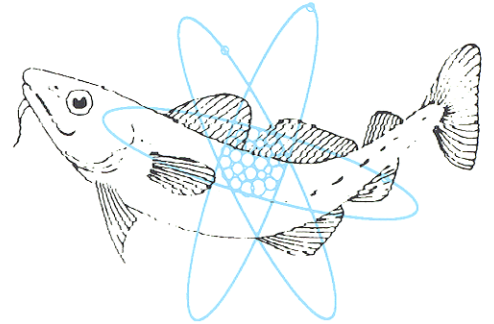


AQUATIC ENVIRONMENT MONITORING REPORT

Number 34



Radioactivity in Surface and Coastal Waters of the British Isles, 1991



Directorate of Fisheries Research
Lowestoft, 1993

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD
DIRECTORATE OF FISHERIES RESEARCH

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**Radioactivity in Surface and Coastal Waters
of the British Isles, 1991**

LOWESTOFT
1993

The author: W C Camplin, BSc MSc MSRP, is a Grade 7 Officer (Principal Scientific Officer) at MAFF Directorate of Fisheries Research, Fisheries Laboratory, Lowestoft, Suffolk NR33 0HT.

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1. INTRODUCTION

This report presents the results of the environmental monitoring programme carried out during 1991 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, 1992(a)) and the programme operated by Her Majesty's Inspectorate of Pollution (HMIP, 1992) 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 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.

To set the monitoring results from our regular programme in context, liquid radioactive discharges from UK nuclear establishments to the aquatic environment in 1991 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, 1992(a), (b); Scottish Office, 1991, 1992), the latest available data being for the year 1990. Details of the 1991 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 1991. 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 1991 are also stated in Table 1.

For completeness, it should be noted that radiological safety for US Navy operations in Holy Loch in 1991 was the responsibility of the US Navy in association with the Ministry of Defence who publish information annually (Fuller and Casey, 1992).

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 1991, 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. In the context of a new Convention on the Protection of the Marine Environment of the North-east Atlantic (PARCOM, 1992), the UK Government agreed a 15-year ban on the sea disposal of all radioactive waste to 1 January 2008. The Convention provides for the possibility of extending the ban, by unanimous agreement of Contracting Parties, for a further ten years. However, the Government has not ruled out sea disposal for large items of low-level radioactive waste, such as boilers from decommissioned nuclear power stations, as a safe longer-term option, but will keep under review whether the 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).

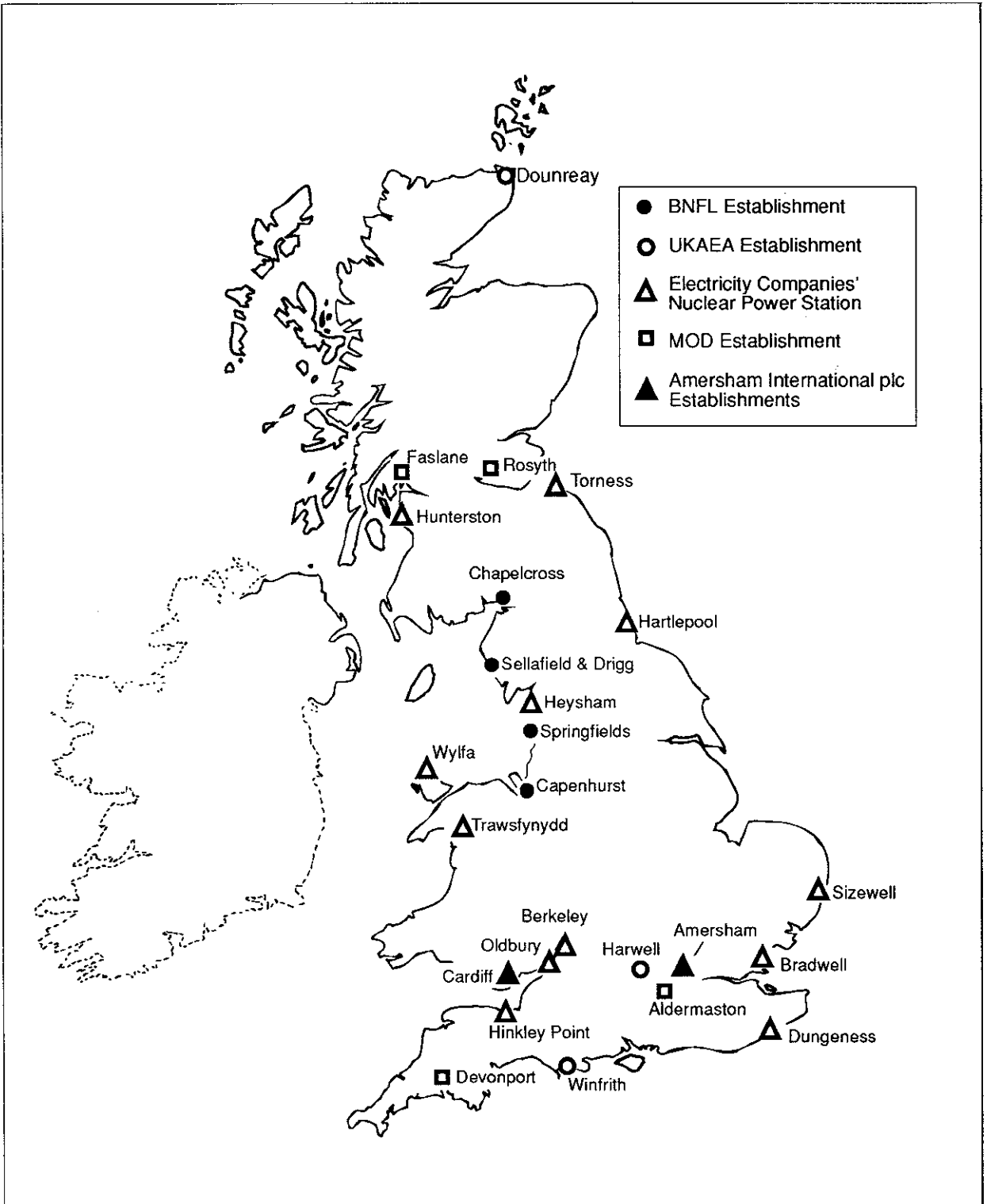


Figure1. UK nuclear establishments giving rise to principal discharges of liquid radioactive waste

Table 1. Principal discharges of liquid radioactive waste from UK nuclear establishments, 1991

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1991	
			TBq ⁽¹²⁾	% of limit ⁽¹³⁾
British Nuclear Fuels plc				
Sellafield	Total alpha	10	2.13	21
Sea pipelines	Total beta	500	62.2	12
	Tritium	3500	1800	52
	Carbon-14	4	2.44	61
	Cobalt-60	8	0.087	1.1
	Strontium-90	35	4.09	12
	Zirconium-95 + Niobium-95	180	12.4	6.9
	Technetium-99	10	3.86	39
	Ruthenium-106	170	18.7	11
	Iodine-129	0.4	0.159	40
	Caesium-134	10	0.765	7.7
	Caesium-137	110	15.6	14
	Cerium-144	22	1.73	7.9
	Plutonium alpha	7	1.08	15
	Plutonium-241	170	29.5	17
	Americium-241	3	0.744	25
Seaburn sewer	Total activity	0.148	0.00108	< 1
Drigg ²				
Sea pipeline	Total alpha	0.1	0.0005	< 1
	Total beta ¹	0.3	0.014	4.7
	Tritium	120	2.2	1.8
Stream ¹⁷	Total alpha	9 10 ⁴	730	< 1
	Total beta ¹	1.2 10 ⁶	5000	< 1
	Tritium	6 10 ⁸	5.4 10 ⁵	< 1
Springfields ¹⁴	Total alpha	13.32	0.143	1.4
	Total beta	444	32.5	9.8
	Total alpha	4	0.0271	2.7
	Total beta	240	5.94	9.9
	Technetium-99	0.6	0.0192	13
	Thorium-230	2	0.0042	< 1
	Thorium-232	0.2	0.0003	< 1
	Neptunium-237	0.04	0.0003	3.0
	Uranium	0.15	0.0184	49
Chapelcross	Total alpha	0.1	0.0002	< 1
	Total beta ¹	25	0.11	< 1
	Tritium	5.5	1.87	34
Capenhurst				
Rivacre Brook	Uranium	0.02	0.00293	15
	Uranium daughters	0.02	0.0077	39
	Non-uranic alpha	0.003	0.000136	4.5
	Technetium-99	0.1	0.00767	7.8
Meols outfall	Technetium-99	0.148	NIL	NIL
United Kingdom Atomic Energy Authority				
Winfrith				
(inner pipeline)	Total alpha	0.3	0.00286	< 1
	Tritium	650	13.2	2.0
	Cobalt-60	10	0.152	1.5
	Zinc-65	6	0.0213	< 1
	Other radionuclides	80	0.492	< 1
(outer pipeline)	Total alpha	0.004	0.000172	4.3
	Tritium	1	0.128	13
	Other radionuclides	0.01	0.00034	3.4
Harwell	Total activity ^{1,3}	8.88	0.231	2.6
	Tritium	8.88	0.444	5.0
Dounreay	Total alpha ⁴	0.75	0.03	4.1
	Total beta ¹	110	5.6	5.0
	Tritium	130	0.82	< 1
	Cobalt-60	1.0	0.04	4.0
	Strontium-90	12	1.1	9.0
	Zirconium-95 + Niobium-95	6.0	0.02	< 1
	Ruthenium-106	12	0.52	4.3
	Silver-110m	0.4	0.04	8.8
	Caesium-137	50	3.5	7.1
	Cerium-144	12	0.04	< 1
	Plutonium-241	15	0.563	3.8
	Curium-242	1.0	0.003	< 1
Nuclear Electric plc				
Berkeley ⁵	Total activity ¹	7.4	0.200	8.1
	Tritium	55.5	0.095	< 1
	Total activity ^{1,7}	0.4	0.174	65
	Tritium	8	0.177	3.3
	Caesium-137	0.2	0.122	92
Bradwell	Total activity ¹	7.4	0.453	6.1
	Tritium	55.5	1.37	2.5
	Zinc-65	0.185	0.00021	< 1
Dungeness				
'A' Station	Total activity ¹	7.4	0.374	5.1
	Tritium	74	0.492	< 1
'B' Station	Total activity ^{1,5}	4	0.0103	< 1
	Tritium	650	76.1	12
	Sulphur-35	25	0.379	1.5
Hartlepool	Total activity ^{1,5}	4	0.036	< 1
	Tritium	1850	142	7.7
	Sulphur-35	7.5	0.35	4.7

Table 1. continued

Establishment	Radioactivity	Discharge limit (annual equivalent), TBq	Discharges during 1991	
			TBq ⁽¹²⁾	% of limit ⁽¹³⁾
Heysham				
Station 1	Total activity ^{1,5}	4	0.026	< 1
	Tritium	1850	309	17
	Sulphur-35	7.5	0.69	9.2
Station 2	Tritium	1200	107	8.9
	Sulphur-35	7	0.002	< 1
	Cobalt-60	0.036	0.00143	4.0
	Other radionuclides	0.45	0.007	1.5
Hinkley Point				
'A' Station	Total activity ^{1,7}	1.0	0.286	29
	Tritium	25	0.781	3.1
	Caesium-137	1.5	0.443	30
'B' Station	Total activity ^{1,5,8}	0.25	0.022	8.8
	Tritium	650	277	43
	Sulphur-35	2.0	1.51	76
	Cobalt-60	0.035	0.004	11
Oldbury ¹⁴	Total activity ¹	3.7	0.284	10
	Tritium	74	0.202	< 1
	Total activity ^{1,7}	1.3	0.083	26
	Tritium	25	0.069	1.1
	Caesium-137	0.7	0.006	3.4
Sizewell	Total activity ¹	7.4	0.47	6.4
	Tritium	111	5.6	5.0
Trawsfynydd ¹⁵	Total activity ¹	1.48	0.271	22
	Tritium	74	0.31	2.5
	Caesium-137	0.259	0.0284	13
	Total activity ^{1,7,16}	0.72	0.0250	21
	Tritium	12	0.0467	2.3
	Strontium-90	0.08	0.00232	17
	Caesium-137	0.05	0.00536	64
Wylfa	Total activity ¹	2.405	0.0877	3.6
	Tritium	148	5.68	3.8
Scottish Nuclear Ltd				
Hunterston				
'A' Station	Total activity ¹	7.5	0.28	3.7
	Tritium	48	0.25	< 1
'B' Station	Total activity ^{1,5}	3.7	0.04	1.1
	Tritium	1480	257	17
	Sulphur-35	26	1.48	5.7
Torness	Total alpha	0.0045	0.000009	< 1
	Beta activity ^{1,5,8}	0.45	0.0054	1.2
	Tritium	1200	132	11
	Sulphur-35	10	0.044	< 1
	Cobalt-60	0.05	0.0014	2.8
Ministry of Defence (Procurement Executive)				
Aldermaston	Total activity ^{1,3}	5.8	0.047	< 1
	Tritium	5.8	0.017	< 1
Ministry of Defence (Navy Department)				
Devonport ⁹	Total activity ^{1,8}	0.002	0.000151	7.5
	Tritium	0.12	0.0432	36
	Cobalt-60	0.016	0.00116	7.2
Faslane	Total activity ¹	0.037	0.00011	< 1
Rosyth ¹⁰	Total alpha	1 10 ⁻⁶	6 10 ⁻⁷	60
	Beta activity ^{1,8}	0.01	0.0002	2.0
	Tritium	0.01	0.0015	15
	Cobalt-60	0.055	0.0005	< 1
Amersham International plc				
Amersham	Total activity ^{1,3}	2.7	0.9	34
	Tritium	14.8	0.013	< 1
Cardiff	Beta/gamma activity ¹¹	0.096	0.018	19
	Tritium	1400	555	40
	Carbon-14	2	1.33	67

¹ Excluding tritium

² Authorisation was varied with effect from 1 January 1991

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 May 1991. The first block of data relates to the period 1 January 1991 to 30 April 1991; the second block of data relates to the period 1 May 1991 to 31 December 1991. '% limit' refers to the equivalent limit for 4 months or 8 months respectively

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. Data quoted to 3 significant figures except where fewer significant figures are provided in source documents

¹³ Data quoted to 2 significant figures except when values are less than 1%

¹⁴ Authorisation was revised with effect from 1 October 1991. The first block of data relates to the period 1 January 1991 to 30 September 1991; the second block of data relates to the period 1 October 1991 to 31 December 1991. '% limit' refers to the equivalent limit for 9 months or 3 months respectively

¹⁵ Authorisation was revised with effect from 1 November 1991. The first block of data relates to the period 1 January 1991 to 31 October 1991; the second block of data relates to the period 1 November 1991 to 31 December 1991. '% limit' refers to the equivalent limit for 10 months or 2 months respectively

¹⁶ Excluding strontium-90

¹⁷ Values are expressed in terms of concentrations of activity in Bq m⁻³

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

3.1 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 2. 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 2; however, these conditions may vary, sometimes significantly. Natural radionuclides are not normally reported in the tables unless there is reason to believe that waste discharges may have increased their levels in the environment.

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, 1992). Alpha-emitting thorium, uranium and transuranic nuclides are chemically separated and analysed by

Table 2. 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	0.5
Niobium-95	0.5
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

alpha spectrometry using silicon surface-barrier detectors (Baker, 1984; 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 3.2). Detection limits are usually much lower for radionuclides analysed using these procedures than for gamma-emitting radionuclides.

With the exception of total beta analyses, radioactive decay of radionuclides is taken into account by correcting the activity measured at the time of counting to a value representing the activity in the sample at the time of collection. A decay correction for total beta analyses is not carried out because the activity measured is due to a mixture of several radionuclides each with different half-lives and samples are generally counted soon after collection as indicated above. For the relatively short-lived radionuclides protactinium-233 and thorium-234, the ingrowth of activity from their parent radionuclides is also taken into account when deriving the activity in the sample at the time of collection. In keeping with normal practice, the concentrations of very short-lived (< 3 days) radionuclides which are supported by their parents are not reported in the tables. However, the concentrations of parents are quoted and it can be assumed that the concentrations of the daughter products are approximately equal to those of the parents. Examples of such very short-lived radionuclides are yttrium-90, rhodium-103m, rhodium-106m, barium-137m and protactinium-234m which are formed by decay of strontium-90, ruthenium-103, ruthenium-106, caesium-137 and thorium-234 respectively.

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 dosimeters 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.

3.2 Methods of presentation of measurements

The tables of monitoring results generally contain summarised values of observations obtained during the year under review. The data are generally quoted to two significant figures but it should be noted that values near to the limits of detection will not have the precision implied by using two significant figures. 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 3.3. 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 unsustainable) 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.

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 3.3).

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.

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 (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 3 lists representative values to be expected from natural sources of natural radioactivity. Further discussion of natural radioactivity is given in section 11 of this report.

Table 3. 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 products	200 to 400	⁴⁰ K and decay of U and Th
Mud	700 to 1000	"

Gamma dose rates in air over intertidal sediments: 0.03-0.1 mGy h⁻¹

* Except sediments for which dry concentrations apply

* 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

3.3 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 Publication 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 appropriate dose of the '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, 1984(a); ICRP, 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 gamma 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). The exposure of gonads from beta radiation is assessed using the methods described by Hunt (1992). 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; ICRP, 1991). 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, 1992(b)) 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 a solid waste disposal site and nuclear power plant supplying electricity to the national grid. We regularly monitor the environmental consequences of discharges of liquid radioactive waste from five BNFL sites, namely Sellafield, Drigg, Springfields, Capenhurst and, on behalf of the Scottish Office, Chapelcross.

4.1 Sellafield and Drigg, Cumbria

Liquid radioactive wastes from both Sellafield and Drigg are discharged under separate authorisations effectively to the same body of water on the Irish Sea coastline. The sites are therefore considered together for the purpose of our environmental monitoring.

Operations and facilities at Sellafield 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 3.3. 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 1991 are summarised in Table 1, and were within the more stringent limits set by the Authorising Departments. The site ion-exchange effluent plant (SIXEP) and the salt evaporator operated during 1991 and there was no major shutdown of the reprocessing plant. Discharges continued at the low level typical of recent years. Total alpha discharges, at 2.13 TBq, were virtually unchanged as compared with 1990 (2.16 TBq) whereas total beta discharges declined (1991: 62.2 TBq, 1990: 70.9 TBq) due largely to a fall in caesium-137 discharges by about 30%. There were small increases in the discharges of ruthenium-106, zirconium-95 and niobium-95.

The main function of the Drigg site is to receive solid radioactive wastes from Sellafield and other UK nuclear and non-nuclear sites and to dispose of them in engineered trenches on land. On 1 January 1991 a Variation to the Authorisation for disposals came into effect which allowed for the discharge of leachate from the trenches through a new 1 km marine pipeline. Previously the leachate was discharged into a stream which runs across the site into the intertidal part of the River Irt. The limits for activity to be discharged through the marine pipeline and for concentrations of residual activity in the Drigg Stream are given in Table 1. Levels in 1991 were well within these limits.

The amounts of activity discharged from the pipeline are small compared with those discharged from the Sellafield site. MAFF marine monitoring of the Drigg site is subsumed within the Sellafield programme which is described in the remainder of this sub-section. The contribution to exposures due to Drigg discharges is negligible compared with that due to Sellafield and any effects of Drigg discharges could not be detected in 1991 above those due to Sellafield. Monitoring of the Drigg Stream is carried out by HMIP (HMIP, 1992).

Our regular monitoring of Sellafield continued during 1991. 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 1991, 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 4(a). Data are listed by location of sampling or landing point, in approximate order of increasing distance from Sellafield. So as to be representative of consumption by the public, samples are generally obtained from commercial sources. However, to minimise the risk of underestimating exposures, and as certain 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 is now difficult to detect due to decreasing concentrations of caesium-134. However, radiocaesium in fish from the Kattegat and Skaggeiak 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 resi-

dence 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 3.2).

Concentrations of radiocaesium in fish from the eastern Irish Sea in 1991 were generally similar to those in 1990. 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 generally lower than those in 1990, 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 1991, are listed in Table 4(b). Analyses of samples of fish for carbon-14, strontium-90, technetium-99 and promethium-147 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 1991 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 5 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: for example, lobsters tend to concentrate technetium-99 when compared with crabs. In addition, 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 has also been true for mobile nuclides in the past. However, since the importance of caesium-137 associated with sediment has increased relative to the source of direct discharges, concentrations of this nuclide in molluscs have tended to be higher than those for crustaceans. Concentrations of

beta/gamma-emitting radionuclides in shellfish in 1991 were generally similar to those in 1990, with some evidence of small local increases for ruthenium-106, zirconium-95 and niobium-95 in line with increases in discharges.

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 3.2). The data for 1991 are presented in Table 6. 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 1991, when compared with 1990, concentrations of transuranic nuclides in fish and shellfish generally showed small decreases, in line with the expected trend.

Concentrations of natural radionuclides in fish and shellfish in the Sellafield area are presented in Section 11.

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 variables 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 generally 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 1991. 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 estimating doses to consumers it is not sufficient to determine only the total consumption rates of fish and shellfish together. Our experience (illustrated by Tables 4-6) has shown, however, that for a given area within each of the classes fish, crustaceans and molluscs, the concentrations of given nuclides in representative samples are relatively constant. For each of the 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 1991 were not significantly different from those in 1990 (Camplin, 1992), 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 60% crabs and 40% 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 4(a). Beta/gamma radioactivity in fish from the Irish Sea vicinity and further afield, 1991

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	5	180	0.86	38
"	Plaice	2	170	0.50	31
"	Grey mullet	1	170	0.38	24
Sellafield offshore area ¹	Cod	3	170	0.67	30
"	Plaice	4	130	0.15	15
"	Dab	4	160	0.24	20
"	Herring	1	140	0.79	23
"	Whiting	3	160	0.32	36
Ravenglass ²	Cod	17	150	0.38	29
"	Plaice	3	130	0.22	17
"	Flounder	3	230	0.62	31
"	Saithe	1	170	0.54	34
"	Whiting	2	130	0.60	31
"	Pout whiting	1	130	0.68	30
"	Salmon	1	94	ND	1.4
"	Whitebait	1	120	0.42	17
"	Sea trout	1	99	ND	6.7
Whitchaven ²	Cod	4	140	0.14	15
"	Plaice	4	110	0.19	15
"	Herring	1	120	0.16	12
"	Ray	3	88	0.17	9.8
Haverigg ¹	Flounder	1	150	ND	38
Morecambe Bay ¹	Flounder	5	140	0.56	39
"	Plaice	2	120	ND	16
"	Bass	1	150	0.33	37
"	Whitebait	1	100	0.19	22
Cumbrian rivers ⁴	Sea trout	5	130	0.10	19
Fleetwood ²	Cod	4	140	0.24	17
"	Plaice	4	110	0.08	11
"	Fish meal ⁵	4	260	0.08	4.7
Isle of Man ²	Cod	4	120	0.05	7.0
"	Plaice	3	87	0.06	4.1
"	Herring	4	120	0.05	5.1
"	Witch	1	77	ND	2.5
Inner Solway ¹	Flounder	4	160	0.56	64
"	Salmon	1	130	ND	0.42
"	Sea trout	2	130	"	8.6
Kircudbright ²	Plaice	2	110	"	6.8
North Anglesey ¹	Plaice	2	98	"	3.0
"	Ray	2	97	"	1.7
"	Spurdog	1	91	"	8.7
Northern Ireland ²	Cod	4	130	0.09	9.6
"	Whiting	8	130	0.80	9.0
"	Herring	4	120	ND	5.6
"	Spurdog	5	92	"	7.9
"	Saithe	1	120	"	11
Ayr ²	Cod	2	140	0.07	6.3
"	Plaice	2	91	ND	7.4
Loch Leven ¹	Salmon	1	110	"	1.4
Minch ¹	Cod	5	130	"	1.3
"	Plaice	5	120	"	1.3
"	Mackerel	1	110	"	0.29
"	Haddock	5	120	0.02	0.83
"	Herring	1	120	ND	0.46
West of Scotland ¹	Mackerel	4	100	"	0.24
Shetland ¹	Fish meal ⁵	3	360	"	0.81
"	Fish oil	4	ND	"	ND

Table 4(a). Continued

Sampling area/ landing point	Sample	No. of sampling observa- tions ³	Mean radioactivity concentration (wet), Bq kg ⁻¹		
			Total beta	¹³⁴ Cs	¹³⁷ Cs
Northern North Sea ¹	Cod	5	110	ND	0.87
"	Plaice	4	100	"	0.73
"	Haddock	7	100	"	0.55
"	Herring	4	120	"	0.49
"	Mackerel	2	NA	"	0.19
"	Saithe	1	"	"	0.89
Mid-North Sea ¹	Cod	6	120	0.01	2.1
"	Plaice	7	93	0.01	0.77
"	Herring	5	120	ND	0.77
"	Haddock	2	NA	"	0.92
"	Whiting	2	"	"	1.5
"	Mackerel	1	"	"	0.37
Southern North Sea ¹	Cod	3	130	"	1.1
"	Plaice	2	89	"	0.81
"	Herring	2	130	"	0.93
English Channel ¹	Cod	1	97	0.07	0.98
"	Mackerel	1	130	ND	0.48
"	Hake	1	89	"	0.37
"	Plaice	3	87	"	0.28
"	Pollack	1	120	"	0.56
"	Whiting	2	95	"	0.87
"	Pout whiting	1	110	0.06	0.46
Kattegat and Skagerrak ¹	Cod	2	120	2.0	18
Skagerrak ¹	Herring	1	120	1.1	11
Norwegian Sea ¹	Cod	1	110	ND	0.97
Iceland area ¹	Cod	2	110	"	0.22
Icelandic processed ²	Cod	2	110	"	0.35
Greenland area ¹	Cod	1	90	"	0.34

NA = not analysed; ND = not detected; ¹ Sampling area; ² Landing point; ³ See sub-section 3.2 for definition; ⁴ Samples collected from a number of rivers by North West Water; ⁵ Concentrations refer to weight of sample as supplied

Table 4(b). Other beta/gamma radioactivity in fish from the Irish Sea vicinity and further afield, 1991

Sampling area/ landing point	Sample	No. of sampling observa- tions ³	Mean radioactivity concentration (wet), Bq kg ⁻¹				
			¹⁴ C	⁶⁰ Co	⁹⁰ Sr	⁹⁹ Tc	¹⁴⁷ Pm
Sellafield coastal area ¹	Cod	5	NA	0.06	NA	NA	NA
Sellafield offshore area ¹	Cod	3	74	0.14	0.072	0.22	0.10
"	Plaice	4	76	ND	0.058	0.40	0.0098
Ravenglass ²	Whitebait	1	NA	"	0.45	NA	NA
Whitehaven ²	Cod	4	33	"	0.20	"	"
"	Plaice	4	48	"	0.039	"	"
Morecambe Bay ¹	Flounder	5	36	"	NA	"	"
"	Plaice	2	48	0.42	"	"	"
"	Whitebait	1	NA	ND	0.80	"	"
Fleetwood ²	Fish meal ⁵	4	"	"	0.14	"	"
"	Cod	4	31	"	NA	"	"
"	Plaice	4	41	"	"	"	"
Isle of Man ²	Plaice	3	30	"	"	"	"
Inner Solway ¹	Flounder	4	36	"	"	"	"
North Anglesey ¹	Ray	2	29	"	"	"	"
"	Spurdog	1	41	"	"	"	"
Northern Ireland ²	Herring	4	NA	0.35	"	"	"
West of Scotland ¹	Mackerel	1	19	ND	"	"	"
Shetland ¹	Fish meal ⁵	3	NA	0.38	0.62	"	"
Northern North Sea ¹	Haddock	4	15	ND	NA	"	"
Mid-North Sea ¹	Cod	4	15	0.05	"	"	"
"	Plaice	4	16	ND	"	"	"
Iceland area ¹	Cod	2	16	"	"	"	"
Icelandic processed ²	Cod	2	21	"	"	"	"

ND = not detected; NA = not analysed; ¹ Sampling area; ² Landing point; ³ See sub-section 3.2 for definition; ⁴ Samples collected from a number of rivers by North West Water; ⁵ Concentrations refer to weight of sample as supplied

Table 5. Beta/gamma radioactivity in shellfish from the Irish Sea vicinity and further afield, 1991

Sampling point/ landing area	Sample	No. of sampling observa- tions ³	Mean radioactivity concentration (wet)*, Bq kg ⁻¹										
			Total beta	¹⁴ C	⁶⁰ Co	⁶⁵ Zn	⁹⁰ Sr	⁹⁵ Zr	⁹⁵ Nb	⁹⁹ Tc	¹⁰³ Ru	¹⁰⁶ Ru	^{110m} Ag
Sellafield coastal area ¹	Crabs	8	110	100	0.06	ND	0.97	0.16	ND	3.5	ND	10	6.0
	Lobsters	10	270	110	0.84	"	0.25	ND	"	220	"	3.2	8.3
	Winkles ⁴	12	320	74	3.4	"	7.0	7.2	6.7	44	0.28	88	20
	" ⁵	3	240	NA	1.5	"	NA	6.0	1.9	NA	ND	42	17
	" ⁶	3	440	"	5.4	"	"	17	13	"	1.0	120	33
	Mussels ⁴	4	230	"	2.6	0.06	"	1.3	2.4	"	0.04	62	1.0
"	Limpets	4	420	"	3.4	ND	"	3.2	3.0	"	ND	40	9.8
Sellafield offshore area ¹	Whelks	1	260	"	5.7	"	"	0.51	0.88	"	"	110	21
St Bees ¹	Winkles	4	370	54	3.6	"	13	9.0	9.0	20	0.32	96	24
	Mussels	4	250	NA	2.8	"	NA	8.1	4.5	NA	0.46	87	19
	Limpets	4	350	"	3.4	"	"	8.9	7.7	"	0.36	78	15
Nethertown ¹	Winkles	12	400	71	4.2	"	12	20	16	21	0.86	130	32
	Limpets	1	310	NA	2.0	"	NA	2.5	ND	NA	ND	93	32
	Mussels	4	NA	"	3.2	"	"	ND	"	"	"	130	14
Drigg ¹	Winkles	4	380	73	5.3	"	7.5	5.7	10	110	0.53	130	39
Ravenglass ¹	Mussels	4	220	NA	3.8	"	NA	0.53	1.1	NA	0.11	78	0.71
	Cockles	4	220	"	6.7	"	"	2.9	4.2	"	ND	55	5.2
Ravenglass ²	Crabs	2	120	85	1.5	"	0.89	ND	ND	4.8	"	9.4	4.5
	Lobsters	2	210	88	0.37	"	0.14	"	"	130	"	ND	4.6
	Whelks	2	180	NA	5.3	"	NA	"	"	NA	"	50	14
Tam Bay ¹	Winkles	5	340	"	3.6	"	"	9.0	10	"	0.73	120	40
Saltom Bay ¹	"	4	420	"	2.1	"	"	1.9	3.1	"	0.12	25	5.1
Whitehaven ¹	Winkles	1	300	"	0.81	"	"	ND	ND	"	ND	17	5.2
	Mussels	2	160	"	0.95	"	"	"	"	"	"	12	13
Whitehaven ²	<i>Nephtrops</i>	4	130	"	ND	"	"	"	"	"	"	ND	ND
	Whelks	4	120	"	0.57	"	"	"	"	"	"	2.6	0.94
Parton ¹	Winkles	4	200	"	1.2	"	"	1.7	1.5	"	0.13	28	6.6
Roosebeck ¹	Pacific oysters	4	77	"	0.26	0.14	"	ND	ND	"	ND	3.1	4.6
Haverigg ¹ ₂	Crabs	1	45	"	0.26	ND	"	"	"	"	"	2.1	1.9
	Cockles	2	160	"	2.9	"	"	1.7	2.0	"	"	35	0.69
Millom ¹	Mussels	2	150	"	0.85	"	"	2.3	ND	"	"	24	0.69
Whitrigg Scar ¹	Shrimps	1	81	"	0.43	"	"	ND	"	"	"	ND	5.7
Morecambe Bay ¹	"	4	85	"	ND	"	0.07	"	"	"	"	"	ND
	Cockles	4	89	"	1.1	"	0.81	"	"	"	"	4.1	0.04
Heysham ¹	Mussels	4	92	"	0.46	"	NA	"	"	"	"	5.2	ND
	Cockles	4	71	"	1.0	"	"	"	"	"	"	3.0	"
Fleetwood ²	Squid	1	83	"	ND	"	"	"	"	"	"	ND	"
	Whelks	4	120	"	0.31	"	"	"	"	"	"	0.64	0.40
Isle of Man ²	Scallops	4	110	"	ND	"	"	"	"	"	"	ND	0.10
	Queens	1	120	"	"	"	"	"	"	"	"	"	1.2
Inner Solway ¹	Shrimps	4	83	"	"	"	"	"	"	"	"	"	0.20
Southerness ¹	Winkles	4	170	"	0.76	"	"	"	"	"	"	7.7	2.5
Kirkcudbright ²	Scallops	4	53	"	0.03	"	"	"	"	"	"	ND	ND
	Queens	4	98	"	0.02	"	"	"	"	"	"	"	0.21
North Solway coast ¹	Winkles	4	120	"	1.1	"	"	"	"	"	"	9.7	2.8
	Cockles	3	120	"	0.97	"	"	"	"	"	"	3.0	0.09
Wirral ¹	Shrimps	2	51	"	ND	"	"	"	"	0.70	"	ND	ND
	Cockles	5	62	"	0.29	"	"	"	"	1.4	"	0.17	"
Conwy ²	Mussels	2	49	"	ND	"	"	"	"	ND	"	ND	"
Northern Ireland ²	<i>Nephtrops</i>	8	100	"	"	"	"	"	"	"	"	"	"
	Winkles	4	95	"	0.03	"	"	"	"	"	"	"	0.10
Minch ¹	<i>Nephtrops</i>	4	88	"	ND	"	"	"	"	"	"	"	ND
Northern North Sea ¹	"	2	96	"	"	"	"	"	"	"	"	"	"
Mid-North Sea ¹	Mussels	4	40	"	0.11	"	"	"	"	"	"	"	"
Southern North Sea ¹	Cockles	4	38	"	0.89	"	"	"	"	"	"	0.22	"
	Mussels	3	50	"	ND	"	"	"	"	"	"	ND	"

Table 5. Continued

Sampling point/ landing area	Sample	No. of sampling observa- tions ³	Mean radioactivity concentration (wet)*, Bq kg ⁻¹						
			¹²⁵ Sb	¹³⁴ Cs	¹³⁷ Cs	¹⁴⁴ Ce	¹⁴⁷ Pm	¹⁵⁴ Eu	¹⁵⁵ Eu
Sellafield coastal area ¹	Crabs	8	0.29	ND	8.5	ND	2.2	ND	ND
	Lobsters	10	0.08	0.28	11	"	4.8	"	"
	Winkles ⁴	12	2.4	0.02	22	2.6	7.8	0.64	0.33
	" ⁵	3	7.2	ND	9.6	ND	NA	ND	0.26
	" ⁶	3	4.6	"	26	4.9	"	0.81	0.25
	Mussels ⁴	4	2.3	"	7.7	1.6	"	1.1	0.55
	Limpets	4	3.9	0.09	15	1.7	"	0.85	0.42
Sellafield offshore area ¹	Whelks	1	2.5	ND	6.2	1.1	"	ND	0.65
St Bees ¹	Winkles	4	5.7	0.07	29	3.5	9.9	1.2	0.57
	Mussels	4	2.9	ND	9.6	1.9	NA	0.48	0.31
	Limpets	4	6.8	0.73	25	2.7	"	1.2	0.31
Nethertown ¹	Winkles	12	5.1	0.24	29	6.3	11	1.3	0.52
	Limpets	1	6.1	ND	19	2.2	NA	ND	0.92
	Mussels	4	3.8	0.01	10	2.3	"	0.22	0.26
Drigg ¹	Winkles	4	4.0	ND	18	3.1	11	1.2	0.52
Ravenglass ¹	Mussels	4	2.9	0.06	6.2	ND	NA	0.21	0.28
	Cockles	4	0.59	0.21	14	2.2	"	0.72	0.82
Ravenglass ²	Crabs	2	ND	0.10	5.5	ND	1.5	ND	ND
	Lobsters	2	ND	ND	9.1	"	2.7	"	"
	Whelks	2	1.4	"	4.6	"	NA	"	"
Tam Bay ¹	Winkles	5	2.5	0.13	19	3.3	"	0.48	0.29
Saltom Bay ¹	"	4	3.9	0.06	16	0.26	"	0.28	0.22
Whitehaven ¹	Winkles	1	1.9	0.14	26	ND	"	0.70	0.55
	Mussels	2	1.1	ND	7.8	1.5	"	ND	ND
Whitehaven ²	<i>Nephrops</i>	4	ND	0.14	12	ND	"	"	"
	Whelks	4	"	ND	3.0	"	"	"	"
Parton ¹	Winkles	4	2.4	0.06	19	0.29	"	"	"
Roosebeck ¹	Pacific oysters	4	0.19	0.02	4.9	ND	"	"	"
Haverigg ¹	Crabs	1	ND	ND	2.6	"	"	"	"
	Cockles	2	1.3	0.09	15	2.1	"	0.82	0.56
Millom ¹	Mussels	2	1.0	ND	6.8	0.68	"	ND	ND
Whitrigg Scar ¹	Shrimps	1	ND	"	12	ND	"	"	"
Morecambe Bay ¹	"	4	"	0.10	17	"	"	"	"
	Cockles	4	0.54	0.60	10	"	"	0.14	0.08
Heysham ¹	Mussels	4	0.62	ND	4.7	"	"	ND	ND
	Cockles	4	0.50	0.04	7.8	"	"	0.28	0.07
Fleetwood ²	Squid	1	ND	ND	2	"	"	ND	ND
	Whelks	4	"	"	3.5	"	"	"	"
Isle of Man ²	Scallops	4	"	"	1.5	"	"	"	"
	Queens	1	"	"	0.17	"	"	"	"
Inner Solway ¹	Shrimps	4	"	0.05	18	"	"	"	"
Southerness ¹	Winkles	4	0.66	ND	13	"	"	"	0.04
Kirkcudbright ²	Scallops	4	ND	"	0.74	"	"	"	ND
	Queens	4	"	"	1.5	"	"	"	"
North Solway coast ¹	Winkles	4	0.71	"	4.6	"	"	"	"
	Cockles	3	0.26	"	14	"	"	0.17	"
Wirral ¹	Shrimps	2	ND	0.07	5.4	"	"	ND	"
	Cockles	5	0.10	0.04	4.8	"	"	"	0.50
Conwy ¹	Mussels	2	ND	ND	1.1	"	"	"	ND
Northern Ireland ²	<i>Nephrops</i>	8	"	0.02	3.2	"	"	"	"
	Winkles	4	"	ND	1.5	"	"	"	"
Minch ¹	<i>Nephrops</i>	4	"	"	1.4	"	"	"	"
Northern North Sea ¹	"	2	"	"	0.53	"	"	"	"
Mid-North Sea ¹	Mussels	4	0.08	"	0.29	"	"	"	"
Southern North Sea ¹	Cockles	4	0.03	"	0.86	"	"	"	"
	Mussels	3	ND	"	0.39	"	"	"	"

NA = not analysed; ND = not detected; ¹ Sampling area; ² Landing point; ³ See sub-section 3.2 for definition; ⁴ Samples collected by Consumer 116; ⁵ Samples collected by Consumer 311; ⁶ Samples collected by Consumer 460; ⁷ Landed in Denmark; ⁸ Landed in the Netherlands

Table 6. Transuranic radioactivity in fish and shellfish from the Irish Sea vicinity and further afield, 1991

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	Cod	1	NA	0.0020	0.0092	NA	0.017	ND	0.000040
"	Plaice	1	"	0.0058	0.024	"	0.046	"	0.00011
"	Crabs	3	0.044	0.16	0.70	14	2.9	0.0057	0.011
"	Lobsters	3	0.14	0.13	0.57	11	8.7	0.010	0.028
"	Winkles ⁴	4	0.35	4.2	19	320	33	0.074	0.079
"	" ⁵	2	NA	4.6	20	360	37	0.066	0.10
"	" ⁶	3	"	1.5	6.8	110	11	0.027	0.034
"	Mussels ⁴	1	"	3.4	15	NA	26	0.067	0.063
"	Limpets ⁴	1	"	3.6	17	"	28	0.13	0.075
Sellafield offshore area ¹	Cod	1	0.00049	0.0037	0.016	"	0.032	ND	0.00010
"	Plaice	1	0.001	0.0042	0.019	0.20	0.039	"	0.00010
"	Whelks	1	NA	1.3	5.4	NA	19	"	0.084
St Bees ¹	Mussels	2	"	3.1	14	220	23	0.036	0.066
"	Winkles	4	0.33	4.8	22	350	36	0.14	0.11
"	Limpets	1	NA	4.1	18	NA	30	ND	0.098
Nethertown ¹	Winkles	4	0.62	5.8	25	450	42	0.12	0.14
"	Limpets	1	NA	NA	NA	NA	31	NA	NA
"	Mussels	1	"	"	"	"	27	"	"
Whitrigg ¹	Shrimps	1	"	"	"	"	0.42	"	"
Drigg ¹	Winkles	4	0.40	4.7	21	350	40	0.10	0.10
Ravenglass ¹	Whitebait	1	NA	0.089	0.39	6.3	0.58	0.00057	0.0013
"	Mussels	1	"	3.6	16	270	28	0.037	0.087
"	Cockles	1	"	3.9	18	290	42	0.066	0.13
Ravenglass ²	Cod ⁷	1	"	0.0014	0.0060	NA	0.0097	ND	ND
"	Plaice ⁷	1	"	0.0054	0.024	"	0.040	"	0.00014
"	Crabs ⁸	1	0.036	0.016	0.72	12	2.5	0.010	0.0087
"	Lobsters ⁸	1	0.068	0.079	0.36	5.4	10	ND	0.030
"	Whelks ⁸	1	NA	0.042	1.8	31	4.1	"	0.014
Tam Bay ¹	Winkles	1	"	4.5	20	340	34	0.075	0.11
Whitehaven ¹	Winkles	1	"	NA	NA	NA	21	NA	NA
"	Mussels	1	"	"	"	"	6.7	"	"
Whitehaven ²	Cod	1	"	0.00077	0.0036	"	0.0054	0.000020	0.000020
"	Plaice	1	"	0.00084	0.0043	"	0.0068	ND	0.000020
"	Herring	1	"	0.0061	0.034	"	0.046	0.000090	0.00010
"	Rays	1	"	0.00045	0.0022	"	0.0035	ND	ND
"	<i>Nephrops</i>	1	"	0.018	0.096	"	0.43	"	0.0012
"	Whelks	1	"	0.14	0.69	10	1.2	"	0.0047
Saltom Bay ¹	Winkles	4	"	NA	NA	NA	19	NA	NA
Parton ¹	Winkles	1	"	1.6	7.7	120	12	0.021	0.031
Roosebeck ¹	Pacific oysters	4	"	NA	NA	NA	0.78	NA	NA
Haverigg ²	Crabs	1	"	"	"	"	0.81	"	"
" ₁	Cockles	1	"	3.2	15	"	30	0.043	0.084
Millom ¹	Mussels	1	"	0.90	4.1	"	7.3	ND	0.020
Morecambe Bay ¹	Whitebait	1	"	NA	NA	"	0.46	NA	NA
"	Shrimps	1	"	0.0078	0.039	0.45	0.058	0.000080	0.00010
"	Cockles	1	"	0.62	3.0	39	7.1	ND	0.019
Heysham ¹	Mussels	4	"	0.17	0.84	NA	1.4	"	0.0039
"	Cockles	1	"	0.58	2.9	"	7.6	"	0.017
Fleetwood ²	Cod	1	"	0.00042	0.0022	"	0.0044	"	0.000010
"	Plaice	1	"	0.00049	0.0020	"	0.0041	"	0.000010
"	Fishmeal ⁹	1	"	0.0085	0.045	"	0.067	"	0.00018
"	Whelks	1	"	0.14	0.67	9.2	0.93	"	0.0024
Isle of Man ²	Cod	1	"	0.00026	0.0012	NA	0.0014	0.000010	ND
"	Plaice	1	"	0.00052	0.0028	"	0.0042	0.000020	0.000010
"	Scallops	1	"	0.037	0.19	"	0.062	ND	ND
Inner Solway ¹	Sea trout	1	"	0.00055	0.0023	"	0.0032	"	0.000010
Southerness ¹	Winkles	1	"	0.96	4.4	"	6.8	0.020	0.0093

Table 6. 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
Kirkcudbright ²	Plaice	1	NA	0.0012	0.0064	NA	0.012	ND	0.000030
"	Scallops	1	"	0.031	0.15	"	0.074	"	ND
"	Queens	1	"	0.017	0.089	"	0.10	0.00018	0.00020
North Solway coast ¹	Winkles	1	"	0.41	2.0	"	3.0	ND	0.0034
"	Cockles	1	"	0.96	4.7	"	9.9	"	0.024
Ayr ²	Cod	1	"	0.00023	0.0011	"	0.0016	"	ND
"	Plaice	1	"	0.00044	0.0022	"	0.0038	"	0.000020
Wirral ¹	Cockles	2	"	0.14	0.74	"	2.6	"	0.0039
Conwy ²	Mussels	1	"	0.049	0.24	"	0.40	0.0031	0.0015
North Anglesey ¹	Winkles	1	"	NA	NA	"	0.72	NA	NA
Northern Ireland ²	Whiting	1	"	0.00089	0.0045	"	0.0069	ND	ND
"	<i>Nephrops</i>	1	"	0.0064	0.036	"	0.094	"	0.00017
"	Winkles	1	"	0.055	0.28	"	0.19	"	0.00077
Minch ¹	Cod	1	"	0.000040	0.00019	"	0.00025	ND	ND
"	Haddock	1	"	0.00011	0.00044	"	0.00040	"	"
"	Mackerel	1	"	0.000020	0.00017	"	0.00010	"	"
"	<i>Nephrops</i>	1	"	0.0036	0.019	"	0.053	0.000060	0.000080
Northern North Sea ¹	<i>Nephrops</i>	1	"	0.00078	0.0045	"	0.0038	0.000020	0.000020
"	Cod	1	"	0.000040	0.00025	"	0.00019	ND	ND
"	Haddock	1	"	0.00025	0.0014	"	0.0016	"	"
Mid-North Sea ¹	Mussels ₁₀	1	"	0.000040	0.027	"	0.0088	ND	ND
"	"	1	"	0.00024	0.0027	"	0.0021	"	0.000010
Southern North Sea ¹	Cockles ₁₁	1	"	0.0023	0.0089	"	0.009	0.000080	0.0012
"	"	1	"	0.061	0.32	"	0.63	0.0034	0.0025
"	Mussels	1	"	0.0026	0.015	"	0.0053	ND	0.000010

ND = not detected; NA = not analysed; ¹ Sampling area; ² Landing point; ³ See sub-section 3.2 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 Holland

Table 7(a) summarises exposures in 1991 from artificial radionuclides, calculated on two bases (sub-section 3.3). 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 using dose coefficients calculated on the basis of ICRP-60 methodology (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 from the Irish Sea, 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 1991 was 0.15 mSv. This represents a small reduction from 0.16 mSv reported on the same basis for 1990 (Camplin, 1992), mainly due to decreases of 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 3.3). In 1991, 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 1991 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

Table 7(a). Individual radiation exposures due to consumption of Irish Sea fish and shellfish, 1991

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 } Crustaceans (crabs and lobsters): 6.0 } Molluscs (winkles): 8.3 }	¹⁴ C	0.002	0.002
		⁹⁰ Sr	0.003	0.003
		¹⁰⁶ Ru	0.007	0.010
		¹³⁷ Cs	0.014	0.014
		²³⁷ Np	0.002	0.001
		²³⁸ Pu	0.006	0.004
		²³⁹⁺²⁴⁰ Pu	0.032	0.020
		²⁴¹ Pu	0.011	0.006
		²⁴¹ Am	0.07	0.043
		Total	0.15	0.11
Consumers associated with commercial fisheries: Whitehaven	Fish (plaice and cod): 49 } Crustaceans (<i>Nephrops</i>): 11 } Molluscs (whelks): 6 }	⁹⁹ Tc	0.001	0.002
		¹³⁷ Cs	0.012	0.012
		²³⁹⁺²⁴⁰ Pu	0.003	0.002
		²⁴¹ Am	0.006	0.004
		Total	0.02	0.02
Consumers in Morecambe Bay area	Fish (flounders and plaice): 54 } Crustaceans (shrimps): 21 } Molluscs (cockles and mussels): 22 }	¹⁴ C	0.002	0.002
		¹³⁷ Cs	0.026	0.026
		²³⁸ Pu	0.004	0.002
		²³⁹⁺²⁴⁰ Pu	0.021	0.012
		²⁴¹ Pu	0.008	0.005
		²⁴¹ Am	0.050	0.030
Total	0.11	0.08		
Consumers associated with commercial fisheries: Fleetwood	Fish (plaice and cod): 82 } Crustaceans (shrimps): 17 } Molluscs (cockles and whelks): 23 }	¹⁴ C	0.002	0.002
		¹³⁷ Cs	0.020	0.020
		²³⁸ Pu	0.004	0.002
		²³⁹⁺²⁴⁰ Pu	0.020	0.012
		²⁴¹ Pu	0.002	0.001
		²⁴¹ Am	0.049	0.029
Total	0.10	0.07		
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			0.003	0.003

* Committed effective dose equivalent for comparison with current dose limits and criteria

† Committed effective dose calculated using methodology of ICRP-60

Due to artificial radionuclides; see text for exposures due to natural radionuclides

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 3.3, 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 1991, the committed effective dose to the local critical 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 1991. A predictive model, based on environmental monitoring data taking account of discharge rates, has been used (HMIP and MAFF, 1992). The results are shown in Table 7(b); the total committed effective dose was 0.03 mSv. This dose is likely to be relevant for comparison with the dose constraint for

Table 7(b). Exposure of fish and shellfish consumers near Sellafield due to discharges in 1991, for comparison with the ICRP-60 dose limit

Nuclide	Committed effective dose*, mSv year ⁻¹
¹⁴ C	0.002
⁹⁰ Sr	0.002
¹⁰⁶ Ru	0.014
¹³⁷ Cs	0.003
²³⁹⁺²⁴⁰ Pu	0.003
²⁴¹ Pu	0.002
²⁴¹ Am	0.002
Total#	0.03

* On the basis of a gut transfer factor for Pu and Am of 0.0002 and 0.0005 in winkles and other species respectively (see text)

Includes the small effect of other nuclides

practices, currently under consideration (section 3.3), 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 1991 due to the combined effects of past and current discharges.

Data for natural radionuclides in fish and shellfish are discussed in Section 11; however, the effects on the Sellafield critical group of controlled discharges of natural radionuclides from another west Cumbrian source are considered here for completeness. The exposure of the local group of seafood consumers due to the enhanced concentrations of natural radionuclides in the Sellafield area in 1991 was 0.21 mSv (on the basis of ICRP-60: 0.11 mSv). Most of this was due to the polonium-210 and lead-210 content of molluscs. These exposures may be compared with an average dose of approximately 2.2 mSv year⁻¹ to members of the UK public from all natural sources of radiation (NRPB, 1989).

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 7(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) from artificial radionuclides received by the different groups are given in Table 7(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 1990, on the basis of the appropriate gut transfer factor, the committed effective dose equivalents to the groups at Whitehaven, Fleetwood and Morecambe Bay were slightly less in 1991 (1990: 0.03, 0.14 and 0.11 mSv respectively (Camplin, 1992)). 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 from artificial radionuclides, appropriate to a consumption rate of 15 kg year⁻¹ of fish from landings at Whitehaven and Fleetwood, is also given in Table 7(a). This consumption rate represents an average for typical fish-eating members of the public. The committed effective dose equivalent in 1991 was 0.003 mSv, slightly less than for 1990 (Camplin, 1992).

Collective doses, received during 1991 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; the 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, the English Channel, 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 8. The results for 1991 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. Previous results for 1990 (Camplin, 1992) 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 10 man-Sv for the UK in 1990, given in the previous report (Camplin, 1992), has now been confirmed; the result for other European countries has been reduced from 39 to 37 man-Sv.

Liquid radioactive waste discharges from Sellafield up to the end of 1991 are the main source of collective dose reported in Table 8; 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. 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).

Table 8. Collective doses from fish and shellfish, 1990 and 1991^a

Population	Collective dose, man-Sv			
	ICRP-26*		ICRP-60 ⁺	
	1990	1991 ^a	1990	1991 ^a
UK	10	7	9	6
Other European countries	37	25	36	24

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

⁺ Committed effective dose calculated using methodology of ICRP-60

^a Preliminary data

The preliminary results for 1991, of 7 man-Sv for the UK and 25 man-Sv for other European countries, are less than the results reported for 1990. The reduction is due to changes in concentrations of radiocaesium in fish. It has not been possible to derive a direct estimate of the Chernobyl contribution in coastal seas around the UK for 1991. However, 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 (a) and (b); Aarkrog *et al.*, in press; this report), it is estimated that the collective dose to other European countries from consumption of Baltic Sea fish could have been as much as 100 man-Sv in both 1990 and 1991. These estimates are less than those made by Camplin (1992) because further concentration and catch data have become available for use in the assessment.

The collective dose for the UK, given in Table 8, 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 3.3). In 1991, 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.

It is clear from the statements above, which compare the 1990 and 1991 results for both critical group and collective dose rates, that an important factor determining exposures is the distribution of radioactivity in the marine environment. We maintain a continuing programme of research on marine behaviour and distribution (including budget assessments) of significant radionuclides. Data on the distribution of radiocaesium in sea water are regularly collected by research vessel cruises and a historical database is being published (Camplin and Steele, 1991; Baxter *et al.*, 1992; Baxter and Camplin, in press). The distri-

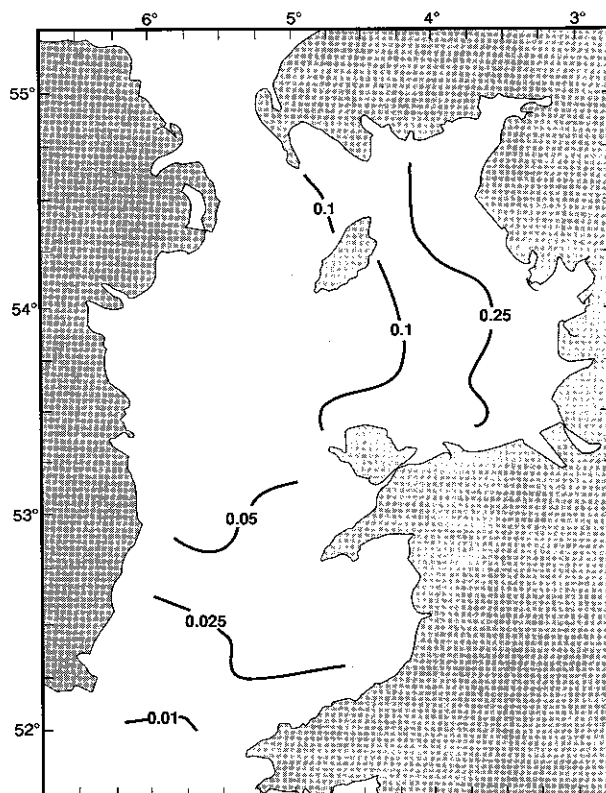


Figure 2. Concentrations ($Bq\ kg^{-1}$) of caesium-137 in filtered water from the Irish Sea, 1991

bution of caesium-137 observed in the Irish Sea in November 1991 is shown in Figure 2. Comparison with the data for March 1989 (Hunt, 1990) shows that concentrations of caesium-137 in sea water in the Irish Sea have not changed significantly. The trend of decreasing concentrations observed in the Irish Sea, in particular since the reduction of discharges of caesium-137 from Sellafield in 1985, following operation of SIXEP, has levelled off to a relatively stable situation. Budget studies for caesium-137 in the Irish Sea, based on cruise data, indicate that there has been no change in the total activity of caesium-137 since March 1989. Our cruise programme in November 1991 included collection of data on the distribution of caesium-137 in sea water west of Scotland; the data are illustrated in Figure 3. Comparison with data for March 1989 (Hunt, 1990) indicates a small increase in the concentrations of caesium-137 in sea water, in particular in the Minch and along the Atlantic side of the Outer Hebrides. This increase is insignificant and may be due to comparison being made between data collected in the spring and in the autumn. Data for the North Sea, collected during August and September 1991, are shown in Figure 4. Comparison with the distribution observed in August and September 1989 (Hunt, 1990) shows a slight reduction in concentrations in the mid and southern North Sea.

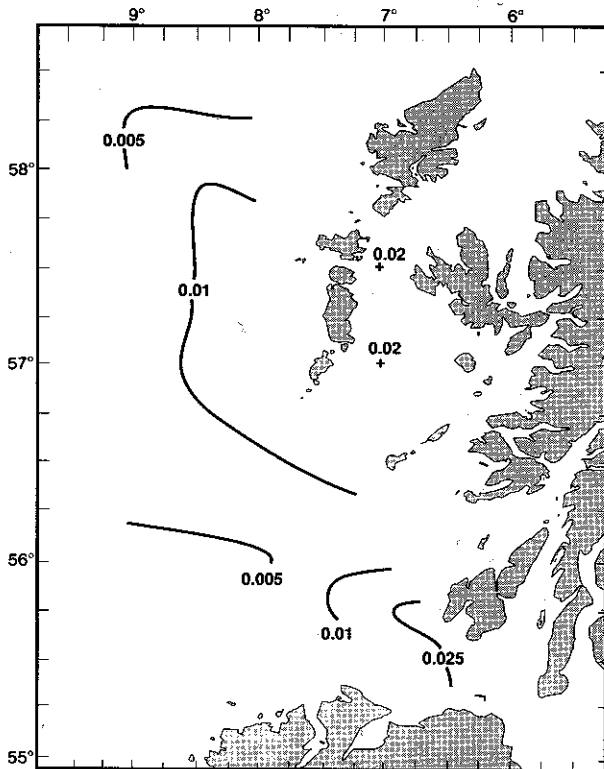


Figure 3. Concentrations (Bq kg^{-1}) of caesium-137 in filtered water from the west of Scotland, 1991

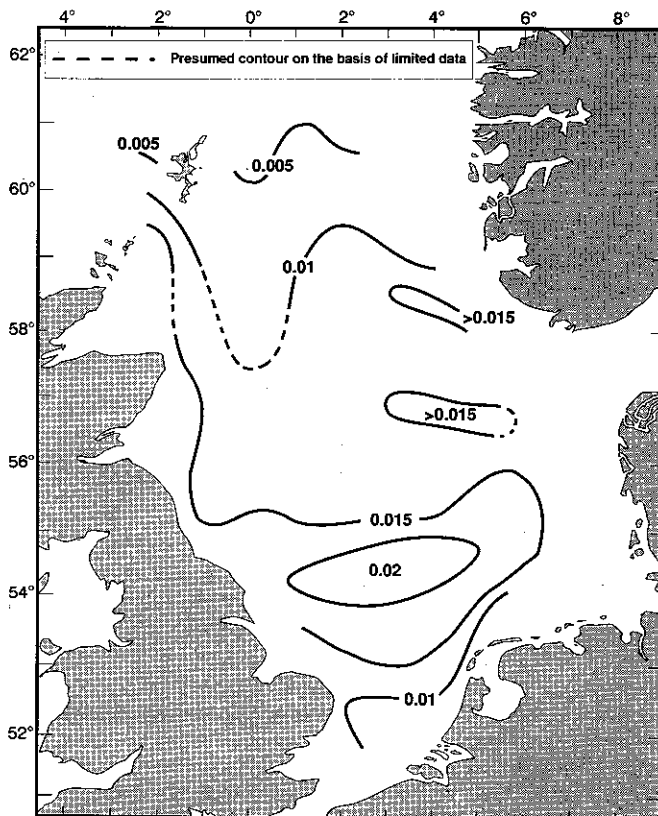


Figure 4. Concentrations (Bq kg^{-1}) of caesium-137 in filtered water from the North Sea, August-September 1991

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 dosimeters. Locations are chosen on account of both dose rates themselves and levels of occupancy by members of the public. Table 9 lists the locations monitored together with the dose rates in air at 1 m above ground level. Monitoring in Scotland is carried out on behalf of the 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, 4.4, 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 1991 generally showed small reductions as compared with those in 1990 (Camplin, 1992).

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 10. Variations similar in cause to those of the dose rates are observed, and comparison with results for 1990 (Camplin, 1992) shows general reductions in line with the behaviour of dose rates with some evidence of small increases for ruthenium-106, zirconium-65 and niobium-95 in line with increases in discharges.

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 1991 was 0.056 mSv, with no need for the addition of dose due to fish and shellfish consumption. In the

Table 9. Gamma radiation dose rates over intertidal areas of the Cumbrian coast and further afield, 1991

Location	Ground type	No. of sampling observations#	Mean gamma dose rate in air at 1 m, $\mu\text{Gy h}^{-1}$
Cumbria			
Rockliffe Marsh	Salt marsh	4	0.095
Burgh Marsh	"	4	0.12
Port Carlisle	Sandy mud	4	0.11
Greenend	Salt marsh	4	0.091
"	Muddy sand	4	0.077
Cardumock Marsh	Salt marsh	4	0.12
Beckbrow	"	4	0.085
Newton Arlosh	"	4	0.14
Calvo Marsh	"	4	0.091
Silloth - silt pond	Mud	5	0.22
Allonby	Sand	4	0.084
Maryport - Christchurch	Mud	4	0.13
Siddick	Sand	4	0.080
Workington Harbour	Mud	4	0.20
Harrington Harbour	"	4	0.16
Whitehaven - outer harbour	Sandy mud	6	0.15
"	Muddy sand	6	0.14
"	Coal/sand	12	0.14
Whitehaven - inner harbour	Sandy mud	8	0.21
"	Mud	1	0.19
"	Mud/sand/stones	3	0.21
" - yacht basin	Mud	12	0.30
St Bees	Sand	4	0.071
Nethertown	Winkle bed	4	0.12
Sellafield	Sand	4	0.083
Seascale	"	4	0.080
"	"	8	0.071
Drigg pipeline	"	8	0.071
Drigg Barn Scar	Mussel bed	4	0.094
Ravenglass - Carleton Marsh	Salt marsh	4	0.34
Ravenglass - salmon garth	Sandy mud	4	0.19
"	Sand/stones	4	0.097
"	Mussel bed	4	0.10
" - boat area	Muddy area	12	0.12
" - " "	Sand	4	0.072
" - ford	Muddy sand	4	0.14
" - River Mite	Salt marsh	4	0.27
" - Ravenvilla	Sandy mud	12	0.17
"	Salt marsh	12	0.32
" - Eskmeals Nature Reserve	"	4	0.30
" - River Esk flooded pasture	"	4	0.23
Newbiggin	Sandy mud	4	0.25
"	Salt marsh	4	0.41
" - west of bridge	Sandy mud	2	0.16
"	Mud/sand/stones	2	0.14
"	Salt marsh	4	0.36
Silecroft	Sand	4	0.066
Haverigg - boat area	Sandy mud	4	0.069
" - river mouth	"	4	0.11
Borwick Rails - Millom	Muddy sand	4	0.11
Low Shaw	Salt marsh	4	0.13
Foxfield	"	4	0.14
Askham	"	4	0.20
Tummer Hill Marsh	"	4	0.23
Walney Channel	Sandy mud	4	0.12
" - Vickers shore	"	4	0.085
" - west shore	Sand	4	0.063
Roa Island	Sandy mud	4	0.089
"	Oyster bed	1	0.076
Roosebeck	Mud/sand/stones	1	0.065
Greenodd	Salt marsh	4	0.097
Sand Gate Marsh - Holker	"	4	0.13
Flookburgh	Muddy sand	4	0.099
High Foulshaw	Salt marsh	4	0.11
Armside	Muddy sand	4	0.080
Lancashire, Merseyside and North Wales			
Jenny Brown's Point	Salt marsh	4	0.081
Morecambe Central Pier	Sandy mud	1	0.080
"	Muddy sand	3	0.088
"	Mussel bed	4	0.079
Half Moon Bay	Sandy mud	4	0.10
Red Nab Point	"	4	0.10
Sunderland Point	"	4	0.092
Sunderland	Mud/sand/stones	4	0.082
Colloway Marsh	Salt marsh	4	0.20

Table 9. Continued

Location	Ground type	No. of sampling observations#	Mean gamma dose rate in air at 1 m, $\mu\text{Gy h}^{-1}$
Lancaster	Salt marsh	4	0.13
Aldcliffe Marsh	"	4	0.17
Conder Green	Sandy mud	4	0.12
"	Salt marsh	4	0.17
Cockerham	Samphire bed	1	0.11
Cockerham Marsh	Salt marsh	4	0.13
Heads - River Wyre	"	4	0.17
Height o' th' hill - River Wyre	"	4	0.20
Hambleton	Mud	4	0.14
"	Salt marsh	4	0.16
"	"	4	0.20
Fleetwood Docks	"	4	0.20
Skippool Creek	Mud	4	0.13
Fleetwood	Sand	4	0.069
Blackpool	"	4	0.053
Crossen Marsh	Mud	4	0.13
"	Salt marsh	4	0.13
Ainsdale	Sand	4	0.054
New Brighton	"	4	0.060
West Kirby	Muddy sand	4	0.065
Rock Ferry	Mud	4	0.12
Runcom	"	4	0.10
"	Salt marsh	4	0.12
Little Neston Marsh	Muddy sand	4	0.076
"	Salt marsh	4	0.092
Flint	Mud	4	0.097
"	Salt marsh	5	0.12
Prestatyn	Sand	4	0.057
Rhyl	Mud	4	0.073
Llandudno	Shingle	4	0.080
Caerhun	Grass	1	0.10
"	Salt marsh	3	0.11
Llanfairfechan	"	3	0.10
Red Wharf Bay	Mud	4	0.072
"	Sand	3	0.051
South-west Scotland			
Garlieston	Muddy sand	4	0.10
Innerwell	"	4	0.094
Carluith	Mud/sand	4	0.085
Kippford Slipway	Muddy sand	4	0.095
" Merse	Salt marsh	4	0.17
Palnackie Harbour	Mud	4	0.11
Carsethorn	Muddy sand	4	0.12

See sub-section 3.2 for definition

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 1991 was similar to that in 1990. Making an allowance for natural background, their external exposure in 1991 was 0.15 mSv, which is less than that in 1990 (0.18 mSv) because of reductions in dose rates in the vicinity of the houseboats. 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 10) 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 10. Radioactivity in sediment from the Cumbrian coast and further afield, 1991

Sampling point and sediment type		No. of sampling observations#	Mean radioactivity concentration (dry), Bq kg ⁻¹								
			Total beta	⁶⁰ Co	⁹⁵ Zr	⁹⁵ Nb	¹⁰³ Ru	¹⁰⁶ Ru	^{110m} Ag	¹²⁵ Sb	¹³⁴ Cs
Cumbria											
Newton Arlosh	Turf	4	1600	2.8	ND	ND	ND	16	ND	ND	6.6
Silloth silt pond	Mud	1	1700	5.5	"	"	"	30	"	"	4.4
Maryport - Christchurch	"	3	3700	13	83	120	2.5	680	5.7	31	7.2
"	Sandy mud	1	1700	7.8	ND	ND	ND	110	ND	12	5.0
Harrington Harbour	Mud	4	3600	8.7	110	120	2.3	430	5.3	18	5.6
Whitehaven - yacht basin	"	4	5200	10	120	130	ND	450	2.7	23	7.1
Whitehaven - inner harbour	Muddy sand	1	5000	5.8	32	ND	"	260	5.4	10	3.4
St Bees	Sand	4	440	2.8	ND	"	"	4.0	ND	0.40	0.63
Sellafield	"	4	580	3.2	1.7	"	"	8.5	"	0.68	0.52
Seascale	"	4	540	2.2	ND	"	"	2.3	"	0.36	ND
Drigg	"	4	480	2.7	1.1	3.0	"	8.9	"	0.72	0.19
Ravenglass - Ravenilla	Sandy mud	5	1700	12	38	39	"	310	1.6	16	3.2
Newbiggin	Mud	4	5800	2.2	37	33	"	390	ND	22	5.9
Millom	Sandy mud	4	980	3.1	13	17	"	63	"	6.0	1.1
Walney Channel	"	4	1100	3.6	11	14	"	100	"	6.7	1.4
Low Shaw	Turf	4	1300	4.4	1.0	ND	"	15	"	2.5	16
Flookburgh shore	Muddy sand	4	730	ND	ND	"	"	ND	"	ND	0.19
Sand Gate marsh	Turf	4	1400	2.5	"	"	"	14	"	2.2	6.5
Lancashire, Merseyside and north Wales											
Morecambe Central Pier	Mud	1	NA	3.6	"	"	"	55	"	7.6	2.8
Half Moon Bay	Sandy mud	4	1100	3.2	2.7	2.0	"	55	"	7.5	2.4
Sunderland Point	"	4	930	2.0	1.0	ND	"	25	"	2.4	1.7
Conder Green	"	1	1200	3.1	ND	"	"	58	"	5.8	3.3
"	Turf	4	1800	5.3	"	"	"	31	"	5.9	7.1
Cockerham Marsh	"	2	990	2.7	"	"	"	14	"	4.8	4.8
Skippool Creek	Mud	4	1900	5.1	"	"	"	50	"	9.1	5.8
Fleetwood	Sand	4	500	ND	"	"	"	ND	"	ND	ND
Blackpool	"	4	230	0.20	"	"	"	"	"	"	"
New Brighton	"	4	430	0.24	0.23	"	"	"	"	"	0.18
West Kirby	Sandy mud	2	580	0.74	ND	"	"	"	"	2.0	0.62
Rock Ferry	Mud	4	1300	3.6	"	"	"	20	"	2.9	3.3
Rhyl	"	4	760	0.75	"	"	"	3.6	"	2.4	0.93
Caerhun	Turf	4	1000	ND	"	"	"	ND	"	ND	6.9
Red Wharf Bay	Mud	4	600	0.23	"	"	"	"	"	0.35	1.1
Cemlyn Bay	"	2	1000	1.7	"	"	"	"	"	ND	2.5
South-west Scotland											
Garlieston	Mud	4	1400	5.6	2.7	3.7	"	67	"	1.5	4.2
Innerwell	"	2	1100	3.2	ND	ND	"	41	"	3.8	1.2
Carlsruith	"	2	1700	5.5	12	14	"	110	"	3.9	4.3
"	Muddy sand	2	910	2.3	ND	ND	"	31	"	ND	1.5
Kippford Merse	Salt marsh	4	2000	9.4	6.9	6.6	"	120	"	12	11
" Slipway	Mud	2	1100	4.5	2.5	4.1	"	71	"	4.7	2.6
"	Muddy sand	1	760	1.9	ND	ND	"	40	"	ND	ND
Palnackie Harbour	Mud	4	1400	4.5	9.7	15	"	120	"	3.9	3.5
Carsethorn	"	2	1100	4.9	3.9	11	"	83	"	5.9	5.2
Northern Ireland											
Carrickhugh House	"	2	560	ND	ND	ND	"	ND	"	ND	ND
Portrush	Sand	2	190	"	"	"	"	"	"	"	"
Larne Lough	Mud	2	850	"	"	"	"	"	"	"	2.8
Groomsport	Sand	2	280	"	"	"	"	"	"	"	ND
Ballymacormick	Mud	2	550	"	"	"	"	"	"	0.80	1.1
Strangford Lough - Island Hill	"	1	570	"	"	"	"	"	"	ND	ND
"	Sandy mud	1	580	"	"	"	"	"	"	"	"
" - Nickey's Point	Mud	2	880	"	"	"	"	"	"	"	1.7
Dundrum Bay	"	2	600	"	"	"	"	"	"	"	ND
Carlingford Lough	"	2	990	"	"	"	"	"	"	"	2.5
Oldmill Bay	"	2	820	"	"	"	"	"	"	"	1.4

Table 10. Continued

Sampling point and sediment type		No. of sampling observations#	Mean radioactivity concentration (dry), 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
Cumbria												
Newton Arlosh	Turf	4	1100	ND	4.6	2.9	NA	NA	NA	210	NA	NA
Silloth silt pond	Mud	1	1100	"	11	6.4	"	"	"	310	"	"
Maryport - Christchurch	"	3	980	65	24	11	130	610	"	910	2.2	2.3
"	Sandy mud	1	1200	ND	20	11	NA	NA	"	550	NA	NA
Harrington Harbour	Mud	4	1000	46	22	12	"	"	"	750	"	"
Whitehaven - yacht basin	"	4	1400	50	29	14	160	730	"	1100	3.2	3.1
Whitehaven - inner harbour	Muddy sand	1	910	23	11	5.5	NA	NA	"	440	NA	NA
St Bees	Sand	4	110	ND	3.8	1.8	"	"	"	130	"	"
Sellafield	"	4	210	0.58	5.8	2.2	"	"	"	220	"	"
Seascale	"	4	140	ND	4.3	2.6	"	"	"	140	"	"
Drigg	"	4	87	0.53	5.5	3.1	"	"	"	200	"	"
Ravenglass - Ravenvilla	Sandy mud	5	530	31	20	11	"	"	"	910	"	"
Newbiggin	Mud	4	950	38	36	19	230	970	16000	1400	1.5	3.0
Millom	Sandy mud	4	310	6.2	6.0	3.5	NA	NA	NA	180	NA	NA
Walney Channel	"	4	310	5.7	8.6	5.1	"	"	"	250	"	"
Low Shaw	Turf	4	990	ND	11	5.5	"	"	"	380	"	"
Flookburgh shore	Muddy sand	4	200	"	ND	ND	"	"	"	49	"	"
Sand Gate marsh	Turf	4	880	"	5.2	3.6	"	"	"	180	"	"
Lancashire, Merseyside and north Wales												
Morecambe Central Pier	Mud	1	660	"	6.6	3.6	"	"	"	280	"	"
Half Moon Bay	Sandy mud	4	460	2.2	5.3	4.3	"	"	"	200	"	"
Sunderland Point	"	4	300	ND	2.5	4.3	"	"	"	110	"	"
Conder Green	"	1	620	"	5.3	5.9	"	"	"	190	"	"
"	Turf	4	1400	"	8.8	5.9	"	"	"	310	"	"
Cockerham Marsh	"	2	600	"	8.8	5.9	"	"	"	150	"	"
Skipool Creek	Mud	4	970	"	8.6	6.7	"	"	"	320	"	"
Fleetwood	Sand	4	44	"	ND	0.27	"	"	"	15	"	"
Blackpool	"	4	14	"	"	0.18	"	"	"	4.2	"	"
New Brighton	"	4	54	"	0.41	0.48	"	"	"	14	"	"
West Kirby	Sandy mud	2	140	"	ND	0.68	"	"	"	24	"	"
Rock Ferry	Mud	4	560	"	2.9	3.5	"	"	"	140	"	"
Rhyl	"	4	190	"	ND	2.3	"	"	"	49	"	"
Caerhun	Turf	4	310	1.5	"	1.7	"	"	"	ND	"	"
Red Wharf Bay	Mud	4	150	ND	"	1.1	"	"	"	38	"	"
Cemlyn Bay	"	2	250	"	"	0.73	7.1	39	"	54	0.17	0.12
South-west Scotland												
Garlieston	Mud	4	450	2.3	7.7	4.8	42	210	"	320	ND	1.0
"	"	2	270	ND	3.0	2.4	NA	NA	"	170	NA	NA
Carlsruith	"	2	410	6.0	8.3	3.3	26	120	"	180	ND	0.61
"	Muddy sand	2	190	ND	ND	1.3	NA	NA	"	220	NA	NA
Kippford Merse	Salt marsh	4	1100	10	16	10	77	380	"	550	1.2	1.4
" Slipway	Mud	2	390	5.1	4.2	2.1	32	160	"	250	ND	0.65
"	Muddy sand	1	280	ND	4.0	4.0	NA	NA	"	220	NA	NA
Palnackie Harbour	Mud	4	500	6.3	7.2	2.9	47	220	"	330	ND	1.1
Carsethorn	"	2	590	4.9	7.4	6.7	NA	NA	"	190	NA	NA
Northern Ireland												
Carrickhugh House	"	2	5.1	ND	ND	ND	0.062	0.45	"	0.46	ND	ND
Portrush	Sand	2	1.6	"	"	"	NA	NA	"	1.2	NA	NA
Larne Lough	Mud	2	150	"	"	3.0	"	"	"	15	"	"
Groomsport	Sand	2	11	"	"	ND	"	"	"	0.52	"	"
Ballymacormick	Mud	2	82	"	"	"	3.3	17	"	21	ND	0.032
Strangford Lough - Island Hill	"	1	24	"	"	"	0.24	1.3	"	0.81	"	ND
"	Sandy mud	1	17	"	"	"	NA	NA	"	ND	NA	NA
" - Nickey's Point	Mud	2	120	"	"	"	3.0	16	"	14	ND	0.028
Dundrum Bay	"	2	16	"	"	"	NA	NA	"	ND	NA	NA
Carlingford Lough	"	2	170	"	"	1.6	2.7	16	"	8.0	ND	ND
Oldmill Bay	"	2	150	"	"	0.99	3.1	15	"	19	0.044	0.050

NA = not analysed

ND = not detected

See sub-section 3.2 for definition

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 dosimeters. Results for 1991 are presented in Table 11. Measured dose rates were similar to those for 1990 (Camplin, 1992). 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 1991 would have been 0.18 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 3.3). Handling of fishing gear therefore continues to be a minor radiation exposure pathway.

appropriate for exposures to skin of members of the public, based on non-stochastic (deterministic) effects (sub-section 3.3). Handling of fishing gear therefore continues to be a minor radiation exposure pathway.

4.1.4 Porphyra/laverbread pathway

No harvesting of *Porphyra* in the Sellafield vicinity, for consumption after being made into laverbread, was reported in 1991; 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 1991 are presented in Table 12. Samples of laverbread from the major manufacturers are regularly collected from markets in South Wales and analysed. Results for 1991 are presented in Table 13. The exposure of critical laverbread consumers was less than 0.005 mSv, confirming the virtual abeyance of this exposure pathway.

Table 11. Beta radiation dose rates on contact with fishing gear on vessels operating off Sellafield, 1991

Vessel	Type of gear	No. of sampling observations#	Mean beta dose rate $\mu\text{Sv h}^{-1}$
A	Nets	4	0.25
	Ropes	4	0.12
B	Nets	7	0.24
	Ropes	7	0.28
D	Gill nets	3	0.22
	Pots	1	0.42
E	Gill nets	4	0.32
	Nets	4	0.48
M	Nets	4	0.23
	Ropes	4	0.14
Q	Gill nets	4	0.34
	Pots	1	0.31
R	Nets	4	0.20

See sub-section 3.2 for definition

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 1991 is presented in Table 14. 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 3.3). It is not considered likely that anyone has received a dose to skin in excess of this limit.

Table 12. Radioactivity in Porphyra from UK shorelines of the Irish Sea, 1991

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	300	NA	0.60	NA	1.7	1.4	NA	0.82	120	4.6	3.9
Seascale	52*	NA	"	0.72	"	5.3	5.1	"	1.0	130	3.5	3.7
Sr Bees	4	230	25	0.52	0.88	2.9	2.8	1.8	0.66	76	1.6	3.6
Knock Bay	4	180	NA	ND	NA	ND	ND	NA	ND	0.86	ND	ND

Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet), Bq kg ⁻¹										
		¹³⁴ Cs	¹³⁷ Cs	¹⁴⁴ Ce	¹⁵⁴ Eu	¹⁵⁵ Eu	²³⁸ Pu	²³⁹ Pu+ ²⁴⁰ Pu	²⁴¹ Pu	²⁴¹ Am	²⁴² Cm	²⁴³ Cm+ ²⁴⁴ Cm
Braystones South	4	0.07	5.3	0.47	0.12	0.16	1.4	6.4	97	12	0.30	0.028
Seascale	52*	ND	11	1.3	0.05	0.14	NA	NA	NA	17	NA	NA
Sr Bees	4	"	5.1	0.93	0.20	ND	"	"	81	12	"	"
Knock Bay	4	"	0.82	ND	ND	"	"	"	NA	0.25	"	"

ND = not detected

NA = not analysed

See sub-section 3.2 for definition

* These samples were counted wet to provide a rapid result

Table 13. Radioactivity in laverbread from South Wales, 1991

Manufacturer	No. of sampling observations#	Mean radioactivity concentration (wet), Bq kg ⁻¹			
		Total beta	⁶⁰ Co	¹³⁷ Cs	²⁴¹ Am
A	3	59	ND	0.64	0.19
C	4	53	0.04	0.48	0.15
D	2	67	0.05	0.46	ND
E	1	90	ND	0.46	"

ND = not detected

See sub-section 3.2 for definition

Table 14. Summary of contact beta and gamma dose rate monitoring of intertidal areas of Cumbria, 1991

Month	No. of items detected (> 0.01 mGy h ⁻¹ but below 0.1 mGy h ⁻¹)	Location and dose rates (mGy h ⁻¹) of items 0.1 mGy h ⁻¹ and above
January	-	-
February	-	-
March	-	-
April	-	-
May	1	-
June	-	-
July	-	-
August	-	-
September	-	-
October	1	-
November	-	-
December	-	-

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 15 presents the results of measurements in 1991 on marine plants from shorelines of the Irish Sea and further afield. Although small quantities of samphire and *Rhodomenia* 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 the Scottish Office. Analyses of samples collected in Northern Ireland are carried out on behalf of the DOE(NI).

Table 15. Radioactivity in marine plants from shorelines of the Irish Sea and further afield, 1991

Type of seaweed and 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
<i>Fucus vesiculosus</i>												
Sellafield	4	1300	NA	2.3	2.9	5.4	3.0	1100	0.09	22	14	3.7
Nethertown	2	1200	"	2.0	NA	2.4	1.5	NA	ND	14	16	1.5
Gutterby	1	800	"	0.79	"	1.0	ND	"	"	4.5	4.1	1.0
St Bees	4	820	28	1.4	2.1	3.3	1.6	630	"	11	6.3	1.9
Workington Harbour	1	310	NA	0.47	NA	0.77	ND	NA	"	3.4	0.38	0.44
Half Moon Bay	4	500	"	0.34	"	ND	"	"	"	0.57	ND	1.0
Port William	4	300	"	0.23	"	"	"	"	"	ND	"	0.08
Rascarrel Bay	1	310	"	ND	"	"	"	"	"	"	"	ND
Garlicton	4	370	"	0.75	"	0.59	0.18	"	"	0.98	0.14	1.8
Auchencairn	4	380	"	0.64	"	0.42	ND	"	"	1.1	0.38	0.95
Cape Wrath	1	160	"	ND	"	ND	"	6.1	"	ND	ND	ND
Wick	1	210	"	"	"	"	"	13	"	"	"	"
Ardglass	1	61	"	"	"	"	"	NA	"	"	"	"
Portrush	3	210	"	"	"	"	"	"	"	"	"	"
Portmadog	1	85	"	"	"	"	"	"	"	"	"	0.15
Fishguard	2	210	"	"	"	"	"	4.0	"	"	"	0.14
Lavernock Point	2	190	"	"	"	"	"	NA	"	"	"	ND
Isles of Scilly	1	260	"	"	"	"	"	1.2	"	"	"	"
<i>Fucus serratus</i>												
Rascarrel Bay	1	290	"	0.54	"	"	"	NA	"	"	0.47	0.81
Gutterby	1	550	"	1.8	"	0.8	"	"	"	10	3.2	1.5
Nethertown	1	630	"	1.9	"	1.2	"	"	"	26	11	1.4
<i>Fucus spiralis</i>												
Ardglass	2	210	"	ND	"	ND	"	"	"	ND	ND	ND
Portrush	1	220	"	"	"	"	"	"	"	"	"	"
<i>Ascophylum nodosum</i>												
Ardglass	1	280	"	"	"	"	"	"	"	"	"	0.34
<i>Rhodomenia spp.</i>												
St Bees	2	500	"	0.37	"	18	"	"	"	82	6.1	1.1
Ballymacomick	1	1800	"	ND	"	ND	"	"	"	ND	ND	ND
Strangford Lough	4	760	"	"	"	"	"	"	"	"	"	"
<i>Dilsea carnosa</i>												
St Bees	1	410	"	0.77	"	44	"	"	"	99	9.6	3.9
<i>Laminaria digitata</i>												
St Bees	1	520	"	ND	"	15	5.5	"	"	29	7.4	1.1
<i>Laminaria sacharina</i>												
Isle of Man	2	790	"	"	"	ND	ND	"	"	ND	ND	ND
Samphire												
Rabbit Cat How, Ravenglass	1	34	"	0.05	"	"	"	"	"	1.1	"	"
Cockerham Marsh	1	41	"	ND	"	"	"	"	"	ND	"	"
Llanfairfechan	1	43	"	"	"	"	"	"	"	"	"	"

Table 15. Continued

Type of seaweed and sampling point	No. of sampling observations#	Mean radioactivity concentration (wet), Bq kg ⁻¹										
		¹³⁴ Cs	¹³⁷ Cs	¹⁴⁴ Ce	¹⁴⁷ Pm	¹⁵⁴ Eu	¹⁵⁵ Eu	²³⁸ Pu	²³⁹ Pu+ ²⁴⁰ Pu	²⁴¹ Am	²⁴² Cm	²⁴³ Cm+ ²⁴⁴ Cm
<i>Fucus vesiculosus</i>												
Sellafield	4	0.38	22	0.85	3.2	ND	ND	NA	NA	7.1	NA	NA
Nethertown	2	0.32	16	ND	NA	"	"	"	"	4.9	"	"
Gutterby	1	ND	14	"	"	"	0.46	"	"	2.5	"	"
St Bees	4	0.24	16	0.31	"	"	0.08	"	"	5.8	"	"
Workington Harbour	1	0.12	7.7	ND	"	"	ND	"	"	2.4	"	"
Half Moon Bay	4	0.19	22	"	"	"	"	"	"	1.1	"	"
Port William	4	0.03	5.4	"	"	"	"	"	"	0.43	"	"
Rascarrel Bay	1	ND	10	"	"	"	"	"	"	2.5	"	"
Garlieston	4	0.05	12	"	"	"	0.11	"	"	4.2	"	"
Auchencairn	4	0.09	18	"	"	"	ND	"	"	3.9	"	"
Cape Wrath	1	ND	0.99	"	"	"	"	"	"	ND	"	"
Wick	1	0.17	1.6	"	"	"	0.33	"	"	"	"	"
Ardglass	1	ND	1.3	"	"	"	ND	"	"	"	"	"
Portrush	3	"	0.96	"	"	"	"	"	"	0.10	"	"
Portmadog	1	0.08	0.75	"	"	"	0.14	"	"	ND	"	"
Fishguard	2	ND	0.31	"	"	"	0.10	"	"	"	"	"
Lavernock Point	2	"	0.38	"	"	"	ND	"	"	"	"	"
Isles of Scilly	1	"	ND	"	"	"	"	"	"	"	"	"
<i>Fucus serratus</i>												
Rascarrel Bay	1	"	8.9	"	"	"	"	"	"	2.1	"	"
Gutterby	1	0.17	11	"	"	"	0.26	"	"	4.2	"	"
Nethertown	1	0.14	13	"	"	0.18	ND	"	"	3.5	"	"
<i>Fucus spiralis</i>												
Ardglass	2	ND	3.4	"	"	ND	"	"	"	ND	"	"
Portrush	1	"	ND	"	"	"	"	"	"	"	"	"
<i>Ascophyllum nodosum</i>												
Ardglass	1	"	1.8	"	"	"	"	"	"	"	"	"
<i>Rhodomenia spp.</i>												
St Bees	2	0.54	36	2.4	"	"	"	"	"	15	"	"
Ballymacormick	1	ND	17	ND	"	"	"	"	"	3.7	"	"
Strangford Lough	4	0.07	4.4	"	"	"	"	0.083	0.43	0.50	ND	0.00086
<i>Dilsea carnosa</i>												
St Bees	1	ND	13	3.2	"	"	0.59	NA	NA	18	NA	NA
<i>Laminaria digitata</i>												
St Bees	1	"	13	ND	"	"	ND	"	"	4.4	"	"
<i>Laminaria sacharina</i>												
Isle of Man	2	"	2.9	"	"	"	0.10	"	"	ND	"	"
Samphire												
Rabbit Cat How, Ravenglass	1	0.03	2.5	"	"	0.11	ND	"	"	2.2	"	"
Cockerham Marsh	1	ND	3.3	"	"	ND	"	"	"	1.0	"	"
Llanfairfechan	1	"	2.0	"	"	"	"	"	"	0.21	"	"

NA = not analysed
 ND = not detected
 # See sub-section 3.2 for definition

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. Discharges of beta-emitting radionuclides reduced in 1991 because uranium ore concentrate was not processed for approximately 8 months of the year. Public radiation exposure in this vicinity, as a result of site discharges, is low; there is, however, a greater contribution due to Sellafield discharges. The most important pathway is external

exposure, due to adsorption of radioactivity on the muddy areas of river banks and in salt marshes. The amounts of time for which members of the public are subject to such exposure are 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). Other activities which have significant occupancies are wildfowling which takes place in intertidal areas and marshes bordering the estuary and angling which is popular in the Preston area (Hunt, 1992). We regularly monitor gamma and beta dose rates in relevant areas including muddy creeks where houseboats are moored, and some of these measurements are supported by analyses of

sediments. In 1991, we continued to investigate the fish and shellfish consumption pathway by analysing locally-obtained samples, including analyses for isotopes of thorium.

Results for 1991 are shown in Tables 16(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. Concentrations of most radionuclides decreased in 1991 compared with 1990 because of reduced discharges from Springfields and reductions in the recent past of discharges from Sellafield. 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. 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 generally less than for 1990. Exposure of the critical group of houseboat dwellers in 1991, including the Sellafield component, was 0.15 mSv, a reduction from the value for 1990 which was due to the decline in dose rates. 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 dose contribution due to discharges in 1991 from Springfields has been calculated from appropriate models (HMIP and MAFF, 1991). The contribution is estimated to be 0.01 mSv. This dose, in addition to those considered below, is likely to be relevant for comparison with the dose constraint for practices, currently under consideration (section 3.3), 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 1991 due to the combined effects of past and current discharges.

Table 16(a). Radioactivity in environmental materials near Springfields, 1991

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹										
			Total beta	⁶⁰ Co	¹⁰⁶ Ru	¹²⁵ Sb	¹³⁴ Cs	¹³⁷ Cs	¹⁵⁴ Eu	¹⁵⁵ Eu	²²⁸ Th	²³⁰ Th	²³² Th
Bass	Ribble Estuary	1	180	ND	ND	ND	0.29	38	ND	ND	0.0027	0.00096	0.0010
Grey mullet	"	1	95	"	"	"	ND	13	"	"	NA	NA	NA
Sea trout	"	1	110	"	"	"	0.19	14	"	"	"	"	"
Shrimps	"	1	73	"	"	"	ND	7.6	"	"	0.013	0.018	0.0047
Cockles	"	2	110	0.47	1.2	"	"	10	"	"	0.71	0.81	0.37
Sand	"	2	290	ND	ND	"	0.50	46	"	"	0.72	12	0.68
Turf	Hesketh Bank	4	1500	3.6	5.3	1.6	5.2	950	6.1	4.0	NA	NA	NA
Mud	Pipeline	4	67000	1.8	27	5.2	2.5	450	4.3	ND	37	410	37
"	Becconsall	4	28000	4.4	51	5.9	5.4	800	1.3	"	46	500	47
"	Penwortham	4	59000	2.7	32	2.1	4.5	570	3.9	"	49	1100	47
"	Deepdale Brook	4	2700	ND	ND	1.5	4.1	39	ND	6.9	33	390	33
"	Rock Ferry	4	1300	3.6	20	2.9	3.3	560	2.9	3.5	NA	NA	NA
"	Skippool Creek	4	1900	5.1	50	9.1	5.8	970	8.6	6.7	"	"	"

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹									
			²³⁴ Th	²³³ Pa	²³⁴ U	²³⁵ U+	²³⁸ U	²³⁷ Np	²³⁸ Pu	²³⁹ Pu+	²⁴¹ Am	²⁴³ Cm+
Bass	Ribble Estuary	1	ND	ND	NA	NA	NA	NA	NA	NA	ND	NA
Grey mullet	"	1	"	"	"	"	"	"	"	"	"	"
Sea trout	"	1	"	"	"	"	"	"	"	"	"	"
Shrimps	"	1	"	"	"	"	"	"	0.0070	0.033	"	0.000080
Cockles	"	2	"	"	"	"	"	0.19	0.53	2.6	5.8	0.013
Sand	"	2	"	"	"	"	"	NA	NA	NA	13	NA
Turf	Hesketh Bank	4	"	"	"	"	"	"	"	"	210	"
Mud	Pipeline	4	180000	"	43	1.9	38	"	"	"	150	"
"	Becconsall	4	61000	"	43	1.7	39	"	"	"	270	"
"	Penwortham	4	160000	"	59	2.8	51	3.1	"	"	190	"
"	Deepdale Brook	4	1200	4.4	1200	57	1100	4.4	"	"	ND	"
"	Rock Ferry	4	ND	ND	NA	NA	NA	NA	"	"	140	"
"	Skippool Creek	4	"	"	"	"	"	"	"	"	320	"

NA = not analysed

ND = not detected

See sub-section 3.2 for definition

* Except for sediment where dry concentrations apply

Table 16(b). Monitoring of radiation dose rates near Springfields, 1991

Location	Material	No. of sampling observations#	$\mu\text{Gy h}^{-1}$
Gamma dose rates at 1 m over intertidal areas			
Lytham	Mud	4	0.17
"	Salt marsh	4	0.18
Lytham Boatyard	Mud	4	0.12
Hesketh Bank	"	4	0.13
"	Salt marsh	4	0.14
Freckleton	Mud	4	0.13
Beaconsall	"	5	0.13
Hutton Marsh	"	4	0.16
"	Salt marsh	4	0.15
Pipeline	Mud	3	0.10
"	Sandy mud	1	0.16
Pipeline (south bank)	Mud	4	0.12
"	Salt marsh	4	0.16
Penwortham	Mud/sand/stones	2	0.089
"	Mud	2	0.17
Lower Penwortham	"	2	0.17
"	Muddy sand	2	0.088
"	Grass	4	0.099
River Darwen	Sand	4	0.073
"	Grass	4	0.079
Beta dose rates			$\mu\text{Sv h}^{-1}$
River Darwen	Mud/sand/stones	4	0.94
"	Grass	4	0.60
Hesketh Bank	Mud	4	1.5
Hutton Marsh	"	4	7.9
Lower Penwortham	"	4	18
"	Grass	4	12
Lytham	Mud	4	3.3
Pipeline (south bank)	"	4	7.6
Penwortham	"	4	29
Ribble estuary	Gill net	1	2.5

See sub-section 3.2 for definition

The exposure of wildfowlers and anglers was assessed as being 0.02 mSv in 1991 on the basis of ICRP-26 and 0.03 mSv using ICRP-60. In both cases the effects of beta-emitting nuclides have been considered in addition to gamma emitters. The reason for a slightly higher dose using ICRP-60 is that skin dose contributes to effective dose in the new ICRP recommendations. Most of the dose is due to Springfields discharges and is well within the 1 mSv limit for members of the public.

The critical group for skin irradiation was wildfowlers with skin exposures of 1.5 mSv in 1991. This is 3% of the relevant ICRP-recommended dose limit for members of the public.

4.3 Capenhurst, Cheshire

The main function of the Capenhurst Works is enrichment of uranium. Radioactive waste arising, 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. No discharges from Capenhurst took place via Meols in 1991 (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 1991 are presented in Table 17. 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 shellfish consumers, a potential critical group, in the vicinity of the Wirral in 1991 amounted to 0.04 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 0.03 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. Concentrations of radionuclides in materials from the Rivacre Brook in 1991 show the effects of Capenhurst discharges 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 by the Scottish Office. A recent habits survey has established that three groups of people could receive radiation exposures of potential importance. The first of these groups 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 and the third are wildfowlers who are exposed whilst on salt marshes. Our monitoring, which is carried out on behalf of the Scottish Office, reflects these pathways. Samples of *Fucus vesiculosus*, as useful indicators, are also analysed. The results of monitoring in 1991 are presented in Tables 18(a) and (b).

Concentrations of artificial radionuclides in the Chapelcross vicinity are mostly due to Sellafield discharges, and the general levels of nuclides given in Table 18(a) are consistent with values expected at this distance from Sellafield. Concentrations of radiocaesium in 1991 were generally similar to those in 1990. The exposure of the critical group of fishermen

Table 17. Radioactivity in environmental materials near Capenhurst, 1991

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹								
			Total beta	⁶⁰ Co	⁹⁹ Tc	¹⁰⁶ Ru	¹²⁵ Sb	¹³⁴ Cs	¹³⁷ Cs	¹⁵⁵ Eu	²³⁴ Th
Cockles	Dee estuary	5	62	0.29	1.4	0.17	0.10	0.04	4.8	0.05	6.4
<i>Fucus spiralis</i>	Hoylake	3	180	ND	23	ND	0.13	ND	14	0.19	9.0
Shrimps	"	2	51	"	0.70	"	ND	0.07	5.4	ND	ND
<i>Cladophoraceae rupestris</i>	Rivacre Brook	2	2400	0.04	770	"	0.13	0.15	1.8	0.86	810
Mud	"	2	2700	0.51	1900	"	ND	1.4	17	2.7	640

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹								
			²³⁴ U	²³⁵ U+ ²³⁶ U	²³⁸ U	²³³ Pa	²³⁷ Np	²³⁸ Pu	²³⁹ Pu+ ²⁴⁰ Pu	²⁴¹ Am	²⁴³ Cm+ ²⁴⁴ Cm
Cockles	Dee estuary	5	NA	NA	NA	0.52	NA	0.14	0.74	2.6	0.0039
<i>Fucus spiralis</i>	Hoylake	3	"	"	"	ND	"	NA	NA	1.5	NA
Shrimps	"	2	"	"	"	"	"	"	"	ND	"
<i>Cladophoraceae rupestris</i>	Rivacre Brook	2	170	14	130	5.9	55	"	"	"	"
Mud	"	2	500	34	300	68	90	"	"	"	"

NA = not analysed
 ND = not detected
 # See sub-section 3.2 for definition
 * Except for sediment where dry concentration apply

Table 18(a). Radioactivity in environmental materials near Chapelcross, 1991

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹								
		Total beta	¹⁴ C	⁶⁰ Co	⁹⁵ Zr	⁹⁵ Nb	⁹⁹ Tc	¹⁰⁶ Ru	^{110m} Ag	¹²⁵ Sb
Flounder	4	160	32	ND	ND	ND	NA	ND	ND	ND
Salmon	1	130	NA	"	"	"	"	"	"	"
Sea trout	2	130	"	"	"	"	"	"	"	"
Shrimps	4	83	"	"	"	"	"	0.20	"	"
<i>Fucus vesiculosus</i>	4	370	"	0.36	0.14	"	81	"	ND	0.12
Sandy mud	4	840	"	1.8	1.8	1.6	NA	23	"	0.75

Material	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	²⁴² Cm	²⁴³ Cm+ ²⁴⁴ Cm
Flounder	4	0.56	64	ND	ND	NA	NA	ND	NA	NA
Salmon	1	ND	0.42	"	"	"	"	"	"	"
Sea trout	2	"	8.6	"	"	0.00060	0.0020	0.0032	ND	0.000010
Shrimps	4	0.05	18	"	"	NA	NA	ND	NA	NA
<i>Fucus vesiculosus</i>	4	0.17	39	"	0.21	0.54	2.5	2.4	0.0041	0.010
Sandy mud	4	2.7	440	0.92	1.7	12	56	82	ND	0.14

ND = not detected; NA = not analysed
 * Except for sediment where dry concentrations apply
 # See sub-section 3.2 for definition

Table 18(b). Monitoring of radiation dose rates near Chapelcross, 1991

Location	Material	No. of sampling observations#	µSv h ⁻¹
Beta dose rates on nets			
Seafield	Stake nets	2	0.48
Gamma dose rates at 1 m over intertidal areas			
Seafield	Sandy mud	4	0.11
"	Saltmarsh	4	0.094
Battle Hill	Sandy mud	4	0.086
Brownhouses	"	4	0.095
Dornoch Brow	Muddy sand	2	0.083
"	Saltmarsh	4	0.10

See sub-section 3.2 for definition

who consume seafood and are exposed to external radiation over intertidal areas was 0.02 mSv in 1991, which is 2% of the ICRP-recommended principal dose limit of 1 mSv year⁻¹ for members of the public. The reduction in dose for this group from 0.07 mSv in 1990 was due to a decrease in consumption and occupancy rates. The exposure of the skin of fishermen, due to handling nets, was 0.12 mSv which is much less than 1% of the ICRP-recommended dose limit appropriate for exposures to skin of members of the public. Wildfowlers received a dose of 0.01 mSv or 1% of the principal dose limit for 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, 1992), 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. Liquid radioactive wastes are created as a result of decommissioning and decontamination operations and nuclear-related research and development. Liquid waste arisings are small and discharges are made under authorisation to the River Thames at

Sutton Courtenay. During 1991, 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 upstream of Sutton Courtenay at Standlake 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. In addition, gamma dose rates were measured on the river bank near the outfall.

Recent habits surveys have identified anglers as a potential critical group which may be affected by discharges into the river. Their occupancy of the river bank has been assessed to estimate their external exposures. Consumption of freshwater fish was also considered but none was found. Nevertheless, it is considered prudent to include a component in the assessment of the anglers' exposure and a hypothetical consumption of fish at a rate of 1 kg year⁻¹ was assumed.

The results of the monitoring are shown in Tables 19(a) and (b). The concentrations of artificial radioactivity detected were very low. Concentrations of some nuclides, notably chromium-51, cobalt-60 and caesium-137, were enhanced close to the outfall, but the

Table 19(a). Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Harwell, 1991

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹												
			Total beta	¹⁴ C	³⁵ S	⁵¹ Cr	⁵⁷ Co	⁵⁸ Co	⁶⁰ Co	¹³⁴ Cs	¹³⁷ Cs	¹⁵² Eu	²³⁸ Pu	²³⁹ Pu+ ²⁴⁰ Pu	²⁴¹ Am
Pike	Outfall (Sutton Courtenay)	2	140	NA	NA	ND	ND	ND	ND	0.29	16	ND	0.000040	0.00024	0.00018
	Standlake	2	98	23	7.7	"	"	"	"	ND	0.17	"	0.000017	0.00011	0.00017
	Staines	2	110	NA	ND	"	"	"	"	"	0.58	"	NA	NA	ND
<i>Nuphar lutea</i>	Sutton Courtenay	1	54	"	NA	15	"	"	1.9	0.12	2.3	0.11	"	"	"
	Sutton Pools	1	41	"	"	9.1	"	"	ND	ND	0.06	ND	"	"	"
	Staines	1	45	"	"	ND	1.2	0.30	0.12	"	0.75	"	"	"	"
Sandy mud	Sutton Courtenay	1	1200	"	"	"	1.6	ND	32	1.9	650	"	"	"	"
Mud	Staines	1	430	"	"	"	2.5	"	1.9	ND	51	"	"	"	"
	Sutton Pools	1	230	"	"	"	ND	"	ND	"	1.5	"	"	"	"

NA = not analysed

ND = not detected

* Except for sediment where dry concentrations apply

See sub-section 3.2 for definition

Table 19(b). Monitoring of gamma dose rates near Harwell, 1991

Location	Ground type	No. of sampling observations#	µGy h ⁻¹
Gamma dose rates at 1 m over river bank			
Sutton Courtenay	Soil	1	0.078

See sub-section 3.2 for definition

levels were very small in terms of any radiological effect. Gamma dose rates were indistinguishable from natural background. External exposures were calculated using a model based on concentrations of radionuclides in sediment (Hunt, 1984). The radiation dose to anglers in 1991 from fish consumption and external occupancy of the river bank would have been 0.004 mSv, or 0.4% of the ICRP-recommended principal dose limit of 1 mSv year⁻¹.

5.2 Winfrith Technology Centre, Dorset

The principal source of liquid radioactive wastes at this establishment in 1991 was decommissioning and decontamination of the Steam Generating Heavy Water Reactor (SGHWR) which ceased power production in September 1990. Discharges in 1991 were substantially less than those in 1990 because regular decontamination of the primary coolant circuit was no longer needed. The wastes from decommissioning operations are disposed of under authorisation to deep water in Weymouth Bay. The radiological significance of the discharges from Winfrith is small and mainly due to activation products from decommissioning of the SGHWR. 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 Tables 20(a) and (b).

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, declined in 1991 as compared with previous years; this was due to the closure of the SGHWR noted above. The radiation dose to the critical group of fish and shellfish consumers (Smith and Hunt, 1989) was 0.009 mSv, or less than 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 by the Scottish Office. 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 1991 were generally greater than those in 1990 reflecting the campaigns of reprocessing of reactor fuel. Our surveys near Dounreay are carried out on behalf of the Scottish Office. Monitoring in 1991 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 Tables 21(a) and (b).

Habits surveys have confirmed the existence of four potentially critical exposure pathways, 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 1991 has confirmed that the exposure of these fishermen remained low, at 0.01 mSv, or less than 0.1% of the ICRP-recommended dose limit of 50 mSv year⁻¹ for skin exposures (see sub-section 3.3).

The second potentially critical pathway arises also from the uptake of radioactivity by particulate material which accumulates in rocky areas of the foreshore and presents a potential source of exposure, mainly to gamma radiation, of those who visit these areas. In 1991, we carried out monitoring of sludge at Oigin's Geo; concentrations of some radionuclides increased and others decreased compared with 1990 but were 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 pathway 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 1991 were similar in fish and crabs to those for 1990 but there were increases in silver-110m and transuranics in lobsters. Nevertheless, 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 pathway is due to consumption of molluscs and external exposure during collection. Gamma dose rates were measured over collecting areas and winkles were analysed for their radioactivity content. Gamma dose rates over the main collecting areas reduced in 1991 and the radiation dose due to a combination of consumption of molluscs and external exposure during collection was 0.01 mSv in 1991 or 1% of the ICRP-recommended principal dose limit of 1 mSv year⁻¹, a reduction from 0.02 mSv in 1990. This pathway was the critical one at Dounreay in 1991.

Table 20(a). Radioactivity in environmental materials near Winfrith, 1991

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹									
			Total beta	¹⁴ C	⁵⁴ Mn	⁵⁸ Co	⁶⁰ Co	⁶⁵ Zn	¹⁰⁶ Ru	^{110m} Ag	¹²⁵ Sb	
Plaice	Weymouth Bay	2	85	14	ND	ND	ND	ND	ND	ND	ND	ND
Crabs	"	7	63	NA	"	"	7.2	9.2	"	"	"	"
Lobsters	"	2	61	"	"	"	2.4	7.1	"	"	"	"
Native oysters	Poole	2	38	"	"	"	1.1	43	"	"	0.14	"
Portuguese oysters	Chesil	1	54	"	"	"	0.60	0.51	"	"	1.8	"
Cockles	Poole	2	52	"	"	"	4.8	0.33	"	"	ND	"
Scallops	Weymouth Bay	3	96	"	0.46	"	2.1	2.5	"	"	"	0.14
Squid	"	2	64	"	ND	"	ND	0.20	"	"	"	ND
Whelks	"	2	100	"	"	"	16	24	"	"	"	"
"	Poole Bay	2	100	"	"	"	6.0	16	"	"	"	"
<i>Fucus serratus</i>	Arish Mell	1	300	"	0.61	0.67	33	4.6	"	"	"	"
	Kimmeridge	2	160	"	0.24	0.22	15	1.0	"	"	"	"
	Swanage	2	210	"	0.30	0.11	16	1.0	"	"	"	"
	Bognor Rock	2	260	"	ND	ND	5.9	ND	"	"	"	"
	Hengistbury Head	2	210	"	0.11	"	12	0.50	"	"	"	"
	Weymouth	2	170	"	ND	"	9.6	0.51	"	"	"	"
	Chesil	2	180	"	"	"	1.1	ND	"	"	"	"
	Lyme Regis	2	220	"	"	"	0.83	"	"	"	"	"
	Sandgate	2	240	"	"	"	6.0	0.11	0.46	"	"	"
Mud	Kimmeridge	2	340	"	"	"	9.0	0.80	ND	"	"	"
	Poole Harbour	2	420	"	"	"	14	ND	"	"	"	"
	Hardway	2	640	"	"	"	16	"	"	"	"	"
	Rye Harbour	2	520	"	"	"	8.3	"	"	"	"	"

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹								
			¹³⁴ Cs	¹³⁷ Cs	¹⁵⁵ Eu	²³⁸ Pu	²³⁹ Pu+ ²⁴⁰ Pu	²⁴¹ Am	²⁴² Cm	²⁴³ Cm+ ²⁴⁴ Cm	
Plaice	Weymouth Bay	2	ND	0.43	ND	NA	NA	ND	NA	NA	
Crabs	"	7	"	0.02	"	0.00047	0.0015	0.0018	0.000047	0.00012	
Lobsters	"	2	"	0.14	"	NA	NA	ND	NA	NA	
Native oysters	Poole	2	"	ND	"	"	"	"	"	"	
Portuguese oysters	Chesil	1	"	0.24	"	"	"	"	"	"	
Cockles	Poole	2	"	0.08	"	"	"	"	"	"	
Scallops	Weymouth Bay	3	"	0.14	"	0.0022	0.0078	0.0031	ND	0.00008	
Squid	"	2	"	0.07	"	NA	NA	ND	NA	NA	
Whelks	"	2	"	ND	"	0.0019	0.0074	0.0066	ND	0.00029	
"	Poole Bay	2	"	0.10	"	0.0011	0.0044	0.0046	"	0.00020	
<i>Fucus serratus</i>	Arish Mell	1	"	ND	"	NA	NA	ND	NA	NA	
	Kimmeridge	2	"	"	"	"	"	"	"	"	
	Swanage	2	"	0.07	"	"	"	"	"	"	
	Bognor Rock	2	"	0.18	"	"	"	"	"	"	
	Hengistbury Head	2	"	0.07	0.22	"	"	"	"	"	
	Weymouth	2	0.13	ND	ND	"	"	"	"	"	
	Chesil	2	"	ND	"	"	"	"	"	"	
	Lyme Regis	2	"	0.09	"	"	"	"	"	"	
	Sandgate	2	"	0.28	"	"	"	"	"	"	
Mud	Kimmeridge	2	"	2.3	0.70	"	"	"	"	"	
	Poole Harbour	2	"	5.2	2.4	0.17	0.75	0.56	ND	0.0098	
	Hardway	2	"	4.7	2.4	NA	NA	ND	NA	NA	
	Rye Harbour	2	"	3.0	2.1	"	"	"	"	"	

NA = not analysed

ND = not detected

* Except for sediment where dry concentrations apply

See sub-section 3.2 for definition

Table 20(b). Monitoring of radiation dose rates near Winfrith, 1991

Location	Ground type	No. of sampling observations#	µGy h ⁻¹
Gamma dose rates at 1 m over intertidal areas			
Kimmeridge	Sand	2	0.064
Poole Harbour	Mud	2	0.058
Hardway	"	2	0.061
Rye Harbour	"	2	0.066
Beta dose rates on fishing gear			
			µSv h ⁻¹
Weymouth Bay	Pots	3	ND
"	Nets	1	"

ND = not detected

See sub-section 3.2 for definition

Table 21(a). Radioactivity in environmental materials near Dounreay, 1991

Sampling point and material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹								
		Total beta	¹⁴ C	⁶⁰ Co	⁹⁹ Tc	¹⁰⁶ Ru	^{110m} Ag	¹²⁵ Sb	¹³⁴ Cs	¹³⁷ Cs
Pipeline										
Cod	4	110	19	ND	NA	ND	ND	ND	ND	1.4
Crabs	4	67	NA	"	"	"	2.0	"	"	0.30
Lobsters	4	83	"	0.08	"	"	26	"	"	0.57
Sandside Bay										
Winkles	4	100	"	1.4	"	2.3	78	"	"	0.22
Sand	4	500	"	0.08	"	ND	ND	"	0.14	7.1
<i>Fucus vesiculosus</i>	4	340	"	1.7	85	1.2	6.1	"	0.31	2.1
Oigins Geo										
Sludge	4	5500	"	230	NA	4700	510	170	12	160
Brims Ness										
Winkles	4	100	"	1.8	"	3.5	80	ND	ND	0.26
<i>Fucus vesiculosus</i>	3	290	"	2.0	"	ND	5.6	"	0.76	1.2
<i>Fucus spiralis</i>	1	190	"	2.0	"	0.77	5.5	"	0.20	1.4

Sampling point and material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹							
		¹⁴⁴ Ce	¹⁵⁵ Eu	²³⁸ Pu	²³⁹ Pu+ ²⁴⁰ Pu	²⁴¹ Pu	²⁴¹ Am	²⁴² Cm	²⁴³ Cm+ ²⁴⁴ Cm
Pipeline									
Cod	4	ND	ND	0.00015	0.00069	NA	0.0012	0.000020	0.000010
Crabs	4	"	"	0.0036	0.012	"	0.015	0.0057	0.00057
Lobsters	4	"	"	0.012	0.035	"	0.35	0.027	0.12
Sandside Bay									
Winkles	4	0.88	"	0.088	0.22	3.7	0.47	0.048	0.013
Sand	4	ND	2.4	2.7	11	NA	9.7	0.31	0.15
<i>Fucus vesiculosus</i>	4	0.47	0.12	NA	NA	"	0.027	NA	NA
Oigins Geo									
Sludge	4	240	69	110	260	"	195	38	7.0
Brims Ness									
Winkles	4	0.29	ND	0.098	0.28	"	0.54	0.055	0.017
<i>Fucus vesiculosus</i>	3	ND	"	NA	NA	"	0.048	NA	NA
<i>Fucus spiralis</i>	1	"	"	"	"	"	ND	"	"

NA = not analysed

ND = not detected

* Except for sediment where dry concentrations apply

See sub-section 3.2 for definition

Table 21(b). Monitoring of gamma dose rates near Dounreay, 1991

Location	Ground type	No. of sampling observations#	µGy h ⁻¹
Gamma dose rates at 1 m over intertidal areas			
Oigins Geo	Intertidal sediment	4	0.16
Sandside Bay	Sand	1	0.059
"	Sand/stones	1	0.10
"	Winkle bed	3	0.11

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 Technology Centre. Liquid radioactive wastes from both Berkeley and Oldbury are discharged to the same stretch of the Severn Estuary.

The stations are therefore considered together for the purpose of our environmental monitoring. Although there has been a substantial reduction in the consumption of locally-caught shrimps, a recent habits survey has confirmed that 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 1991 are presented in Tables 22(a) and (b). 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

Table 22(a). Radioactivity in environmental materials near Berkeley and Oldbury nuclear power stations, 1991

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹											
		Total beta	¹⁴ C	³⁵ S	⁶⁰ Co	¹³⁴ Cs	¹³⁷ Cs	¹⁵⁵ Eu	²³⁸ Pu	²³⁹ Pu+ ²⁴⁰ Pu	²⁴¹ Am	²⁴² Cm	²⁴³ Cm+ ²⁴⁴ Cm
Cod	1	170	150	NA	ND	ND	1.8	ND	NA	NA	ND	NA	NA
Flounder	3	190	740	"	"	"	0.85	"	"	"	"	"	"
Eel	1	110	NA	"	"	"	1.5	"	"	"	"	"	"
Elvers	1	78	"	"	"	"	ND	"	"	"	"	"	"
Shrimps	3	71	120	"	"	"	0.31	"	"	"	"	"	"
<i>Fucus vesiculosus</i>	2	180	NA	20	1.6	2.4	21	"	"	"	"	"	"
Mud:													
area of pipelines	4	890	"	NA	ND	2.5	44	2.0	"	"	"	"	"
Lydney	2	670	"	"	0.16	0.58	29	2.0	0.12	0.69	0.67	0.0026	0.011

NA = not analysed

ND = not detected

* Except for sediment where dry concentrations apply

See sub-section 3.2 for definition

Table 22(b). Monitoring of gamma dose rates near Berkeley and Oldbury nuclear power stations, 1991

Location	Ground type	No. of sampling observations#	µGy h ⁻¹
Gamma dose rates at 1 m over intertidal areas			
Salmon Lodge	Mud	2	0.075
Severn House Farm putcher rank	"	2	0.071
Guscar Rocks	"	2	0.080
Lydney Locks	"	2	0.070
Berkeley pipeline	"	2	0.074
Sharpness	"	2	0.067

See sub-section 3.2 for definition

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 the external exposure of the critical group of fish and shellfish consumers. Their total exposure due to liquid waste discharges was low, at 0.008 mSv or 0.8% 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.

Measurements for 1991 are summarised in Tables 23(a) and (b). In fish and shellfish, artificial radioactivity was detected due to the combined effects of discharges from the station, Sellafield discharges, and fallout. Apportionment of the effects of these sources is difficult because of the low levels detected. Concen-

Table 23(a). Radioactivity in environmental materials near Bradwell nuclear power station, 1991

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹						
		Total beta	¹⁴ C	⁶⁰ Co	⁶⁵ Zn	⁹⁹ Tc	^{110m} Ag	¹³⁴ Cs
Bass	1	100	NA	ND	ND	NA	ND	0.38
Flounder	1	91	16	"	"	"	"	ND
Whiting	1	120	NA	"	"	"	"	"
Crabs	1	82	"	0.23	"	"	"	"
Native oysters	2	91	"	0.50	8.0	"	"	"
Pacific oysters	1	33	"	ND	1.3	"	0.17	"
Winkles	2	84	"	0.68	0.70	"	ND	"
<i>Fucus vesiculosus</i>	2	140	"	0.78	ND	3.7	"	0.38
Mud	8	710	"	4.5	"	NA	"	2.3

Material	No. of sampling observations#	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
Bass	1	2.2	ND	NA	NA	ND	NA	NA
Flounder	1	0.99	"	"	"	"	"	"
Whiting	1	1.5	"	"	"	"	"	"
Crabs	1	0.48	"	"	"	"	"	"
Native oysters	2	0.41	"	0.00062	0.0024	0.0067	0.000050	0.00044
Pacific oysters	1	0.09	"	NA	NA	ND	NA	NA
Winkles	2	0.80	"	0.0049	0.021	0.021	0.00010	0.00086
<i>Fucus vesiculosus</i>	2	2.1	"	NA	NA	ND	NA	NA
Mud	8	29	1.5	"	"	"	"	"

NA = not analysed

ND = not detected

* Except for sediment where dry concentrations apply

See sub-section 3.2 for definition

Table 23(b). Monitoring of gamma dose rates near Bradwell, 1991

Location	Ground type	No. of sampling observations#	μGy h ⁻¹
Gamma dose rates at 1 m over intertidal areas			
Pipeline	Mud	2	0.25
1.5 km east of pipeline	"	2	0.069
Waterside	"	2	0.064
West Mersea	"	2	0.062
Maldon	"	2	0.059

See sub-section 3.2 for definition

trations 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 0.009 mSv or 0.9% 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. *Fucus serratus* is analysed as an indicator material. The results for 1991 are given in Tables 24(a) and (b).

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 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

Table 24(a). Radioactivity in environmental materials near Dungeness nuclear power stations, 1991

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹										
		Total beta	¹⁴ C	⁶⁰ Co	⁶⁵ Zn	¹⁰⁶ Ru	¹³⁷ Cs	¹⁵⁵ Eu	²³⁸ Pu	²³⁹ Pu+	²⁴⁰ Pu	²⁴¹ Am
Plaice	3	100	24	ND	ND	ND	0.34	ND	NA	NA	ND	NA
Cod	2	130	NA	"	"	"	0.92	"	"	"	"	"
Bass	1	110	"	"	"	"	1.6	"	"	"	"	"
Shrimps	2	110	"	0.37	0.11	"	0.16	"	"	"	"	"
Whelks	3	97	"	0.84	0.61	0.92	ND	"	"	"	"	"
<i>Fucus serratus</i>	2	240	"	6.0	0.10	0.46	0.27	"	"	"	"	"
Mud	2	520	"	8.3	ND	ND	3.0	2.0	0.10	0.49	0.34	0.029
Sand	4	200	"	1.6	"	"	0.14	ND	NA	NA	ND	NA

NA = not analysed

ND - not detected

* Except for sediment where dry concentrations apply

See sub-section 3.2 for definition

Table 24(b). Monitoring of gamma dose rates near Dungeness nuclear power stations, 1991

Location	Ground type	No. of sampling observations#	µGy h ⁻¹
Gamma dose rates at 1 m over intertidal areas			
Camber Sands	Sand	2	0.050
Old Lifeboat Station	"	1	0.047
"	Shingle	1	0.038
Pilot Inn	Sand	1	0.053
"	Shingle	1	0.039
Rye Harbour	Mud	2	0.066

See sub-section 3.2 for definition

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 0.007 mSv or 0.7% of the ICRP-recommended principal dose limit of 1 mSv year⁻¹.

Table 25(a). Radioactivity in environmental materials near Hartlepool nuclear power station, 1991

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹								
		Total beta	¹⁴ C	⁹⁹ Tc	¹³⁷ Cs	¹⁵⁵ Eu	²³⁸ Pu	²³⁹ Pu+ ²⁴⁰ Pu	²⁴¹ Am	²⁴³ Cm+ ²⁴⁴ Cm
Plaice	2	87	31	NA	0.55	ND	NA	NA	ND	NA
Cod	2	130	NA	"	1.4	"	"	"	"	"
Crabs	2	76	"	"	0.37	"	0.00065	0.0033	0.0027	ND
Shrimps	1	84	"	"	0.28	"	NA	NA	ND	NA
Winkles	2	140	"	"	0.55	"	0.0058	0.031	0.015	0.000050
<i>Fucus spiralis</i>	2	190	"	"	0.43	"	NA	NA	ND	NA
<i>Fucus vesiculosus</i>	2	260	"	3.8	0.48	0.06	"	"	"	"
Mud	4	770	"	NA	23	2.6	"	"	"	"
Coal/sand	2	190	"	"	1.8	ND	"	"	"	"

NA = not analysed

ND = not detected

* Except for sediment where dry concentrations apply

See sub-section 3.2 for definition

Table 25(b). Monitoring of gamma dose rates near Hartlepool nuclear power station, 1991

Location	Ground type	No. of sampling observations#	µGy h ⁻¹
Gamma dose rates at 1 m over intertidal areas			
Greatham Creek	Mud	2	0.075
Little Scar	Coal/sand	2	0.054
North Gare	Sand	2	0.056
Paddy's Hole	Mud	2	0.092

See sub-section 3.2 for definition

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 1991 are shown in Tables 25(a) and (b). Concentrations of radiocaesium and transuranics were mainly due to discharges from Sellafield and to weapons-test 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.

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 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 food-stuff.

The results for 1991 are given in Tables 26(a) and (b). These mainly reflect discharges from Sellafield; the effect of discharges from Heysham was not detectable above this background. The radiation exposure in 1991 to the critical group of fishermen was 0.11 mSv (on the basis of ICRP-60: 0.09 mSv) which is well within the ICRP-recommended principal dose limit of 1 mSv year⁻¹. Concentrations of radioactivity in samphire were of negligible radiological significance.

Table 26(a). Radioactivity in environmental materials near Heysham nuclear power stations, 1991

Material	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	¹⁰⁶ Ru	¹²⁵ Sb	¹³⁴ Cs
Flounder	5	120	36	ND	NA	ND	ND	NA	ND	ND	0.56
Plaice	2	120	48	0.42	"	"	"	"	"	"	ND
Bass	1	150	NA	ND	"	"	"	"	"	"	0.33
Whitebait	1	100	"	"	0.80	"	"	"	"	"	0.19
Cockles	4	71	"	1.0	NA	"	"	"	3.0	0.5	0.04
Mussels	4	92	"	0.46	"	"	"	"	5.2	0.62	ND
<i>Fucus vesiculosus</i>	4	500	"	0.34	"	"	"	310	0.57	1.0	0.19
Samphire	1	41	"	ND	"	"	"	NA	ND	ND	ND
Sandy mud											
Half Moon Bay	4	1100	"	3.2	"	2.7	2.0	"	55	7.5	2.4
Sunderland Point	4	930	"	2.0	"	1.0	ND	"	25	2.4	1.7
Conder Green	1	1200	"	3.1	"	ND	"	"	58	5.8	3.3
Mud											
Morecambe Central Pier	1	NA	"	3.6	"	"	"	"	55	7.6	2.8
Turf											
Conder Green	4	1800	"	5.3	"	"	"	"	31	5.9	7.1
Cockerham Marsh	2	990	"	2.7	"	"	"	"	14	ND	4.8

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹							
		¹³⁷ Cs	¹⁴⁴ Ce	¹⁵⁴ Eu	¹⁵⁵ Eu	²³⁸ Pu	²³⁹ Pu+ ²⁴⁰ Pu	²⁴¹ Am	²⁴³ Cm+ ²⁴⁴ Cm
Flounder	5	39	ND	ND	ND	NA	NA	ND	NA
Plaice	2	16	"	"	"	"	"	"	"
Bass	1	37	"	"	"	"	"	"	"
Whitebait	1	22	"	"	"	"	"	0.46	"
Cockles	4	7.8	"	0.28	0.07	0.58	2.9	7.6	0.017
Mussels	4	4.7	"	ND	ND	0.17	0.84	1.4	0.0039
<i>Fucus vesiculosus</i>	4	22	"	"	"	NA	NA	1.1	NA
Samphire	1	3.3	"	"	"	"	"	1.0	"
Sandy mud									
Half Moon Bay	4	460	2.2	5.3	4.3	25	110	190	0.33
Sunderland Point	4	300	ND	2.5	4.3	NA	NA	110	NA
Conder Green	1	620	"	5.3	5.9	"	"	190	"
Mud									
Morecambe Central Pier	1	660	"	6.6	3.6	"	"	280	"
Turf									
Conder Green	4	1400	"	8.8	5.9	"	"	310	"
Cockerham Marsh	2	600	"	3.2	2.2	"	"	150	"

NA = not analysed

ND = not detected

* Except for sediment where dry concentrations apply

See sub-section 3.2 for definition

Table 26(b). Monitoring of gamma dose rates near Heysham nuclear power stations, 1991

Location	Material	No. of sampling observations#	µGy h ⁻¹
Gamma dose rates at 1 m over intertidal areas			
Morecambe Central Pier	Sandy mud	1	0.080
"	Mussel bed	4	0.079
"	Muddy sand	3	0.088
Half Moon Bay	Sandy mud	4	0.10
Pipeline	Muddy sand	4	0.074
Red Nab Point	Sandy mud	4	0.10
Sunderland Point	"	4	0.092
Sunderland	Mud/sand/stones	4	0.082
Colloway Marsh	Salt marsh	4	0.20
Lancaster	"	4	0.13
Aldcliffe Marsh	"	4	0.17
Conder Green	Sandy mud	4	0.12
"	Salt marsh	4	0.17
Cockerham marsh	Samphire bed	1	0.11
"	Salt marsh	4	0.13

See sub-section 3.2 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 1991, presented in Tables 27(a) and (b), 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 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 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 high-rate fish and shellfish consumers. Their total exposure due to liquid waste discharges was low, at 0.008 mSv or 0.8% of the ICRP-recommended principal dose limit of 1 mSv year⁻¹.

Table 27(a). Radioactivity in environmental materials near Hinkley Point nuclear power stations, 1991

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹														
		Total beta	¹⁴ C	³⁵ S	⁵⁴ Mn	⁶⁰ Co	^{110m} Ag	¹³⁴ Cs	¹³⁷ Cs	¹⁵⁵ Eu	²³⁸ Pu	²³⁹ Pu+	²⁴⁰ Pu	²⁴¹ Am	²⁴³ Cm+	²⁴⁴ Cm
Flounder	3	140	150	17	ND	ND	ND	0.10	1.2	ND	NA	NA	ND	NA		
Shrimps	2	89	93	16	"	"	"	0.04	0.54	"	0.00022	0.0010	0.0012	0.000020		
<i>Fucus vesiculosus</i>	2	240	NA	39	2.8	1.7	0.21	0.48	2.2	"	NA	NA	NA	NA		
Sand	1	252	"	NA	ND	0.56	ND	1.4	9.0	"	"	"	"	"		
Muddy sand	1	452	"	"	0.95	1.1	"	0.89	16	1.1	"	"	"	"		
Mud	4	850	"	"	ND	0.91	"	2.3	39	1.3	"	"	"	"		

NA = not analysed

ND = not detected

* Except for sediment where dry concentrations apply

See sub-section 3.2 for definition

Table 27(b). Monitoring of gamma dose rates near Hinkley Point nuclear power stations, 1991

Location	Ground type	No. of sampling observations#	µGy h ⁻¹
Gamma dose rates at 1 m over intertidal areas			
0.8 km east of pipeline	Mud	2	0.070
0.8 km west of pipeline	"	2	0.15
1.6 km east of pipeline	"	2	0.062
Pipeline	"	2	0.080
River Parrett	"	2	0.067

See sub-section 3.2 for definition

6.7 Hunterston, Ayrshire

This establishment comprises 'A' and 'B' stations; the 'A' station was designed for magnox-type reactors and the 'B' station for 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 by the Scottish Office. 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 the Scottish Office, samples of fish and shellfish and carry out gamma dose

rate measurements on the foreshore. In 1991 the sampling included velvet swimming crabs in view of the importance of this fishery. 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 1991 are shown in Tables 28(a) and (b).

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. In 1991, 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 28(a). Radioactivity in environmental materials near Hunterston nuclear power stations, 1991

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹												
		Total beta	¹⁴ C	⁵⁸ Co	⁶⁰ Co	⁶⁵ Zn	^{110m} Ag	¹³⁴ Cs	¹³⁷ Cs	²³⁸ Pu	²³⁹ Pu+	²⁴⁰ Pu	²⁴¹ Am	²⁴² Cm
Cod	2	120	21	ND	ND	ND	ND	ND	6.1	NA	NA	ND	NA	NA
Grey mullet	1	120	NA	"	"	"	"	"	5.6	"	"	"	"	"
Saithe	3	120	"	"	"	"	"	"	8.3	"	"	"	"	"
Crabs	1	61	"	"	"	"	"	"	1.2	"	"	"	"	"
Velvet swimming crabs	2	57	"	"	0.44	"	"	0.12	1.3	"	"	"	"	"
<i>Nephrops</i>	2	100	"	"	ND	"	"	ND	4.4	"	"	"	"	"
Lobsters	1	91	"	"	"	"	"	"	1.6	"	"	"	"	"
Oysters	1	110	"	"	0.28	0.65	0.91	"	0.54	"	"	"	"	"
Winkles	4	90	"	0.16	8.3	0.14	2.3	"	2.0	0.058	0.24	0.10	0.0015	0.0045
<i>Fucus vesiculosus</i>	1	350	"	0.69	15	ND	0.48	"	5.4	NA	NA	ND	NA	NA
<i>Fucus spiralis</i>	3	260	"	0.64	10	"	0.09	0.16	5.3	0.087	0.38	0.059	0.0014	0.0028
Sand	4	190	"	ND	2.6	"	ND	0.44	22	NA	NA	0.31	NA	NA

NA = not analysed

ND = not detected

* Except for sand where dry concentrations apply

See sub-section 3.2 for definition

Table 28(b). Monitoring of gamma dose rates near Hunterston nuclear power stations, 1991

Location	Ground type	No. of sampling observations#	µGy h ⁻¹
Gamma dose rates at 1 m over intertidal areas			
0.5 km north of pipeline	Sand	2	0.051
0.5 km south of pipeline	Sand/stones	2	0.069

See sub-section 3.2 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 1991 are shown in Tables 29(a) and (b).

Table 29(a). Radioactivity in environmental materials near Sizewell nuclear power station, 1991

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+
Cod	1	130	22	ND	ND	1.1	ND	NA	NA	ND	NA	NA
Plaice	1	84	NA	"	"	0.67	"	"	"	"	"	"
Flounder	1	110	"	"	"	1.3	"	"	"	"	"	"
Crabs	3	65	"	0.20	"	0.35	"	0.00020	0.001	0.0017	0.000080	
Shrimps	1	56	"	ND	0.54	1.2	"	0.0010	0.0045	0.0078	0.000050	
Pacific oysters	1	84	"	"	ND	0.56	"	NA	NA	ND	NA	
Whelks	1	87	"	0.92	"	ND	"	"	"	"	"	
Mud	2	720	"	2.8	"	22	0.86	"	"	"	"	

NA = not analysed

ND = not detected

* Except for sediment where dry concentrations apply

See sub-section 3.2 for definition

Table 29(b). Monitoring of gamma dose rates near Sizewell nuclear power station, 1991

Location	Ground type	No. of sampling observations#	µGy h ⁻¹
Gamma dose rates at 1 m over intertidal areas			
Pipeline	Sand	2	0.047
Dunwich	"	2	0.044
Rifle range	"	2	0.043
Sizewell Hall	"	2	0.044
Aldeburgh	"	2	0.044
Southwold Harbour	Mud	2	0.062

See sub-section 3.2 for definition

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 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 the Scottish Office. Our investigations, on behalf of the Scottish Office, 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 *Fucus vesiculosus* 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 1991 are shown in Tables 30(a) and (b). Concentrations of artificial radionuclides were mainly due to the distant effects of Sellafield discharges and to fallout, though trace levels of activation products were likely to have been due to discharges from the station. 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 30(a). Radioactivity in environmental materials near Torness nuclear power station, 1991

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹												
		Total beta	¹⁴ C	⁵⁴ Mn	⁹⁹ Tc	⁶⁰ Co	^{110m} Ag	¹³⁴ Cs	¹³⁷ Cs	¹⁵⁵ Eu	²³⁸ Pu	²³⁹ Pu+ ²⁴⁰ Pu	²⁴¹ Am	²⁴³ Cm+ ²⁴⁴ Cm
Cod	2	110	23	ND	NA	ND	ND	ND	1.8	ND	NA	NA	ND	NA
Crabs	3	86	NA	"	"	"	"	"	0.21	"	"	"	"	"
Lobsters	2	68	"	"	"	"	"	"	0.16	"	"	"	"	"
<i>Nephrops</i>	4	86	"	"	"	"	"	"	0.80	"	0.00060	0.0030	0.0047	0.000020
Winkles	4	91	"	"	"	0.82	0.20	"	0.29	"	NA	NA	ND	NA
<i>Fucus vesiculosus</i>	2	230	"	2.9	13	2.6	ND	"	0.58	"	"	"	"	"
Mud														
Dunbar Inner Harbour	2	510	"	ND	NA	ND	"	0.83	28	0.74	"	"	"	"
Sandy mud														
Aberlady Bay	1	740	"	"	"	"	"	ND	15	ND	"	"	"	"
Barns Ness	1	470	"	"	"	"	"	"	21	"	"	"	"	"
Eyemouth Harbour	1	670	"	"	"	"	"	2.9	58	2.1	"	"	"	"
Sand														
Thomton Loch Beach	2	210	"	"	"	"	"	ND	2.6	0.27	"	"	"	"

NA = not analysed

ND = not detected

* Except for sediment where dry concentrations apply

See sub-section 3.2 for definition

Table 30(b). Monitoring of radiation dose rates near Torness, 1991

Location	Material	No. of sampling observations#	µSv h ⁻¹
Beta dose rates on nets			
Cove	Pots	2	0.14
Dunbar Harbour	Nets	2	0.10
Gamma dose rates at 1 m over intertidal areas			
			µGy h ⁻¹
Barns Ness	Mud/sand/stones	2	0.060
"	Rock	1	0.057
Skateraw Harbour	Sand	2	0.053
Thomton Loch Beach	"	2	0.047

See sub-section 3.2 for definition

6.10 Trawsfynydd, Gwynedd

Discharges from this station are made to the freshwater Lake Trawsfynydd under authorisation of the Welsh Office and HMIP. 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 group is exposed through consumption of fish caught in the lake and external exposure over the lake shoreline; 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 1991, a small amount of perch. 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 (Leonard, 1989).

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 1991, 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 Tables 31(a) and (b).

Discharges of radiocaesium from the power station in 1991 decreased as compared with 1990 (Table 1) and have remained within authorised limits. The concentrations of caesium-137 in lake water also decreased in 1991; however, concentrations slightly increased in trout and perch and this may be due to the delayed effect of higher discharges and water concentrations in 1990 as compared with 1989. Concentrations of

Table 31(a). Radioactivity in environmental materials near Trawsfynydd nuclear power station, 1991

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹									
		Total beta	¹⁴ C	³⁵ S	⁵⁴ Mn	⁶⁰ Co	⁹⁰ Sr	⁹⁵ Zr	⁹⁵ Nb	¹⁰⁶ Ru	¹²⁵ Sb
Brown trout	12	590	51	64	ND	0.03	9.0	ND	ND	ND	ND
Rainbow trout	10	130	22	16	"	ND	1.7	"	"	"	"
Rainbow trout (hatchery)	1	110	NA	NA	"	"	3.4	"	"	"	"
Perch	8	1000	43	75	"	"	5.4	"	"	"	"
Rudd	1	710	NA	NA	"	"	NA	"	"	"	"
Eel	2	400	"	ND	"	0.34	3.6	"	"	"	"
<i>Fontinalis</i>											
Afon Prysor	3	170	"	"	"	ND	NA	"	"	"	"
Gwylan Stream	3	3700	"	"	2.2	20	"	1.1	"	110	420
Mud											
Pipeline (bankside)	2	6000	"	"	3.7	170	"	4.5	38	630	1100
Hot lagoon	2	11000	"	"	4.7	150	"	11	51	1200	1900
Cold lagoon	2	11000	"	"	1.4	140	"	3.1	13	1000	1800
South end of lake	1	1700	"	"	ND	9.6	"	ND	ND	ND	63
Gwylan Stream	3	3200	"	"	"	23	"	"	"	45	190
Peat											
Near cooling water outlet	3	3100	"	"	"	44	"	"	"	120	520
Hot lagoon	2	2700	"	"	"	54	"	"	"	130	470
South end of lake	1	710	"	"	"	3.5	"	"	"	ND	72
Cae Adda boat mooring	2	1900	"	"	1.5	20	"	"	"	140	330
Bailey bridge	2	3000	"	"	ND	18	"	"	"	94	230
Water											
Bailey bridge	4	NA	"	"	NA	NA	"	NA	NA	NA	NA
Cold lagoon	4	"	"	"	"	"	"	"	"	"	"

Material	No. of sampling observations#	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	12	100	420	ND	ND	ND	0.00036	0.0013	0.0019	0.00020	0.000035
Rainbow trout	10	2.9	12	"	"	"	0.00018	0.00060	0.00061	0.00015	0.000015
Rainbow trout (hatchery)	1	1.1	4.5	"	"	"	0.000050	0.00015	0.0025	0.00015	0.000020
Perch	8	180	870	"	"	"	0.00011	0.00045	0.00074	0.00017	0.000040
Rudd	1	140	590	"	"	"	NA	NA	NA	NA	NA
Eel	2	57	330	"	"	"	0.000070	0.00023	0.00039	ND	0.000020
<i>Fontinalis</i>											
Afon Prysor	3	1.8	19	"	"	1.1	NA	NA	ND	NA	NA
Gwylan Stream	3	20	110	32	0.42	3.3	"	"	0.92	"	"
Mud											
Pipeline (bankside)	2	510	3800	380	25	12	"	"	56	"	"
Hot lagoon	2	690	7100	690	50	35	35	100	150	23	7.4
Cold lagoon	2	1000	8200	450	25	28	NA	NA	71	NA	NA
South end of lake	1	54	1200	ND	ND	ND	"	"	2.1	"	"
Gwylan Stream	3	120	1700	7.2	"	2.0	"	"	1.0	"	"
Peat											
Near cooling water outlet	3	72	1100	46	10	ND	"	"	NA	"	"
Hot lagoon	2	61	730	86	22	"	6.2	23	35	2.8	1.1
South end of lake	1	18	241	ND	ND	"	NA	NA	ND	NA	NA
Cae Adda boat mooring	2	200	1300	46	"	"	"	"	"	"	"
Bailey bridge	2	260	1800	57	"	"	"	"	"	"	"
Water											
Bailey bridge	4	0.050	0.16	NA	NA	NA	"	"	NA	"	"
Cold lagoon	4	0.061	0.19	"	"	"	"	"	"	"	"

NA = not analysed

ND = not detected

* Except for mud and peat where dry concentrations apply

See sub-section 3.2 for definition

Table 31(b). Monitoring of gamma dose rates near Trawsfynydd nuclear power station, 1991

Location	Ground type	No. of sampling observations#	µGy h ⁻¹
Gamma dose rates at 1 m over areas near lake shoreline			
Bailey bridge	Peat	2	0.085
South end of lake	"	2	0.084
Cae Adda boat mooring	Mud	2	0.064

See sub-section 3.2 for definition

radiocaesium in fish from the lake due to Chernobyl are now very small compared with those due to discharges from the power station. In 1991, 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 1991, members of the critical group of fish consumers received 0.11 mSv, which is well within the ICRP-recommended principal dose

limit of 1 mSv year⁻¹. The exposure has slightly increased when compared with that of 1990 (Camplin, 1992) and this was due to the increased concentrations in fish. 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 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 1991 are presented in Tables 32(a) and (b).

Concentrations of artificial radionuclides were mainly due to the distant effects of Sellafield discharges though trace levels of activation products were likely to have been due to discharges from the station. Data for 1991 indicates that the radiation exposure of the critical group of high-rate fish and shellfish consumers was low, at 0.007 mSv, or 0.7% 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 32(a). Radioactivity in environmental materials near Wylfa nuclear power station, 1991

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹															
		Total beta	¹⁴ C	⁵⁴ Mn	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
Plaice	2	98	27	ND	ND	ND	ND	ND	3.0	ND	NA	NA	ND	NA	NA		
Crabs	2	75	NA	"	0.17	"	"	"	1.6	"	"	"	"	"	"	"	"
Winkles	2	84	"	"	0.20	"	"	"	1.5	"	0.048	0.24	0.31	0.0016	0.00099		
<i>Fucus vesiculosus</i>	6	200	"	0.58	0.54	0.13	0.17	0.06	3.8	"	NA	NA	0.17	NA	NA		
Mud	2	1000	"	ND	1.7	ND	ND	2.5	250	0.73	7.1	39	54	0.16	0.12		

NA = not analysed

ND = not detected

*Except for sediment where dry concentrations apply

See sub-section 3.2 for definition

Table 32(b). Monitoring of gamma dose rates near Wylfa nuclear power station, 1991

Location	Ground type	No. of sampling observations#	µGy h ⁻¹
Gamma dose rates at 1 m over intertidal areas			
Amlwch Harbour	Rock	4	0.091
Cemaes Bay	Sand	6	0.057
Cemlyn Bay	Mud	4	0.083

See sub-section 3.2 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, 1992). In 1991, 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 (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 1991, we continued a small programme of fisheries-related monitoring. This included monitoring upstream of nuclear sites on the Thames at Standlake to indicate background levels remote from nuclear establishments. Analyses were carried out of

pike, with *Nuphar lutea* (yellow water lily) and sediments as indicator materials. In addition, gamma dose rates were measured on the river bank near the outfall.

Recent habits surveys have identified anglers as a potential critical group which may be affected by discharges into the river. Their occupancy of the river bank has been assessed to estimate their external exposures. Consumption of freshwater fish was also considered but none was found. Nevertheless, it is considered prudent to include a component in the assessment of the anglers' exposure and a hypothetical consumption of fish at a rate of 1 kg year⁻¹ was assumed.

The results of the monitoring are shown in Tables 33(a) and (b). The concentrations of artificial radioactivity detected were very low. Concentrations of plutonium were not significantly different from the level expected due to fallout. Gamma dose rates were indistinguishable from natural background. External exposures were calculated using a model based on concentrations of radionuclides in sediment (Hunt, 1984). The overall radiological significance was very low: the radiation dose to anglers from occupancy of the river bank near the outfall and consumption of fish 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 33(a). Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Aldermaston, 1991

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	¹³⁷ Cs	¹⁵⁵ Eu	²³⁸ Pu	²³⁹ Pu+ ²⁴⁰ Pu	²⁴¹ Am
Pike	Standlake	2	98	23	7.7	ND	ND	ND	0.17	ND	0.000017	0.00011	0.00017
	Pangbourne	2	110	NA	NA	"	"	"	0.91	"	0.000035	0.00016	0.00018
	Staines	2	110	"	ND	"	"	"	0.57	"	NA	NA	ND
<i>Nuphar lutea</i>	Pangbourne	1	43	"	NA	"	"	0.28	1.8	0.04	"	"	"
	Staines	1	45	"	"	1.2	0.30	0.12	0.75	ND	"	"	"
Mud	Pangbourne	1	260	"	"	ND	ND	1.2	15	"	"	"	"
	Staines	1	430	"	"	2.5	"	1.9	51	"	"	"	"

NA = not analysed

ND = not detected

* Except for sediment where dry concentrations apply

See sub-section 3.2 for definition

Table 33(b). Monitoring of gamma dose rates near Aldermaston, 1991

Location	Ground type	No. of sampling observations#	µGy h ⁻¹
Gamma dose rates at 1 m over river bank			
Pangbourne	Grass	1	0.052

See sub-section 3.2 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 (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 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 measure-

ments 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 1991 are presented in Table 34. 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 1991, 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 low near all of these naval establishments, at less than 0.02 mSv year⁻¹. This represents less than 2% of the ICRP-recommended principal dose limit of 1 mSv year⁻¹.

Table 34. Radioactivity in environmental materials and gamma dose rates near naval establishments, 1991

Establishment	Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹													Gamma dose rates at 1 m over intertidal areas	
			Total beta	⁶⁰ Co	^{110m} Ag	¹²⁵ Sb	¹³⁴ Cs	¹³⁷ Cs	¹⁴⁴ Ce	¹⁵⁵ Eu	²³⁸ Pu	²³⁹ Pu+ ²⁴⁰ Pu	²⁴¹ Am	²⁴² Cm	²⁴³ Cm+ ²⁴⁴ Cm	No. of sampling observations#	µGy h ⁻¹
Chatham	Mud	3	690	3.8	ND	ND	0.64	16	ND	0.59	NA	NA	ND	NA	NA	5	0.060
Devonport	Mussels	2	50	0.21	"	"	ND	0.50	"	ND	"	"	"	"	"		
"	<i>Fucus vesiculosus</i>	2	NA	0.20	"	"	"	0.15	"	"	"	"	"	"	"		
"	Mud	6	"	0.55	"	"	"	5.2	"	1.4	0.024	0.50	0.16	ND	ND	12	0.069
Faslane	Winkles	1	110	5.8	0.66	"	"	2.5	"	ND	NA	NA	ND	NA	NA		
"	Mud	2	NA	45	1.5	4.9	1.8	77	2.2	1.5	"	"	0.49	"	"	10	0.062
Rosyth	Crabs	2	"	ND	ND	ND	ND	0.25	ND	0.11	"	"	ND	"	"		
"	<i>Fucus vesiculosus</i>	2	"	"	"	"	"	0.81	"	ND	"	"	0.12	"	"		
"	Mud	11	770	"	"	"	1.3	33	"	0.80	"	"	ND	"	"	10	0.062
Holy Loch	Muddy sand	2	NA	2.0	"	"	0.46	20	"	ND	"	"	"	"	"	12	0.062

NA = not analysed

ND = not detected

* Except for sediment where dry concentrations apply

See sub-section 3.2 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 the HMIP (HMIP, 1992). However, in 1991, 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 1991, we continued our small programme of monitoring of fish and other aquatic materials in surveillance of the effects of these discharges, including monitoring at Standlake on the Thames which is remote from nuclear establishments. Analyses were carried out of pike and perch with *Nuphar lutea* (yellow water lily) and sediments as indicator materials. In addition, gamma dose rates were measured on the river bank near the outfall.

Recent habits surveys have identified anglers as a potential critical group which may be affected by discharges into the canal/river system. Their occupancy of the river bank has been assessed to estimate their external exposures. Consumption of freshwater fish was also considered but none was found. Nevertheless, it is considered prudent to include a component in the assessment of the anglers' exposure and a hypothetical consumption of fish at a rate of 1 kg year⁻¹ was assumed.

The results of the monitoring are presented in Tables 35(a) and (b). The concentrations of radioactivity detected were very low. Concentrations of some

Table 35(a). Radioactivity in environmental materials from the River Thames catchment in surveillance of the effects of liquid radioactive waste discharges from Amersham, 1991

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹													
			Total beta	¹⁴ C	³⁵ S	⁵⁴ Mn	⁵⁷ Co	⁵⁸ Co	⁶⁰ Co	⁶⁵ Zn	¹³⁴ Cs	¹³⁷ Cs	¹⁵⁵ Eu	²³⁸ Pu	²³⁹ Pu+ ²⁴⁰ Pu	²⁴¹ Am
Pike	Standlake	2	98	23	7.7	ND	ND	ND	ND	ND	ND	0.17	ND	0.000017	0.00011	0.00017
	Grand Union Canal	2	130	96	31	"	0.02	"	"	"	"	0.56	"	NA	NA	ND
	Staines	2	110	NA	ND	"	ND	"	"	"	"	0.58	"	"	"	"
Perch	Grand Union Canal	1	140	"	NA	"	0.37	"	"	0.72	"	0.96	"	"	"	"
<i>Nuphar lutea</i>	Grand Union Canal	1	59	"	"	0.15	7.1	1.7	"	0.60	"	0.11	"	"	"	"
	Staines	1	45	"	"	ND	1.2	0.30	0.12	ND	"	0.75	"	"	"	"
Mud	Grand Union Canal	1	190	"	"	"	25	4.5	0.79	3.6	0.61	12	0.67	"	"	"
	Staines	1	430	"	"	"	2.5	ND	1.9	ND	ND	51	ND	"	"	"
Muddy sand	Frays River, Yiewsley	1	400	"	"	"	3.3	"	0.44	0.73	0.67	18	1.9	"	"	"

NA = not analysed

ND = not detected

* Except sediment where dry concentrations apply

See sub-section 3.2 for definition

Table 35(b). Monitoring of gamma dose rates near Amersham, 1991

Location	Ground type	No. of sampling observations#	µGy h ⁻¹
Gamma dose rates at 1 m over canal bank			
Grand Union Canal	Grass	1	0.044

See sub-section 3.2 for definition

radionuclides were slightly enhanced close to the outfall, but the overall effect was of very low radiological significance. Gamma dose rates were indistinguishable from natural background. External exposures were calculated using a model based on concentrations of radionuclides in sediment (Hunt, 1984). If any fish were eaten, 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(a). Radioactivity in environmental materials near Cardiff, 1991

Material	No. of sampling observations#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹						
		Total beta [†]	¹⁴ C	³⁵ S	¹³¹ I	¹³⁴ Cs	¹³⁷ Cs	¹⁵⁵ Ba
Flounder	4	320	810	12	ND	ND	0.47	ND
Mussels	1	360	1200	NA	"	"	0.71	"
<i>Fucus serratus</i>	1	150	18	"	1.3	"	0.28	"
<i>Fucus vesiculosus</i>	2	190	NA	"	ND	"	0.38	"
<i>Fucus spiralis</i>	3	130	19	25	2.2	"	0.28	0.72
Mud	3	990	13	NA	ND	1.4	41	ND
Sandy mud	1	330	17	"	"	ND	5.4	"

NA = not analysed

ND = not detected

* Except sediment where dry concentrations apply

See sub-section 3.2 for definition

[†] Includes contribution from carbon-14 at low counting efficiency due to the low energy of beta particles emitted by this radionuclide

Table 36(b). Monitoring of gamma dose rates near Cardiff, 1991

Location	Ground type	No. of sampling observations#	µGy h ⁻¹
Gamma dose rates at 1 m over intertidal areas			
East of pipeline	Mud	2	0.071
West of pipeline	"	2	0.061

See sub-section 3.2 for definition

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 1991 are presented in Tables 36(a) and (b). Of the separate radionuclides listed, only carbon-14 and sulphur-35 were discharged by this establishment in 1991; 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 including external irradiation was 0.02 mSv or 2% of the ICRP-recommended principal dose limit of 1 mSv year⁻¹. The external irradiation of the critical group was 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.*, 1992). 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 1991 are given in Table 37. 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 37. Radioactivity in environmental materials from the Channel Islands, 1991

Material	Sampling area/ landing point	No. of sampling observa- tions#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹									
			Total beta	¹⁴ C	⁵⁴ Mn	⁶⁰ Co	⁶⁵ Zn	¹⁰⁶ Ru	⁹⁰ Sr	⁹⁹ Tc	^{110m} Ag	
Rays	Guemsey ²	1	99	NA	ND	ND	ND	ND	NA	NA	ND	
Crabs	Guemsey ²	1	56	"	"	3.0	"	"	"	"	0.57	
	Jersey ²	1	88	"	"	0.89	"	1.6	"	"	0.70	
Lobsters	Aldemey ¹	3	69	26	"	2.0	0.11	ND	"	"	0.87	0.15
	Casquets											
	Guemsey ²	1	61	NA	"	0.52	ND	"	"	NA	ND	
	Jersey ²	1	81	"	"	0.68	"	"	"	"	1.5	
Oysters	Aldemey ¹	1	51	"	"	0.66	"	"	"	"	"	ND
	Casquets											
Jersey ²	1	90	"	"	0.62	"	2.0	"	"	"	2.1	
Limpets	Guemsey ¹	1	92	"	"	0.68	"	ND	"	"	"	ND
	Jersey ¹											
Ormers	La Rozel	1	140	"	"	0.82	"	"	"	"	"	0.26
	Aldemey East	1	100	"	"	1.9	"	"	"	"	"	ND
Porphyra	Guemsey ¹	1	180	"	"	1.2	"	"	"	"	"	"
	Aldemey ¹	3	160	"	0.02	0.63	"	2.0	"	"	"	"
	Quenard Point											
	Guemsey ¹	4	120	"	ND	0.15	"	0.53	"	"	"	"
Fermain Bay	3	190	"	"	0.37	"	1.8	"	"	"	"	
Fucus serratus	Jersey ¹	1	280	"	"	3.1	"	1.0	"	"	"	"
	Corbiere											
	Guemsey ¹	4	170	"	"	1.7	"	1.0	0.11	"	"	
	Fermain Bay	4	280	"	0.08	3.4	"	1.6	0.34	"	"	
	Jersey ¹	4	280	"	0.13	3.5	"	1.7	0.23	"	"	
Laminaria digitata	Aldemey ¹	4	280	"	0.13	3.5	"	1.7	0.23	"	"	
	Quenard Point	4	280	"	0.13	3.5	"	1.7	0.23	"	"	
Mud	Jersey ¹	4	350	"	ND	0.28	"	1.0	NA	"	"	"
	Verclut											
Sand	Jersey ¹	1	610	"	2.5	32	"	15	"	"	"	"
	St Helier											
Sand	Guemsey ¹	1	370	"	ND	1.4	"	ND	"	"	"	"
	Bordeaux Harbour											
	Aldemey ¹	2	430	"	0.7	9.0	"	7.0	"	"	"	

Material	Sampling area/ landing point	No. of sampling observa- tions#	Mean radioactivity concentration (wet)*, Bq kg ⁻¹								
			¹²⁵ Sb	¹³⁷ Cs	¹⁵⁴ Eu	¹⁵⁵ Eu	²³⁸ Pu	²³⁹ Pu+ ²⁴⁰ Pu	²⁴¹ Am	²⁴² Cm	²⁴³ Cm+ ²⁴⁴ Cm
Rays	Guemsey ²	1	ND	0.78	ND	ND	0.00014	0.00050	0.00093	ND	0.000020
Crabs	Guemsey ²	1	"	0.14	"	"	0.0011	0.0016	0.0060	0.000050	0.0021
	Jersey ²	1	"	0.11	"	"	0.0016	0.0029	0.0053	0.000040	0.0014
Lobsters	Aldemey ¹	3	"	0.05	"	"	0.0011	0.0017	0.0057	ND	0.0022
	Casquets										
	Guemsey ²	1	"	ND	"	"	0.00063	0.0021	0.0029	0.00011	0.00050
	Jersey ²	1	"	"	"	"	0.0012	0.0031	0.0093	0.00010	0.0021
Oysters	Aldemey ¹	1	"	"	"	"	0.00095	0.0020	0.021	0.00039	0.0085
	Casquets										
Jersey ²	1	"	0.11	"	"	0.012	0.019	0.021	0.00016	0.0046	
Limpets	Guemsey ¹	1	"	ND	"	"	NA	NA	ND	NA	NA
	Jersey ¹										
Ormers	La Rozel	1	"	0.08	"	"	0.0072	0.013	0.020	0.00012	0.0049
	Aldemey East	1	"	0.42	"	"	0.012	0.014	0.026	0.00017	0.010
	Guemsey ¹	1	"	ND	"	"	NA	NA	ND	NA	NA
	Jersey ¹										
Porphyra	Aldemey ¹	3	"	0.021	"	"	"	"	"	"	"
	Quenard Point										
	Guemsey ¹	4	"	0.013	"	"	"	"	"	"	"
	Fermain Bay	3	"	0.18	"	"	"	"	"	"	"
Fucus serratus	Jersey ¹	1	0.18	0.27	"	"	"	"	"	"	"
	Corbiere										
	Guemsey ¹	4	ND	0.07	"	0.06	0.019	0.031	0.014	0.00012	0.0036
Laminaria digitata	Jersey ¹	4	0.18	0.21	"	ND	0.053	0.074	0.034	0.00024	0.0097
	La Rozel										
	Aldemey ¹	4	ND	0.22	"	0.10	0.040	0.056	0.032	0.00035	0.0097
Mud	Jersey ¹	4	0.03	0.23	"	0.04	NA	NA	ND	NA	NA
	Verclut										
Sand	Jersey ¹	1	2.2	6.2	1.8	2.6	1.3	2.7	4.1	0.058	0.98
	St Helier										
Sand	Guemsey ¹	1	ND	2.3	ND	ND	0.096	0.36	0.31	0.0027	0.065
	Bordeaux Harbour										
	Aldemey ¹	2	3.0	3.8	0.30	1.1	NA	NA	0.56	NA	NA

1 = Sampling area
2 = Landing point
NA = not analysed
ND = not detected
* Except for sediment where dry concentrations apply
See sub-section 3.2 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 1991, 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 1991 are presented in this section. Sampling locations were mostly in areas of relatively high deposition of fallout from Chernobyl, namely Cumbria, North Wales and parts of Scotland. Samples from areas of low deposition in

England were also obtained for completeness and comparison. Monitoring in Northern Ireland and the Isle of Man was discontinued in view of the low levels detected in recent years.

Table 38 presents 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 twenty-five, depending on availability and radiological importance. The maximum concentrations measured in samples from a given location were generally a factor of three to four times greater than the average value. Artificial radionuclides, other than those of radiocaesium, in 1991, were no longer detectable from the Chernobyl accident.

Table 38. Caesium radioactivity in freshwater fish, 1991

Location	Species	No. of samples	Mean radioactivity concentration (wet), Bq kg ⁻¹	
			¹³⁴ Cs	¹³⁷ Cs
England				
Branthwaite	Rainbow trout	1	ND	ND
Narborough	"	1	"	"
Ennerdale Water	Brown trout	21	1.6	49
"	Char	12	0.67	21
Loweswater	Brown trout	8	2.3	32
"	Pike	1	7.8	99
"	Perch	10	4.6	57
"	Eel	1	4.4	45
Devoke Water	"	1	61	670
"	Brown trout	11	0.80	23
River Teme	Chub	1	ND	0.18
River Esk	Salmon	1	"	1.4
"	Sea trout	1	"	6.7
River Derwent	"	1	"	19
River Duddon	"	2	"	14
River Ehen	"	1	0.15	12
River Kent	"	1	0.37	37
River Calder	Brown trout	1	4.6	51
Wales				
Llyn Trawsfynydd	Brown trout	130	110	440
"	Rainbow trout	10	2.9	12
"	Perch	59	190	900
"	Rudd	1	140	590
"	Eel	2	57	330
Llyn Goddionduon	Brown trout	8	6.8	68
Scotland				
Loch Dee, Dumfries and Galloway	Brown trout	17	19	180
Loch Garry, Tayside region	"	1	5.0	73
"	Char	1	ND	49
River Almond	Rainbow trout	1	"	ND
River Annan	Salmon	1	"	0.42
"	Sea trout	2	"	8.6
Loch Leven, Glencoe	Salmon	1	"	1.4
River Tay	"	1	"	ND
"	Sea trout	1	"	"

ND = not detected

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, in recognition of the potential radiological significance of this species; although rainbow trout are more commonly eaten, their radiocaesium concentrations were generally low compared with wild brown trout, because rainbow trout are mostly hatchery-reared and fed on relatively uncontaminated food prior to release. Perch and eels had the highest concentrations of any of the freshwater species but, as they are not eaten in large quantities, their radiological significance is low. Where there are data for the same species and locations to compare with results for 1990 (Camplin, 1992) 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 1991 than those in 1990, continuing the reducing trend that began in the latter part of 1987 (Camplin, 1992). Figure 5 shows a plot of mean total radiocaesium concentrations in brown trout from Ennerdale Water against time. In recent years, the rate of decline has reduced and it is likely that levels have now become more stable. The exception to this trend in radiocaesium concentrations at Trawsfynydd has been discussed in sub-section 6.10.

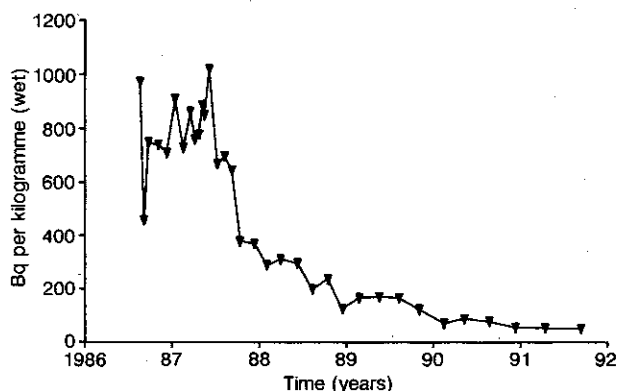


Figure 5. Mean total caesium in brown trout muscle — Ennerdale Water, 1991

Radiation exposures have been estimated using a procedure based on cautious assumptions, as previously (Camplin, 1992). 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 for ingestion, provided as described in sub-section 3.3. Estimates of dose are presented in Table 39.

Table 39. Estimates of maximum dose* from Chernobyl to adults due to consumption of freshwater fish from areas of high deposition of fallout, 1991

Region	Location	Exposure, mSv	
		ICRP-26+	ICRP-60#
England	Ennerdale Water	0.025	0.025
Wales	Llyn Goddionduon	0.037	0.037
Scotland	Loch Dee	0.10	0.10

* 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

The ICRP (ICRP, 1984(b)) 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. 1991 was outside this period but, as was the case in 1990, 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. NATURAL RADIONUCLIDES

In view of the radiological importance of natural radionuclides to fish and shellfish consumers (Pentreath *et al.*, 1989; Rollo *et al.*, in press) we have begun a limited programme of monitoring these radionuclides in the UK marine environment. Previous surveys (Rollo *et al.*, in press) have established that an important source is the Albright and Wilson chemical plant at Whitehaven in Cumbria which has manufactured phosphoric acid from imported phosphate ore. Phosphogypsum, a waste product of this process, has been discharged as a liquid slurry by pipeline to Saltom Bay. The discharge is authorised by HMIP and contains low levels of natural radioactivity consisting mainly of thorium, uranium and their daughter products.

Discharges are expected to be substantially reduced during 1992 due to changes in waste treatment techniques and the cessation of use of phosphate ore.

The results of MAFF monitoring for natural radioactivity near the site prior to 1991 are being published (Rollo *et al.*, in press). Tables 40(a) and (b) show the results for 1991. The data have been separated into those samples collected from the Irish Sea and those collected from elsewhere. The former may be affected by discharges from Whitehaven whereas the latter can be considered to be at background levels. Analytical effort has focussed on polonium-210 which tends to concentrate in marine species. Concentrations of polonium-210 and other natural radionuclides are enhanced near the site but quickly reduce to background levels further away. The critical radiation exposure pathway is internal irradiation, due to the

ingestion of natural radioactivity in local fish and shellfish. The critical group consists of people who consume seafood collected from Saltom Bay and Parton. A preliminary assessment indicates a dose of approximately 0.5 mSv in 1991 on the basis of ICRP-26 from the enhanced concentrations of natural radionuclides taking into account background concentrations. However, this would fall on the basis of ICRP-60 to approximately 0.27 mSv. The dose results mainly from the consumption of winkles containing polonium-210 and is within the ICRP-recommended principal dose limit of 1 mSv year⁻¹. The fish and shellfish consumed by the critical group also contains artificial radionuclides due to Sellafield discharges. The additional exposure due to artificial radionuclides has been calculated using data from sub-section 4.1.

In 1991 these exposures were small adding 0.03 mSv (ICRP-26 and ICRP-60) to the doses above.

Table 40(a). Natural radioactivity in fish and shellfish from the Irish Sea, 1991

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet), Bq kg ⁻¹							
			²¹⁰ Po	²²⁶ Ra	²²⁸ Th	²³⁰ Th	²³² Th	²³⁴ U	²³⁵ U	²³⁸ U
Winkles	Saltom Bay	4	350	NA	NA	NA	NA	NA	NA	NA
	Parton	4	120	2.9	0.92	28	0.72	15	0.57	14.55
	North Harrington	4	86	NA	NA	NA	NA	NA	NA	NA
	Fleswick Bay	4	54	"	"	"	"	"	"	"
	Nethertown	11	34	"	"	"	"	"	"	"
	Southernness	3	25	"	"	"	"	"	"	"
Mussels	Tarn Bay	5	23	"	"	"	"	"	"	"
	Parton	2	390	"	"	"	"	"	"	"
	Nethertown	4	95	"	"	"	"	"	"	"
	Whitehaven Inner Harbour	1	750	"	"	"	"	"	"	"
Whelks	Ravenglass	4	64	"	"	"	"	"	"	"
	Parton	1	8.9	ND	"	"	"	0.30	0.012	0.27
Cockles	Ribble	1	21	"	0.71	0.81	0.37	NA	NA	NA
	Wirral	3	18	"	NA	NA	NA	"	"	"
Crab	Parton	3	44	0.26	0.13	0.068	0.011	0.10	0.0052	0.096
Cod	Parton	3	1.6	ND	0.017	0.0032	0.00044	0.0053	0.00030	0.0050
Bass	Ribble	1	NA	NA	0.0027	0.00096	0.0010	NA	NA	NA

NA = not analysed

ND = not detected

See sub-section 3.2 for definition

Table 40(b). Natural radioactivity in fish and shellfish from areas other than the Irish Sea, 1991

Material	Sampling point	No. of sampling observations#	Mean radioactivity concentration (wet), Bq kg ⁻¹							
			²¹⁰ Po	²²⁶ Ra	²²⁸ Th	²³⁰ Th	²³² Th	²³⁴ U	²³⁵ U	²³⁸ U
Winkles	Torness	4	13	0.080	0.089	0.038	0.063	0.71	0.024	0.62
	Sandside Bay	4	18	NA	NA	NA	NA	NA	NA	NA
	Fort William	1	30	"	"	"	"	"	"	"
	Kinlochleven	1	38	"	"	"	"	"	"	"
Mussels	Wash	3	56	"	"	"	"	"	"	"
	Fort William	1	33	"	"	"	"	"	"	"
	Kinlochleven	1	61	"	"	"	"	"	"	"
Crab	Torness	3	17	0.030	0.040	0.0084	0.010	0.055	0.0017	0.046
Lobster	"	2	5.2	ND	0.0096	0.0026	0.0014	0.040	0.0015	0.035
Cod	Mid-North Sea	3	0.28	"	0.0054	0.00081	0.00097	0.0045	0.0002	0.0039

NA = not analysed

ND = not detected

See sub-section 3.2 for definition

12. SUMMARY AND CONCLUSIONS

A summary of estimated public radiation exposures in 1991, relating to liquid radioactive waste discharges from nuclear establishments, is presented in Table 41. 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 1991. 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 3.3). 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 1991, the doses are much less than those in Table 41. At other sites, committed effective doses, from discharges in 1991, would also be less than or equal to those in Table 41, 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 due to artificial radionuclides near Sellafield decreased slightly in 1991, as compared with 1990, due to decreases of 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 1991. 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.

Exposures of the externally-exposed group of houseboat dwellers in the area of the Ribble estuary decreased from 0.18 mSv in 1990 to 0.15 mSv in 1991. This was due to a general reduction in dose rates over sediments following the earlier decreases in discharges of radiocaesium from Sellafield.

The maximum skin exposures in 1991 of 1.5 mSv were in the Ribble estuary. The dose limit for non-stochastic (deterministic) effects is 50 mSv year⁻¹. This exposure is therefore less than 3% of the relevant dose limit.

Near Trawsfynydd, concentrations of radiocaesium in fish from the lake slightly increased in 1991, following earlier increases in discharges. As a consequence, exposures of the high-rate fish consumers increased from 0.09 mSv in 1990 to 0.11 mSv in 1991, though the increase was small. These doses are well within the dose limit for members of the public.

In this year's report we have included an assessment of the exposures due to natural radioactivity. These are enhanced above normal levels due to discharges from the Albright and Wilson factory at Whitehaven, Cumbria. Exposure of the critical group of fish and shellfish consumers, due to enhanced concentrations of natural radionuclides, on the basis of current recommendations for dose coefficients for ICRP-26 was approximately 0.5 mSv. However, this would fall on the basis of ICRP-60 to approximately 0.27 mSv. These doses are within the 1 mSv limit for members of the public. The additional dose received by the critical group due to artificial radionuclides from the Sellafield site was 0.03 mSv (ICRP-26 and ICRP-60). Details are given in section 11. Discharges from Albright and Wilson are expected to be substantially reduced during 1992 due to changes in waste treatment techniques and the cessation of use of phosphate ore. The exposure from enhanced concentrations of natural radionuclides to the Sellafield fish and shellfish consumers was 0.21 mSv (on the basis of ICRP-60: 0.11 mSv).

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 1991 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

Table 41. Summarised estimates of public radiation exposure from discharges of liquid radioactive waste in the UK, 1991

Establishment	Radiation exposure pathway	Critical group	Exposure, mSv	
			ICRP-26+	ICRP-60*
British Nuclear Fuels plc Sellafield and Drigg ^a	Fish and shellfish consumption	Local fishing community	0.15	0.11
	External	Houseboat dwellers (River Ribble)	0.15	0.15
	Handling of fishing gear	Local fishing community	0.18#	0.18#
	<i>Porphyra</i> /laverbread consumption	Consumers in South Wales	<0.005	<0.005
Springfields	External	Houseboat dwellers (River Ribble)	0.15 ^a	0.15 ^a
	"	Wildfowlers	0.02 ^b	0.03 ^b
	" (skin)	"	1.5#	1.5#
	"	Anglers	0.02 ^b	0.03 ^b
Capenhurst	Shellfish consumption	Local fishing community	0.04 ^a	0.03 ^a
Chapelcross	Fish and shellfish consumption	Local fishermen	0.02 ^a	0.02 ^a
	External			
	External	Wildfowlers	0.01 ^a	0.01 ^a
	Handling of fishing gear	Local fishermen	0.12# ^a	0.12# ^a
United Kingdom Atomic Energy Authority Harwell	Fish consumption	Anglers	0.004	0.004
	External			
Winfrith	Fish and shellfish consumption	Local fishing community	0.009	0.009
Dounreay	Handling of fishing gear	Local fishermen	0.01# ^b	0.01# ^b
	External	Local community	0.006 ^b	0.006 ^b
	Fish and crustacean consumption	Local fishing community	<0.005 ^b	<0.005 ^b
	Mollusc consumption	Mollusc collectors	0.01 ^b	0.01 ^b
	External			
Nuclear Power Stations Operated by the Electricity Companies Berkeley and Oldbury	Fish and shellfish consumption	Local fishing community	0.008 ^b	0.008 ^b
	External			
Bradwell	Fish and shellfish consumption	Houseboat dwellers	0.009 ^b	0.009 ^b
	External			
Dungeness	External	Bait diggers	0.007	0.007
	Fish and shellfish consumption			
Hartlepool	Fish and shellfish consumption	Local fishing community	<0.005 ^a	<0.005 ^a
Heysham	Shellfish consumption	Local fishermen	0.11 ^a	0.09 ^a
	External			
Hinkley Point	Fish and shellfish consumption	Local fishing community	0.008 ^b	0.008 ^b
	External			
Hunterston	Fish and shellfish consumption	Local fishing community	0.01 ^a	0.01 ^a
	External			
Sizewell	Fish and shellfish consumption	Local fishing community	<0.005 ^b	<0.005 ^b
	External			
Tomess	Fish and shellfish consumption	Local fishing community	<0.005 ^a	<0.005 ^a
	External			
Trawsfynydd	Fish consumption	Local fishing community	0.11	0.11
	External			
Wylfa	Fish and shellfish consumption	Local fishing community	0.007 ^a	0.006 ^a
	External			
Defence Establishments Aldermaston	Fish consumption	Anglers	<0.005	<0.005
	External			
Chatham	External	Houseboat dwellers	0.007	0.007
Devonport	Fish and shellfish consumption	Local community	<0.005	<0.005
	External			
Faslane	Fish and shellfish consumption	Anglers	0.01 ^a	0.01 ^a
	External			
Rosyth	External	Dredgermen	0.005 ^a	0.005 ^a
Holy Loch	External	Local community	<0.005 ^a	<0.005 ^a
Amersham International plc Amersham	Fish consumption	Anglers	<0.005	<0.005
	External			
Cardiff	Fish and shellfish consumption	Local fishing community	0.02	0.02
	External			
Albright and Wilson Ltd Whitehaven ^c	Fish and shellfish consumption	Local fishing community	0.52	0.27

^a 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 3.3)

Exposure to skin, to be compared with the ICRP-recommended dose limit of 50 mSv year⁻¹ (see sub-section 3.3)

^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 3.3). Many of these doses should not be strictly 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

^x These estimates include the effects of discharges from Drigg but exclude the effects of natural radionuclides. The contribution due to Drigg is negligible. The exposure due to enhanced concentrations of natural radionuclides in 1991 was 0.21 mSv (on the basis of ICRP-60: 0.11 mSv)

^c These estimates include the effects of enhanced concentrations of natural radionuclides but exclude a small contribution from the effects of artificial radionuclides from other sites. The exposure due to artificial radionuclides in 1991 was 0.03 mSv (ICRP-26 and ICRP-60)

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. Our preliminary assessment of the collective committed effective dose equivalent to the UK population in 1991 was 7 man-Sv, slightly less than the value for 1990 (10 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 25 man-Sv in 1991, also less than the value for 1990 (37 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 100 man-Sv to the collective dose to other European countries in both 1990 and 1991.

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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 S W Conney F Skelding W Hendrickson N Wood
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	J Church

APPENDIX 2. Dosimetric data

Radionuclidet	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	0.0	1.60 10 ⁻¹¹	1.80 10 ⁻¹¹
Carbon-14	5.73 10 ³	0.0	5.60 10 ⁻¹⁰	5.60 10 ⁻¹⁰
Sulphur-35	2.39 10 ⁻¹	0.0	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
Iron-55	2.7	1.691 10 ⁻³	4.46 10 ⁻¹⁰	3.40 10 ⁻¹⁰
Cobalt-57	7.42 10 ⁻¹	1.25 10 ⁻¹	3.10 10 ⁻¹⁰	1.00 10 ⁻⁹
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	0.0	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	0.0	1.56 10 ⁻⁹	2.10 10 ⁻⁹
Polonium-210	3.79 10 ⁻¹	0.0	4.35 10 ⁻⁷	2.10 10 ⁻⁷
Radium-226†	1.60 10 ³	1.765	2.96 10 ⁻⁷	2.20 10 ⁻⁷
Thorium-228†	1.91	1.567	3.42 10 ⁻⁷	2.32 10 ⁻⁷
Thorium-230	7.7 10 ⁴	1.553 10 ⁻³	3.45 10 ⁻⁷	1.80 10 ⁻⁷
Thorium-232	1.41 10 ¹⁰	1.332 10 ⁻³	1.83 10 ⁻⁶	9.20 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 5×10^{-4} for consumption of all foodstuffs except Irish Sea winkles

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



Ministry of Agriculture, Fisheries and Food
Directorate of Fisheries Research
Fisheries Laboratory
Lowestoft
Suffolk
NR33 0HT
England