	1	"	0.00013	0.00072	"	0.00016	"	"
	Nephrops	1	"	0.00072	0.0046	"	0.0048	"	0.00002
Shetland[1]	Fish meal[9]	1	"	0.0012	0.0085	"	0.0015	"	ND
Northern North Sea[1]	Cod	1	"	0.00007	0.00030	"	0.00036	"	0.00001
	Haddock	1	"	0.00011	0.00052	"	0.00054	"	ND
	Nephrops	1	"	0.00080	0.0038	"	0.0060	0.00015	0.00010
Mid North Sea[1]	Mussels	1	"	0.0045	0.027	"	0.0067	ND	ND
	Mussels[10]	1	"	0.00025	0.0044	"	0.0021	"	"
Southern North Sea[1]	Mussels	1	"	0.0026	0.015	"	0.0047	"	"
	Cockles	1	"	0.0020	0.0083	"	0.0094	"	0.00091
	Cockles[11]	1	"	0.0018	0.0062	"	0.0065	"	0.00051
Icelandic processed	Cod	1	"	0.00005	0.00024	"	0.00022	"	ND

ND = not detected
NA = not analysed
1 Sampling area
2 Landing point
3 See sub-section 3.3 for definition
4 Samples collected by Consumer 116
5 Samples collected by Consumer 460
6 Samples collected by Consumer 311
7 Samples provided by Fisherman A
8 Samples provided by Fisherman B
9 Concentrations refer to weight as supplied
10 Landed in Denmark
11 Landed in The Netherlands

Table 8(a). Individual radiation exposures due to consumption of Irish Sea fish and shellfish, 1990

Exposed population	Consumption rate used in assessment (see text), kg year^{-1}		Nuclide	Exposure, mSv	
				ICRP-26*	ICRP-60#
Consumers in local fishing community	Fish (plaice and cod):	37	^{90}Sr	0.004	0.003
	Crustaceans (crabs and lobsters):	6.0	^{106}Ru	0.005	0.008
	Molluscs (winkles):	8.3	^{137}Cs	0.015	0.015
			^{238}Pu	0.007	0.004
			$^{239+240}Pu$	0.034	0.021
			^{241}Pu	0.012	0.007
			^{241}Am	0.075	0.045
			Total	0.16	0.11
Consumers associated with commercial fisheries: Whitehaven	Fish (plaice and cod):	49	^{99}Tc	0.002	0.004
	Crustaceans (*Nephrops*):	11	^{137}Cs	0.013	0.013
	Molluscs (whelks):	6	$^{239+240}Pu$	0.004	0.003
			^{241}Am	0.008	0.005
			Total	0.03	0.03
Consumers in Morecambe Bay area	Fish (flounders and plaice):	54	^{137}Cs	0.035	0.035
	Crustaceans (shrimps):	21	$^{239+240}Pu$	0.025	0.014
	Molluscs (cockles and mussels):	23	^{241}Am	0.056	0.033
			Total	0.14	0.10
Consumers associated with commercial fisheries: Fleetwood	Fish (plaice and cod):	82	^{137}Cs	0.023	0.023
	Crustaceans (shrimps):	17	$^{239+240}Pu$	0.022	0.013
	Molluscs (cockles and whelks)	23	^{241}Am	0.053	0.031
			Total	0.11	0.08
Typical member of the fish-eating public consuming fish landed at Whitehaven/Fleetwood	Fish (plaice and cod):	15	^{137}Cs	0.003	0.003
			Total	0.004	0.004

* *Committed effective dose equivalent for comparison with current dose limits and criteria*
 # Committed effective dose calculated using methodology of ICRP-60

Table 8(a) summarises exposures in 1990, calculated on two bases (sub-section 3.4). For each exposed group, the committed effective dose equivalent is given using the existing methodology of ICRP-26, compared with results for committed effective dose calculated on the basis of ICRP-60's dose coefficients (Appendix 2 of this report). In both cases, the contributions of individual radionuclides are given; for simplicity, only the more important of these are listed. Hence, it is not to be expected that the sums of the listed contributions will necessarily equal the totals presented. Both methods of calculation use accepted values for gut transfer factors of transuranics (i.e. 0.0002 for winkles near Sellafield, 0.0005 in other cases) (Hunt *et al.*, 1990; NRPB, 1990). On the basis of ICRP-26, the committed effective dose equivalent to the local critical group in 1990 was 0.16 mSv. This represents a small reduction from 0.19 mSv reported on the same basis for 1989 (Hunt, 1990), mainly due to decreases noted above in the concentrations of ruthenium-106 and transuranics in shellfish. These committed effective dose equivalents, on the basis of ICRP-26, are within the ICRP-recommended principal dose limit for members of the public of 1 mSv year^{-1}.

Continuing with ICRP-26 methodology, the exposure of the critical group has also been considered in comparison with the recommendation on lifetime exposure (sub-section 3.4). In 1990, and in recent previous years, realistically-assessed exposures were within the principal dose limit of 1 mSv year^{-1}. For a few years prior to this, exposures were in excess of 1 mSv year^{-1} but within the ICRP-recommended subsidiary dose limit of 5 mSv year^{-1}. There has been an overall decline in concentrations of radiologically significant nuclides in environmental materials as a result of reduced discharges; consumption rates of shellfish would need to increase substantially for exposures to exceed the principal dose limit. These exposures are now considered likely to remain below the 1 mSv year^{-1} level, and dose rates above this level have not occurred for long enough for lifetime exposures to have exceeded, on average, 1 mSv year^{-1}. This statement takes account of predicted exposures from future discharges (Hunt, 1986).

The recommendations of ICRP-60 have not yet been adopted by the UK Government, but their effects are considered here to provide up-to-date information and as an aid to further study of the implications of these recommendations. The committed effective dose to the local critical group in 1990 was 0.11 mSv. Differences for individual radionuclides, from the ICRP-26 calculation, reflect the revised tissue weighting factors, which give, for example, increased exposures for ruthenium-106 but reductions for the transuranic nuclides. Using ICRP-60 methodology, this committed effective dose should not strictly be compared directly with the dose limit for a practice of 1 mSv year^{-1}, because a significant contribution is due to the effects of radioactivity already in the environment, which can only be subject to intervention. However, as discussed in sub-section 3.4, we are considering whether it would be appropriate to use 1 mSv year^{-1} as a level against which to compare the combined effects of current and past discharges, calculated using ICRP-60 dose coefficients. If this level were exceeded, then intervention might need to be considered. In 1990, the committed effective dose to the local criticial group of 0.11 mSv was substantially less than this 1 mSv intervention level.

In addition, to aid consideration of ICRP-60 in relation to practices, we have calculated the exposure of the local group of seafood consumers due to discharges during 1990. A predictive model, based on environmental monitoring data taking account of discharge rates, has been used (Hunt and Marshall, 1989). The results are shown in Table 8(b); the total committed effective dose was 0.03 mSv. This dose is likely to be relevant for comparison with the dose constraint for practices, currently under consideration (section 3.4), but it is well within the ICRP-recommended dose limit for practices of 1 mSv year^{-1}. It is also a small fraction of the dose received in 1990 due to the combined effects of past and current discharges.

Table 8(b). Exposure of fish and shellfish consumers near Sellafield, due to discharges in 1990, for comparison with the ICRP-60 dose limit

Nuclide	Committed effective dose*, mSv year^{-1}
^{90}Sr	0.001
^{106}Ru	0.013
^{137}Cs	0.004
^{238}Pu	0.001
$^{239+240}Pu$	0.003
^{241}Pu	0.002
^{241}Am	0.002
Total#	0.03

** On the basis of a gut transfer factor of 0.0002 for Pu and Am in molluscs (see text)*
 # Includes the small effect of other nuclides

Consumption rates in the wider fishing communities of Cumbria and northern Lancashire have been kept under review. Consumption rates of groups associated with commercial fisheries in Whitehaven, Fleetwood and the Morecambe Bay area are given in Table 8(a), together with the species whose radioactivity concentrations, following the information from habits surveys, formed the basis of the assessments. Because high-rate consumers in all areas may eat both fish and shellfish, the critical groups have been defined by the maximising procedure of summing exposures due to the component consumption rates. The committed effective dose equivalents (ICRP-26) received by the groups are given in Table 8(a). The results for Whitehaven were less than those for Morecambe Bay or Fleetwood, mainly because of lower consumption rates and radioactivity concentrations in molluscs. In comparison with the results for 1989, on the basis of the appropriate gut transfer factor, the committed effective dose equivalents to the groups at Whitehaven and Fleetwood were the same in 1990 (0.03 mSv and 0.11 mSv respectively) and in the Morecambe Bay area were slightly less in 1990 (0.14 mSv compared with 0.15 mSv in 1989). Doses were well within the ICRP-recommended principal dose limit for members of the public of 1 mSv year^{-1}.

The committed effective dose equivalent, appropriate to a consumption rate of 15 kg year^{-1} of fish from landings at Whitehaven and Fleetwood, is also given in Table 8(a). This consumption rate represents an average for typical fish-eating members of the public. The committed effective dose equivalent in 1990 was 0.004 mSv, the same as that for 1989 (Hunt, 1990).

Comparison of the exposures reported in Table 8(a) with those due to ingestion of natural polonium-210 in fish and shellfish is of interest. For the high consumption rate groups, dose rates of about 0.3 mSv year^{-1} could be received (Rollo *et al.*, in press). The exposures reported here may also be compared with the average dose of approximately 2.2 mSv year^{-1} to members of the UK public from all natural sources of radiation (Hughes *et al.*, 1988).

Collective doses, received during 1990 from consumption of fish and shellfish, have been estimated for the UK and other European countries. In general, the method used has been to combine data on actual fish and shellfish landings from relevant sea areas with average radioactivity concentrations in fish and shellfish caught in these areas. This method differs from that based on modelling of water movements and a (usually) fixed catch rate for different sea areas; this modelling method generally derives the collective dose to be received over a number of years as a result of discharges during the year under review, and the results are not readily comparable with those based on the present method. Sea areas considered in this assessment include the Irish Sea, Scottish waters, the North Sea, Baltic Sea, Norwegian Sea, Spitzbergen/ Bear Island area and the Barents Sea. Corrections have been made for the fraction of fish or shellfish consumed. The contribution of weapons-test fallout to the radioactivity concentrations has been 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, poultry and farm-reared fish. Consumption of food products from these animals gives rise to a small contribution to the collective dose, and this has been included. The results are presented in Table 9. The results for 1990 are preliminary, being based on landings statistics provided by the International Council for the Exploration of the Sea (ICES); where data are not yet available, the previous year's data have been used. The doses have been calculated using both ICRP-26 and ICRP-60 methodology. ICRP-60 doses are slightly less than those of ICRP-26, due to reductions in dosimetric factors for transuranics. Further discussion in this section refers to the ICRP-26 data. Results for 1989 have been revised to take account of updated landings statistics and an improved assessment of concentrations in areas remote from Sellafield. The preliminary result of 20 man-Sv for the UK in 1989, given in the previous report (Hunt, 1990), has been reduced to 13 man-Sv on this basis; the result for other European countries has been increased from 30 to 45 man-Sv.

Liquid radioactive waste discharges from Sellafield up to the end of 1990 are the main source of collective dose reported in Table 9; by comparison, the effect of liquid discharges from other establishments is very small. The small contribution due to fallout from the Chernobyl reactor accident to the Irish Sea, Scottish waters and the North Sea has been included. Most of the collective dose is due to radiocaesium in edible fish; the contribution due to shellfish is generally minor. Also relatively small is the contribution, again mainly from radiocaesium, due to fish offal and industrial fisheries (Hunt and Jefferies, 1981). Other radionuclides which contribute to the collective dose, but in even smaller proportions, are strontium-90, through both fish and shellfish, and the transuranics, mainly through shellfish. It should be noted that for transuranics the doses per unit intake allow for the long body half-times, so that the small contributions estimated for the transuranics are committed in the future rather than already received (sub-section 3.4). The contribution of pathways other than fish and shellfish consumption (e.g. external exposure) to the collective dose from Sellafield liquid discharges is relatively small (Hunt and Jefferies, 1981).

The preliminary results for 1990, of 10 man-Sv for the UK and 39 man-Sv for other European countries, are less than the results now reported for 1989. The reduction is due to changes in concentrations of radio-

Table 9. Collective doses from fish and shellfish, 1989 and 1990[a]

Population	Collective dose, man-Sv			
	ICRP-26*		ICRP-60#	
	1989	1990[a]	1989	1990[a]
UK	13	10	12	9
Other European countries	45	39	44	38

** Committed effective dose equivalent for use with current system of dose limitation*

 # Committed effective dose calculated using methodology of ICRP-60

[a] Preliminary data

caesium in fish. It has not been possible to derive a direct estimate of the Chernobyl contribution in coastal seas around the UK for 1990; however, based on the contribution estimated in the past, in 1990 this would have amounted to less than 10% of the totals for the UK population and for other countries, excluding the effect of fish from the Baltic Sea. On the basis of concentrations of radioactivity, due to the effects of the Chernobyl accident, in fish from the Baltic Sea (Ilus *et al.*, in press; Aarkrog *et al.*, 1991), it is estimated that the collective dose to other European countries, from consumption of Baltic Sea fish could have been as much as 150 man-Sv in both 1989 and 1990.

The collective dose for the UK, given in Table 9, may be compared on a *per caput* basis with the annual dose equivalent, averaged over the population, of 2.2 mSv due to natural background radiation (see sub-section 3.4). In 1990, the preliminary UK collective dose through the fish and shellfish pathway as a result of liquid radioactive waste disposal operations amounted to less than 0.01% of this level.

4.1.2 External exposure

A further important pathway leading to radiation exposure as a result of Sellafield discharges derives from uptake of gamma-emitting radionuclides by intertidal sediments in areas frequented by the public. In general, it is the fine-grained muds and silts prevalent in estuaries and harbours, rather than the coarser-grained sands to be found on open beaches, which adsorb the radioactivity more readily. Gamma dose rates currently observed are mainly due to radiocaesium.

We regularly monitor a range of coastal locations, both in the Sellafield vicinity and further afield, using portable gamma-radiation dosemeters. Locations are chosen on account of both dose rates themselves and levels of occupancy by members of the public. Table 10 lists the locations monitored together with the dose

Table 10. Gamma radiation dose rates over intertidal areas of the Cumbrian coast and further afield, 1990

Location	Ground type	No. of sampling observa-tions#	Mean gamma dose rate in air at 1m, μGy h^{-1}
Cumbria			
Burgh marsh	Salt marsh	4	0.098
Greenend	" "	4	0.097
"	Muddy sand	4	0.078
Siddick	Sand	4	0.078
Silloth - outer harbour	Mud	1	0.13
" - silt pond	"	1	0.24
Maryport Christchurch	"	4	0.13
Workington harbour	"	4	0.19
Harrington harbour	"	4	0.19
Whitehaven outer harbour	Muddy sand	12	0.15
" " "	Coal/sand	12	0.14
" inner "	Sandy mud	12	0.22
" yacht basin	Mud	12	0.32
St Bees	Sand	4	0.073
Nethertown winkle beds	Rock	4	0.12
Sellafield	Sand	4	0.087
Seascale	"	4	0.086
Drigg pipeline	"	4	0.076
" beach	"	4	0.073
" Barn Scar	Mussel bed	4	0.10
Ravenglass - salmon garth	Sandy mud	5	0.17
" " "	Sand/stones	3	0.10
" " "	Mussel bed	4	0.11
" - boats area	Sandy mud	12	0.13
" " "	Sand	4	0.074
" - ford area	Sandy mud	4	0.15
" - Ravenvilla	Mud	3	0.18
" "	Sandy mud	9	0.18
" "	Salt marsh	12	0.35
" - Eskmeals	" "	4	0.35
" - Muncaster Flooded Pasture	" "	4	0.28
Newbiggin	Sandy mud	4	0.29
"	Salt marsh	4	0.41
" - west of bridge	Sandy mud	4	0.16
" " " "	Salt marsh	4	0.39
Haverigg	Mud	4	0.12
"	Sandy mud	4	0.070
Millom	" "	4	0.11
Tummer Hill Marsh	Salt marsh	4	0.24
Walney Channel	Sandy mud	4	0.13
" Vickers shore	" "	4	0.099
" west shore	Sand	4	0.062
Low Shaw	Salt marsh	4	0.14
Flookburgh	Sandy mud	4	0.10
Lancashire, Merseyside and North Wales			
Jenny Brown's Point	Salt marsh	4	0.090
Sunderland Point	Sandy mud	4	0.11
Sunderland	Mud/sand/stones	4	0.085
Colloway	Salt marsh	4	0.21
Skirton Weir	Mud	2	0.11
Skippool	"	4	0.14
Fleetwood	Sand	4	0.070
Blackpool	"	4	0.057
Lytham Creek	Mud	4	0.14
Freckleton	"	4	0.15
Becconsall	Mud	4	0.16
Ainsdale	Sand	4	0.057
New Brighton	"	4	0.067
Mersey (Rock Ferry)	Mud	4	0.13
Llandudno	Shingle	4	0.083
Prestatyn	Sand	4	0.054
South-west Scotland			
Garlieston	Sandy mud	4	0.096
Innerwell	Mud	4	0.11
Kippford - slipway	"	4	0.10
" - jetty	Sandy mud	4	0.090
" - merse	Salt marsh	4	0.18
Palnackie harbour	Mud	4	0.13
Carsethorn	Sandy mud	4	0.11

 # See sub-section 3.3 for definition

Table 11. Radioactivity in sediment from the Cumbrian coast and further afield, 1990

Sampling point and sediment type		No. of sampling observa-tions#	Mean radioactivity concentration (dry), $Bq\ kg^{-1}$								
			Total beta	^{60}Co	^{95}Zr	^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
Cumbria											
Silloth outer harbour	(mud)	1	NA	4.3	ND	ND	42	ND	2.3	470	ND
" silt pond	(")	1	"	15	3.1	2.5	130	12	16	1800	12
Maryport harbour	(")	4	3500	18	51	69	480	22	8.3	1000	63
Workington harbour	(")	2	3400	15	19	33	270	13	9.8	1300	36
Harrington	(")	4	3000	16	31	34	310	18	7.0	800	37
Whitehaven	(")	4	5500	19	50	62	380	22	12	1500	58
St Bees	(sand)	4	470	3.1	ND	ND	4.1	ND	0.5	120	ND
Sellafield	(")	4	580	3.7	1.7	"	11	0.8	1.4	230	1.7
Seascale	(")	4	680	2.9	5.5	"	7.9	ND	0.2	150	ND
Drigg	(")	4	590	3.4	ND	"	13	0.4	0.2	100	1.6
Ravenglass-Ravenvilla	(sandy mud)	4	2000	17	27	51	350	22	4.2	650	51
Newbiggin	(mud)	4	2700	30	21	ND	440	25	6.8	970	40
Millom	(sandy mud)	4	1500	9.1	25	27	280	11	2.6	510	30
Walney Island	(mud)	4	1700	9.2	46	51	290	16	2.8	550	36
Walney Road Bridge	(sandy mud)	1	2400	15	71	70	550	26	3.6	590	70
Low Shaw	(turf)	4	1800	6.5	ND	ND	61	3.1	31	1100	ND
Flookburgh	(muddy sand)	4	700	0.4	"	"	2.8	1.4	0.9	190	"
Lancashire and Merseyside											
Heysham	(mud)	4	1500	5.6	4.5	2.2	69	12	3.3	510	3.8
Sunderland Pt	(")	4	1200	2.7	1.9	0.6	34	4.1	2.3	370	ND
Skippool Creek	(")	4	2200	9.2	3.3	2.5	71	8.3	8.2	1000	"
Fleetwood	(sand)	4	320	ND	ND	ND	ND	0.2	0.4	41	"
Blackpool	(")	4	240	"	"	"	"	ND	ND	16	"
New Brighton	(")	4	230	"	"	"	"	"	"	12	"
Rock Ferry	(mud)	4	1500	1.4	"	"	"	1.2	3.7	600	"
Isle of Man	(")	1	850	ND	"	"	"	2.8	9.4	130	"
"	(sand)	1	520	"	"	"	"	ND	ND	17	"
South-west Scotland											
Garlieston	(mud)	4	1500	7.9	7.0	6.5	92	4.2	6.8	490	9.9
Innerwell	(")	2	900	5.4	ND	ND	45	ND	4.6	290	3.6
Kippford slipway	(")	4	1200	5.3	1.9	"	60	3.9	3.6	420	ND
Kippford merse	(marsh)	4	2400	19	4.4	"	150	2.4	12	1000	11
Palnackie	(mud)	4	1400	6.0	ND	"	66	1.8	4.1	550	3.6
Carsethorn	(")	1	1100	4.0	"	"	41	ND	3.1	360	ND
"	(muddy sand)	1	590	1.9	"	"	9.1	"	1.1	170	"
Northern Ireland											
Strangford Lough*	(mud)	2	710	ND	"	"	ND	ND	1.5	83	"
Strangford Lough**	(")	1	600	"	"	"	"	"	ND	39	"
Groomsport	(sand)	2	260	"	"	"	"	"	"	12	"
Carlingford Lough	(mud)	2	1000	"	"	"	3.9	"	3.7	160	"
Dundrum Bay	(sandy mud)	2	680	"	"	"	ND	"	ND	16	"
Larne Lough	(mud)	2	820	"	"	"	"	"	3.2	180	"
Lough Foyle	(")	2	590	"	"	"	"	"	ND	4.7	"
Belfast Lough	(")	2	500	"	"	"	"	"	1.4	71	"

Table 11. Continued

Sampling point and sediment type		No. of sampling observa-tions#	Mean radioactivity concentration (dry), Bq kg^{-1}							
			^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Cumbria										
Silloth outer harbour	(mud)	1	6.9	8.5	NA	NA	NA	210	NA	NA
" silt pond	(")	1	18	12	"	"	"	750	"	"
Maryport harbour	(")	4	29	15	140	680	"	1000	ND	1.9
Workington harbour	(")	2	30	15	NA	NA	"	920	NA	NA
Harrington	(")	4	20	14	"	"	"	670	"	"
Whitehaven	(")	4	31	20	150	740	"	1100	2.9	2.8
St Bees	(sand)	4	3.7	2.3	NA	NA	"	140	NA	NA
Sellafield	(")	4	6.9	3.2	"	"	"	250	"	"
Seascale	(")	4	5.7	3.4	"	"	"	190	"	"
Drigg	(")	4	7.3	3.7	"	"	"	250	"	"
Ravenglass-Ravenvilla	(sandy mud)	4	28	13	"	"	"	990	"	"
Newbiggin	(mud)	4	40	25	240	1000	17000	1400	3.6	3.2
Millom	(sandy mud)	4	16	8.1	NA	NA	NA	510	NA	NA
Walney Island	(mud)	4	17	10	"	"	"	560	"	"
Walney Road Bridge	(sandy mud)	1	24	19	"	"	"	710	"	"
Low Shaw	(turf)	4	18	7.3	"	"	"	450	"	"
Flookburgh	(muddy sand)	4	0.5	1.2	"	"	"	45	"	"
Lancashire and Merseyside										
Heysham	(mud)	4	6.9	5.5	35	170	"	260	ND	1.0
Sunderland Pt	(")	4	3.1	4.3	NA	NA	"	120	NA	NA
Skippool Creek	(")	4	11	7.6	"	"	"	340	"	"
Fleetwood	(sand)	4	ND	ND	"	"	"	12	"	"
Blackpool	(")	4	"	"	"	"	"	3.5	"	"
New Brighton	(")	4	"	"	"	"	"	0.7	"	"
Rock Ferry	(mud)	4	1.5	2.5	"	"	"	130	"	"
Isle of Man	(")	1	ND	3.6	"	"	"	ND	"	"
"	(sand)	1	"	1.8	"	"	"	1.8	"	"
South-west Scotland										
Garlieston	(mud)	4	11	7.4	44	210	"	320	1.1	1.0
Innerwell	(")	2	7.0	3.8	NA	NA	"	160	NA	NA
Kippford slipway	(")	4	7.7	4.6	36	180	"	270	ND	0.75
Kippford merse	(marsh)	4	15	9.7	85	430	"	620	1.8	2.4
Palnackie	(mud)	4	11	8.1	42	200	"	300	ND	0.46
Carsethorn	(")	1	ND	10	NA	NA	"	130	NA	NA
"	(muddy sand)	1	"	4.4	"	"	"	53	"	"
Northern Ireland										
Strangford Lough*	(mud)	2	"	ND	1.8	9.5	"	8.0	ND	0.017
Strangford Lough**	(")	1	"	1.4	0.47	2.5	"	1.4	"	0.0040
Groomsport	(sand)	2	"	ND	NA	NA	"	ND	"	NA
Carlingford Lough	(mud)	2	"	1.3	2.3	13	"	6.8	"	0.021
Dundrum Bay	(sandy mud)	2	"	ND	NA	NA	"	ND	"	NA
Larne Lough	(mud)	2	"	1.3	"	"	"	12	"	"
Lough Foyle	(")	2	"	1.8	0.024	0.18	"	0.19	"	ND
Belfast Lough	(")	2	"	ND	2.7	14	"	18	"	0.033

NA = not analysed
ND = not detected
** Nickey's Point*
*** Island Hill*
 # See sub-section 3.3 for definition

rates in air at 1 m above ground level. Monitoring in Scotland is carried out on behalf of the departments of the Scottish Office. Dose rates on Irish Sea shorelines, near other nuclear establishments which reflect Sellafield discharges, are given later in this report (see sub-sections 4.2, 4.3, 4.4, 6.5, 6.11). Variations in sediment type account for the quite marked fluctuations in dose rate, superimposed on a general decrease with increasing distance from Sellafield. Dose rates over intertidal areas in 1990 showed general reductions as compared with those in 1989 (Hunt, 1990).

We also regularly monitor radioactivity concentrations in sediments, 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 11. Variations similar in cause to those of the dose rates are observed, and comparison with results for 1989 (Hunt, 1990) shows general reductions in line with the behaviour of dose rates.

To identify those members of the public subject to the highest external exposures, occupancies of different locations need to be considered. We keep under review the amounts of time spent by members of the public on intertidal areas of coastline bordering the north-eastern Irish Sea; activities leading to significant external exposures are sparse and our surveys cover a wide area including Cumbria, Lancashire (Doddington *et al.*, 1990) and the north Solway coast (Doddington *et al.*, 1989). In western Cumbria, combining dose rates and occupancy times, the maximum external exposure in 1990 was 0.067 mSv, with no need for the addition of dose due to fish and shellfish consumption. In the wider area, including Cumbria, Lancashire and the north Solway coast, on the basis of dose rates and occupancy times, it is considered that persons who live on board boats in the Ribble estuary are representative of those who receive the highest external exposures from the effects of discharges from Sellafield (see sub-section 4.2). Their occupancy of boats in 1990 was similar to that in 1989. Making an allowance for natural background, their external exposure in 1990 was 0.18 mSv, which is not significantly different from that in 1989 (0.17 mSv). The exposure was within the ICRP-recommended principal dose limit of 1 mSv year^{-1} for members of the public. Additional exposure of these people, due to consumption of fish and shellfish and handling of fishing gear, was negligible. Most of the external exposure of the houseboat dwellers was due to the radioactivity already in the environment as a result of past discharges from Sellafield. Exposures of these houseboat dwellers due to Springfields discharges are considered in sub-section 4.2.

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

It is to be noted that the levels of radionuclide concentrations in sediments (shown in Table 11) give rise to only very minor radiation exposures to the public following inhalation of resuspended particulates, including those from the surf zone (Pattenden *et al.*, 1981).

Table 12. Beta radiation dose rates on contact with fishing gear on vessels operating off Sellafield, 1990

Vessel	Type of gear	No. of sampling observations#	Mean beta dose rate in tissue, µSv h^{-1}
A	Nets	4	0.22
	Ropes	4	ND
B	Nets	8	0.39
	Ropes	8	0.26
D	Gill nets	2	0.28
	Pots	3	0.39
	Ropes	1	ND
E	Nets	3	0.37
	Gill nets	4	0.3
J	Gill nets	1	0.22
	Pots	1	0.33
M	Nets	4	0.22
	Ropes	4	0.22
Q	Gill nets	3	0.55
R	Nets	3	0.22

 # See sub-section 3.3 for definition
ND = not detected

4.1.3 Fishing gear

During immersion in sea water, fishing gear may entrain particles of sediment on which radioactivity is adsorbed. Fishermen handling this gear may be exposed to external radiation, mainly to skin from beta particles. We regularly monitor fishing gear using portable beta dosemeters. Results for 1990 are presented in Table 12. Revised dose rate conversion factors were used in 1990 as compared with 1989, and measured dose rates were higher as a consequence. Our habits surveys keep under review the amounts of time spent by fishermen handling their gear; for those most exposed, 500 h year^{-1} is appropriate. The maximum exposure from handling of fishing gear in 1990 would have been 0.12 mSv, which is well within 1% of the ICRP-recommended dose limit appropriate for exposures to skin of members of the public, based on non-stochastic (deterministic) effects (sub-section 3.4). Handling of fishing gear therefore continues to be a minor radiation exposure pathway.

Table 13. Radioactivity in Porphyra from UK shorelines of the Irish Sea, 1990

Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet), Bq kg^{-1}										
		Total beta	^{14}C	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{99}Tc	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb
Braystones South	4	380	NA	0.9	NA	0.4	0.5	NA	0.6	150	2.7	4.0
Seascale	53*	NA	"	1.0	"	0.7	0.8	"	0.6	98	ND	4.3
St Bees	4	260	18	0.6	0.42	1.2	0.8	0.94	0.4	93	0.2	4.2
Knock Bay	4	200	NA	ND	NA	ND	ND	NA	ND	0.5	ND	ND

Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet), Bq kg^{-1}									
		^{134}Cs	^{137}Cs	^{144}Ce	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Pu	^{241}Am	^{242}Cm	$^{243}Cm+^{244}Cm$
Braystones South	4	ND	9.8	ND	0.1	2.0	9.6	150	15	0.012	0.042
Seascale	53*	0.01	10	0.6	ND	NA	NA	NA	13	NA	NA
St Bees	4	ND	4.4	0.7	0.2	0.90	4.2	70	7.6	0.015	0.020
Knock Bay	4	ND	0.9	ND	ND	NA	NA	NA	0.12	NA	NA

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

Table 14. Radioactivity in laverbread from South Wales, 1990

Manufacturer	No. of sampling observations#	Mean radioactivity concentration (wet), Bq kg^{-1}			
		Total beta	^{60}Co	^{137}Cs	^{241}Am
A	4	75	ND	0.4	ND
C	4	52	0.1	0.6	0.2
D	4	53	ND	0.5	0.2
E	1	55	"	0.3	ND

ND = not detected
 # See sub-section 3.3 for definition

Table 15. Summary of contact beta and gamma dose rate monitoring of intertidal areas of Cumbria, 1990

Month	No. of items detected (> 0.01 mGy h^{-1} but below 0.1 mGy h^{-1})	Locations and dose rates (mGy h^{-1}) of items 0.1 mGy h^{-1} and above
January	1	-
February	-	-
March	3	-
April	-	-
May	-	-
June	-	-
July	-	-
August	1	-
September	-	
October	2	-
November	-	Ehen Spit: 0.18
December	1	-

4.1.4 Porphyra/laverbread pathway

No harvesting of *Porphyra* in the Sellafield vicinity, for consumption after being made into laverbread, was reported in 1990; this pathway has therefore remained essentially dormant. However, monitoring has continued in view of its potential importance and the value of *Porphyra* as an indicator material. Samples of *Porphyra* are regularly collected from selected locations along UK shorelines of the Irish Sea. Results of analyses for 1990 are presented in Table 13. Samples of laverbread from the major manufacturers are regularly collected from markets in South Wales and analysed. Results for 1990 are presented in Table 14. The exposure of critical laverbread consumers was 0.005 mSv, confirming the virtual abeyance of this exposure pathway.

4.1.5 Contact dose-rate monitoring of intertidal areas

We regularly monitor contact beta and gamma dose rates in intertidal areas to locate and remove any material with unusual levels of contamination. A summary of items detected during 1990 is presented in Table 15. The rate of detection has continued to decline. The presence of contaminated items only represents a pathway for exposure of the public in the unlikely event of prolonged contact with them. The ICRP-26 standard, with which to compare the dose rates, is the recommended dose limit of 50 mSv $year^{-1}$ for exposures to skin of members of the public (sub-section 3.4). It is not considered likely that anyone has received a dose to skin in excess of this limit.

4.1.6 *Other surveys*

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

Seaweeds are useful indicator materials; they may concentrate certain radionuclides, so they greatly facilitate measurement and assist in the tracing of these radionuclides in the environment. Table 16 presents the results of measurements in 1990 on marine plants from shorelines of the Irish Sea and further afield. Although small quantities of samphire and *Rhodymenia* may be eaten, concentrations of radioactivity are of negligible radiological significance. *Fucus* seaweeds are useful indicators, particularly of fission product radionuclides other than ruthenium-106; samples of *Fucus vesiculosus* are collected both in the Sellafield vicinity and further afield, and the results are presented here. Monitoring in Scotland is carried out on behalf of departments of the Scottish Office. Analyses of samples collected in Northern Ireland are carried out on behalf of the DOE(NI).

4.2 Springfields, Lancashire

This establishment is mainly concerned with the manufacture of fuel elements for nuclear reactors and the production of uranium hexafluoride. Radioactive waste arisings are of low radiological significance, consisting mainly of thorium and uranium and their decay products; liquid discharges are made by pipeline to the Ribble estuary. Public radiation exposure in this vicinity, as a result of these discharges, is very low; there is, however, a greater contribution due to Sellafield discharges. The critical pathway is external exposure, due to adsorption of radioactivity on the muddy areas of river banks. The amounts of time for which members of the public are subject to such exposure is kept under review. The critical group consists of people who live on houseboats moored in muddy creeks of the Ribble estuary, and is the same group which is affected by discharges from Sellafield (sub-section 4.1.2). We regularly monitor dose rates in relevant areas including muddy creeks where houseboats are moored, and some of these measurements are supported by analyses of sediments. In 1990, we continued to investigate the fish and shellfish consumption pathway by analysing locally-obtained samples, including analyses for isotopes of thorium.

Results for 1990 are shown in Table 17(a) and (b). Radionuclides detected, which were due to Springfields discharges, were isotopes of thorium, uranium and neptunium and their decay products. Other radionuclides present were mainly from Sellafield. The concentrations of these radionuclides in environmental materials were of low radiological significance; in particular, the relatively high concentrations of thorium-234 do not give rise to significant exposures, because of the low radioactivity of this nuclide. Concentrations of thorium isotopes in fish from the Ribble estuary were not significantly different from those expected from natural sources. Any exposures due to Springfields-derived radionuclides in shellfish would have been a small fraction of the total, most of which is due to Sellafield discharges, as considered in sub-section 4.1.1. The concentrations of thorium isotopes in mud in areas outside the Ribble estuary were consistent with natural sources, as were concentrations of thorium isotopes in sand.

Gamma dose rates over intertidal areas were similar to those for 1989. Exposure of the critical group of houseboat dwellers in 1990, including the Sellafield component, was 0.18 mSv which is not significantly different from the value for 1989. The exposure was within the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$ for members of the public. Most of this exposure was due to the radioactivity already in the environment as a result of past discharges from Sellafield. To help the process of interpreting the ICRP-60 recommendations, the contribution due to discharges in 1990 from Springfields has been calculated from appropriate models (HMIP and MAFF, 1991). The contribution is estimated to be 0.02 mSv. This dose is likely to be relevant for comparison with the dose constraint for practices, currently under consideration (section 3.4), but it is well within the ICRP-recommended dose limit for practices of 1 mSv $year^{-1}$. It is also a small fraction of the dose received in 1990 due to the combined effects of past and current discharges.

Monitoring of fishing gear was carried out using portable beta dosemeters. Results for 1990 are shown in Table 17(b). It is estimated that the maximum exposure to skin of fishermen due to handling nets was 0.60 mSv, which is less than 2% of the ICRP-recommended dose limit appropriate for exposures to skin of members of the public.

Table 16. Radioactivity in marine plants from shorelines of the Irish Sea and further afield, 1990

Type of seaweed and sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet), Bq kg^{-1}										
		Total beta	^{14}C	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{99}Tc	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs
Fucus vesiculosus												
Sellafield	4	1500	NA	3.4	2.3	2.1	ND	1500	21	2.7	5.3	0.6
St Bees	4	1000	23	2.0	1.8	1.7	0.9	850	10	1.3	3.4	0.3
Heysham	4	460	NA	0.5	NA	ND	ND	NA	0.2	ND	1.5	0.3
Port William	4	320	"	0.2	"	"	"	"	ND	"	ND	0.2
Garlieston	4	380	"	1.1	"	0.09	0.1	"	1.7	"	0.8	0.1
Auchencairn	4	410	"	1.0	"	ND	ND	"	0.4	"	0.7	0.3
Cape Wrath	1	290	"	ND	"	"	"	"	ND	"	ND	ND
Wick	1	250	"	"	"	"	"	"	"	"	"	"
Ardglass	1	440	"	"	"	"	"	"	"	"	"	"
Portrush	4	220	"	"	"	"	"	"	"	"	"	"
Porthmadog	2	130	"	"	"	"	"	"	"	"	0.2	0.1
Fishguard	1	280	"	"	"	"	"	"	"	"	ND	ND
Lavernock Point	1	250	"	"	"		"	"	"	"	"	"
Scilly Isles	2	130	"	"	"	"	"	"	"	"	"	"
Grimsby	1	250	"	"	"	"	"	"	"	"	"	0.1
Fucus spiralis												
St Bees	1	NA	11	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ardglass	2	260	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND
Samphire												
Ravenglass	1	36	"	"	"	"	"	"	"	"	"	"
Heysham	1	53	"	"	"	"	"	"	0.9	"	"	0.06
Rhodymenia												
St Bees	2	620	"	0.7	"	3.7	"	"	110	0.5	1.8	0.9
Strangford Lough	4	750	"	0.4	"	ND	"	"	ND	ND	ND	ND
Laminaria digitata												
Isle of Man	1	61	"	ND	"	"	"	"	"	"	"	"
Alaria esculenta												
Isle of Man	3	330	"	"	"	"	"	"	"	"	"	"

Type of seaweed and sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet), Bq kg^{-1}									
		^{137}Cs	^{144}Ce	^{147}Pm	^{154}Eu	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm+^{244}Cm$
Fucus vesiculosus											
Sellafield	4	26	ND	2.9	ND	ND	3.9	17	7.0	0.021	0.017
St Bees	4	21	"	NA	"	0.04	2.1	9.5	5.2	0.024	0.016
Heysham	4	23	"	"	"	ND	NA	NA	1.3	NA	NA
Port William	4	5.4	"	"	"	"	"	"	0.17	"	"
Garlieston	4	13	"	"	"	"	"	"	5.7	"	"
Auchencairn	4	20	"	"	"	"	"	"	4.0	"	"
Cape Wrath	1	0.9	"	"	"	"	"	"	ND	"	"
Wick	1	0.8	"	"	"	"	"	"	"	"	"
Ardglass	1	5.2	"	"	"	"	"	"	"	"	"
Portrush	4	0.6	"	"	"	"	"	"	"	"	"
Porthmadog	2	1.2	"	"	"	0.07	"	"	"	"	"
Fishguard	1	0.9	"	"	"	0.8	"	"	"	"	"
Lavernock Point	1	0.7	"	"	"	0.2	"	"	"	"	"
Scilly Isles	2	0.1	"	"	"	ND	"	"	"	"	"
Grimsby	1	1.6	"	"	"	0.2	"	"	"	"	"
Fucus spiralis											
St Bees	1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ardglass	2	2.7	ND	ND	ND	ND	ND	ND	ND	ND	ND
Samphire											
Ravenglass	1	6.8	"	"	"	"	"	"	0.70	"	"
Heysham	1	7.4	"	"	"	"	"	"	2.5	"	"
Rhodymenia											
St Bees	2	45	2.0	"	0.7	"	1.8	8.4	20	0.088	0.067
Strangford Lough	4	4.7	ND	"	ND	"	0.12	0.54	0.47	ND	0.00089
Laminaria digitata											
Isle of Man	1	3.2	"	"	"	"	NA	NA	ND	NA	NA
Alaria esculenta											
Isle of Man	3	1.4	"	"	"	"	"	"	0.023	"	"

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

Table 17(a). Radioactivity in environmental materials near Springfields, 1990

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}											
			Total beta	^{60}Co	^{95}Zr	^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu	^{228}Th
Bass	Ribble Estuary	1	140	ND	ND	ND	ND	ND	0.5	32	ND	ND	ND	0.0044
Eel	" "	1	93	"	"	"	"	"	0.4	24	"	"	"	NA
Grey mullet	" "	1	130	"	"	"	"	"	ND	19	"	"	"	"
Sea trout	" "	1	150	"	"	"	"	"	0.4	3.7	"	"	"	"
Shrimps	" "	1	93	"	"	"	"	"	ND	6.7	"	"	"	0.0084
Cockles	" "	2	130	1.9	"	"	1.8	0.6	"	11	"	"	"	0.62
Mud	Pipeline outlet	4	41000	4.2	"	"	34	6.0	4.0	660	"	8.1	1.5	40
	Becconsall	4	36000	5.5	"	"	34	2.3	6.8	870	"	6.5	1.9	46
	Penwortham	4	120000	4.0	"	"	38	0.9	6.0	660	4.3	4.8	1.5	50
	Freckleton	1	38000	5.8	"	"	84	ND	9.3	1000	ND	10	7.6	NA
	Lytham Creek	1	26000	6.6	"	"	81	"	6.0	1000	"	7.5	ND	"
	Skippool Creek	4	2200	9.2	3.3	2.5	71	8.3	8.2	1000	"	11	7.6	35
	Rock Ferry	4	1500	1.4	ND	ND	ND	1.2	3.7	600	"	1.5	2.5	43
	Deepdale Brook	4	2700	ND	"	"	"	ND	4.8	43	"	ND	5.5	30
Sand	Ribble Estuary	1	600	"	"	"	"	"	ND	32	"	"	ND	13

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}											
			^{230}Th	^{232}Th	^{233}Pa	^{234}Th	^{234}U	^{235}U	^{237}Np	^{238}U	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{243}Cm+ ^{244}Cm
Bass	Ribble Estuary	1	0.0020	0.00070	ND	ND	NA	NA	NA	NA	NA	NA	ND	NA
Eel	" "	1	NA	NA	"	"	"	"	"	"	"	"	"	"
Grey mullet	" "	1	"	"	"	"	"	"	"	"	"	"	"	"
Sea trout	" "	1	"	"	"	"	"	"	"	"	"	"	"	"
Shrimps	" "	1	0.0085	0.0040	"	"	"	"	"	"	"	"	"	"
Cockles	" "	2	0.75	0.36	"	"	"	"	0.20	"	"	"	5.5	"
Mud	Pipeline outlet	4	200	42	"	95000	34	1.4	NA	33	26	130	200	0.41
	Becconsall	4	290	50	"	81000	41	1.9	"	40	NA	NA	280	NA
	Penwortham	4	530	58	42	220000	74	3.6	"	64	"	"	230	"
	Freckleton	1	NA	NA	ND	75000	NA	NA	"	NA	"	"	330	"
	Lytham Creek	1	"	"	"	43000	"	"	"	"	"	"	350	"
	Skippool Creek	4	78	38	"	ND	27	1.1	"	30	"	"	340	"
	Rock Ferry	4	68	46	"	"	NA	NA	"	NA	"	"	130	"
	Deepdale Brook	4	320	30	17	1500	1200	71	"	1000	"	"	ND	"
Sand	Ribble Estuary	1	17	13	ND	ND	NA	NA	"	NA	"	"	9.5	"

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

Table 17(b). Monitoring of dose rates near Springfields, 1990

Location	Material	No. of sampling observations#	µGy h^{-1}
Gamma dose rates at 1 m over intertidal areas			
Pipeline outlet	Mud	4	0.15
Freckleton	"	4	0.15
Becconsall	"	4	0.16
Lytham	"	4	0.14
Penwortham	"	4	0.16
Beta dose rates on nets			µSv h^{-1}
Ribble estuary	Net	1	1.3
" "	Gill net	1	3.0

 # See sub-section 3.3 for definition

4.3 Capenhurst, Cheshire

The main function of the Capenhurst Works is enrichment of uranium. Radioactive waste arisings, mainly of uranium and its daughter products, and technetium-99 and neptunium-237 from recycled fuel, are minor; the Works has authorisations to dispose of small amounts of radioactivity in liquid wastes to the Rivacre Brook and to the North Wirral sewage outfall at Meols. In May 1989, the Rivacre Brook authorisation was varied to control more radionuclides specifically, prior to the operation of a new decontamination plant. This plant commenced active operation in August 1989 and there were increased discharges of technetium-99 to the Rivacre Brook in 1990 as compared with 1989, in line with the plant throughput. No discharges from Capenhurst took place via Meols in

Table 18. Radioactivity in environmental materials in the vicinity of the Wirral, 1990

Material	Sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
			Total beta	^{60}Co	^{99}Tc	^{125}Sb	^{134}Cs	^{137}Cs	^{155}Eu	^{233}Pa	^{234}Th
Shrimps	Hoylake	2	72	0.3	0.7	ND	ND	7.1	ND	ND	ND
Cockles	Dee Estuary	2	69	0.4	1.1	"	"	7.0	"	"	"
Fucus spiralis	Hoylake	2	240	0.1	33	0.5	"	17	"	"	"
" "	Little Orme	1	430	ND	NA	0.2	0.1	5.9	"	"	"
Water weed *Cladophora rupestris*	Rivacre Brook	2	590	0.2	450	ND	ND	0.6	0.7	140	430
Mud	Rivacre Brook	2	3700	0.4	2500	"	3.6	31	11	130	1900

Material	Sampling point	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			^{234}U	^{235}U+ ^{236}U	^{237}Np	^{238}U	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{243}Cm+ ^{244}Cm
Shrimps	Hoylake	2	NA	NA	NA	NA	NA	NA	ND	NA
Cockles	Dee Estuary	2	"	"	"	"	0.33	1.7	3.0	0.011
Fucus spiralis	Hoylake	2	"	"	"	"	NA	NA	1.3	NA
	Little Orme	1	"	"	"	"	"	"	ND	"
Water weed *Cladophora rupestris*	Rivacre Brook	2	"	"	"	"	"	"	"	"
Mud	Rivacre Brook	2	810	47	180	530	"	"	"	"

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

1990 (see Table 1). We have established an environmental monitoring programme related to the pathways which could be of radiological significance due to both disposal routes. Aquatic plants are also sampled as indicator materials. It is to be noted that the programme is much more extensive than is technically justified by the potential radiological hazard from Capenhurst discharges.

Results for 1990 are presented in Table 18. The concentrations of artificial radioactivity in marine samples are mainly due to Sellafield discharges and are consistent with values expected at this distance from Sellafield. Concentrations of technetium-99 were low, reflecting the low levels of discharges of this radionuclide from Sellafield. Exposure of potentially critical shellfish consumers in the vicinity of the Wirral in 1990 amounted to 0.06 mSv, which is within the ICRP-recommended principal dose limit of 1 mSv year^{-1} for members of the public. The effective dose, calculated on the basis of ICRP-60, was 0.04 mSv. This exposure was mainly due to transuranic nuclides from Sellafield; only a tiny fraction was due to technetium-99, which was almost entirely from Sellafield discharges. There were increases in concentrations of radionuclides in materials from the Rivacre Brook in 1990 but these concentrations were of extremely low radiological significance.

4.4 Chapelcross, Dumfriesshire

At this establishment, BNFL operates a magnox-type nuclear power station. Liquid waste is discharged to the Solway Firth under authorisation of Scottish Government Authorities. A recent habits survey has confirmed the significance of two pathways leading to public radiation exposures which are of potential importance. The first of these comprises fishermen who consume local seafood and are exposed to external radiation whilst tending stake nets. The second group are fishermen who receive skin exposures whilst handling nets. Our monitoring, which is carried out on behalf of departments of the Scottish Office, continued to reflect these pathways. Samples of *Fucus* seaweeds, as useful indicators, are also analysed. The results of monitoring in 1990 are presented in Table 19(a) and (b).

Table 19(a). Radioactivity in environmental materials in the vicinity of Chapelcross, 1990

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			Total beta	^{14}C	^{54}Mn	^{60}Co	^{95}Zr	^{95}Nb	^{106}Ru	^{125}Sb
Flounder	Seafield	4	180	22	ND	ND	ND	ND	ND	ND
Salmon	"	1	160	NA	"	"	"	"	"	"
Sea trout	"	2	140	"	"	"	"	"	"	"
Shrimps	"	4	100	"	"	"	"	"	"	"
Fucus vesiculosus	"	4	340	"	0.1	0.7	"	"	0.8	0.6
Sandy mud	"	2	1300	"	ND	2.9	1.2	1.9	41	3.6
Muddy sand	"	2	840	"	"	ND	ND	ND	6.8	ND

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			^{134}Cs	^{137}Cs	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{243}Cm+ ^{244}Cm
Flounder	Seafield	4	0.6	65	ND	ND	NA	NA	ND	NA
Salmon	"	1	ND	1.1	"	"	"	"	"	"
Sea trout	"	2	"	15	"	"	0.00060	0.0030	0.0042	0.00001
Shrimps	"	4	0.2	21	"	"	NA	NA	ND	NA
Fucus vesiculosus	"	4	0.4	39	"	0.2	0.65	3.1	3.2	0.0065
Sandy mud	"	2	5.4	620	5.4	ND	NA	NA	120	NA
Muddy sand	"	2	2.1	270	ND	"	10	51	76	0.21

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

Table 19(b). Monitoring of dose rates near Chapelcross, 1990

Location	Material	No. of sampling observations#	µSv h^{-1}
Beta dose rates on nets			
Seafield	Stake net	2	0.50
Gamma dose rates at 1 m over intertidal areas			µGy h^{-1}
Seafield	Sandy mud	4	0.097
"	Salt marsh	4	0.097
Battle Hill	Sandy mud	4	0.097
Browhouses	" "	4	0.10
Dornoch Brow	Muddy sand	2	0.097
" "	Salt marsh	4	0.11

 # See sub-section 3.3 for definition

Concentrations of artificial radionuclides in the Chapelcross vicinity are mostly due to Sellafield discharges, and the general levels of nuclides given in Table 19(a) are consistent with values expected at this distance from Sellafield. Concentrations of radiocaesium in 1990 were generally similar to those in 1989. The exposure of the critical group of fishermen who consume seafood and are exposed to external radiation over intertidal areas was 0.07 mSv in 1990, which is 7% of the ICRP-recommended principal dose limit of 1 mSv year^{-1} for members of the public. The exposure of the skin of fishermen, due to handling nets, was 0.23 mSv which is much less than 1% of the ICRP-recommended dose limit appropriate for exposures to skin of members of the public. The magnitude of the Chapelcross discharges indicates that the local contribution would have been a tiny fraction of these exposures, most of it being due to Sellafield discharges.

5. UNITED KINGDOM ATOMIC ENERGY AUTHORITY (UKAEA)

We have continued our regular monitoring of the environmental impact of liquid radioactive discharges from the Winfrith Technology Centre and from AEA Technology, Dounreay. Liquid radioactive wastes also arise at the UKAEA Harwell Laboratory. In common with such wastes from other nuclear establishments in the Thames Valley area, these are discharged into the River Thames catchment; whilst monitoring of the drinking water pathway is carried out by HMIP (HMIP, 1991), we have continued our small programme of monitoring of fish and other aquatic materials, and the results are presented in this section.

5.1 Harwell Laboratory, Oxfordshire

At this establishment the UKAEA operates research facilities, including, for part of 1990, low-power nuclear research reactors. These reactors ceased operation during 1990. Liquid radioactive waste arisings are small and discharges are made under authorisation to the River Thames at Sutton Courtenay. During 1990, we continued our small programme of monitoring of fish and other aquatic materials from the Thames catchment in surveillance of fisheries-related exposure pathways. In addition, sampling was carried out in the River Teme, Shropshire to indicate background levels remote from nuclear establishments. Analyses were carried out of available fish species, with *Nuphar lutea* (yellow water lily) and sediments as indicator materials.

The results of this monitoring are shown in Table 20. The concentrations of artificial radioactivity detected were very low. Concentrations of some nuclides, most notably caesium-137 in sediment, were enhanced close to the outfall, but the levels were very small in terms of any radiological effect. External exposures were calculated using a model based on concentrations of radionuclides in sediment (Hunt, 1984). If any fish were eaten, even at rates typical of enthusiastic trout consumers, the radiation dose in 1990, including that from external exposure due to occupancy of the river bank near the outfall for times typical of enthusiastic anglers, would have been 0.008 mSv, or less than 1% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$.

Table 20. Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Harwell, 1990

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}									
			Total beta	^{14}C	^{35}S	^{60}Co	^{125}Sb	^{134}Cs	^{137}Cs	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am
Pike	Outfall	2	110	NA	NA	0.09	ND	0.1	5.8	0.00003	0.00012	0.00023
	Upstream of Harwell outfall	2	110	14	14	ND	"	ND	ND	0.00002	0.00008	0.00012
	Staines	1	120	NA	ND	"	"	"	0.6	NA	NA	ND
Chub	Outfall	1	100	"	NA	"	"	"	0.9	"	"	"
	Upstream of Harwell outfall	1	99	"	"	"	"	"	ND	"	"	"
	River Teme	1	97	ND	28	"	"	"	0.2	0.00003	0.00009	0.00014
Rainbow trout	East Hendred (Ginge Brook)	1	96	NA	"	"	"	"	0.3	NA	NA	ND
Nuphar lutea	Sutton Courtenay	1	36	"	"	3.0	"	"	1.5	"	"	"
	Staines	1	34	"	"	0.3	"	"	0.3	"	"	"
	Sutton Pools	1	27	"	"	ND	"	"	ND	"	"	"
Mud	Sutton Pools	1	520	"	"	"	"	"	6.2	"	"	"
Muddy sand	Staines	1	340	"	"	0.9	"	"	20	"	"	"
Sandy mud	Sutton Courtenay	1	790	"	"	57	6.6	3.3	190	"	"	"

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

5.2 Winfrith Technology Centre, Dorset

The principal source of liquid radioactive wastes at this establishment is the Steam Generating Heavy Water Reactor which ceased power production in September 1990. Most of the activity in these wastes (see Table 1) is due to tritium from the moderator and coolant, but small amounts of activation products, including manganese-54, cobalt-60 and zinc-65, are removed during decontamination of the reactor's pressure circuit. These wastes are disposed of under authorisation to deep water in Weymouth Bay. In 1990, the wastes continued to be subjected to treatment and storage, mainly to allow the short-lived zinc-65 to decay before release. The radiological significance of the discharges from Winfrith is small and mainly due to the activation products rather than to tritium. Re-concentration of activation products by shellfish, followed by local consumption, constitutes the critical exposure pathway; this is reflected in our monitoring programme. External gamma radiation dose rates are monitored at Kimmeridge and in Poole Harbour where the intertidal sediment has the potential to adsorb radioactivity. In addition, monitoring of environmental materials and gamma dose rates at a number of locations along the south coast provides additional information on the distribution of radioactivity from all sources. Data are presented in Table 21.

The impact of Winfrith discharges, as in previous years, was mainly observed in the concentrations of activation product radionuclides. The concentrations of the shorter-lived of these radionuclides, particularly zinc-65, continued to decline in 1990 as compared with previous years; this was likely to have been due to the treatment procedures noted above. The radiation dose to the critical group of fish and shellfish consumers (Smith and Hunt, 1989) was 0.01 mSv, or 1% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$. External gamma radiation dose rates, and dose rates on fishing nets, measured using portable instruments, continued to be indistinguishable from levels typical of the natural background.

5.3 AEA Technology, Dounreay, Caithness

Liquid radioactive waste discharges from this establishment are made to the Pentland Firth under authorisation of Scottish Government Authorities. Discharges include a minor contribution from the adjoining reactor site (Vulcan Naval Reactor Test Establishment) which is operated by the Ministry of Defence (Procurement Executive). Discharges from Dounreay in 1990 were generally less than those in 1989 reflecting the campaigns of reprocessing of reactor fuel. Our surveys near Dounreay are carried out on behalf of departments of the Scottish Office. Monitoring in 1990 continued to include sampling of fish and shellfish from the area of the Dounreay outfall and other materials further afield, with associated gamma dose rate measurements. The results are presented in Table 22.

Recent habits surveys have confirmed the existence of four potentially critical exposure groups, three of which involve external irradiation. The first of these is due to radioactivity adsorbed mainly on fine particulate matter becoming entrained on fishing gear which is regularly handled. This results in skin dose, mainly from beta particles, to the hands and forearms of fishermen. The most exposed group is represented by a small number of people who operate a salmon fishery from Sandside Bay, close to Dounreay. Our regular measurements in previous years have shown that, at current rates of discharge, the average dose rates on nets would be low. Monitoring by the UKAEA in 1990 has confirmed that the exposure of these fishermen remained low, at 0.02 mSv, or less than 0.1% of the ICRP-recommended dose limit of 50 mSv $year^{-1}$ for skin exposures (see sub-section 3.4).

The second potentially critical group arises also from the uptake of radioactivity by particulate material which accumulates in rocky areas of the foreshore and presents a potential source of exposure, mainly to gamma radiation, of those who visit these areas. In 1990, we carried out monitoring of sludge at Oigin's Geo; concentrations of radioactivity were generally less than those in 1989 and consistent with the range of levels expected due to normal Dounreay operations. We also carried out measurements of gamma dose rates above areas of the foreshore. Public radiation exposure via this pathway remained low, at 0.006 mSv or less than 1% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$.

The third potentially critical group involves internal exposure of consumers of locally-collected fish and crustaceans; we sample fish, crabs and lobsters from the outfall area to enable this pathway to be kept under review. Additionally, as in previous years, seaweed was sampled as an indicator material. Concentrations of radionuclides in 1990 were similar to those for 1989. Exposures from consumption of fish and crustaceans continued to be low: for high-rate consumers, the radiation dose was less than 0.005 mSv or 0.5% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$.

The fourth potential critical group is mollusc collectors and consumers. Gamma dose rates were measured over collecting areas and winkles were analysed for their radioactivity content. The radiation dose due to a combination of consumption of molluscs and external exposure during collection was 0.02 mSv in 1990 or 2% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$.

Table 21. Radioactivity in environmental materials and gamma dose rates from the vicinity of Winfrith, 1990

Material	Sampling point	No. of sampling observa- tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
			Total beta	^{54}Mn	^{55}Fe	^{58}Co	^{60}Co	^{65}Zn	^{106}Ru
Plaice	Weymouth Bay	3	98	ND	0.3	ND	ND	ND	ND
Cod	Weymouth Bay	1	140	"	NA	"	0.3	0.6	"
Pollack	Weymouth Bay	1	110	"	"	"	ND	ND	"
Squid	Weymouth Bay	1	70	"	"	"	"	"	"
Crabs	Weymouth Bay	8	79	0.07	14	0.03	9.6	33	"
Spider crabs	Weymouth Bay	1	66	ND	NA	ND	44	21	"
Lobsters	Weymouth Bay	2	84	0.1	"	"	3.7	19	"
Oysters	Poole	2	67	ND	"	"	0.9	60	"
Cockles	Poole	2	63	"	"	0.2	12	2.0	"
Scallops	Weymouth Bay	5	110	4.2	"	ND	6.9	19	"
Whelks	Weymouth Bay	2	82	ND	"	"	6.1	31	"
	Poole Bay	2	89	"	"	"	10	48	"
	West Bay	1	82	"	0.7	"	2.0	6.0	"
Fucus serratus	Arish Mell	1	190	2.9	NA	5.4	77	13	"
	Kimmeridge	2	170	2.2	"	2.8	40	4.8	"
	Swanage	2	180	0.8	"	1.9	29	3.4	"
	Hengistbury Head	2	180	0.4	"	0.5	16	1.9	"
	Bognor Rock	2	190	ND	"	ND	7.7	0.2	0.4
	Sandgate	2	260	"	"	"	7.5	0.3	1.1
	Weymouth	2	190	1.0	"	1.0	21	2.5	ND
	Chesil	2	160	ND	"	ND	1.9	ND	"
	Lyme Regis	2	140	"	"	"	1.1	"	"
Mud	Kimmeridge	2	550	0.3	"	0.7	16	4.2	"
	Poole Harbour	2	160	0.4	"	ND	14	ND	"
	Hardway	2	740	1.0	"	"	24	2.0	"
	Rye Harbour	2	510	0.6	"	"	22	ND	4.3

Material	Sampling point	No. of sampling observa- tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
			^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Plaice	Weymouth Bay	3	0.5	ND	NA	NA	ND	NA	NA
Cod	Weymouth Bay	1	0.5	"	"	"	"	"	"
Pollack	Weymouth Bay	1	0.6	"	"	"	"	"	"
Squid	Weymouth Bay	1	ND	"	"	"	"	"	"
Crabs	Weymouth Bay	8	"	"	0.00033	0.0013	0.0022	0.00002	0.00011
Spider crabs	Weymouth Bay	1	"	"	NA	NA	ND	NA	NA
Lobsters	Weymouth Bay	2	0.1	"	"	"	"	"	"
Oysters	Poole	2	ND	"	"	"	"	"	"
Cockles	Poole	2	"	"	"	"	"	"	"
Scallops	Weymouth Bay	5	0.2	"	0.0016	0.0050	0.0018	ND	0.00005
Whelks	Weymouth Bay	2	ND	"	0.0012	0.0046	0.0046	"	0.00024
	Poole Bay	2	"	"	NA	NA	ND	NA	NA
	West Bay	1	"	"	0.0010	0.0053	0.0058	ND	0.00047
Fucus serratus	Arish Mell	1	"	"	NA	NA	ND	NA	NA
	Kimmeridge	2	"	"	"	"	"	"	"
	Swanage	2	0.2	"	"	"	"	"	"
	Hengistbury Head	2	0.2	"	"	"	"	"	"
	Bognor Rock	2	ND	"	"	"	"	"	"
	Sandgate	2	0.2	"	"	"	"	"	"
	Weymouth	2	0.1	"	"	"	"	"	"
	Chesil	2	0.06	"	"	"	"	"	"
	Lyme Regis	2	0.2	"	"	"	"	"	"
Mud	Kimmeridge	2	2.1	"	"	"	"	"	"
	Poole Harbour	2	3.8	"	0.097	0.49	0.36	ND	0.0065
	Hardway	2	4.6	"	NA	NA	ND	NA	NA
	Rye Harbour	2	4.2	1.0	0.14	0.64	0.42	ND	0.038

Mean gamma dose rate in air at 1m over intertidal sediments

Location		Ground type	μGy h^{-1}
Kimmeridge	(2 sampling observations):	Shingle	0.085
Poole Harbour	(2 sampling observations):	Mud	0.050
Hardway	(2 sampling observations):	"	0.063
Rye Harbour	(2 sampling observations):	"	0.063

Mean beta radiation dose rate on contact with fishing gear

Pots	(2 sampling observations):	ND
Nets	(1 sampling observation):	"

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

Table 22. Radioactivity in environmental materials and gamma dose rates from the vicinity of Dounreay, 1990

Sampling point and material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, $Bq\ kg^{-1}$								
		Total beta	^{14}C	^{54}Mn	^{58}Co	^{60}Co	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs
Area of outfall										
Cod	4	120	ND	ND	ND	ND	ND	ND	ND	ND
Crabs	4	82	NA	"	"	"	"	1.9	"	"
Lobsters	4	83	"	"	"	"	"	7.2	"	"
Sandside Bay										
Winkles	4	90	"	0.8	"	1.3	0.9	42	"	"
Fucus spiralis	1	280	"	3.9	"	3.3	6.6	4.9	"	0.5
Fucus vesiculosus	3	270	"	5.8	"	1.2	ND	1.9	"	ND
Sand	4	480	"	ND	"	0.3	"	ND	"	0.1
Oigins Geo										
Sludge	4	4400	"	340	85	120	2000	280	67	13
Brims Ness										
Winkles	4	110	"	1.0	ND	2.6	1.8	75	ND	ND
Fucus vesiculosus	4	330	"	5.1	"	2.2	1.0	3.6	"	0.3

Sampling point and material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, $Bq\ kg^{-1}$									
		^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Area of outfall											
Cod	4	1.8	ND	ND	ND	0.00007	0.00030	NA	0.00051	ND	ND
Crabs	4	0.3	"	"	"	0.0015	0.0066	"	0.011	0.0026	0.00044
Lobsters	4	0.5	"	"	"	0.0029	0.011	"	0.052	0.0045	0.0016
Sandside Bay											
Winkles	4	0.9	1.0	"	"	0.060	0.20	2.6	0.32	0.050	0.0097
Fucus spiralis	1	2.4	1.8	"	2.2	NA	NA	NA	1.3	NA	NA
Fucus vesiculosus	3	1.1	ND	"	ND	"	"	"	ND	"	"
Sand	4	8.4	0.5	3.4	3.6	3.1	12	"	10	0.26	0.17
Oigins Geo											
Sludge	4	150	530	140	420	110	320	"	390	300	31
Brims Ness											
Winkles	4	0.7	1.2	ND	0.3	0.17	0.50	"	0.97	0.20	0.039
Fucus vesiculosus	4	2.5	0.9	"	0.5	NA	NA	"	ND	NA	NA

	$\mu Gy\ h^{-1}$
Mean gamma dose rate in air at 1m over intertidal sediment: Oigins Geo (6 sampling observations):	0.15
Mean gamma dose rate in air at 1m over intertidal sand: Sandside (1 sampling observation):	0.054
Mean gamma dose rate in air at 1m over winkle beds: Sandside (2 sampling observations):	0.13

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

6. NUCLEAR POWER STATIONS OPERATED BY THE ELECTRICITY COMPANIES

All but two of these sites are in England or Wales and are operated by Nuclear Electric plc. The power stations at Hunterston and Torness are operated by Scottish Nuclear Ltd.

6.1 Berkeley, Gloucestershire and Oldbury, Avon

Berkeley Power Station ceased electricity generation in March 1989, but radioactive wastes still need to be disposed of as part of decommissioning operations; in addition there is a component to these wastes from the adjoining Berkeley Nuclear Laboratories. Liquid radioactive wastes from both Berkeley and Oldbury are discharged to the same stretch of the Severn Estuary.

Table 23. Radioactivity in environmental materials and gamma dose rates near Berkeley and Oldbury nuclear power stations, 1990

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}									
		Total beta	^{14}C	^{60}Co	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am	$^{243}Cm+^{244}Cm$
Flounders	3	100	110	ND	ND	0.9	ND	NA	NA	ND	NA
Eel	1	83	NA	"	"	1.2	"	"	"	"	"
Elver	1	76	"	"	"	0.2	"	"	"	"	"
Shrimps	1	82	"	"	"	0.4	"	"	"	"	"
Fucus vesiculosus	2	250	"	1.3	1.6	20	"	"	"	"	"
Mud: area of outfalls	4	850	"	0.2	2.2	41	1.1	"	"	"	"
Lydney	2	820	"	ND	2.0	34	2.3	0.13	0.63	0.52	0.021

Gamma dose rates in air at 1m over intertidal areas in the vicinity of Berkeley and Oldbury

Location	Ground type	No. of sampling observations#	µGy h^{-1}
Berkeley pipeline outlet	Mud	2	0.075
Guscar Rocks	"	2	0.077
Lydney Locks	"	2	0.068
Sharpness	"	2	0.070
Salmon Lodge	"	2	0.081
Severn House Farm Putcher Rank	"	2	0.089

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

The stations are therefore considered together for the purpose of our environmental monitoring. The two potentially critical pathways for public radiation exposure are internal irradiation following consumption of locally-caught fish and shellfish, and external exposure from occupancy of muddy intertidal areas. We therefore analyse samples of fish and shellfish and monitor gamma dose rates over sediment. In addition, measurements of external exposure are supported by analyses of intertidal mud, and *Fucus vesiculosus* is collected as an indicator material.

Data for 1990 are presented in Table 23. The only artificial radioactivity detected in fish and shellfish was due to carbon-14 and radiocaesium. Concentrations of these radionuclides represent the combined effect of discharges from the stations, other nuclear establishments discharging into the Bristol Channel, fallout, and possibly include a small Sellafield-derived component. Apportionment is difficult at the low levels detected. Very small concentrations of other artificial radionuclides, in addition to radiocaesium, were detected in mud and seaweed but, taken together, were of low radiological significance. Directly-measured gamma dose rates over intertidal mud continued to be indistinguishable from the natural background, thus a calculation based on concentrations of radionuclides in sediments has been used (Hunt, 1984) to estimate exposure of the critical group of fish and shellfish consumers. Their total exposure due to liquid waste discharges was low, at 0.007 mSv or 0.7% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}.

6.2 Bradwell, Essex

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

Table 24. Radioactivity in environmental materials and gamma dose rates near Bradwell nuclear power station, 1990

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		Total beta	^{54}Mn	^{60}Co	^{65}Zn	^{103}Ru	^{106}Ru	^{110m}Ag	^{125}Sb
Mixed fish	3	100	ND	ND	ND	ND	ND	ND	ND
Native oyster	2	100	"	0.2	6.6	"	"	0.5	"
Pacific oyster	1	56	"	ND	1.4	"	"	ND	"
Whelks	2	79	"	"	ND	"	"	"	"
Fucus vesiculosus	2	290	"	1.1	"	"	"	"	"
Mud	7	780	0.1	7.5	"	0.2	1.2	"	0.5

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{243}Cm+ ^{244}Cm
Mixed fish	3	ND	1.0	ND	NA	NA	ND	NA
Native oyster	2	"	0.3	"	0.00045	0.0020	0.0048	0.00031
Pacific oyster	1	"	ND	"	NA	NA	ND	NA
Whelks	2	"	0.1	"	"	"	"	"
Fucus vesiculosus	2	0.08	1.4	0.1	"	"	"	"
Mud	7	0.6	25	0.8	"	"	"	"

Gamma dose rates in air at 1m over intertidal areas in the vicinity of Bradwell

Location	Ground type	No. of sampling observa-tions#	µGy h^{-1}
Pipeline outlet	Mud	2	0.12
1.5 km east of outfall	"	1	0.068
" " " "	Sand	1	0.058
Waterside	Mud	2	0.069
West Mersea	"	3	0.071
" "	Salt marsh	1	0.067

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

Measurements for 1990 are summarised in Table 24. In fish and shellfish, artificial radioactivity was detected due to the combined effects of discharges from the station, Sèllafield discharges, and fallout. Apportionment of the effects of these sources is difficult because of the low levels detected. Concentrations of artificial radionuclides in sediment and seaweed were also low. Gamma dose rates, as directly measured, were indistinguishable from the natural background with the exception of the measurements close to the station which were affected by direct radiation. A calculation based on concentrations of radionuclides in sediments has been used (Hunt, 1984) to estimate the external exposure of the critical group of houseboat dwellers. This exposure, including the effects of consumption pathways, was small, amounting to 0.01 mSv or 1% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}.

6.3 Dungeness, Kent

There are two, essentially separate, 'A' and 'B' nuclear power stations on this site; the 'A' station is powered by magnox-type reactors and the 'B' station by advanced gas-cooled reactors (AGRs). Discharges are made via separate, but adjacent, outfalls and for the purposes of our environmental monitoring are considered together. There are two potentially critical radiation exposure pathways as a result of liquid radioactive waste discharges: internal irradiation due to consumption of locally-caught fish and shellfish, and external exposure from occupancy of the foreshore. Our monitoring programme therefore includes analyses of fish and shellfish and gamma dose rate surveys of the intertidal areas. Samples of sediment are also collected and analysed. Seaweed is analysed as an indicator material. The results for 1990 are given in Table 25.

Table 25. Radioactivity in environmental materials and gamma dose rates near Dungeness nuclear power station, 1990

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}												
		Total beta	^{14}C	^{54}Mn	^{60}Co	^{65}Zn	^{95}Zr	^{106}Ru	^{137}Cs	^{155}Eu	^{238}Pu	$^{239}Pu+$ ^{240}Pu	^{241}Am	$^{243}Cm+$ ^{244}Cm
Bass	1	98	NA	ND	ND	ND	ND	ND	1.8	ND	NA	NA	ND	NA
Cod	2	120	"	"	"	"	"	"	1.0	"	"	"	"	"
Dab	2	75	"	"	"	"	"	"	0.7	"	"	"	"	"
Plaice	4	93	28	"	"	"	"	"	0.4	"	"	"	"	"
Shrimps	2	110	NA	"	0.5	0.2	"	0.9	0.3	"	"	"	"	"
Whelks	4	100	"	"	1.7	1.9	"	0.9	0.03	"	"	"	"	"
Fucus serratus	2	260	"	"	7.5	0.3	"	1.1	0.2	"	"	"	"	"
Sand	4	150	"	"	1.9	ND	0.5	ND	0.4	0.2	"	"	"	"
Mud	2	510	"	0.6	22	"	ND	4.3	4.2	1.0	0.14	0.64	0.42	0.038

Gamma dose rates in air at 1m over intertidal areas in the vicinity of Dungeness

Location	Ground type	No. of sampling observa-tions#	µGy h^{-1}
Old lifeboat station	Sand	1	0.050
" " "	Shingle	1	0.040
Pilot Inn	Sand	1	0.045
" "	Sand/silt	1	0.062
Camber sands	Sand	2	0.056
Rye Harbour	Mud	2	0.063
Folkestone	Sand	1	0.050

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

Concentrations of radiocaesium are attributable to discharges from the stations and from Sellafield, with a small contribution due to weapons-test fallout. Apportionment is difficult at these low levels. Trace levels of manganese-54, cobalt-60 and zinc-65 in some materials are likely to be due mainly to discharges from Winfrith rather than to Dungeness, as demonstrated by the indicator sampling programme described in sub-section 5.2. Trace amounts of ruthenium-106 were also detected in shellfish, sediment and seaweed. Our monitoring programme in the Channel Islands (section 9) shows that the French reprocessing plant at Cap de la Hague may be the source of this radionuclide. The small concentrations of transuranics in silt were similar to levels observed at other sites remote from Sellafield. The critical group comprises local bait diggers who also eat fish and shellfish. Gamma dose rates over intertidal sediments, measured using portable instruments, were indistinguishable from the natural background, thus the external exposure of the critical group has been based on a calculation using concentrations of radionuclides in sediment (Hunt, 1984). The total exposure of the critical group due to liquid discharges from Dungeness was low, at 0.01 mSv or 1% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}.

6.4 Hartlepool, Cleveland

This station is powered by twin AGRs. Discharges of liquid radioactive wastes are made under authorisation to the North Sea. The critical pathway for radiation exposure of the public near the station is internal irradiation following consumption of local fish and shellfish. Collectors of small coal, which is washed ashore along this stretch of coast, account for the highest beach occupancies.

Results of our monitoring programme carried out in 1990 are shown in Table 26. Concentrations of radiocaesium and transuranics were mainly due to discharges from Sellafield and to fallout. The radiation exposure of the critical group of local fish and shellfish consumers was low, at less than 0.005 mSv or 0.5% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}. Gamma radiation dose rates over intertidal sediments, as directly measured, continued to be indistinguishable from the natural background.

Table 26. Radioactivity in environmental materials and gamma dose rates near Hartlepool nuclear power station, 1990

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}									
		Total beta	^{14}C	^{60}Co	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{243}Cm+ ^{244}Cm
Plaice	2	100	15	ND	ND	0.8	ND	NA	NA	ND	NA
Cod	2	140	NA	"	"	1.9	"	"	"	"	"
Crabs	2	71	"	"	"	0.2	"	0.00029	0.0016	0.0012	0.00001
Shrimps	1	57	"	"	"	0.4	"	NA	NA	ND	NA
Winkles	2	120	"	0.1	"	0.7	"	0.0046	0.024	0.010	ND
Fucus vesiculosus	2	240	"	ND	"	0.7	"	NA	NA	ND	NA
Coal/sand	2	250	"	"	"	3.0	0.6	"	"	"	"
Mud	2	820	"	"	0.5	35	0.7	"	"	"	"

Gamma dose rates in air at 1m over intertidal areas in the vicinity of Hartlepool

Location	Ground type	No. of sampling observations#	µGy h^{-1}
Little Scar	Coal/sand	2	0.053
Paddy's Hole	Mud	2	0.082
North Gare	Sand	2	0.051

NA = not analysed

ND = not detected

* *Except for sediment where dry concentrations apply*

 # See sub-section 3.3 for definition

6.5 Heysham, Lancashire

This establishment comprises two, essentially separate, nuclear power stations both powered by AGRs. Discharges of liquid radioactive waste from both stations are made under authorisation to Morecambe Bay via adjacent outfalls, and for the purposes of our environmental monitoring are considered together. The potentially critical radiation exposure pathways are due to internal irradiation following consumption of locally-caught fish and shellfish and external exposure from occupancy of intertidal areas. Our monitoring programme includes analyses of fish and shellfish and measurements of gamma dose rates over intertidal areas. Samples of sediment are also analysed, and *Fucus vesiculosus* is monitored as an indicator material. Samphire is also collected and analysed because of its use as a foodstuff.

The results for 1990 are given in Table 27. These mainly reflect discharges from Sellafield; the effect of discharges from Heysham was not detectable above this background. The radiation exposure in 1990 to the critical group of fish and shellfish consumers in the Morecambe Bay area was 0.14 mSv (on the basis of ICRP-60: 0.10 mSv), as given in sub-section 4.1.1. The doses due to the combined effects of external exposure and consumption of seafood to individuals of the local fishing community were less than the dose calculated for the critical group of consumers in Morecambe Bay. The critical group of those subject to external exposure were wildfowlers in the Lune estuary. Their exposure in 1990 was 0.05 mSv. Both exposures are within the ICRP-recommended principal dose limit of 1mSv year^{-1}. Concentrations of radioactivity in samphire were of negligible radiological significance.

Table 27. Radioactivity in environmental materials and gamma dose rates near Heysham nuclear power station, 1990

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
		Total beta	^{14}C	^{60}Co	^{95}Zr	^{95}Nb	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs
Flounder	4	160	46	ND	ND	ND	ND	ND	0.4	54
Plaice	3	130	35	"	"	"	"	"	0.07	25
Bass	2	170	NA	"	"	"	"	"	0.6	50
Whitebait	1	94	"	"	"	"	"	"	0.3	20
Cockles	4	85	"	1.4	"	"	3.7	0.5	0.06	8.7
Mussels	4	71	"	0.3	"	"	2.1	0.2	0.1	4.5
Fucus vesiculosus	4	460	"	0.5	"	"	0.2	1.5	0.3	23
Samphire	1	53	"	ND	"	"	0.9	ND	0.06	7.4
Muddy sand:										
Sunderland Point	4	1200	"	2.7	1.9	0.6	34	4.1	2.3	370
Half Moon Bay	4	1500	"	5.6	4.5	2.2	69	12	3.3	510

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
		^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Flounder	4	ND	ND	ND	NA	NA	ND	NA	NA
Plaice	3	"	"	"	"	"	"	"	"
Bass	2	"	"	"	"	"	"	"	"
Whitebait	1	"	"	"	"	"	"	"	"
Cockles	4	"	0.07	0.1	0.68	3.4	8.4	0.033	0.011
Mussels	4	"	ND	ND	0.23	1.1	1.8	ND	0.0054
Fucus vesiculosus	4	"	"	"	NA	NA	1.3	NA	NA
Samphire	1	"	"	"	"	"	2.5	"	"
Muddy Sand:									
Sunderland Point	4	"	2.8	4.3	"	"	ND	"	"
Half Moon Bay	4	3.8	6.9	5.5	35	170	260	ND	1.0

Gamma dose rates in air at 1m over intertidal areas in the vicinity of Heysham

Location	Ground type	No. of sampling observa-tions#	µGy h^{-1}
Area of outfall	Muddy sand	4	0.082
Half Moon Bay	" "	4	0.088
Red Nab Point	Sandy mud	4	0.11
Morecambe Central Pier	" "	4	0.090
" " "	Mussel bed	4	0.079
Sunderland Point	Sandy mud	4	0.11
Colloway Marsh	Salt marsh	4	0.21
Skerton Weir	Mud	2	0.10

NA = not analysed

ND = not detected

** Except for sediment where dry concentrations apply*

 # See sub-section 3.3 for definition

6.6 Hinkley Point, Somerset

At this establishment there are two essentially separate 'A' and 'B' nuclear power stations; the 'A' station is powered by magnox-type reactors and the 'B' station by AGRs. Liquid radioactive waste discharges are made via the same outfall and for the purposes of our environmental monitoring they are considered together. Those members of the public subject to the greatest (but still small) radiation exposures as a result of these discharges are those who eat large amounts of locally-caught fish and shrimps and spend time on silty intertidal areas (Doddington *et al.*, 1988). Our monitoring programme includes analyses of locally-caught fish and shellfish, and external exposure is monitored by means of gamma dose rate measurements, supported by analyses of sediment. In addition, *Fucus* seaweed is monitored as an indicator material.

The results for 1990, presented in Table 28, indicate concentrations of radionuclides representing the combined effect of releases from the stations, from other establishments which discharge to the Bristol Channel, from Sellafield, and from fallout. Apportionment is difficult at the low levels detected. 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, measured using portable instruments, were indistinguishable from the natural background with the exception of the measurements at one location close to the station. A calculation based on concentrations of radionuclides in sediments has been used (Hunt, 1984) to estimate the external exposure of the high-rate fish and shellfish consumers. Their total exposure due to liquid waste discharges was low, at 0.006 mSv or 0.6% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$.

Table 28. Radioactivity in environmental materials and gamma dose rates near Hinkley Point nuclear power station, 1990

Material	No. of sampling observ-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}												
		Total beta	^{14}C	^{54}Mn	^{60}Co	^{65}Zn	^{90}Sr	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am	$^{243}Cm+^{244}Cm$
Flounder	1	140	54	ND	ND	ND	NA	0.2	1.8	ND	NA	NA	ND	NA
Shrimps	2	99	80	"	"	"	0.18	0.07	0.7	"	0.00016	0.00068	0.00071	0.00003
Fucus vesiculosus	2	230	NA	1.4	1.5	0.09	NA	0.6	3.5	"	NA	NA	ND	NA
Mud	4	1000	"	0.2	0.6	ND	"	2.2	44	1.6	"	"	"	"
Muddy sand	3	360	"	0.1	0.3	"	"	0.9	9.0	0.3	"	"	"	"

Gamma dose rates in air at 1m over intertidal areas in the vicinity of Hinkley

Location	Ground type	No. of sampling observa-tions#	µGy h^{-1}
0.8 km west of pipe	Muddy sand	2	0.12
Pipeline outlet	"	2	0.080
0.8 km east of pipe	Mud	2	0.066
1.6 km east of pipe	"	2	0.075
Combwich	"	1	0.068
River Parrett	"	2	0.075

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

6.7 Hunterston, Ayrshire

This establishment comprises 'A' and 'B' stations; the 'A' station is powered by magnox-type reactors and the 'B' station by AGRs. The 'A' station ceased power production at the end of March 1990. Liquid radioactive waste discharges are made to the Firth of Clyde under authorisation of Scottish Government Authorities. There are two pathways which contribute to the radiation exposure of the critical group: fish and shellfish consumption leading to internal irradiation, and occupancy of intertidal areas leading to external exposure. We regularly monitor, on behalf of departments of the Scottish Office, samples of fish and shellfish and carry out gamma dose rate measurements on the foreshore. Samples of sand are analysed in support of the gamma dose rate measurements and *Fucus* seaweed is analysed as an indicator material. The results of monitoring in 1990 are shown in Table 29.

The concentrations of artificial radioactivity in this area are predominantly due to Sellafield discharges, the general values being consistent with those to be expected at this distance from Sellafield. Concentrations of radiocaesium generally declined in 1990 following the overall reductions in Sellafield discharges over the past few years. In 1990, the exposure of members of the critical group of fish and shellfish consumers near Hunterston was low, at 0.01 mSv or 1% of the principal ICRP-recommended dose limit of 1 mSv $year^{-1}$. The small amounts of activation products observed in molluscs, seaweed and sand were mainly due to discharges from the 'B' station. However, they gave rise to but a small fraction of the above exposure and their radiological significance was negligible. Gamma radiation dose rates directly measured over intertidal sediments were indistinguishable from the natural background, but a small contribution to the exposure of the critical group given above was included, based on a calculation (Hunt, 1984) using measured concentrations of radionuclides in sand.

Table 29. Radioactivity in environmental materials and gamma dose rates near Hunterston nuclear power station, 1990

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}															
		Total beta	^{14}C	^{54}Mn	^{58}Co	^{59}Fe	^{60}Co	^{65}Zn	^{110m}Ag	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm+^{244}Cm$
Cod	2	120	ND	ND	ND	ND	ND	ND	ND	0.09	5.2	ND	NA	NA	ND	NA	NA
Grey mullet	1	130	"	"	"	"	"	"	"	0.4	7.3	"	"	"	"	"	"
Saithe	2	140	"	"	"	"	"	"	"	0.4	9.5	"	"	"	"	"	"
Lobster	1	90	"	"	"	"	1.3	"	"	ND	2.1	"	"	"	"	"	"
Crab	2	71	"	"	"	"	0.3	"	"	"	1.0	"	"	"	"	"	"
Nephrops	2	110	"	"	"	"	ND	"	"	"	5.0	"	"	"	"	"	"
Oyster	1	50	"	"	"	"	0.5	1.6	1.4	"	0.7	"	"	"	"	"	"
Winkles	4	100	"	9.0	0.2	"	8.5	0.4	2.2	"	2.7	"	0.052	0.19	0.087	0.0025	0.0051
Fucus spiralis	4	250	"	35	1.6	1.0	11	1.0	0.4	0.4	4.7	"	0.094	0.41	0.10	0.0034	0.0043
Sand	4	240	"	4.9	ND	ND	1.8	ND	ND	0.3	17	0.7	NA	NA	ND	NA	NA

Gamma dose rates in air at 1m over intertidal areas in the vicinity of Hunterston

Location	Ground type	No. of sampling observations#	μGy h^{-1}
0.5 km north of pipeline	Sand	4	0.062
0.5 km south of pipeline	Sand/stones	4	0.079

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

Table 30. Radioactivity in environmental materials and gamma dose rates near Sizewell nuclear power station, 1990

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}										
		Total beta	^{14}C	^{60}Co	^{65}Zn	^{110m}Ag	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am
Whiting	1	130	15	ND	ND	ND	ND	1.7	ND	NA	NA	ND
Sole	1	110	NA	"	"	"	"	1.0	"	"	"	"
Lobster	2	61	"	"	"	0.2	"	0.5	"	"	"	"
Shrimp	1	86	"	"	"	ND	0.3	1.6	"	0.00017	0.00085	0.0016
Crab	1	64	"	0.4	"	"	ND	0.4	"	NA	NA	ND
Native oyster	1	81	"	ND	"	"	"	ND	"	"	"	"
Pacific oyster	1	79	"	"	0.5	"	"	0.5	"	"	"	"
Mud	2	740	"	6.2	ND	"	0.6	24	1.1	"	"	"

Gamma dose rates in air at 1m over intertidal areas in the vicinity of Sizewell

Location	Ground type	No. of sampling observa-tions#	μGy h^{-1}
Pipeline outlet	Sand	2	0.046
Dunwich	"	2	0.043
Rifle range	"	2	0.043
Sizewell Hall	"	2	0.042
Aldeburgh	Sand/shingle	2	0.041
Southwold Harbour	Mud	2	0.059

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

6.8 Sizewell, Suffolk

At this establishment there is an 'A' station powered by magnox-type reactors; a 'B' station, to be powered by a PWR, is under construction. Radioactive liquid effluent from the 'A' station is discharged under authorisation to the North Sea. Our monitoring reflects the two potentially critical radiation exposure pathways of fish and shellfish consumption leading to internal irradiation, and occupancy of intertidal areas giving rise to external exposure (Leonard and Smith, 1982). The results of this monitoring in 1990 are shown in Table 30.

The radioactivity concentrations represent the combined effect of discharges from the 'A' station and from Sellafield, as well as of fallout. Apportionment is difficult at the low levels detected. Trace levels of cobalt-60 and zinc-65 in some shellfish and mud are likely to have been due to discharges from the station, but their radiological significance was negligible. The total radiation exposure of local fish and shellfish consumers was low, at less than 0.005 mSv or 0.5% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}. Directly-measured gamma dose rates, as in previous years, were indistinguishable from the natural background; however, the above exposure of the critical group includes a small contribution for their external exposure based on a calculation (Hunt, 1984) using radionuclide concentrations in sediment.

6.9 Torness, East Lothian

This station, which is powered by two AGRs, came into operation at the end of 1987. Discharges of radioactive wastes to the North Sea are authorised by Scottish Government Authorities. Our investigations, on behalf of these Authorities, have shown that potentially critical pathways for radiation exposure of the public are internal irradiation from consumption of local fish and shellfish and external exposure from occupancy of intertidal areas. These pathways form the basis of our regular monitoring programme (Leonard and Hall, 1989). Samples of fish and shellfish are collected and analysed, and samples of seaweed are monitored as indicator materials. Measurements are also made of gamma dose rates over intertidal areas, supported by analyses of sediment, and beta dose rates on fishing gear.

Results of this monitoring in 1990 are shown in Table 31. Concentrations of artificial radionuclides were mainly due to the distant effects of Sellafield discharges and to fallout. Radiation exposure of the critical group of fish and shellfish consumers was low, at less than 0.005 mSv, or 0.5% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}. This exposure includes a small contribution due to external radiation, calculated on the basis of radionuclide concentrations in sediment (Hunt, 1984); as directly measured, gamma dose rates remained indistinguishable from the natural background. This also applies to beta dose rates on contact with fishing gear.

Table 31. Radioactivity in environmental materials and gamma dose rates near Torness nuclear power station, 1990

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}											
		Total beta	^{14}C	^{60}Co	^{110m}Ag	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Cod	2	130	ND	ND	ND	ND	2.2	ND	NA	NA	ND	NA	NA
Crabs	2	70	NA	"	0.4	"	0.4	"	"	"	"	"	"
Lobster	1	71	"	"	ND	"	0.5	"	"	"	"	"	"
Nephrops	4	92	"	"	"	"	1.0	"	0.00079	0.0045	0.0041	0.00003	0.00002
Winkles	4	88	"	"	0.7	"	0.5	"	NA	NA	ND	NA	NA
Fucus vesiculosus	2	260	"	"	ND	"	0.8	"	"	"	"	"	"
Mud													
Dunbar Inner Harbour	2	730	"	"	"	2.2	49	"	"	"	"	"	"
Eyemouth Harbour	1	550	"	"	"	0.8	21	1.5	"	"	"	"	"
Aberlady Bay	1	350	"	1.5	"	0.6	16	ND	"	"	"	"	"
Sand													
Thornton Loch Beach	2	200	"	ND	"	ND	3.3	"	"	"	"	"	"
Muddy sand													
Barns Ness	1	310	"	"	"	0.6	7.0	"	"	"	"	"	"

Gamma dose rates in air at 1m over intertidal areas in the vicinity of Torness

Location	Ground type	No. of sampling observa-tions#	µGy h^{-1}
Belhaven North Beach	Sand	2	0.056
Barns Ness	Rock	2	0.077
Skateraw Harbour	Sand	2	0.060
Thornton Loch Beach	"	2	0.058
Pease Bay Beach	"	2	0.061

Mean beta dose rate on contact with fishing gear

Pots (2 sampling observations): ND
Nets (2 sampling observations): "

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

6.10 Trawsfynydd, Gwynedd

Discharges from this station are made to the freshwater Lake Trawsfynydd under authorisation of the Welsh Office. Because of the limited volume of water available for dispersion they are of greater radiological significance than those from other UK nuclear power stations which discharge to estuarine or coastal waters. The critical radiation exposure pathway is due to consumption of fish caught in the lake; the important radionuclides are those of caesium and, to a lesser extent, strontium-90. Species of fish regularly consumed are brown trout, rainbow trout and, in 1990, a small amount of perch; consumption rates of brown trout were less than in 1989. Perch and most brown trout are indigenous to the lake but rainbow trout, and sometimes brown trout, are introduced from a hatchery. Because of the limited period which they spend in the lake, introduced fish generally exhibit lower radiocaesium concentrations than those of indigenous fish.

Our monitoring programme reflects the exposure pathways. Samples of brown trout, rainbow trout, perch and other fish are regularly analysed. Gamma dose rates over lake shoreline areas are also regularly monitored, and these measurements are supported by analyses of shoreline sediments. As part of our research programme, mud and peat from the lake bed are also analysed; these materials contribute radioactivity to the fishes' diet. Additional information is gained from analyses of the moss *Fontinalis* which is a sensitive indicator for a number of radionuclides, and from analyses of lake water. Our enhanced monitoring programme, which was increased in 1986 following the Chernobyl accident, continued. The results of our additional monitoring are reported in section 10. Our regular programme of monitoring of fish at Trawsfynydd continued during 1990, and is reported here to present a balanced picture of public radiation exposures for the whole year. The results of our regular monitoring are shown in Table 32.

Table 32. Radioactivity in environmental materials and gamma dose rates near Trawsfynydd nuclear power station, 1990

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}										
		Total beta	^{14}C	^{35}S	^{54}Mn	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{103}Ru	^{106}Ru	^{125}Sb
Brown trout	10	500	38	110	ND	0.05	8.4	ND	ND	ND	ND	ND
Rainbow trout	8	150	26	62	"	ND	3.6	"	"	"	"	"
Rainbow trout (hatchery)	1	98	NA	NA	"	"	5.1	"	"	"	"	"
Perch	9	940	49	280	"	"	5.0	"	"	"	"	"
Rudd	1	490	NA	NA	"	"	NA	"	"	"	"	"
Fontinalis												
Afon Prysor	2	220	"	"	"	"	"	"	"	"	"	"
Gwylan Stream	2	1400	"	"	3.6	30	"	"	"	"	65	640
Mud												
Near cooling water outfall	2	2600	"	"	ND	73	"	"	"	"	41	120
Hot lagoon	2	NA	"	"	"	170	"	45	180	"	890	1300
Cae Adda boat mooring	1	1200	"	"	"	6.7	"	ND	ND	"	ND	27
Bailey bridge	1	NA	"	"	"	11	"	"	"	"	"	29
Gwylan Stream	2	2900	"	"	"	15	"	"	"	"	17	51
Peat												
Hot lagoon	2	1500	"	"	"	40	"	"	"	"	ND	90
South end of lake	2	1900	"	"	"	7.8	"	"	"	"	"	25
Cae Adda boat mooring	1	720	"	"	"	ND	"	"	"	"	"	31
Bailey bridge	1	3300	"	"	"	17	"	28	94	12	310	360
Water												
Bailey bridge	4	NA	"	"	NA	NA	0.16	NA	NA	NA	NA	NA
Cold lagoon	4	"	"	"	"	"	0.16	"	"	"	"	"

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}									
		^{134}Cs	^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Brown trout	10	73	340	ND	ND	ND	0.00033	0.0013	0.0020	0.00023	0.00003
Rainbow trout	8	5.4	19	"	"	"	0.00014	0.00043	0.00061	0.00033	0.00003
Rainbow trout (hatchery)	1	1.0	2.3	"	"	"	0.00005	0.00023	0.00018	0.00014	ND
Perch	9	160	740	"	"	"	0.00014	0.00044	0.00064	0.00014	0.00002
Rudd	1	70	370	"	"	"	NA	NA	ND	NA	NA
Fontinalis											
Afon Prysor	2	3.9	29	"	"	"	"	"	"	"	"
Gwylan Stream	2	18	94	32	1.4	3.2	"	"	"	"	"
Mud											
Near cooling water outfall	2	93	1700	18	8.7	8.0	"	"	22	"	"
Hot lagoon	2	660	6700	620	54	36	"	"	140	"	"
Cae Adda boat mooring	1	160	670	ND	ND	ND	"	"	ND	"	"
Bailey bridge	1	130	1900	17	"	"	"	"	7.8	"	"
Gwylan Stream	2	59	1600	ND	"	"	"	"	ND	"	"
Peat											
Hot lagoon	2	34	450	14	"	"	2.7	11	17	0.53	0.42
South end of lake	2	37	1200	ND	"	"	NA	NA	0.8	NA	NA
Cae Adda boat mooring	1	64	230	"	"	"	"	"	ND	"	"
Bailey bridge	1	320	2400	230	"	"	"	"	"	"	"
Water											
Bailey bridge	4	0.10	0.27	NA	NA	NA	"	"	NA	"	"
Cold lagoon	4	0.095	0.27	"	"	"	"	"	"	"	"

Gamma dose rates in air at 1m over areas near lake shoreline

Location	Ground type	No. of sampling observa-tions#	µGy h^{-1}
Bailey bridge	Peat	2	0.098
South end of lake	"	2	0.088
Cae Adda boat mooring	Mud	2	0.069

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

Discharges of radiocaesium from the power station in 1990 slightly increased as compared with 1989 (see Table 1). All discharges have, however, remained within authorised limits. There were small increases in the concentrations of caesium-137 in fish and water from the lake. In 1990, as in previous years, transuranic nuclides from station discharges and fallout were also observed in fish; these concentrations continued to be of negligible radiological significance.

It is estimated that, in 1990, members of the critical group of fish consumers received 0.09 mSv, which is within the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$. The exposure was the same when compared with that of 1989 (Hunt, 1990) and this was mainly due to the balance of increasing concentrations and reducing consumption rates. Gamma dose rates, measured using portable instruments, were difficult to distinguish from values to be expected from the natural background. However, the exposure of the critical group given above includes a small contribution due to lakeside external exposure based on a calculation (Hunt, 1984) using radionuclide concentrations in sediment.

6.11 Wylfa, Gwynedd

Liquid radioactive wastes from this station are discharged to the Irish Sea under authorisation of the Welsh Office. The two potentially critical pathways are due to consumption of local fish and shellfish and to occupancy of intertidal areas. Monitoring is carried out in respect of these pathways. Samples of sediment are analysed in support of the gamma dose rate measurements, and the indicator seaweed *Fucus vesiculosus* is also sampled. The results of monitoring in 1990 are presented in Table 33.

Any effects of discharges from this station are masked by Sellafield-derived radioactivity. Concentrations of artificial radionuclides in environmental materials were consistent with those expected at this distance from Sellafield. Data for 1990 confirmed that the critical group consisted of high-rate fish and shellfish consumers, and that their radiation exposure was 0.01 mSv, or 1% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$. The magnitude of discharges from the station indicate that the local contribution would have been a small fraction of this exposure. Gamma dose rates, measured using portable instruments, continued to be difficult to distinguish from the natural background, but a small contribution due to external exposure of the critical group has been included in the above total; this contribution was based on a calculation using concentrations of radionuclides in sediments (Hunt, 1984).

Table 33. Radioactivity in environmental materials and gamma dose rates near Wylfa nuclear power station, 1990

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}													
		Total beta	^{14}C	^{54}Mn	^{60}Co	^{65}Zn	^{106}Ru	^{110m}Ag	^{134}Cs	^{137}Cs	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am	$^{243}Cm+^{244}Cm$
Plaice	2	100	NA	ND	0.3	ND	ND	ND	ND	2.5	ND	NA	NA	ND	NA
Dogfish	2	110	20	"	ND	"	"	"	0.2	12	"	0.00009	0.00042	0.00074	ND
Crabs	2	89	NA	"	"	"	"	0.07	ND	1.7	"	NA	NA	ND	NA
Winkles	2	88	"	"	0.4	"	0.7	0.2	"	3.7	"	0.20	0.98	1.3	0.0030
Mussels	2	38	"	"	ND	"	ND	ND	"	1.1	"	0.046	0.22	0.35	0.00086
Fucus spiralis	2	280	"	1.3	2.7	0.4	"	0.9	"	5.6	"	NA	NA	1.0	NA
Fucus vesiculosus	5	270	"	0.8	1.2	ND	"	0.4	"	6.0	0.04	"	"	0.6	"
Mud	2	1200	"	ND	2.4	"	"	ND	4.2	320	ND	9.6	48	71	0.16

Gamma dose rates in air at 1m over intertidal areas in the vicinity of Wylfa

Location	Ground type	No. of sampling observations#	μGy h^{-1}
Cemaes Bay	Sand	8	0.056
Cemlyn Bay	Mud	4	0.084
Amlwch Harbour	Rock	4	0.091

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

7. DEFENCE ESTABLISHMENTS

We have continued our regular monitoring of the effects of liquid radioactive waste discharges to sea from naval establishments, and the results are reported in this section. Liquid radioactive wastes are also discharged from the Atomic Weapons Establishment, Aldermaston, to the River Thames. For this site, the drinking water pathway is monitored by HMIP (HMIP, 1991). In 1990, however, we continued our small programme of monitoring of fish and other aquatic materials in surveillance of discharges to the Thames catchment from Aldermaston and other nuclear establishments. The relevant results are reported in this section.

7.1 Atomic Weapons Establishment, Aldermaston, Berkshire

Liquid radioactive waste discharges are small (see Table 1) and are made under agreement with MAFF and HMIP to the River Thames at Pangbourne. As explained above, the drinking water pathway is investigated by HMIP but, in 1990, we continued a small programme of fisheries-related monitoring. This included monitoring in the River Teme, Shropshire to indicate background levels remote from nuclear establishments. Analyses were carried out of available fish species, with *Nuphar lutea* (yellow water lily) and sediments as indicator materials.

The results of this monitoring are shown in Table 34. The concentrations of artificial radioactivity detected were very low. Concentrations of plutonium were not significantly different from the level expected due to fallout. The overall effect was of very low radiological significance: if any fish were eaten, even at rates typical of enthusiastic trout consumers, the radiation dose, together with that due to occupancy of the river bank near the outfall for times typical of enthusiastic anglers, would have been less than 0.005 mSv or less than 0.5% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}.

Table 34. Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from the Atomic Weapons Establishment, Aldermaston, 1990

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}							
			Total beta	^{14}C	^{35}S	^{60}Co	^{137}Cs	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am
Pike	Pangbourne	1	130	NA	NA	ND	0.7	0.00003	0.00015	0.00012
	Staines	1	120	"	ND	"	0.6	NA	NA	ND
Chub	River Teme	1	97	ND	28	"	0.2	0.00003	0.00009	0.00014
Nuphar lutea	Pangbourne	1	25	NA	NA	0.1	0.6	NA	NA	ND
	Staines	1	34	"	"	0.3	0.3	"	"	"
	Sutton Pools	1	27	"	"	ND	ND	"	"	"
Mud	Pangbourne	1	310	"	"	2.4	29	"	"	"
	Sutton Pools	1	520	"	"	ND	6.2	"	"	"
Muddy sand	Staines	1	338	"	"	0.9	20	"	"	"

NA = not analysed

ND = not detected

* *Except for sediment where dry concentrations apply*

 # See sub-section 3.3 for definition

7.2 Naval establishments

Liquid wastes containing small quantities of radioactivity are discharged from the establishments at Devonport, Faslane and Rosyth under authorisation/agreement with the relevant Authorising Departments (see Table 1). We carry out monitoring programmes near all of these establishments and, in the case of Faslane and Rosyth, on behalf of departments of the Scottish Office. Monitoring is also carried out in the Holy Loch (sub-section 2.1). Monitoring near Chatham also continues in surveillance of the effects of past discharges.

Public radiation exposures due to the effects of any discharges from these establishments are primarily due to external radiation from sediments, the nuclide of main importance being cobalt-60. Our regular assessments of doses to critical groups take account of the effects of discharges from other nuclear establishments (e.g. Sellafield) as well as exposure pathways additional to external radiation, such as any consumption of fish and shellfish. We regularly carry out measurements of gamma dose rates near all establishments; these are supported by analyses of sediments. Marine foodstuffs and seaweed are also analysed where appropriate.

Results of monitoring in 1990 are presented in Table 35. The small concentrations of cobalt-60 mainly reflect discharges from the establishments; levels of radiocaesium are mainly due to discharges from Sellafield. Gamma dose rates over intertidal sediments, directly measured using portable instruments, remained indistinguishable from the natural background, such that public radiation exposure has been estimated by calculation based on concentrations of radionuclides in sediments (Hunt, 1984) as well as on occupancy times from habits surveys. In 1990, the exposure of critical groups, including the effects of other sources and taking account of consumption of marine foods and occupancy times, continued to remain very low near all of these naval establishments, and at less than 0.01 mSv $year^{-1}$. This represents less than 1% of the ICRP-recommended principal dose limit of 1 mSv $year^{-1}$.

Table 35. Radioactivity in environmental materials and gamma dose rates near naval establishments, 1990

Establishment	Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}								Mean gamma dose rates in air at 1m	
			Total beta	^{60}Co	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{155}Eu	^{241}Am	No. of sampling observations#	uGy h^{-1}
Chatham	Mud	2	NA	4.8	ND	ND	ND	19	1.3	ND	6	0.065
Devonport	Mussels	2	65	0.2	"	"	"	0.3	ND	"	NP	NP
	Fucus vesiculosus	2	NA	0.3	"	"	"	0.07	"	"	"	"
	Mud	6	"	ND	"	"	"	3.3	0.6	"	12	0.073
Faslane	Mud	2	"	14	"	2.8	1.8	76	ND	"	10	0.066
Rosyth	Crab	2	"	ND	"	ND	ND	0.5	"	"	NP	NP
	Fucus vesiculosus	2	"	0.1	"	"	"	1.0	"	"	"	"
	Mud	10	"	0.2	"	"	1.3	28	0.8	"	10	0.068
Holy Loch	Winkles	1	120	0.2	0.3	"	ND	3.0	ND	0.1	NP	NP
	Mud	2	NA	3.6	ND	"	1.2	32	"	ND	12	0.059

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

8. AMERSHAM INTERNATIONAL PLC

This company manufactures radioactive materials for use in medicine, research and industry. The company's principal 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 HMIP (HMIP, 1991). However, in 1990, we continued our small programme of fisheries-related monitoring in connection with discharges of liquid radioactive wastes to the Thames and its catchment. Results relevant to the Amersham Laboratory are presented in this section. Our monitoring programme in surveillance of discharges from the Cardiff Laboratory has continued, and the results of this programme are also presented.

8.1 Amersham Laboratory, Buckinghamshire

Discharges of liquid radioactive wastes are made under authorisation to the Maple Cross sewage works; releases enter the Grand Union Canal and the River Colne. In 1990, we continued our small programme of monitoring of fish and other aquatic materials in surveillance of the effects of these discharges, including monitoring at locations remote from nuclear establishments. Analyses were carried out of available fish species with *Nuphar lutea* (yellow water lily) and sediments as indicator materials.

The results of this monitoring are presented in Table 36. The concentrations of radioactivity detected were very low. Concentrations of some radionuclides were slightly enhanced close to the outfall, but the overall effect was of very low radiological significance. If any fish were eaten, even at rates typical of enthusiastic trout consumers, the radiation dose, including that due to occupancy of river or canal banks near the outfall for times typical of enthusiastic anglers, would have been less than 0.005 mSv or less than 0.5% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}.

Table 36. Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Amersham International plc, Amersham, 1990

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg^{-1}											
			Total beta	^{14}C	^{35}S	^{57}Co	^{58}Co	^{60}Co	^{65}Zn	^{137}Cs	^{155}Eu	^{238}Pu	$^{239}Pu+^{240}Pu$	^{241}Am
Pike	Grand Union Canal	2	150	130	9.1	ND	ND	ND	ND	0.7	ND	NA	NA	ND
	Staines	1	120	NA	ND	"	"	"	"	0.6	"	"	"	"
Chub	River Teme	1	97	ND	28	"	"	"	"	0.2	"	0.00003	0.00009	0.00014
Rainbow trout	Huntsmoor	1	130	NA	NA	"	ND	ND	ND	0.5	ND	NA	NA	ND
Nuphar lutea	Grand Union Canal	1	50	"	"	"	0.3	"	0.4	ND	"	"	"	"
	Staines	1	34	"	"	"	ND	0.3	ND	0.3	"	"	"	"
	Sutton Pools	1	27	"	"	"	"	ND	"	ND	"	"	"	"
Mud	Grand Union Canal	1	340	"	"	11	5.2	2.1	5.0	8.4	3.2	"	"	"
	Sutton Pools	1	520	"	"	ND	ND	ND	ND	6.2	ND	"	"	"
Muddy sand	Staines	1	340	"	"	"	"	0.9	"	20	"	"	"	"

NA = not analysed

ND = not detected

** Except sediment where dry concentrations apply*

 # See sub-section 3.3 for definition

Table 37. Radioactivity in environmental materials and gamma dose rates near the outfall of the sewer serving Amersham International plc, Cardiff, 1990

Material	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}						
		Total beta†	^{14}C	^{35}S	^{131}I	^{134}Cs	^{137}Cs	^{155}Eu
Flounder	5	290	790	30	ND	ND	0.6	ND
Fucus spiralis	3	190	17	390	0.4	"	0.5	0.05
Fucus vesiculosus	1	140	14	NA	ND	"	0.5	ND
Mud	4	820	14	"	"	1.5	31	1.0

Mean gamma dose rate in air at 1m over intertidal mud (4 sampling observations): 0.068 µGy h^{-1}

NA = not analysed
ND = not detected
* *Except for sediment where dry concentrations apply*
# *See sub-section 3.3 for definition*
† *Includes contribution from carbon-14 at low counting efficiency due to the low energy of beta particles emitted by this radionuclide*

8.2 Cardiff Laboratory

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

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

The results of monitoring in 1990 are presented in Table 37. Of the separate radionuclides listed, only carbon-14 and sulphur-35 were discharged by this establishment in 1990; the presence of the other radionuclides was therefore due to the combined background effects noted above. Small amounts of iodine-131 detected in seaweed are likely to have been due to discharges from a local hospital. The exposure of the critical group of fish and shellfish consumers was 0.02 mSv or 2% of the ICRP-recommended principal dose limit of 1 mSv year^{-1}. This exposure includes a small contribution due to external irradiation of the critical group, calculated on the basis of concentrations of radionuclides in sediment (Hunt, 1984). Gamma dose rates over sediment, as measured using portable instruments, were indistinguishable from those expected from the natural background.

9. CHANNEL ISLANDS MONITORING

A full review of monitoring on the Channel Islands was carried out in 1989 and an assessment of the radiological significance of artificial radionuclides in marine pathways was made (Leonard *et al.*, in press). The review established that there was no need to make major changes to monitoring on the Islands and that individual doses to the critical group were no more than about 0.01 mSv year^{-1}.

We have continued to analyse marine environmental samples provided by the Channel Islands States, mainly 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 and because of their use as fertilisers.

The results for 1990 are given in Table 38. Concentrations of caesium-137 in fish and shellfish were low and generally similar to those in previous years. Apportionment to different sources, including fallout, is difficult in view of the low levels detected. The presence of transuranics and ruthenium-106 in environmental materials may be attributed to discharges from the plant at Cap de la Hague. However, the concentrations of artificial radionuclides in each of these materials continued to be of negligible radiological significance.

Table 38. Radioactivity in environmental materials and gamma dose rates from the Channel Islands, 1990

Material	Sampling area	No. of sampling observa- tions#	Mean radioactivity concentration (wet)*, $Bq\ kg^{-1}$									
			Total beta	^{14}C	^{54}Mn	^{60}Co	^{65}Zn	^{90}Sr	^{99}Tc	^{106}Ru	^{110m}Ag	^{125}Sb
Rays	Guernsey[2]	1	110	NA	ND	ND	ND	NA	NA	ND	ND	ND
Crabs	Guernsey[2]	1	84	"	"	1.4	0.9	"	"	1.8	0.6	"
	Jersey[2]	1	76	"	"	0.9	ND	"	"	1.5	1.5	"
	Alderney[1] Casquets	2	77	20	"	3.9	"	"	1.8	5.3	0.8	"
Lobsters	Jersey[2]	1	81	NA	"	ND	"	"	NA	ND	ND	"
	Alderney[1] Casquets	2	97	"	"	0.9	"	"	"	2.0	0.5	"
Oysters	Jersey[2]	1	91	"	"	1.0	0.8	"	"	5.9	3.4	"
Limpets	Jersey[1] La Rozel	1	89	"	"	1.1	ND	"	"	5.3	0.6	"
	Guernsey[1]	1	91	"	"	0.9	"	"	"	2.7	ND	"
	Alderney[1]	1	84	"	"	1.3	"	"	"	8.4	0.7	"
Porphyra	Jersey[1] Greve de Lecq	3	260	"	ND	0.9	"	"	"	17	ND	"
	Guernsey[1] Fermain Bay	3	140	"	"	0.3	"	"	"	2.5	"	"
	Bordeaux Harbour	1	150	"	"	0.3	"	"	"	8.6	"	"
	Moulin Huet Bay	1	200	"	"	1.2	"	"	"	24	"	"
	Alderney[1] Quenard Point	4	160	"	0.03	1.1	"	"	"	12	"	"
Fucus serratus	Jersey[1] La Rozel	4	370	"	0.03	5.3	"	0.19	"	4.9	0.1	0.1
	Corbiere	1	310	"	ND	5.4	"	NA	"	7.0	ND	0.2
	Guernsey[1] Fermain Bay	4	310	"	"	3.2	"	0.20	"	3.2	ND	ND
	Alderney[1] Quenard Point	4	270	"	0.03	4.6	"	0.14	"	5.4	0.1	0.2
Laminaria digitata	Jersey[1] Verclut	4	420	"	ND	0.4	"	NA	"	3.4	0.04	0.08
Mud	Jersey[1] St Helier Harbour	1	620	"	3.9	47	"	"	"	87	ND	2.1
	Guernsey[1] St Sampsons Harbour	2	630	"	0.7	8.2	"	"	"	19	"	2.3
Muddy sand	Guernsey[1] Bordeaux Harbour	1	470	"	ND	1.6	"	"	"	3.3	"	1.2
Sand	Alderney[1] Little Crabbe Harbour	1	480	"	"	4.2	"	"	"	15	"	3.1

Table 38. Continued

Material	Sampling Area	No. of sampling observa-tions#	Mean radioactivity concentration (wet)*, Bq kg^{-1}								
			^{134}Cs	^{137}Cs	^{154}Eu	^{155}Eu	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Am	^{242}Cm	^{243}Cm+ ^{244}Cm
Rays	Guernsey[2]	1	ND	1.3	ND	ND	0.00039	0.0015	0.0017	ND	ND
Crabs	Guernsey[2]	1	"	0.2	"	"	0.0012	0.0019	0.0048	"	0.0020
	Jersey[2]	1	"	0.2	"	"	0.00093	0.0015	0.0056	0.00005	0.0022
	Alderney[1] Casquets	2	"	0.1	"	"	0.0035	0.0041	0.0093	0.00010	0.0036
Lobsters	Jersey[2]	1	"	ND	"	"	NA	NA	ND	NA	NA
	Alderney[1] Casquets	2	"	"	"	"	0.0015	0.0017	0.0063	0.00015	0.0026
Oysters	Jersey[2]	1	"	0.2	"	"	0.011	0.018	0.017	0.00017	0.0050
Limpets	Jersey[1] La Rozel	1	"	0.2	"	"	0.0058	0.0091	0.013	0.00023	0.0034
	Guernsey[1]	1	"	ND	"	"	NA	NA	ND	NA	NA
	Alderney[1]	1	"	"	"	"	0.018	0.019	0.043	0.0010	0.0092
Porphyra	Jersey[1] Greve de Lecq	3	"	0.06	"	"	NA	NA	ND	NA	NA
	Guernsey[1]										
	Fermain Bay	3	"	ND	"	"	"	"	"	"	"
	Bordeaux Harbour	1	"	0.4	"	"	"	"	"	"	"
	Moulin Huet Bay	1	"	ND	"	"	"	"	"	"	"
	Alderney[1] Quenard Point	4	"	0.07	"	"	"	"	"	"	"
Fucus serratus	Jersey[1]										
	La Rozel	4	"	0.3	"	"	0.064	0.086	0.034	0.00050	0.0098
	Corbiere	1	"	0.3	"	0.3	NA	NA	ND	NA	NA
	Guernsey[1] Fermain Bay	4	"	0.2	"	ND	0.029	0.047	0.020	0.00023	0.0063
	Alderney[1] Quenard Point	4	"	0.2	"	0.04	0.059	0.063	0.036	0.00044	0.014
Laminaria digitata	Jersey[1] Verclut	4	"	0.3	"	ND	NA	NA	ND	NA	NA
Mud	Jersey[1] St Helier Harbour	1	"	11	4.9	3.8	2.4	4.8	7.2	ND	2.1
	Guernsey[1] St Sampsons Harbour	2	0.2	5.7	ND	0.7	0.48	1.2	1.4	0.016	0.34
Muddy sand	Guernsey[1] Bordeaux Harbour	1	ND	2.6	"	0.6	0.12	0.37	0.34	ND	0.075
Sand	Alderney[1] Little Crabbe Harbour	1	"	3.7	"	ND	NA	NA	ND	NA	NA

[1] = Sampling area
[2] = Landing point
NA = not analysed
ND = not detected
** Except for sediment where dry concentrations apply*
 # See sub-section 3.3 for definition

10. MONITORING OF THE FRESHWATER ENVIRONMENT FOR RADIOACTIVITY FROM THE CHERNOBYL REACTOR ACCIDENT

We continued surveillance of the effects of fallout from this accident in 1990, but at a reduced scale of effort. Parts of the freshwater environment continued to show the effect of fallout from Chernobyl. The results of our additional monitoring for 1990 are presented in this section. The sampling locations are shown in Figure 2. They are mostly in areas of relatively high deposition of fallout from Chernobyl, namely Cumbria, North Wales and parts of Scotland, but samples from Northern Ireland, the Isle of Man and areas of low deposition were also obtained for completeness and comparison.

Tables 39-42 present concentrations of caesium-134 and -137 in fish, giving the averaged results of all analyses carried out at each location on samples taken during the year. The number of samples analysed is specified. The sample size, in terms of the number of individual fish, varied from one to about ten, depending on availability and radiological importance. The maximum concentrations in samples from a given location varied by up to a factor of two or three times the average value. Artificial radionuclides, other than those of radiocaesium, in 1990, were no longer detectable from the Chernobyl accident.

Concentrations of radiocaesium in freshwater fish varied widely between locations, reflecting the areas of deposition of radioactivity from Chernobyl. Most samples analysed were of brown trout (Table 39), in recognition of the potential radiological significance of this species; although rainbow trout are more commonly eaten, their radiocaesium concentrations were generally low (Table 40) compared with wild brown trout, because rainbow trout are mostly hatchery-reared and fed on relatively uncontaminated food prior to release. Perch (Table 41) had the highest concentrations of any of the freshwater species but, as they are not eaten in large quantities, their radiological significance is low. Other species (Table 42) had generally similar or lower radiocaesium concentrations than brown trout or pike taken from the same river or lake. Where there are data for the same species and locations to compare with results for 1989 (Hunt, 1990) there are still likely to be fluctuations, such as those due to sample size or to the contribution of hatchery-reared fish, but concentrations of radiocaesium were generally lower in 1990 than those in 1989, continuing the reducing trend that began in the latter part of 1987 (Hunt, 1989). The exception to this trend in radiocaesium concentrations at Trawsfynydd has been discussed in sub-section 6.10.

Table 39. Caesium radioactivity in brown trout, 1990

Location	No. of samples	Mean radioactivity concentration (wet), $Bq\ kg^{-1}$	
		^{134}Cs	^{137}Cs
England			
Devoke Water	10	26	180
Ennerdale Water	47	5.5	66
Loweswater	8	3.0	32
Wales			
Bala Lake	1	ND	19
Llyn Conwy	4	19	140
Llyn Elsi	9	15	110
Llyn Goddionduon	6	39	250
Llyn Ogwen	5	39	290
Llyn Trawsfynydd	85	78	360
Scotland			
Loch of Harray	1	ND	15
Lochan Fada	1	"	76
Loch Dee	13	26	200
Loch Doon	1	6	71
Loch Garry, Tayside Region	1	19	100
River Leader	1	ND	ND
River Tummel	1	10	78
Loch of Girlsta	1	33	210
Northern Ireland			
Altnahinch Dam	1	ND	56
Isle of Man			
River Druidale	1	22	120

ND = not detected

Table 40. Caesium radioactivity in rainbow trout, 1990

Location	No. of samples	Mean radioactivity concentration (wet), $Bq\ kg^{-1}$	
		^{134}Cs	^{137}Cs
England			
Cogra Moss	1	ND	ND
Narborough	1	"	"
Branthwaite	1	"	"
Wales			
Llyn Elsi	1	9.8	54
Llyn Trawsfynydd	12	4.7	17
Scotland			
Water of Ae	1	ND	ND
Northern Ireland			
Altnahinch Dam	1	ND	ND

ND = not detected

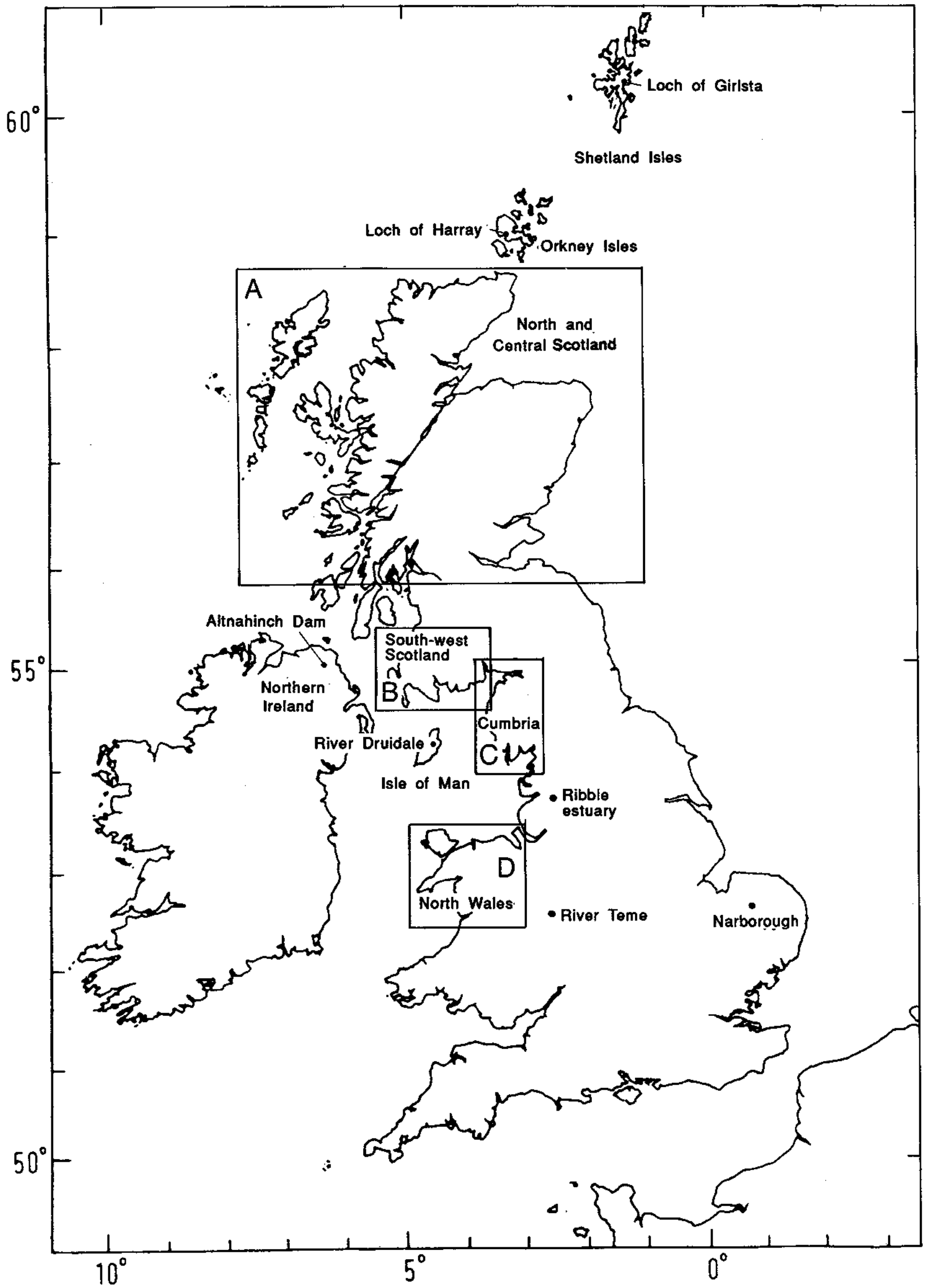

Figure 2. Sampling locations for monitoring of the freshwater environment for radioactivity from Chernobyl

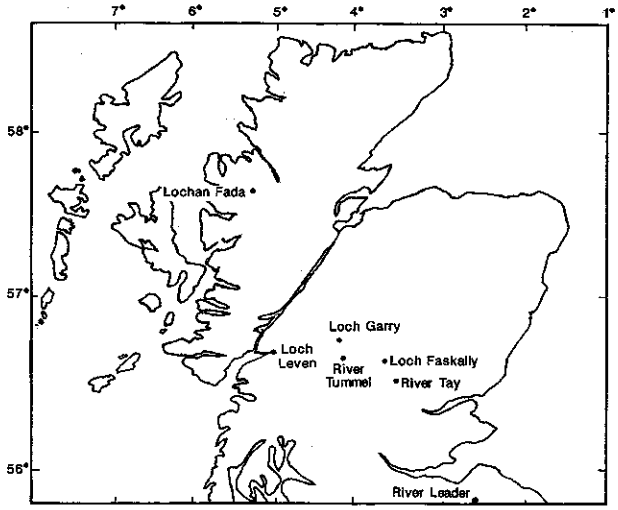

Figure 2 (Inset A). Sampling locations in northern and central Scotland

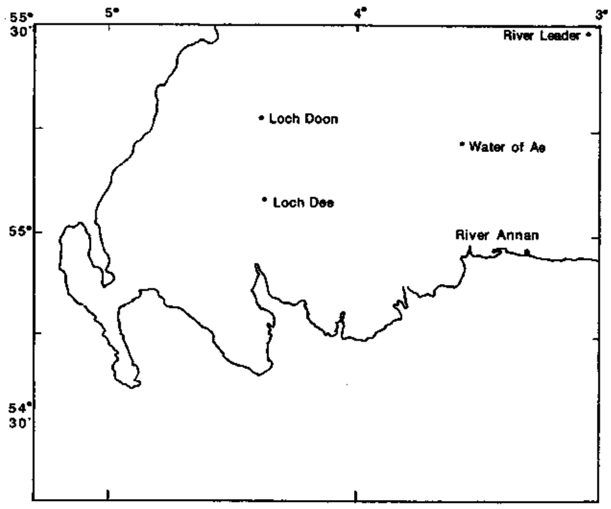

Figure 2 (Inset B). Sampling locations in southwestern Scotland

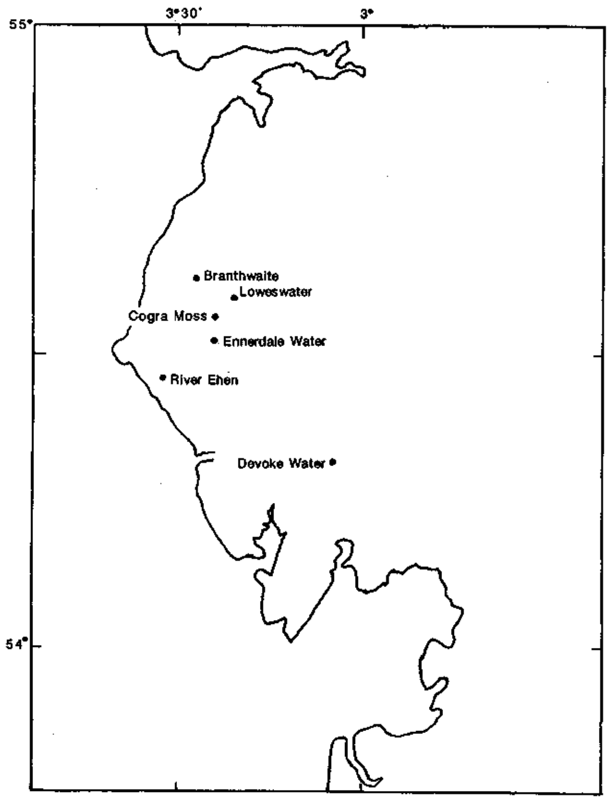

Figure 2 (Inset C). Sampling locations in Cumbria

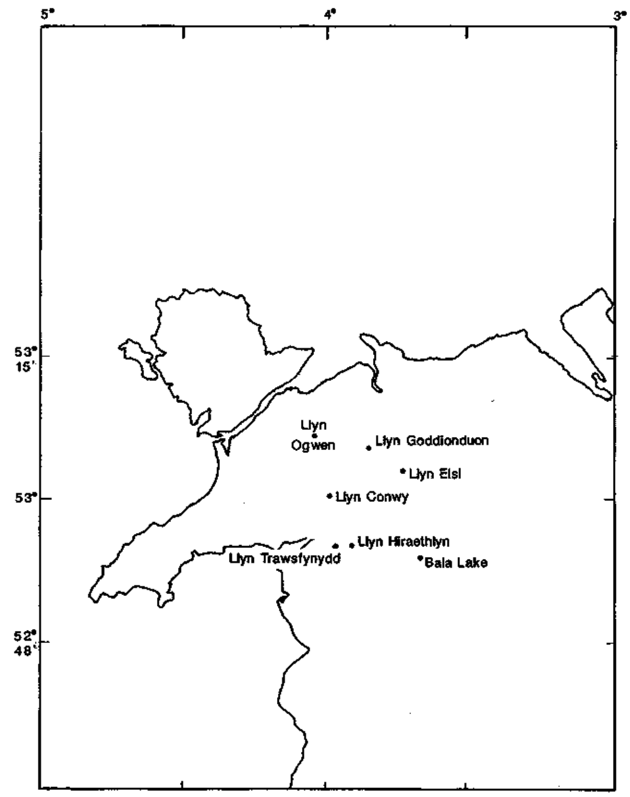

Figure 2 (Inset D). Sampling locations in North Wales

Table 41. Caesium radioactivity in perch, 1990

Location	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
		^{134}Cs	^{137}Cs
England			
Devoke Water	1	190	1300
Loweswater	5	12	94
Wales			
Llyn Hiraethlyn	1	15	120
Llyn Trawsfynydd	57	200	780
Scotland			
Loch Faskally	1	10	68
Loch Doon	1	27	210

ND = not detected

Table 42. Caesium radioactivity in other species of fish, 1990

Location	Species	No. of samples	Mean radioactivity concentration (wet), Bq kg^{-1}	
			^{134}Cs	^{137}Cs
England				
Ennerdale Water	Char	16	3.1	56
River Teme	Chub	1	ND	0.2
Ribble Estuary	Sea Trout	1	0.4	3.7
Loweswater	Pike	1	7.7	75
"	Eels	1	14	67
River Ehen	"	1	ND	11
Wales				
Bala Lake	Gwyniad	4	ND	10
"	Roach	6	"	9.9
"	Pike	10	9.3	62
Llyn Trawsfynydd	Rudd	1	70	370
Scotland				
River Tay	Salmon	1	ND	ND
River Annan	"	1	"	1.1
"	SeaTrout	2	"	15
Loch Doon	Char	1	14	110
River Tummel	Grayling	1	10	73
Loch Garry, Tayside region	Char	1	14	93
Loch Leven	Salmon	1	ND	1.1
Loch Faskally	Pike	1	24	180

ND = not detected

Table 43. Estimates of maximum dose* from Chernobyl to adults due to consumption of freshwater fish from areas of high deposition of fallout, 1990

Region	Location	Exposure, mSv	
		ICRP-26†	ICRP-60#
England	Devoke Water	0.10	0.10
Wales	Llyn Ogwen	0.16	0.16
Scotland	Loch Dee	0.11	0.11
Northern Ireland	Altnahinch Dam	0.027	0.027
Isle of Man	River Druidale	0.072	0.072

** These data are likely to overestimate actual exposures. See text for a description of the bases of the estimates*

† Committed effective dose equivalent for comparison with current dose criteria

 # Committed effective dose calculated using methodology of ICRP-60

Radiation exposures have been estimated using a procedure based on cautious assumptions, as previously (Hunt, 1989). A consumption rate of brown trout of 37 kg year^{-1}, sustained for one year, was taken to be representative of adults subject to the highest exposures. Actual exposures are likely to be lower, not only because this consumption rate is cautious (Leonard *et al.*, 1990) but also because, in practice, hatchery-reared or farmed fish of much lower radiocaesium concentrations may contribute to the diet. Exposures of children and infants would be likely to be lower than those for adults. Concentrations of radiocaesium in brown trout, representative of the highest in each region, were chosen. Effective doses were estimated using dose coefficients per unit intake, provided as described in sub-section 3.4. Estimates of dose are presented in Table 43.

The ICRP (ICRP, 1984b) provides guidance in the context of emergencies, which includes suggested levels of dose below which particular countermeasures would not be warranted. The suggested level of effective dose equivalent is 5 mSv in the first year. 1990 was outside this period but, as was the case in 1989, the estimated doses for all areas of the UK were less than 1 mSv year^{-1}. It can be shown that organ doses (in this case the lower large intestine is the critical organ) are not more limiting. Given that these dose estimates are cautious, it is clear that contamination of freshwater fish from fallout from Chernobyl was only of minor radiological importance. The collective dose from consumption of freshwater fish is likely to have been very small, as estimates have shown (Camplin *et al.*, 1986). The more significant contribution to collective dose, but still of low importance, was from consumption of marine fish, as considered in sub-section 4.1.1.

11. SUMMARY AND CONCLUSIONS

A summary of estimated public radiation exposures in 1990, relating to liquid radioactive waste discharges from nuclear establishments, is presented in Table 44. The exposures are expressed on two bases. For each exposed group, the committed effective dose equivalent is given using the existing methodology of ICRP-26 compared with results for committed effective dose calculated on the basis of ICRP-60. Where appropriate, doses to skin are given. Both methods incorporate accepted values for gut transfer factors of transuranics, i.e. 0.0002 for winkles in the Irish Sea, 0.0005 in other cases. Committed effective dose equivalents, on the basis of ICRP-26, were all within the ICRP-recommended principal dose limit of 1 mSv year^{-1} for members of the public.

The recommendations of ICRP-60 have not yet been adopted by the UK Government, but their effects are considered here to provide up-to-date information and as an aid to further study of the implications of these recommendations. Committed effective doses, on the basis of ICRP-60, were well within 1 mSv in 1990. However, using ICRP-60 methodology, it is not appropriate to compare these committed effective doses directly with the dose limit of 1 mSv year^{-1} because a significant contribution may be due to the effects of radioactivity already in the environment, which is subject to 'intervention' rather than being a 'practice' (sub-section 3.4). For Sellafield and Springfields (sub-sections 4.1 and 4.2), it has been shown that, when committed effective doses are calculated due to discharges in 1990, the doses are much less than those in Table 44. At other sites, committed effective doses, from discharges in 1990, would also be less than or equal to those in Table 44, depending upon the contribution due to radioactivity already in the environment. These committed effective doses would also therefore be well within the ICRP-60 dose limit of 1 mSv year^{-1} for members of the public.

The more important contributions to exposures from the effects of discharges from Sellafield were due to radiocaesium and transuranic radionuclides. Details are given in sub-section 4.1. Exposures of high-rate fish and shellfish consumers near Sellafield decreased slightly in 1990, as compared with 1989, due to decreases in the concentrations of ruthenium-106 and transuranic nuclides in shellfish. There was no significant change in fish and shellfish consumption rates by the group of high-rate fish and shellfish consumers near Sellafield in 1990. Consumption rates could increase again in the future, but it is considered unlikely that exposures, calculated using realistic parameters, will again exceed the 1 mSv year^{-1} level. Further reductions in discharges of radiologically significant nuclides are planned when the enhanced actinide removal plant (EARP) commences operation, scheduled for 1993. Dose rates which were above the 1 mSv year^{-1} level in the past did not occur for long enough for lifetime exposure to have exceeded 1 mSv year^{-1} on average, and thus the dose limitation objectives of ICRP-26 will be met.

Gamma dose rates over intertidal areas in the Ribble estuary, and occupancy values, were similar to those for 1989, as was the resulting exposure of the critical group of houseboat dwellers of 0.18 mSv.

The maximum exposure to the skin of fishermen handling nets in 1990 was 0.60 mSv. The dose limit for non-stochastic (deterministic) effects is 50 mSv year^{-1}. This exposure is therefore less than 2% of the relevant dose limit.

Near Trawsfynydd, concentrations of radiocaesium in fish from the lake increased in 1990, but the consumption rate of the radiologically important species, brown trout, decreased. As a consequence, exposures were similar to those of 1989.

Radioactivity from Sellafield contributed to exposures near many other nuclear establishments. Since apportionment of exposure to radioactivity of local origin is often difficult, the exposures from all artificial sources (including the small contribution due to weapons-test fallout) are quoted in Table 44, with appropriate footnotes. The effects of fallout from the Chernobyl accident are now difficult to detect in the marine environment of the UK. The continuing effect of fallout from Chernobyl on the freshwater environment is described in section 10; concentrations of radiocaesium have generally diminished in 1990 and conservative estimates of exposures were, as before, within 1 mSv year^{-1}.

As in previous years, collective doses have also been considered. The most significant radioactive waste discharges giving rise to collective dose were those from Sellafield, radiocaesium being the most significant component. Details are given in sub-section 4.1.1. The contribution to collective dose due to fallout from Chernobyl has been considered; this contribution is small except for fish from the Baltic Sea which are not widely eaten in the UK. The preliminary collective committed effective dose equivalent to the UK population in 1990 was 10 man-Sv, slightly less than the value for 1989 (13 man-Sv). For the population of other European countries, excluding the effects of the Chernobyl accident on Baltic Sea fish, the preliminary collective committed effective dose equivalent was 39 man-Sv in 1990, also less than the value for 1989 (45 man-Sv). The decreases reflect the reductions in discharges from Sellafield over the past decade and the decreased contribution from Chernobyl. It is estimated that the effects of the Chernobyl accident on Baltic Sea fish could have added a further 150 man-Sv to the collective dose to other European countries in both 1989 and 1990.

Table 44. Summarised estimates of public radiation exposure from discharges of liquid radioactive waste in the UK, 1990

Establishment	Radiation exposure pathway	Critical group	Exposure, mSv ICRP-26+	Exposure, mSv ICRP-60†
British Nuclear Fuels plc				
Sellafield	Fish and shellfish consumption External Handling of fishing gear *Porphyra*/laverbread consumption	Local fishing community Houseboat dwellers (River Ribble) Local fishing community Consumers in South Wales	0.16 0.18 0.12# 0.005	0.11 0.18 0.12# <0.005
Springfields	External Handling of fishing gear	Houseboat dwellers (River Ribble) Local fishing community	0.18a 0.60#	0.18a 0.60#
Capenhurst	Shellfish consumption	Local fishing community	0.06a	0.04a
Chapelcross	Fish and shellfish consumption } External } Handling of fishing gear	Local fishermen Local fishermen	0.07a 0.23#a	0.06a 0.23#a
United Kingdom Atomic Energy Authority				
Harwell	Fish consumption } External }	Anglers*	0.008	0.008
Winfrith	Fish and shellfish consumption	Local fishing community	0.01	0.01
Dounreay	Handling of fishing gear External Fish and crustacean consumption Mollusc consumption } External }	Local fishermen Local community Local fishing community Mollusc collectors	0.02#b 0.006b <0.005b 0.02b	0.02#b 0.006b <0.005b 0.02b
Nuclear Power Stations Operated by the Electricity Companies				
Berkeley and Oldbury	Fish and shellfish consumption } External }	Local fishing community	0.007b	0.007b
Bradwell	Fish and shellfish consumption } External }	Houseboat dwellers	0.01b	0.01b
Dungeness	External } Fish and shellfish consumption }	Bait diggers	0.01	0.01
Hartlepool	Fish and shellfish consumption	Local fishing community	<0.005a	<0.005a
Heysham	Fish and shellfish consumption External	Local fishing community Wildfowlers	0.14a 0.05a	0.10a 0.05a
Hinkley Point	Fish and shellfish consumption } External }	Local fishing community	0.006b	0.006b
Hunterston	Fish and shellfish consumption } External }	Local fishing community	0.01a	0.01a
Sizewell	Fish and shellfish consumption } External }	Local fishing community	<0.005b	<0.005b
Torness	Fish and shellfish consumption } External }	Local fishing community	<0.005a	<0.005a
Trawsfynydd	Fish consumption } External }	Local fishing community	0.09	0.09
Wylfa	Fish and shellfish consumption } External }	Local fishing community	0.01a	0.01a
Defence Establishments				
Aldermaston	Fish consumption } External }	Anglers*	<0.005	<0.005
Chatham	External	Houseboat dwellers	0.008	0.008
Devonport	Fish and shellfish consumption } External }	Local community	<0.005	<0.005
Faslane	Fish and shellfish consumption } External }	Anglers	0.009a	0.009a
Rosyth	External	Dredgermen	<0.005a	<0.005a
Holy Loch	External	Local community	<0.005a	<0.005a
Amersham International plc				
Amersham	Fish consumption } External }	Anglers*	<0.005	<0.005
Cardiff	Fish and shellfish consumption } External }	Local fishing community	0.02	0.02

+ Unless otherwise stated, represents the committed effective dose equivalent, to be compared with the ICRP-recommended principal dose limit of 1 mSv year⁻¹ or with the subsidiary limit of 5 mSv year⁻¹ provided the lifetime average does not exceed 1 mSv year⁻¹ see sub-section 3.4)

** A notional group with maximising consumption and occupancy rates has been assumed (see text)*

 # Exposure to skin, to be compared with the ICRP-recommended dose limit of 50 mSv year⁻¹ (see sub-section 3.4)

a Mainly due to discharges from Sellafield

b Partly due to discharges from Sellafield

† Unless otherwise stated, represents committed effective dose calculated using methodology of ICRP-60 (see sub-section 3.4). Many of these doses should not strictly be compared with the dose limit of 1 mSv year⁻¹ because there is a significant contribution due to past discharges. See text for a comparison in important cases

12. REFERENCES

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13. RECENT PUBLICATIONS ON RADIOACTIVITY IN THE AQUATIC ENVIRONMENT BY STAFF OF THE DIRECTORATE OF FISHERIES RESEARCH

**Note: Where all authors are not from MAFF, MAFF authors are indicated by italics*

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APPENDIX 1. Areas of work related to the monitoring programme and staff responsibilities

	Area of work	Staff
1.	Inspection of nuclear sites	G J Hunt B D Smith P G W Jones D G Turner S W Conney
2.	Management of the monitoring programme and fieldwork	D R P Leonard C J Gough P Caldwell J D Parr J R Tipple R J Woodhead T M Jeffs
3.	Assessment of radiation exposure	W C Camplin T E Eaton A J Baxter S F N Rollo T C Doddington L M Thurston L Duckett
4.	Analysis of samples	G A Sutton A Taylor P A Smedley D J Coles L A Goldspink T A Bailey R Hillier K A Langston S Cogan M J Howes G Santillo B R Harvey M B Lovett R D Ibbett D J Allington P Blowers A K Young J D Coward R A Bonfield H S Emerson I McMeekan
5.	Provision of laboratory and field equipment	I A Huggins W J Meadows G E Moore D J Andrews R J Read M Sherlock M D Baldwin M H Beach
6.	Data analysis	K Keable

APPENDIX 2. Dosimetric data

Radionuclide#	Half-life(years)	Mean γ energy (MeV per disintegration)	Dose* per unit intake by ingestion using the following methodology (Sv Bq^{-1})	
			ICRP-26	ICRP-60
Hydrogen-3	$1.24\ 10^{1}$	0.000	$1.60\ 10^{-11}$	$1.80\ 10^{-11}$
Carbon-14	$5.73\ 10^{3}$	0.000	$5.60\ 10^{-10}$	$5.60\ 10^{-10}$
Sulphur-35	$2.39\ 10^{-1}$	0.000	$6.95\ 10^{-10}$	$7.00\ 10^{-10}$
Manganese-54	$8.56\ 10^{-1}$	$8.364\ 10^{-1}$	$7.24\ 10^{-10}$	$7.30\ 10^{-10}$
Cobalt-58	$1.94\ 10^{-1}$	$9.976\ 10^{-1}$	$9.40\ 10^{-10}$	$1.00\ 10^{-9}$
Cobalt-60	5.27	2.500	$7.04\ 10^{-9}$	$7.20\ 10^{-9}$
Zinc-65	$6.67\ 10^{-1}$	$5.845\ 10^{-1}$	$3.90\ 10^{-9}$	$3.80\ 10^{-9}$
Strontium-90#	$2.91\ 10^{1}$	$3.163\ 10^{-3}$	$3.77\ 10^{-8}$	$3.22\ 10^{-8}$
Zirconium-95#	$1.75\ 10^{-1}$	1.505	$1.72\ 10^{-9}$	$2.06\ 10^{-9}$
Niobium-95	$9.62\ 10^{-2}$	$7.660\ 10^{-1}$	$6.80\ 10^{-10}$	$7.70\ 10^{-10}$
Technetium-99	$2.13\ 10^{5}$	0.000	$3.46\ 10^{-10}$	$6.70\ 10^{-10}$
Ruthenium-103#	$1.07\ 10^{-1}$	$4.685\ 10^{-1}$	$8.10\ 10^{-10}$	$1.10\ 10^{-9}$
Ruthenium-106#	1.01	$2.049\ 10^{-1}$	$7.50\ 10^{-9}$	$1.10\ 10^{-8}$
Silver-110 m#	$6.84\ 10^{-1}$	2.740	$2.89\ 10^{-9}$	$3.00\ 10^{-9}$
Antimony-125	2.77	$4.312\ 10^{-1}$	$7.02\ 10^{-10}$	$9.80\ 10^{-10}$
Iodine-129	$1.57\ 10^{7}$	$2.463\ 10^{-2}$	$6.40\ 10^{-8}$	$1.10\ 10^{-7}$
Caesium-134	2.06	1.550	$1.90\ 10^{-8}$	$1.90\ 10^{-8}$
Caesium-137#	$3.00\ 10^{1}$	$5.651\ 10^{-1}$	$1.30\ 10^{-8}$	$1.30\ 10^{-8}$
Barium-140#	$3.49\ 10^{-2}$	2.502	$4.41\ 10^{-9}$	$6.50\ 10^{-9}$
Cerium-144#	$7.78\ 10^{-1}$	$5.282\ 10^{-2}$	$5.80\ 10^{-9}$	$8.80\ 10^{-9}$
Promethium-147	2.62	$4.374\ 10^{-6}$	$2.55\ 10^{-10}$	$4.40\ 10^{-10}$
Europium-154	8.80	1.237	$2.47\ 10^{-9}$	$3.10\ 10^{-9}$
Europium-155	4.96	$6.062\ 10^{-2}$	$3.68\ 10^{-10}$	$5.30\ 10^{-10}$
Lead-210#	$2.23\ 10^{1}$	$4.810\ 10^{-3}$	$2.03\ 10^{-6}$	$1.30\ 10^{-6}$
Bismuth-210	$1.37\ 10^{-2}$	0.000	$1.56\ 10^{-9}$	$2.10\ 10^{-9}$
Polonium-210	$3.79\ 10^{-1}$	0.000	$4.35\ 10^{-7}$	$6.20\ 10^{-7}$
Radium-226#	$1.60\ 10^{3}$	1.765	$2.96\ 10^{-7}$	$2.20\ 10^{-7}$
Uranium-238#	$4.47\ 10^{9}$	$2.235\ 10^{-2}$	$6.67\ 10^{-8}$	$4.17\ 10^{-8}$
Neptunium-237#	$2.14\ 10^{6}$	$2.382\ 10^{-1}$	$5.40\ 10^{-7}$	$3.20\ 10^{-7}$
Plutonium-238 (a)	$8.77\ 10^{1}$	$1.812\ 10^{-3}$	$4.30\ 10^{-7}$	$2.60\ 10^{-7}$
Plutonium-238 (b)			$1.70\ 10^{-7}$	$1.10\ 10^{-7}$
Plutonium-240 (a)	$6.54\ 10^{3}$	$1.731\ 10^{-3}$	$4.80\ 10^{-7}$	$2.80\ 10^{-7}$
Plutonium-240 (b)			$1.90\ 10^{-7}$	$1.20\ 10^{-7}$
Plutonium-241 (a)	$1.44\ 10^{1}$	$2.546\ 10^{-6}$	$9.30\ 10^{-9}$	$5.30\ 10^{-9}$
Plutonium-241 (b)			$3.70\ 10^{-9}$	$2.20\ 10^{-9}$
Americium-241(a)	$4.32\ 10^{2}$	$3.253\ 10^{-2}$	$4.90\ 10^{-7}$	$2.90\ 10^{-7}$
Americium-241(b)			$2.00\ 10^{-7}$	$1.20\ 10^{-7}$
Curium-242	$4.46\ 10^{-1}$	$1.832\ 10^{-3}$	$1.80\ 10^{-8}$	$1.60\ 10^{-8}$
Curium-243	$2.85\ 10^{1}$	$1.347\ 10^{-1}$	$3.40\ 10^{-7}$	$2.00\ 10^{-7}$
Curium-244	$1.81\ 10^{1}$	$1.700\ 10^{-3}$	$2.70\ 10^{-7}$	$1.70\ 10^{-7}$

Energy and dose per unit intake data include the effects of radiations of short-lived daughter products

* *ICRP-26 and ICRP-60 data are for committed effective dose equivalents and committed effective doses respectively. References are given in the main text. All data are for adults*

(a) *Gut transfer factor 5 x 10^{-4} for consumption of all foodstuffs except Irish Sea winkles*

(b) *Gut transfer factor 2 x 10^{-4} for consumption of Irish Sea winkles*

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