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NUMBER 3

RADIOACTIVITY IN SURFACE AND COASTAL WATERS OF THE BRITISH ISLES, 1977

G J HUNT

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FOREWORD

This report, although under a new series cover, continues the sequence of reports "Radioactivity in Surface and Coastal Waters of the British Isles" previously published in the now terminated Fisheries Radiobiological Laboratory Technical Report FRL series. The present report describes the results of monitoring, carried out in 1977, of radioactivity in the aquatic environment and in its flora and fauna.

A J Lee
Director of Fisheries Research

CONTENTS

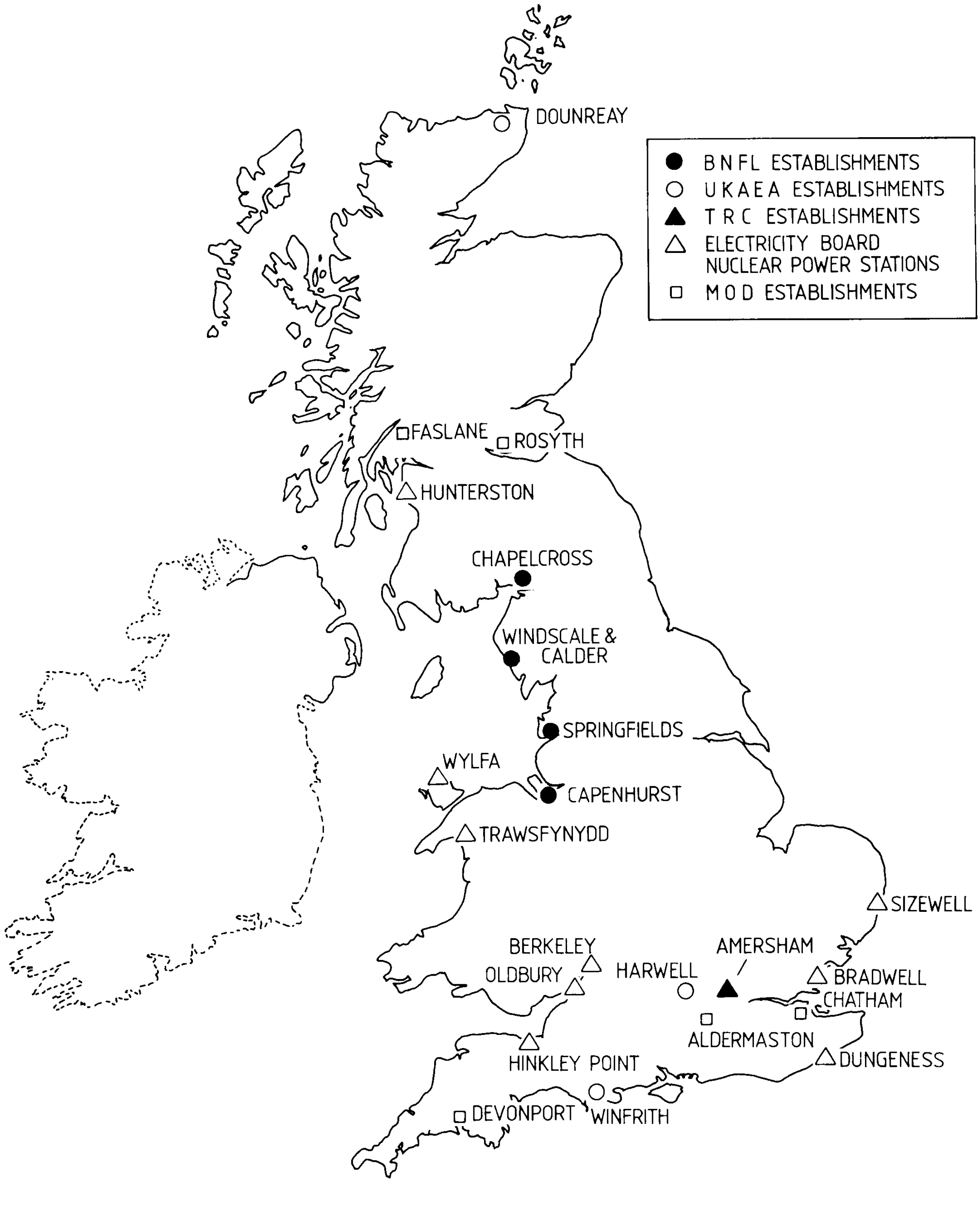

Figure 1 U K nuclear establishments giving rise to principal discharges of liquid radioactive waste.

1. Introduction

This report presents the 1977 results of the environmental monitoring programme carried out by the Fisheries Radiobiological Laboratory (FRL) as part of this Ministry's responsibilities under the Radioactive Substances Act, 1960 (Great Britain – Parliament, 1960). This programme is set up to verify the satisfactory control of liquid radioactive waste discharges to the aquatic environment, and to ensure that the resulting public radiation exposure is within nationally-accepted limits. The monitoring is independent of often similar programmes carried out by nuclear site operators as a condition of their authorisations to discharge radioactive wastes. This report also includes results of monitoring carried out on behalf of departments of the Scottish Office, the Department of the Environment for Northern Ireland, the Channel Islands States and the Republic of Ireland. Where appropriate, the information presented is supplemented by results from FRL's extensive programme of research into the behaviour of radioactivity in the aquatic environment.

To set the monitoring results in proper context, liquid radioactive discharges from UK nuclear establishments to the aquatic environment in 1977 are first summarised. Before exposition of the monitoring results, an explanatory section gives details of how the results are presented and interpreted in terms of public radiation exposures. Included in the same section are details of some presentational changes from the form of previous reports; these changes have been necessitated by the advent of new radiological units and recommendations.

2. Discharges of radioactive waste

Following the Government's response (Great Britain – Parliament, 1977) to the 6th report of the Royal Commission on Environmental Pollution (1976), an annual survey of radioactive discharges is now published by the Environmental Departments. The first such survey, for the year 1977, has already been published (DOE, Scottish & Welsh Offices, 1978) but to enable the data on environmental levels presented in this report readily to be considered in the context of relevant discharges, a summary is included here.

2.1 Liquid radioactive waste

Table 1 lists the principal discharges of liquid radioactive waste from UK nuclear establishments during 1977. The locations of these establishments are shown in Figure 1. Discharge data are derived from the operators' returns. Table 1 also lists the discharge limits which are authorised or, in the case of Crown establishments, administratively agreed. Discharges are given both in terabecquerels (see Section 3.1) and curies. The limits are given only in curies since it is in these units that the limits are currently specified. In some cases, the authorisations specify limits in greater detail than can be summarised in a single table: in particular, where periods shorter than one year are specified the annual equivalent has been used. The limits are generally lower (often very much lower) than the activities which could be released without exceeding the dose limits recommended by the International Commission on Radiological Protection (ICRP), embodied in national policy (Great Britain – Parliament, 1959). For each discharge the percentage of the authorised (or agreed) limit taken up in 1977 is also stated in Table 1.

For completeness, data are included here on the very small discharges into Holy Loch from the US Navy Submarine Base. Radiological safety for the Holy Loch base is the responsibility of the US Navy in association with the Ministry of Defence who have supplied the following information. For the year 1977 the radioactivity released into the waters of Holy Loch was less than 0.04 GBq (1 mCi) of long-lived gamma radioactivity, primarily cobalt–60; less than 0.04 GBq (1 mCi) of fission product radionuclides; and less than 0.4 GBq (10 mCi) of tritium.

2.2 Solid radioactive waste

In addition to receiving most of the above liquid discharges, the marine environment also receives low specific activity packaged solid waste. This is not disposed of in coastal waters, but in the deep Atlantic Ocean about 1000 km south-west of Land's End. Waste from some other West European countries is also disposed of in this area. Disposal operations are carried out annually under the auspices of the Nuclear Energy Agency (NEA) of the Organisation for Economic Cooperation and Development (OECD). In 1977 the waste was disposed of within an area defined by the two lines of longitude 16°W and 17°30' W, and two lines of latitude 10 nautical miles north and 10 nautical miles south respectively of latitude 46°N. Following previous practice, the UK disposal operation was carried out by the Atomic Energy Research Establishment (AERE), Harwell according to the conditions laid down by this Ministry; the operation was observed by a representative of OECD(NEA) to ensure compliance with international agreements. The waste was from several establishments and totalled 2 903 packages of 2 140 tonnes gross weight (300 tonnes net), containing 34 TBq (930 Ci) of alpha activity and 2 769 TBq (74 830 Ci) of beta/ gamma activity including 1 159 TBq (31 328 Ci) tritium. The environmental impact of these disposals is very small. Under such circumstances dose assessments are based on calculation using appropriate models. No environmental monitoring of the dumping area is carried out since effects are not likely to be detected.

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

3.1 SI units

In this report data are presented using the SI (System Internationale) radiological units, recommended for use

Table 1 Principal discharges of liquid radioactive waste from UK nuclear establishments, 1977 (based on Department of the Environment *et al.*, 1978)

Establishment	Radioactivity	Discharge limit (annual equivalent), Ci	Discharge		
			TBq	Ci	% of limit utilised
BRITISH NUCLEAR FUELS LIMITED					
Windscale and Calder					
Sea pipeline	Total beta	300 000	7 132	192 768	64
	Ruthenium-106	60 000	816	22 053	37
	Strontium-90	30 000	427	11 534	38
	Total alpha	6 000	46	1 241	21
Seaburn sewer	Total activity	4	0.015	0.4	10
Springfields	Total alpha	360	0.78	21	6
	Total beta	12 000	148	4 010	33
Chapelcross	Total activity[1]	700	0.34	9.1	1.3
	Tritium	150	0.067	1.8	1.2
Capenhurst					
Rivacre Brook	Total activity[2]	0.04	0.00073	0.02	49
Meols outfall[3]	Technetium-99	4	0.0	0.0	0.0
UNITED KINGDOM ATOMIC ENERGY AUTHORITY					
Winfrith	Total activity	30 000	91	2 457	8.2
	Ruthenium-106	9 000	0.19	5.1	<1
	Strontium-90	1 200	0.26	7.1	<1
	Total alpha	1 200	0.13	3.5	<1
Harwell	Total activity[1,4]	240	1.2	33	14
	Tritium	240	3.5	95	40
Dounreay	Total activity	24 000	34	926	3.9
	Strontium-90	2 400	7.8	210	8.8
	Total alpha	240	0.22	6	2.6
THE RADIOCHEMICAL CENTRE LIMITED					
Amersham	Total activity[1,4]	72	0.56	15	21
	Tritium	400	7.3	196	49
CENTRAL ELECTRICITY GENERATING BOARD					
Berkeley	Total activity[1]	200	5.5	148	74
	Tritium	1 500	1.9	51	3.4
Bradwell	Total activity[1]	200	2.4	66	33
	Zinc-65	5	0.011	0.3	6
	Tritium	1 500	7.4	199	13
Dungeness	Total activity[1]	200	1.7	45	23
	Tritium	2 000	0.96	26	1.3
Hinkley Point[5]					
"A" station	Total activity[1]	200	4.4	120	60
	Tritium	2 000	1.2	33	1.7
"B" station	Total activity[1,6]	100	0.044	1.2	1.2
	Sulphur-35	700	0.048	1.3	<1
	Tritium	18 000	27	739	4.1

Table 1 (continued)

Establishment	Radioactivity	Discharge limit (annual equivalent), Ci	Discharge		
			TBq	Ci	% of limit utilised
CENTRAL ELECTRICITY GENERATING BOARD (continued)					
Oldbury	Total activity[1]	100	2.4	66	66
	Tritium	2 000	0.56	15	<1
Sizewell	Total activity[1]	200	1.6	43	22
	Tritium	3 000	1.6	44	1.5
Trawsfynydd	Total activity[1]	40	0.52	14	34
	Caesium-137	7	0.16	2.9	41
	Tritium	2 000	0.48	13	<1
Wylfa	Total activity[1]	65	0.70	19	29
	Tritium	4 000	11	288	7.2
SOUTH OF SCOTLAND ELECTRICITY BOARD					
Hunterston[5]					
"A" station	Total activity[1]	200	5.4	147	74
	Tritium	1 200	2.1	56	4.6
"B" station	Total activity[1,6]	100	<0.044	<1.2	<1.2
	Sulphur	700	0.044	1.2	<1
	Tritium	18 000	2.0	55	<1
MINISTRY OF DEFENCE (PROCUREMENT EXECUTIVE)					
Aldermaston	Total activity[1,4]	156	0.40	11	7
	Tritium	156	0.11	3	2
MINISTRY OF DEFENCE (NAVY DEPARTMENT)					
Chatham	Total activity[1]	20	0.007	0.20	1
	Cobalt-60	10	0.007	0.20	2
	Tritium	20	0.002	0.046	<1
Devonport	Total activity[1]	4	0.00004	0.001	<1
	Cobalt-60	1	0.00004	0.001	<1
	Tritium	10	0.01	0.3	3
Faslane	Total activity[1]	1	0.0001	0.0028	<1
Rosyth	Total activity[1]	30	0.006	0.16	<1

[1]Excluding tritium.
[2]Excluding uranium and its decay products.
[3]Authorisation granted in September 1977. No discharges were made during 1977.
[4]Authorisation specifies a control formula in which the total activity is calculated in equivalent curies, intended to allow for relative radiotoxicities of different nuclides. The sums of the actual discharges in curies were lower than the values indicated. Column 4 gives equivalent terabecquerels.
[5]Single site authorisations apply where both A and B stations are operating. However, the layout above represents the way in which it has been agreed the authorisations should be apportioned in practice.
[6]Excluding sulphur-35.

in the UK by the British Committee on Radiation Units and Measurements (BCRU, 1978). To assist familiarisation with these units, and to facilitate comparison with results of previous reports, data are quoted in the new units followed in parentheses by the equivalent quantity using the old units. The radiological units used in this report are summarised in Table 2, together with relevant conversion factors.

any of these nuclides indicates non-detectability in each sample in that table.

Pure beta emitters, such as strontium–90 and technetium–99, are chemically separated from samples before beta counting. Transuranic nuclides are chemically separated and analysed by alpha spectrometry using silicon surface-barrier detectors. Radiochemical procedures are generally labour-intensive and are carried out on samples in which these nuclides are of particular relevance, often on an annual bulk (section 3.3).

Table 2 Radiological units used in this report

Quantity	New SI unit and symbol	Definition	Old unit and symbol	Definition	Conversion data
Radioactivity	becquerel (Bq)	disintegration per second	curie (Ci)	3.7×10^{10} disintegrations per second	1 Ci = 3.7 10^{10} Bq 1 Bq = 2.7 10^{-11} Ci = 27 pCi
Notes: 1 The terabecquerel (TBq) is used in this report for radioactive discharges:					1 TBq = 10^{12} Bq = 27 Ci
2 Radioactivity concentrations are given in millibecquerels per gramme (mBq g^{-1}):					1 mBq g^{-1} = 1 Bq kg^{-1} = 27 pCi kg^{-1}
Absorbed dose	gray (Gy)	J kg^{-1} (joule per kilogramme)	rad (rad)	10^{-2} J kg^{-1}	1 rad = 10^{-2} Gy 1 Gy = 100 rad
Dose equivalent	sievert (Sv)	J kg^{-1} x (modifying factors)	rem (rem)	10^{-2} J kg^{-1} x (modifying factors)	1 rem = 10^{-2} Sv = 10 mSv 1 Sv = 10^{2} rem

3.2 Summary of analytical methods

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

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

Except for ruthenium–106 in laverbread, which is analysed using this nuclide's energetic beta particles (Dutton, 1968), gamma emitting nuclides are analysed by gamma spectrometry. This is carried out using both NaI(T1) and Ge(Li) detectors, calibrated using suitable reference sources. The spectra are reduced by computer-aided techniques to give radioactivity concentrations of detected nuclides. For samples of biota and sediments, searches are routinely made for the following artificial gamma emitters: manganese–54, cobalt–60, zinc–65, zirconium–95 plus niobium–95, ruthenium–106, silver–110m, antimony–124 and –125, caesium–134 and –137, and cerium–144. In the tables of results for these materials the absence of a column for

3.3 Methods of presentation of measurements

The tables of monitoring results generally contain summarised values of observations obtained during the year under review. Observations of a given quantity may vary throughout the year; in general any variations are larger than the analytical errors inherent in the observations. The variations may, for example, be due to changes in rates of discharge or to different dispersion conditions in the receiving environment. The presentation of the summarised results reflects the purpose of this monitoring which is interpretation in terms of public radiation exposures. The method of interpretation is described more fully in section 3.4. The appropriate integration period for comparison with recommended limits is one year; standard practice is to combine annual rates of consumption or occupancy of members of the public more highly exposed (the critical group) with the arithmetic means of observed radioactivity concentrations or dose rates respectively during the year. The use of, say, the highest observed (but unsustained) radioactivity concentration with an annual consumption rate would not provide a realistic comparison with the recommended limits, which already embody a number of maximising assumptions. Therefore, the tables present the arithmetic means of observations made during the year. The frequency of sampling reflects the resolution (implying the accuracy) judged to be necessary in the assessment, or, as is largely self-evident, its radiological importance. The number of observations during the year is therefore also given.

Measurements on biota are given in terms of concentrations in wet material as collected. For fish and shellfish, because the purpose is assessment of internal exposure of the consumer, the concentrations apply to the edible fractions. For sediments, whose water content is more variable, dry concentrations are given. Analyses are carried out on samples consisting of a suitably large mass of material; for fish and shellfish these contain a number of individuals of the given species to compensate for statistical variations. Analyses requiring radiochemical separation may be carried out on these samples directly, or on bulks of samples for an appropriate period; in tables combining the results of gamma spectrometry and radiochemical analyses, unless otherwise stated, an annual bulk applies. In the case of gamma dose rates, which are measured using portable instruments, each observation consists of the mean of a number of individual readings at a given location.

At many locations monitored by FRL the results for certain measurements, particularly total beta radioactivity concentrations and gamma dose rates, may be comparable with levels due to natural radioactivity. Further analysis of samples (usually by gamma spectrometry) can indicate the component of total beta radioactivity which may be due to artificial sources and the component due to natural radionuclides (mainly potassium–40 and the decay products of uranium and thorium). In the case of gamma dose rates, an indication of the natural background component can be gained from measurements at similar locations remote from nuclear activities or from experience before these activities began. For both types of measurement, however, experience is also useful; Table 3 lists representative values to be expected from natural sources.

3.4 Methods of interpretation

The monitoring results in this report are interpreted in terms of radiation exposures of the public. The basis against which these exposures are judged are the recommendations of the International Commission on Radiological Protection (ICRP). For many years these recommendations have been endorsed for use in the UK by appropriate advisory bodies; current UK practice is mainly based on ICRP Publication 9 (ICRP, 1966). The most recent recommendations of ICRP are set out in ICRP Publication 26 (ICRP, 1977). The dose limitation system therein embodied has been endorsed by the National Radiological Protection Board (NRPB, 1978) as a satisfactory basis for control of radiation exposures. UK legislation will comply with the Euratom Directive on basic radiation safety standards, the current version of which (Commission of the European Communities, 1976) is based on ICRP Publication 9 but is under review. While, therefore, the recommendations of ICRP Publication 9 are still applicable, the implications of those in ICRP Publication 26 now require consideration, and this is given in this report.

The effect of the new recommendations on the interpretation of the results will be briefly described. Most of the concepts forming the basis of the ICRP Publication 26 dose limitation system are not new. Greater weight than before is given to the principle that "all exposures shall be kept As Low As Reasonably Achievable...." (ALARA). This principle was recognised for the purposes of radioactive waste disposal in the UK policy statement of 1959 (Great Britain – Parliament, 1959) which is currently under review. The

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

Material	Total beta radioactivity concentration (wet)*		
	$mBq\ g^{-1}$	($pCi\ g^{-1}$)	Comments
Fish	40 to 100	1 to 3	Mostly ^{40}K
Shellfish	40 to 100	1 to 3	"
Seaweed	200 to 600	5 to 15	"
Sand	200 to 400	5 to 10	^{40}K and decay products of U and Th
Mud	700 to 1 000	20 to 30	"

Gamma dose rates in air over intertidal sediments:	$\mu Gy\ h^{-1}$	$\mu rad\ h^{-1}$
Sand, shingle	0.03 to 0.05	3 to 5
Mud	0.05 to 0.1	5 to 10

*except sediments for which dry concentrations apply.

new ICRP recommendations serve to re-emphasise the importance of consideration of collective doses in radiological control procedures. As in previous reports, collective doses from liquid radioactive waste discharges continue to be kept under review. The 1959 UK policy objective, which may be related to a limit on collective dose rate, was that the per caput dose to the whole population as a result of radioactive waste disposal should not exceed 1 rem per person in 30 years ,which is approximately 0.33 mSv y^{-1} (33 mrem y^{-1}) per person. While subject to review, this limit has been used for reference purposes in this report. For comparison, the UK per caput dose from natural radiation is approximately 1 mSv y^{-1} (100 mrem y^{-1}) (Taylor *et al*, 1978).

For the purposes of this report, the main changes in the new recommendations are in the method of assessment of individual exposure. The ICRP Publication 9 recommendations specify limits for individual organs, the limit for whole body being 5 mSv y^{-1} (500 mrem y^{-1}) for members of the public. The new recommendations are intended to prevent non-stochastic (threshold) effects and to limit stochastic effects (ie those whose probability depends on the dose) to an acceptable level. To prevent non-stochastic effects, a dose equivalent limit for the public of 50 mSv y^{-1} (5 rem y^{-1}) to any one organ or tissue is prescribed. For stochastic effects, it is recommended that the risk should be equal whether the whole body is irradiated uniformly or non-uniformly; weighting factors proportional to the risk are defined for different organs. The weighted sum is called the effective dose equivalent, and the recommended limit is numerically the same as that previously given for uniform whole body irradiation.

The ICRP also provide secondary limits for internal and external irradiation. For internal irradiation, the limits applicable from the older recommendations are listed as maximum permissible water concentrations in ICRP Publication 2 (ICRP, 1959). Listings also in terms of limits of annual intake, emphasising that one year is the appropriate control period, are given in IAEA Safety Series 9 (IAEA, 1967). For certain radionuclides, in particular those of caesium, more recent data (Medical Research Council, 1975) have become available. In the case of the recommendations of ICRP Publication 26, the secondary limits will be published as Annual Limits of Intake (ALIs). Values for radiation workers have been calculated by the NRPB (Adams *et al*, 1978) according to the ICRP recommendations. No values have been published appropriate to the general public. In this report, values have been derived by dividing the NRPB ALIs by 10 in line with ICRP recommendations on the dose limit for the general public as compared with workers. It is not expected that metabolic differences in certain age groups of the public will for nuclides of main radiological significance in this report render this procedure insufficiently restrictive. For external exposures to penetrating radiation, uniform whole body exposure has been assumed and the appropriate limit, which is the same in both ICRP procedures, has been applied. The measured quantity is absorbed dose in air; the resulting whole body dose equivalent (in consistent units) is in practice very nearly equal to this measured quantity and has been taken to be equal to it.

In order to interpret monitoring results in terms of the recommendations of the ICRP, the remaining data required are, as appropriate, rates of consumption or occupancy. These are obtained by FRL habits surveys near each nuclear establishment of interest. The surveys are kept under review and repeated at intervals. Their purpose is to identify a group (the critical group) of persons more highly exposed through a particular pathway or pathways. This approach has been in use for many years, and is still embodied in the recent recommendations of the ICRP (1977). Critical group habits data may be combined with the secondary limits to obtain derived limits (in older terminology, derived working limits). For simplicity, however, these have not been quoted in this report. The practice adopted is to present the percentage of the appropriate ICRP-recommended dose limit to members of the critical group indicated by the monitoring results. In order to calculate this percentage for internal irradiation, it is assumed that exposure at the appropriate secondary limit for a given nuclide gives rise to the associated ICRP-recommended dose limit. However, the following points should be noted. First, for nuclides with long body retention times, such as the transuranics, exposure at the dose limit is only reached after steady intake at the annual limit for a period of 50 years, taken by the ICRP as a working lifetime. Secondly, for the calculation of effective dose equivalent when applying the procedure of ICRP Publication 26 recommendations, the appropriate ALIs are those as determined by stochastic effects. Non-stochastic effects also require consideration and for certain nuclides the ALIs are more restrictive. However, provided the dose equivalent to each tissue from all nuclides is below the non-stochastic limit, the significance of the exposure is in the effective dose equivalent.

The implications of both ICRP-recommended procedures have been considered when interpreting environmental monitoring results in this report. For purposes of illustration, for some of the results of higher radiological significance, the results of applying both ICRP-recommended procedures have been presented. However, caution should be exercised when comparing them. For example, the effective dose equivalent using the new procedure and whole body dose equivalent using the older procedure, whilst both expressed in sievert or rem, or fractions of the apparently same recommended limit, cannot be regarded as directly comparable. The former gives a measure of the total risk, not of dose equivalent actually received by whole body. Hence some differences between the two quantities may be apparent particularly for nuclides for which the critical organs using ICRP Publication 9 recommendations are not whole body. For most exposures reported, the differences between the results of applying both procedures to a given pathway are not great. For simplicity, for exposures of low significance the separate results are not given; if there is a difference, the more restrictive interpretation has been assumed.

4. **British Nuclear Fuels Limited**

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

4.1 Windscale and Calder, Cumbria

Operations at this establishment include the Windscale nuclear fuel reprocessing plant, the Calder Hall magnox-type nuclear power station and the Windscale Advanced Gas-cooled Reactor (AGR) development. The most significant liquid radioactive waste discharges are from the reprocessing plant, which treats all the irradiated fuel from the UK nuclear power programme. Most of the nuclear waste separated from the fuel is presently stored on site; relatively small quantities of radioactivity are discharged to the north-east Irish Sea, through a twin pipeline which terminates 2.1 km beyond low-water mark. Discharges during 1977 are summarised in Table 1, and were within the limits set by the authorising departments. Discharges of total beta activity, at 64% of the authorised limit, represented a slight increase on 61% for 1976. Total beta discharges are substantially dependent upon releases of radiocaesium which mainly originate from the fuel element storage ponds. In 1977 caesium–137 pipeline discharges totalled 4 478 TBq (121 032 Ci), as compared with the 1976 value of 4 289 TBq (115 926 Ci). Discharges of ruthenium–106 and strontium–90 also increased slightly in 1977. However, discharges of alpha activity (mainly plutonium isotopes and americium–241) continued to decline in 1977, the greatest proportionate decrease being for americium–241.

A substantial monitoring effort was maintained by FRL during 1977, even increasing slightly compared with previous years. The two critical radiation exposure pathways have continued to be from consumption of fish and shellfish and from external exposure. Following established practice, the largest monitoring effort has been expended on these pathways. In 1977 there was no harvesting of *Porphyra* in the immediate Windscale vicinity for manufacture of laverbread but monitoring has continued because the pathway remains potentially important. An extensive research programme has also continued. The aims of this programme are to improve our knowledge of the distribution and behaviour of radionuclides in the marine environment, especially in relation to the critical exposure pathways, and also to provide a means of assessing other pathways of lower current importance, thereby assisting in keeping all exposure pathways under review. Some of the research has been supported by contract with the Commission of the European Communities (CEC). Results from the FRL research programme have been included where relevant.

4.1.1 The fish and shellfish consumption pathway

Public radiation exposure from Windscale discharges by consumption of fish is predominantly due to radiocaesium. Concentrations of total beta activity and caesium–134 and –137 in fish from the vicinity of the Irish Sea and from further afield are given in Table 4. Data are listed by location of sampling or landing point, in approximate order of increasing distance from Windscale. 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, specific surveys are also carried out by FRL, sampling fish from the Windscale vicinity. The location "Windscale Shoreline Area" is close inshore between Braystones and Sellafield. "Windscale Offshore Area" is defined by a rectangle, one nautical mile wide and two nautical miles long, the long side parallel to the shoreline and the most northerly point coinciding with the pipeline outlet. Samples in this category have therefore been caught within 5 km of the pipeline outlet. Table 4 includes the results of analyses by FRL of samples collected by authorities in Northern Ireland and the Irish Republic.

The results reflect the progressive dilution of radiocaesium with increasing distance from Windscale. They also reflect the age of the radioactivity, such that the ratio of caesium–137 to caesium–134 (half-lives 30 years and 2 years respectively) increases with distance. At large distances, and remote from the smaller discharges from elsewhere, concentrations of artificial radioactivity tend towards those from weapons-test fallout. For ^{137}Cs in cod, measurements remote from land run-off indicate a value of about 0.4 mBq g^{-1} (0.01 pCi g^{-1}) from this source. Variations between species for a given area, while not large, are mainly to be explained in terms of residence time in the area as well as feeding habits. These variations are likely to be most apparent in the results close to Windscale because of the relatively steep concentration gradient of radiocaesium in seawater. Because the purpose of the result is dose estimation, results are based on observations which include a large number of individual fish.

Radiation exposure from consumption of shellfish is due in part to radio-caesium, but other nuclides also make significant contributions owing to higher concentration factors in these foods than in fish. Table 5 lists concentrations of total beta activity and beta/gamma emitting nuclides in shellfish from the Irish Sea and further afield. As with fish, concentrations diminish with

Table 4 Beta/gamma radioactivity in fish from the Irish Sea vicinity and further afield, 1977

Sampling area/landing point	Sample	No. of observations	Mean radioactivity concentration (wet), mBq g^{-1} (pCi g^{-1})		
			Total beta	^{134}Cs	^{137}Cs
Windscale shoreline area[1,3]	Cod	1	2 800 (75)	290 (7.9)	2 400 (64)
Windscale offshore area[1,3]	Plaice	4	1 100 (31)	120 (3.1)	940 (25)
	Dab	3	1 000 (28)	81 (2.2)	700 (19)
	Cod	2	1 300 (36)	96 (2.6)	850 (23)
	Whiting	2	1 700 (47)	150 (4.1)	1 300 (34)
	Flounder	4	890 (24)	100 (2.7)	780 (21)
	Pouting	1	1 300 (34)	74 (2.0)	740 (20)
	Gurnard	1	NA	130 (3.4)	1 000 (28)
	Brill	4	810 (22)	85 (2.3)	700 (19)
	Roker	1	2 200 (60)	220 (5.9)	1 600 (42)
Ravenglass[2]	Plaice	5	1 000 (28)	120 (3.2)	1 000 (28)
	Salmon	1	NA	11 (0.30)	67 (1.8)
Whitehaven[2]	Plaice	12	440 (12)	41 (1.1)	350 (9.5)
	Cod	4	370 (10)	32 (0.86)	270 (7.4)
	Herring	4	300 (8.0)	21 (0.57)	220 (5.8)
	Mackerel	1	440 (12)	59 (1.6)	360 (9.8)
Morecambe Bay[1]	Flounder	3	700 (19)	67 (1.8)	630 (17)
Fleetwood[2]	Plaice	4	400 (12)	26 (0.70)	240 (6.4)
	Cod	4	520 (14)	31 (0.85)	290 (7.7)
Cumbria/Lancashire Rivers[4]	Sea trout	9	630 (17)	59 (1.6)	560 (15)
Isle of Man[2]	Plaice	2	260 (6.9)	21 (0.58)	200 (5.4)
	Cod	3	370 (10)	17 (0.45)	170 (4.6)
	Herring	1	240 (6.5)	12 (0.33)	140 (3.7)
Solway[1]	Flounder	1	430 (12)	29 (0.79)	290 (7.8)
	Salmon	1	159 (4.3)	ND	7.0 (0.19)
Wirral[1]	Plaice	1	237 (6.4)	16 (0.44)	140 (3.9)
North Anglesey[1]	Pollack	3	340 (9.1)	20 (0.55)	170 (4.7)
Northern Ireland[2]	Cod	1	190 (5.1)	5.7 (0.16)	67 (1.8)
	Herring	3	260 (7.1)	17 (0.46)	160 (4.4)
Irish Republic[2]	Plaice	2	200 (5.4)	3.7 (0.10)	51 (1.4)
	Cod	4	250 (6.8)	14 (0.39)	140 (3.8)
Minch[1]	Plaice	4	130 (3.5)	1.3 (0.04)	20 (0.54)
	Cod	4	170 (4.7)	3.6 (0.10)	41 (1.1)
	Herring	4	140 (3.7)	1.6 (0.04)	21 (0.57)
Northern North Sea[1]	Plaice	6	110 (3.0)	ND	1.6 (0.04)
	Cod	6	120 (3.1)	"	4.6 (0.12)
	Herring	1	100 (2.7)	"	3.9 (0.11)
	Sand eel	1	74 (2.0)	1.3 (0.04)	7.8 (0.21)
Mid-North Sea[1]	Plaice	2	120 (3.2)	ND	3.5 (0.10)
	Cod	2	120 (3.3)	"	4.3 (0.12)
Southern North Sea[1]	Plaice	2	92 (2.5)	"	1.6 (0.04)
	Cod	2	130 (3.4)	"	3.0 (0.08)
Barents Sea[1]	Cod	2	100 (2.7)	"	0.4 (0.01)

NA = not analysed.
ND = not detected.

[1]Sampling area.
[2]Landing point.
[3]See text for definition.
[4]Samples collected from a number of rivers by the North West River Authority.

Table 5 Beta/gamma radioactivity in shellfish from the Irish Sea and further afield, 1977

Sampling area/landing point	Sample	No. of observations	Mean radioactivity concentration (wet), mBq g^{-1} (pCi g^{-1})				
			Total beta	^{60}Co	^{95}Zr + ^{95}Nb	^{99}Tc	^{106}Ru
Windscale shoreline area[1,3]	Crab	6	2 100 (57)	8.5 (0.23)	13 (0.35)	10 (0.28)	1 100 (30)
	Winkles	5	28 000 (760)	44 (1.2)	1 700 (46)	4.1 (0.11)	20 000 (540)
	Mussels	5	34 000 (930)	20 (0.54)	3 400 (91)	NA	28 000 (750)
Windscale offshore area[1,3]	Lobster	1	3 700 (99)	ND	ND	"	780 (21)
St Bees[1]	Limpets	1	4 200 (110)	"	59 (1.6)	26 (0.70)	3 700 (99)
Whitehaven[2]	*Nephrops*	4	340 (9.2)	"	ND	NA	ND
	Squid	1	120 (3.3)	"	"	"	"
Morecambe Bay[1]	Shrimps	3	480 (13)	"	"	"	20 (0.53)
	Cockles	3	480 (13)	4.1 (0.11)	"	"	200 (5.5)
Isle of Man[2]	Scallops	3	180 (4.8)	ND	"	"	7.0 (0.19)
Kirkcudbright[2]	Scallops	3	150 (4.1)	"	"	"	ND
	Queens	2	230 (6.1)	"	"	"	7.8 (0.21)
Solway[1]	Shrimps	4	230 (6.3)	"	"	"	ND
Southport[1]	Cockles	1	260 (6.9)	2.6 (0.07)	"	4.1 (0.11)	52 (1.4)
Wirral[1]	Shrimps	1	290 (7.8)	ND	"	1.1 (0.03)	ND
North Anglesey[1]	Crab	1	126 (3.4)	"	"	NA	"
	Lobster	1	166 (4.5)	"	"	"	"
	Winkles	3	170 (4.6)	"	"	"	18 (0.48)
Northern Ireland[2]	*Nephrops*	4	185 (5.0)	"	"	"	ND
Irish Republic[2]	*Nephrops*	1	130 (3.4)	"	"	"	"
	Prawns	1	160 (4.3)	"	"	"	"
Clyde[1]	Cockles	4	96 (2.6)	"	"	"	"
	Winkles	4	560 (15)	1.0 (0.03)	"	"	140 (3.7)
	Limpets	3	520 (14)	ND	"	"	120 (3.1)

Sampling area/landing point	Sample	No. of observations	Mean radioactivity concentration (wet), mBq g^{-1} (pCi g^{-1})			
			^{110m}Ag	^{134}Cs	^{137}Cs	^{144}Ce
Windscale shoreline area[1,3]	Crab	6	34 (0.92)	81 (2.2)	630 (17)	4.4 (0.12)
	Winkles	5	160 (4.2)	133 (3.6)	960 (26)	170 (4.5)
	Mussels	5	ND	74 (2.0)	520 (14)	16 (0.43)
Windscale offshore area[1,3]	Lobster	1	29 (0.78)	240 (6.5)	1 900 (52)	ND
St Bees[1]	Limpets	1	ND	48 (1.3)	166 (4.5)	"
Whitehaven[2]	*Nephrops*	4	"	21 (0.56)	190 (5.1)	"
	Squid	1	"	4.1 (0.11)	41 (1.1)	"
Morecambe Bay[1]	Shrimps	3	"	26 (0.71)	230 (6.3)	"
	Cockles	3	"	21 (0.57)	160 (4.3)	2.1 (0.06)
Isle of Man[2]	Scallops	3	"	2.9 (0.08)	31 (0.84)	ND
Kirkcudbright[2]	Scallops	3	"	6.3 (0.17)	63 (1.7)	"
	Queens	2	"	9.6 (0.26)	85 (2.3)	"
Solway[1]	Shrimps	4	"	22 (0.60)	200 (5.4)	"
Southport[1]	Cockles	1	3.3 (0.09)	13 (0.35)	100 (2.8)	"
Wirral[1]	Shrimps	1	ND	17 (0.47)	130 (3.6)	"
North Anglesey[1]	Crab	1	"	3.0 (0.08)	27 (0.72)	"
	Lobster	1	"	4.8 (0.13)	37 (0.99)	"
	Winkles	3	"	2.0 (0.05)	26 (0.71)	"
Northern Ireland[2]	*Nephrops*	4	0.8 (0.02)	4.1 (0.11)	48 (1.3)	"
Irish Republic[2]	*Nephrops*	1	ND	3.3 (0.09)	34 (0.93)	"
	Prawns	1	"	5.7 (0.15)	51 (1.4)	"
Clyde[1]	Cockles	4	"	3.8 (0.10)	27 (0.73)	"
	Winkles	4	"	14 (0.38)	66 (1.8)	"
	Limpets	3	"	14 (0.37)	74 (2.0)	1.8 (0.05)

NA = not analysed.
ND = not detected.

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

Table 6 Transuranic radioactivity in fish and shellfish from the Irish Sea vicinity and further afield, 1977

Sampling area/landing point	Sample	No. of observations	Mean radioactivity concentration (wet), mBq g^{-1} ($pCi\ g^{-1}$)					
			^{238}Pu		$^{239}Pu + ^{240}Pu$		^{241}Am	
Windscale shoreline area[1,6]	Crab	4	1.4	(0.038)	5.7	(0.15)	16	(0.44)
	Winkles	4	74	(2.0)	280	(7.6)	210	(5.7)
	Mussels	4	86	(2.3)	350	(9.5)	300	(8.2)
Windscale offshore area[1,6]	Plaice	4	0.0071	(0.00019)	0.027	(0.00073)	0.037	(0.0010)
	Cod	4	0.0081	(0.00021)	0.030	(0.00080)	0.027	(0.00073)
River Ehen[1,3]	Sea trout	1	0.0015	(0.000040)	0.0070	(0.00019)	0.0074	(0.00020)
St Bees[1]	Limpets	1	4.6	(0.12)	20	(0.54)	27	(0.72)
Whitehaven[2]	Plaice	4	0.0047	(0.00013)	0.018	(0.00049)	0.022	(0.00060)
	Nephrops	4	0.040	(0.0010)	0.17	(0.0047)	0.53	(0.014)
	Herring	1	0.0055	(0.00015)	0.023	(0.00061)	0.024	(0.00066)
	Mackerel	1	0.027	(0.00072)	0.086	(0.0023)	0.051	(0.0014)
Kirkcudbright[2]	Scallops[4]	1	0.33	(0.0089)	1.6	(0.042)	1.0	(0.027)
	Scallops[5]	1	0.075	(0.0020)	0.44	(0.012)	0.19	(0.005)
	Queens[4]	1	0.096	(0.0026)	0.46	(0.013)	0.50	(0.013)
Minch[1]	Plaice	1	0.0021	(0.000058)	0.0077	(0.00021)	0.039	(0.0011)
	Cod	1	0.00054	(0.000015)	0.0028	(0.000077)	0.0059	(0.00016)
	Herring	1	0.0011	(0.000030)	0.0051	(0.00014)	0.0059	(0.00016)

Sampling area/landing point	Sample	No. of observations	Mean radioactivity concentration (wet), mBq g^{-1} ($pCi\ g^{-1}$)			
			^{242}Cm		$^{243}Cm + ^{244}Cm$	
Windscale shoreline area[1,6]	Crab	4	0.29	(0.0080)	0.14	(0.0038)
	Winkles	4	12	(0.32)	1.5	(0.040)
	Mussels	4	6.9	(0.19)	1.2	(0.031)
Windscale offshore area[1,6]	Plaice	4	ND		ND	
	Cod	4	"		"	
River Ehen[1,3]	Sea trout	1	"		"	
St Bees[1]	Limpets	1	0.63	(0.017)	0.22	(0.0060)
Whitehaven[2]	Plaice	4	ND		ND	
	Nephrops	4	0.0031	(0.000083)	0.0022	(0.00006)
	Herring	1	ND		ND	
	Mackerel	1	0.0022	(0.00006)	0.00026	(0.000007)
Kirkcudbright[2]	Scallops[4]	1	0.0048	(0.00013)	0.0048	(0.00013)
	Scallops[5]	1	ND		0.00052	(0.000014)
	Queens[4]	1	0.0056	(0.00015)	0.0015	(0.00004)
Minch[1]	Plaice	1	ND		ND	
	Cod	1	"		"	
	Herring	1	"		"	

ND = not detected.
[1]Sampling area.
[2]Landing point.
[3]Sample collected by North West River Authority.
[4]Sampling area 33 km WNW of Whitehaven.
[5]Sampling area 22 km W of Point of Ayre.
[6]See text for definition.

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

Public radiation exposure from transuranic nuclides in fish and shellfish is lower than from radiocaesium. Analyses for transuranics are also labour-intensive. Therefore, only a selection of samples of fish and shellfish chosen mainly, but not exclusively, on the basis of potential significance have been analysed for transuranic nuclides. The data are presented in Table 6. Concentrations reduce rapidly with distance, consistent with low retention of transuranics in seawater. This behaviour is also reflected in higher concentrations of transuranics in shellfish as compared with fish.

The radiation dose to consumers of fish and shellfish depends upon the product of the mass of foodstuff consumed and its radioactivity concentration; the product of these is summed over time (one year is the appropriate period for comparison with the recommendations of the ICRP), for each of the different species consumed, and for each of the nuclides present allowing for their individual radiotoxicities. In the present situation, because of variations particularly in the first two quantities, a wide range of annual doses is to be expected. The critical group approach, which is well established in the UK and recommended by ICRP for control purposes, is based on identifying groups of individuals in exposed populations subject to the highest radiation dose rates. Of the two main variables in the present case, radioactivity concentrations in fish and shellfish are highest in the coastal area in the vicinity of the pipeline. Hence, eaters of fish and shellfish within the local fishing community represent one exposed population whose consumption rates have been studied, and kept under review, by FRL. The other main variable in the present assessment of individual doses is that of consumption rates. Experience has shown that in addition to the Cumbrian coastal community, the larger population in Cumbria and north Lancashire of those associated with commercial fisheries based primarily at Whitehaven, Fleetwood and in the Morecambe Bay area contains consumers of large quantities of fish and shellfish. This therefore represents a second exposed population kept under review by FRL, even though in general the relevant fishing grounds are further afield than the Cumbrian coastal area and concentrations of radioactivity in fish landed are lower.

The first exposed population, of local consumers, is of relatively small size. The critical group consumption rate for this population is therefore fairly dependent on the extreme (high rate) observation and, as in previous years, the conservative approach has been adopted of making estimates of doses on the basis of this observation. A study is presently being undertaken to investigate whether, following ICRP recommendations and bearing in mind the maximising assumptions already present in internal dose calculations, a somewhat more realistic approach than that of using a single observation would be to select a critical group value from a number of higher rate consumers in this local population. In support of this study, more consumption data are being obtained. For 1977 the maximum observation of 224 g d^{-1} fish and 41 g d^{-1} crustaceans has been used, as for 1976.

In assessing the maximum dose to a local consumer of fish and crustaceans it has been assumed that plaice is representative of his intake of fish. FRL experience both of landings and of consumption indicate that plaice account for the majority of fish consumed, and in any case, there is not a great interspecies difference in radioactivity concentrations for the Windscale Offshore Area (Table 4). A more fundamental assumption made here, erring on the conservative side, is that fish from this area represent the year-round intake of the maximum consumer. During certain seasons it is likely that fish consumed locally are supplemented by supplies from further afield. Consumption data indicate that it is certainly unreasonable to base the assessment on fish from the Shoreline Area. Doses due to consumption of crustaceans are based on radioactivity concentrations for crab from the Shoreline Area, which represents the vicinity in which they are caught by the local community.

Further effort during 1977 has been expended in an attempt to establish whether there is any significant consumption of locally-harvested molluscs. It appears that only relatively small quantities are consumed and by very few people, data being particularly sparse and hard to obtain. In judging the radiological significance of shellfish the variation of concentration of radioactivity with distance has to be borne in mind; the observed rate of highest radiological significance was at most 5 g d^{-1} of winkles from the Shoreline Area. Those few people who may eat as much as this consume only small amounts of fish and crustaceans.

Table 7 summarises doses in 1977, estimated using both ICRP procedures. Estimates based on ICRP Publication 9 recommendations (ICRP, 1966) are given for the critical organs. Except for

Table 7 Individual radiation exposures due to consumption of Irish Sea fish and shellfish, 1977

Exposed population	Consumption rate used in assessment (see text)	Radiation dose equivalent, 1977 (as % of appropriate ICRP-recommended limit[1])						
		To critical organ (ICRP-9)[2]				Effective (ICRP-26)[3]		
Consumers in local fishing community	Maximum consumer: 224 g d^{-1} plaice + 41 g d^{-1} crab (local supplies)	Whole body	29	^{90}Sr	1.5	31	^{90}Sr	0.2
				^{106}Ru	0.02		^{106}Ru	1.9
				^{134}Cs	6.0		^{134}Cs	3.5
				^{137}Cs	21.6		^{137}Cs	21.6
				^{241}Am	0.1		^{241}Am	3.0
Consumers in local fishing community	Maximum consumer: 5 g d^{-1} winkles (local supplies)	Lower large intestine	11	^{106}Ru	10.3	11	^{106}Ru	4.1
				^{137}Cs	0.2		^{137}Cs	0.4
				$^{239}Pu + {}^{240}Pu$	0.05		$^{239}Pu + {}^{240}Pu$	1.3
				^{241}Am	0.05		^{241}Am	4.7
Consumers associated with commercial fisheries (Whitehaven, Fleetwood, Morecambe Bay)	Critical group: 290 g d^{-1} fish +70 g d^{-1} crustaceans +45 g d^{-1} molluscs	Whole body	13	^{90}Sr	1.7	12	^{90}Sr	0.2
				^{106}Ru	0.01		^{106}Ru	0.4
				^{134}Cs	2.3		^{134}Cs	1.4
				^{137}Cs	9.1		^{137}Cs	9.1
				^{241}Am	0.01		^{241}Am	0.4
Typical member of the fish eating public consuming fish landed at Whitehaven/Fleetwood	40 g d^{-1} fish	Whole body	1.2	^{134}Cs	0.2	1.1	^{134}Cs	0.1
				^{137}Cs	1.0		^{137}Cs	1.0

[1]For both whole body (ICRP 1966) and effective (ICRP 1977) dose equivalents, this limit is 5 mSv y^{-1} (0.5 rem y^{-1}).
[2]Using data given in ICRP, 1959; IAEA, 1967; Medical Research Council, 1975.
[3]Using data given in Adams *et al.*, 1978.

mollusc consumption, the critical organ is whole body. On the basis of ICRP Publication 26 recommendations (ICRP, 1977) in all cases under consideration the dose equivalent to each tissue from all nuclides is below the non-stochastic limit. Hence the significance of the exposures is in the effective dose equivalent, for which the ALIs used are those as determined by stochastic effects (see section 3.4). For both ICRP procedures the appropriately summed doses are given, together with the contributions of individual nuclides. For simplicity, only the more important nuclides are listed; hence it is not to be expected that the sums of the contributions given will necessarily equal the totals presented.

For the maximum consumer of fish and crustaceans, the dose in 1977 was at most 31% of the ICRP-recommended limit on the basis of either method, for which the totals are in good agreement. Differences between the doses estimated for individual nuclides are often for those nuclides for which the critical organs on the basis of ICRP Publication 9 recommendations are not whole body (see section 3.4). However, for ^{137}Cs, the most significant nuclide, there is a negligible change. Comments in section 3.4 regarding the dose estimates for transuranics are also relevant. The reduction from the total of 44% calculated for the maximum consumer in 1976 (Mitchell, 1977) was probably mainly due to better environmental dispersion obtaining in 1977 as radiocaesium discharges had not decreased.

For mollusc consumption the total percentages of the appropriate limits on both bases are also in good agreement. Differences in the contributions from individual nuclides are due both to changes in radiotoxicity data and to the effect of the weighting factor on the basis of ICRP Publication 26 recommendations. The reduced significance of ruthenium–106 and the increased significance of the transuranics is to be noted. It is to be emphasised that consumption data for the maximum fish and crustacean eater on the one hand and mollusc eater on the other apply to different individuals. It is therefore not reasonable to sum the relevant maximum effective doses. The maximum consumer of molluscs eats only relatively small quantities of fish and crustaceans. There is no evidence to suggest that any individual was exposed at a higher rate than that already given for the maximum fish and crustacean consumer. This was well within the ICRP-recommended dose limit.

The second exposed population, of consumers associated with commercial fisheries based mainly on Whitehaven, Fleetwood and the Morecambe Bay area, is larger than the population of Cumbrian coastal consumers and consumption rate data are amenable to treatment to deduce critical group averages. Recent habits surveys by FRL in these areas indicate such rates for fish, crustaceans and molluscs to be 290 g d^{-1}, 70 g d^{-1} and 45 g d^{-1} respectively. In the dose assessment the conservative approach has been made of adding together the dose from consumption of all three foods at these combined rates. The dose rate due to intake of fish has been assessed using activity concentrations of fish landed at Whitehaven and Fleetwood. The intake of crustaceans has been based on shrimps from Morecambe Bay :however, for transuranic nuclides activity concentrations in *Nephrops* landed at Whitehaven have been assumed. The intake of molluscs has been based on Morecambe Bay cockles, except for transuranic nuclides for which activity concentrations in scallops collected off Whitehaven have been used. Concentrations in different species, the choice of which is by no means unreasonable, have been used in the case of transuranic nuclides to make best use of available data for 1977. Dose rates to members of this critical group are given in Table 7. The totals, using both methods, are in good agreement. The reduction from 17% of the ICRP recommended limit reported for 1976 (Mitchell, 1977) (based on a consumption of 300 g d^{-1} fish only) was again likely to have been due to the different dispersion conditions.

Dose rates appropriate to a consumption rate of 40 g d^{-1} fish from landings at Whitehaven and Fleetwood are also given. This consumption rate represents an average for typical fish-eating members of the public. The whole body dose rates using both methods are in agreement, and show a reduction from 2.4% reported for 1976.

Collective doses from consumption of fish and, for the first time, shellfish have been calculated for 1977 for the UK and other Western European countries. Most of the collective dose is due to radiocaesium in fish; the small contribution from shellfish includes an even smaller apportionment due to other nuclides. Liquid discharges from Windscale are the main source of collective dose; by comparison, the effect of discharges from other establishments is very small, and that due to fallout has been subtracted. In general, the method of calculation is to combine data on fish and shellfish landings from relevant sea areas with average radioactivity concentrations in fish and shellfish caught in these areas. Corrections are made for the proportion of landed fish or shellfish consumed. The results are presented in Table 8. Revised 1976 data are given for the UK, for which provisional results were previously given (Mitchell, 1977). In addition, a value for the 1976 collective dose to other Western European countries is provided because landings statistics were not available at the time of writing of the 1976 report.

The results show an overall reduction in collective doses for 1977 as compared with 1976. This was largely due to the dispersion conditions; a marked reduction in the contribution from the Irish Sea has been partially offset by an increase in the effect of other sea areas. There was also a general reduction in fish and shellfish landings in 1977, both in the UK and other countries.

The small differences between the results using the two ICRP procedures may be explained as follows. The slightly lower values on the basis of ICRP Publication 26 recommendations (ICRP, 1977) are mainly the result of a revised annual limit of intake for caesium–134 (Adams *et al.*, 1978). For shellfish, which account for less than 10% of the collective doses, assessment on the basis of ICRP Publication 26 recommendations requires other nuclides (mainly ruthenium–106, plutonium–239 and–240, and americium–241) besides radiocaesium to be considered. These additional nuclides do not contribute significantly to whole-body irradiation which is the basis of the calculation according to ICRP Publication 9

Table 8 Collective doses from consumption of fish and shellfish, 1976 and 1977

Population (and size)	Collective dose equivalent, man-Sv (man-rem), based on ICRP-9		Collective effective dose equivalent, man-Sv (man-rem), based on ICRP-26	
	1976	1977	1976	1977
UK (5.5×10^7)	140 (14 000)	89 (8 900)	130 (13 000)	85 (8 500)
Other West European countries (1.4×10^8)	120 (12 000)	80 (8 000)	110 (11 000)	77 (7 700)

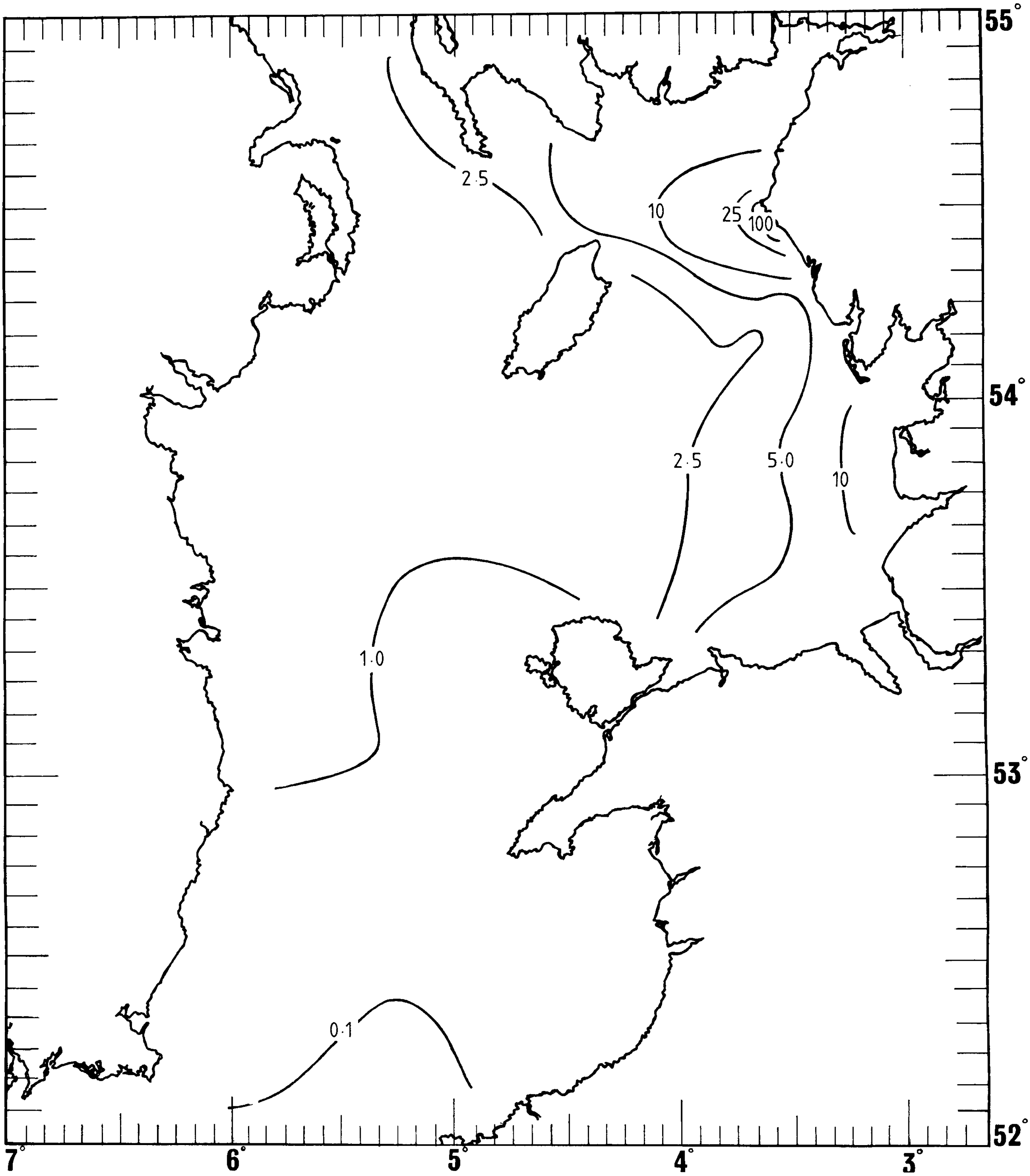

Figure 2 Concentration (Bq kg $^{-1}$) of caesium–137 in filtered water from the Irish Sea, September 1977 (1 Bq ≙ 27 pCi).

recommendations. However, only about a quarter of the collective effective dose from shellfish (ie less than 2% of the total) is due to these other nuclides, and so their effect on the total evaluated according to ICRP Publication 26 recommendations is small. It is to be noted also that in the cases of plutonium and americium the annual limits of intake allow for the long body half times such that the doses for them are committed in the future rather than already received.

The collective doses given in Table 8 may be compared with the 1959 objective of UK radioactive waste disposal policy (Great Britain – Parliament, 1959) (see section 3.4), equivalent to about 0.33 mSv (33 mrem) per person per year. In both 1976 and 1977 the UK collective doses through the fish and shellfish consumption pathways as a result of liquid radioactive waste disposal operations amounted to less than 1% of this limit.

It is clear from the statements above which compare the 1976 and 1977 results for both critical group and collective dose rates that an important factor determining exposures is the distribution of radioactivity in the marine environment. A continuing programme of research is maintained by FRL on marine behaviour and distributions (including budget assessments) of significant radionuclides. Data on the distribution of radiocaesium in seawater are regularly collected by research vessel cruises; the distribution observed in the Irish Sea in September 1977 is shown in Figure 2. Comparison with the data for January 1976 (Mitchell, 1977) indicates a substantial reduction in the radiocaesium inventory of the Irish Sea in 1977.

4.1.2 External exposure

A further important pathway leading to radiation exposure as a result of Windscale discharges arises from uptake of gamma-emitting radionuclides by intertidal sediments in areas frequented by the public. In general, it is the fine grained muds and silts prevalent in estuaries and harbours, rather than the coarser grained sands to be found on open beaches, which adsorb the radioactivity more readily. Gamma dose rates currently observed are mainly due to radiocaesium, ruthenium–106 and zirconium–95 plus niobium–95.

FRL regularly monitors a range of coastal locations both in the Windscale vicinity and further afield using portable gamma-radiation dosemeters. Locations are chosen both on account of dose rates themselves and on levels of occupancy by members of the public. Table 9 lists the locations monitored together with the dose rates in air at 1m above ground level. Monitoring in Scotland is carried out on behalf of departments of the Scottish Office. Dose rates on Irish Sea shorelines near other nuclear establishments which reflect Windscale discharges are given later in this report (see sections 4.2, 4.3, 4.4, 6.5, 6.10). Variations in sediment type account for the quite

Table 9 Gamma radiation dose rates over intertidal areas of the Cumbrian coast and further afield, 1977

Location	Type of sediment	No. of observations	Mean gamma dose rate in air at 1 m	
			$\mu Gy\ h^{-1}$	$\mu rad\ h^{-1}$
Maryport Harbour	Mud	11	0.56	56
Workington Harbour	Silt	8	0.55	55
Whitehaven Harbour	Mud	12	1.05	105
St Bees	Sand	11	0.22	22
Nethertown	Sand	1	0.24	24
Braystones	Coarse sand	12	0.27	27
Sellafield	Sand	7	0.28	28
Seascale	Sand	10	0.25	25
Ravenglass Salmon Garth	Mud/mussel bed	12	0.80	80
Ravenglass small boats area	Sand	12	0.31	31
Newbiggin	Mud	11	1.08	108
Haverigg	Silt	1	0.84	84
Walney Island	Silt	10	0.36	36
Heysham	Silt	4	0.16	16
Mersey*	Silt	12	0.16	16
Garlieston	Silt	1	0.27	27
Kipford	Silt	3	0.20	20

*Results represent the means of levels observed at three points: Eastham Ferry, Rock Ferry, New Ferry.

Table 10 Beta/gamma and transuranic radioactivity in sediment from the Cumbrian coast and further afield, 1977

Sampling point and sediment type		No. of observations	Mean radioactivity concentration (dry), mBq g^{-1} (pCi g^{-1})				
			Total beta	^{60}Co	$^{95}Zr + ^{95}Nb$	^{106}Ru	^{134}Cs
Maryport	(mud)	4	63 000 (1 700)	200 (5.4)	2 700 (72)	19 000 (510)	1 000 (27)
Whitehaven	(")	4	58 000 (1 600)	140 (3.7)	1 300 (34)	12 000 (310)	1 500 (40)
St Bees	(sand)	13	3 400 (91)	3.6 (0.10)	63 (1.7)	290 (7.9)	92 (2.5)
Sellafield	(")	1	3 100 (84)	12 (0.32)	63 (1.7)	410 (11)	89 (2.4)
Seascale	(")	13	4 500 (120)	6.9 (0.19)	122 (3.3)	590 (16)	140 (3.9)
Drigg	(")	2	8 000 (220)	ND	ND	19 (0.52)	401 (0.11)
Newbiggin	(mud)	12	85 000 (2 300)	300 (8.0)	3 600 (96)	29 000 (790)	1 000 (28)
Walney Island	(silt)	5	29 000 (770)	63 (1.7)	740 (20)	4 600 (120)	360 (9.7)
Heysham	(")	4	5 000 (130)	ND	67 (1.8)	520 (14)	160 (4.4)
Fleetwood	(sand)	5	780 (21)	"	ND	12 (0.32)	14 (0.38)
Mersey*	(silt)	12	4 200 (110)	"	"	470 (13)	260 (6.9)
Garlieston	(")	4	5 100 (140)	14 (0.37)	78 (2.1)	1 100 (30)	140 (3.8)
Kirkcudbright	(")	2	5 000 (140)	12 (0.32)	30 (0.82)	1 200 (32)	240 (6.4)
Kipford	(")	3	14 000 (390)	89 (2.4)	810 (22)	6 800 (180)	700 (19)

Sampling point and sediment type		No. of observations	Mean radioactivity concentration (dry), mBq g^{-1} (pCi g^{-1})				
			^{137}Cs	^{144}Ce	^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am
Maryport	(mud)	4	8 000 (220)	4 800 (130)	610 (17)	2 300 (63)	2 200 (60)
Whitehaven	(")	4	12 000 (340)	3 300 (88)	560 (15)	2 300 (62)	2 000 (55)
St Bees	(sand)	13	700 (19)	180 (4.9)	NA	NA	NA
Sellafield	(")	1	700 (19)	260 (6.9)	"	"	"
Seascale	(")	13	1 100 (29)	300 (8.1)	"	"	"
Drigg	(")	2	340 (9.1)	41 (1.1)	"	"	"
Newbiggin	(mud)	12	9 200 (250)	6 700 (180)	950 (26)	3 600 (97)	3 300 (89)
Walney Island	(silt)	5	3 000 (80)	1 100 (29)	NA	NA	NA
Heysham	(")	4	1 300 (35)	180 (4.8)	21 (0.57)	93 (2.5)	140 (3.7)
Fleetwood	(sand)	5	170 (4.7)	ND	NA	NA	NA
Mersey*	(silt)	12	2 400 (64)	93 (2.5)	25 (0.67)	130 (3.4)	170 (4.6)
Garlieston	(")	4	1 300 (35)	210 (5.6)	27 (0.74)	120 (3.3)	160 (4.4)
Kirkcudbright	(")	2	1 800 (49)	310 (8.3)	NA	NA	NA
Kipford	(")	3	5 100 (140)	1 500 (40)	"	"	"

NA = not analysed.
ND = not detected.
*Results represent the means of levels observed in samples from three points: Eastham Ferry, Rock Ferry, New Ferry.

marked fluctuations in dose rate, superimposed on a general decrease with increasing distance from Windscale.

FRL also regularly monitors radioactivity concentrations in sediments. This is both because of relevance to dose rates and in order to keep under review distributions of adsorbed radioactivity. Concentrations of beta/gamma radioactivity and transuranics, in most cases at the same locations as the dose rate measurements, are given in Table 10. Variations similar in cause to those of the dose rates are observed.

To identify those members of the public subject to the highest external exposures, occupancies of different locations need to be considered. FRL keeps under review the amounts of time spent by members of the public on intertidal areas of coastline bordering the north-east Irish Sea; the longest times are often attributable to persons working in these areas. Despite the relatively high dose rate observed in 1977 over mud in Whitehaven Harbour, persons spend only relatively small amounts of time there. It is still considered that, combining dose rates and occupancy times, the critical group is represented by those who frequent areas of the Ravenglass estuary. The highest external exposure is considered to be that of the salmon garth fisherman who works in muddy areas of this estuary. In 1977 his external exposure, after subtracting natural background, was about 4.2% of the ICRP-recommended dose limit of 5 mSv (500 mrem). This exposure represents a reduction from 8% reported for 1976 (Mitchell, 1977). The salmon garth fisherman is not a high-rate consumer of fish or shellfish, so his total exposure is less than the maximum calculated for fish and shellfish eaters. In principle, exposure through each of these pathways is additive, but combination of FRL data on external exposures and consumption rates for 1977 does not produce a significantly higher dose rate than already given for the dose rate due to consumption of fish and shellfish.

4.1.3 *Porphyra*/laverbread pathway

No harvesting of *Porphyra* in the immediate Windscale vicinity for ultimate consumption was reported in 1977; however, a small quantity (harvested on Walney Island) was despatched to South Wales from Barrow-in-Furness during the early part of the year. This pathway has therefore remained essentially dormant. However, in view of its potential importance and the value of *Porphyra* as an indicator, monitoring by FRL has continued. Samples of *Porphyra* are regularly collected from selected locations along the Cumbrian coast and analysed for total beta activity and beta/gamma-emitting nuclides; samples from Braystones are also analysed for transuranics. Results for 1977 are presented in Tables 11 (a) and 11 (b). Samples of

Table 11(a) Beta/gamma radioactivity in *Porphyra* from the Cumbrian coast, 1977

Sampling point	No. of observations	Mean radioactivity concentration (wet), mBq g^{-1} (pCi g^{-1})						
		Total beta	^{60}Co	$^{95}Zr + ^{95}Nb$	^{106}Ru	^{134}Cs	^{137}Cs	^{144}Ce
Nethertown	11	5 600 (150)	2.8 (0.08)	200 (5.5)	5 700 (150)	37 (1.0)	240 (6.6)	ND
Braystones South	12	8 300 (220)	4.6 (0.12)	240 (6.4)	8 400 (230)	44 (1.2)	280 (7.5)	"
Sellafield	10	6 900 (190)	4.7 (0.13)	200 (5.3)	7 000 (190)	44 (1.2)	300 (8.2)	2.6 (0.07)
Seascale	51	11 000 (290)	6.3 (0.17)	590 (16)	8 300 (230)	59 (1.6)	370 (10)	27 (0.74)
Eskmeals	10	3 500 (94)	2.0 (0.06)	67 (1.8)	3 300 (90)	28 (0.77)	200 (5.5)	3.4 (0.09)
Walney Island	4	1 000 (28)	ND	26 (0.70)	850 (23)	13 (0.35)	100 (2.7)	ND

ND = not detected.

Table 11(b) Transuranic radioactivity in *Porphyra* from the Cumbrian coast, 1977

Sampling point	No. of observations	Mean radioactivity concentration (wet), mBq g^{-1} (pCi g^{-1})				
		^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am	^{242}Cm	$^{243}Cm + ^{244}Cm$
Braystones South	2	13 (0.34)	47 (1.3)	31 (0.84)	0.81 (0.022)	0.29 (0.0078)

laverbread from the product of both of the major manufacturers are regularly collected from markets in South Wales and analysed for ruthenium–106. Results for 1977 are presented in Table 12. On the basis of both ICRP procedures the exposure of critical individuals was at most 0.2% of the ICRP-recommended dose limit, confirming the virtual abeyance of this pathway.

Table 12 Radioactivity in laverbread from South Wales, 1977

Manufacturer	No. of observations	^{106}Ru concentration (wet)	
		mBq g^{-1}	pCi g^{-1}
A	49	8.5	0.23
B	44	15	0.40

Table 13 Beta/gamma radioactivity in seaweeds from UK shorelines of the Irish Sea, 1977

Type of seaweed and sampling point	No. of observations	Mean radioactivity concentration (wet), mBq g^{-1} (pCi g^{-1})						
		Total beta	^{60}Co	^{95}Zr + ^{95}Nb	^{106}Ru	^{134}Cs	^{137}Cs	^{144}Ce
Porphyra								
Larbrax	4	250 (6.8)	ND	ND	33 (0.88)	1.0 (0.03)	14 (0.39)	ND
Port William	4	310 (8.5)	"	"	92 (2.5)	3.1 (0.08)	34 (0.91)	"
Garlieston	4	340 (9.3)	0.4 (0.01)	3.7 (0.10)	89 (2.4)	6.4 (0.17)	56 (1.5)	"
Fucus vesiculosus								
Nethertown	1	5 300 (140)	31 (0.85)	290 (7.8)	1 100 (31)	260 (7.0)	1 500 (41)	10 (0.28)
Sellafield	9	6 800 (190)	31 (0.85)	520 (14)	1 800 (49)	230 (6.2)	1 800 (48)	31 (0.83)
Heysham	4	1 100 (29)	ND	ND	41 (1.1)	56 (1.5)	440 (12)	ND
Port William	4	630 (17)	"	"	ND	19 (0.52)	150 (4.0)	"
Garlieston	4	930 (25)	"	3.0 (0.08)	44 (1.2)	41 (1.1)	290 (7.9)	"
Rascarrel	4	1 200 (32)	1.2 (0.03)	3.2 (0.09)	100 (2.8)	48 (1.3)	360 (9.8)	2.3 (0.06)
Brighouse	1	850 (23)	ND	ND	37 (1.0)	28 (0.76)	240 (6.6)	ND
Auchencairn	1	1 100 (29)	"	"	56 (1.5)	41 (1.1)	320 (8.7)	"
Portrush*	4	410 (11)	"	"	ND	4.0 (0.11)	41 (1.1)	"
Millisle*	3	520 (14)	"	"	"	9.4 (0.25)	85 (2.3)	"

ND = not detected.
*Samples may include other seaweeds of *Fucus* type.

Table 14 Beta/gamma radioactivity in seaweeds from the coast of the Irish Republic, 1977

Type of seaweed and sampling point	No. of observations	Mean radioactivity concentration (wet), mBq g^{-1} (pCi g^{-1})			
		Total beta	^{106}Ru	^{134}Cs	^{137}Cs
Porphyra					
Skerries	1	160 (4.3)	ND	1.3 (0.04)	7.4 (0.20)
Colliemore	2	230 (6.2)	"	0.6 (0.02)	10 (0.27)
Dunmore	1	240 (6.6)	32 (0.86)	ND	ND
Fucus-type weed					
Skerries	2	410 (11)	ND	5.2 (0.14)	52 (1.4)
Colliemore	2	520 (14)	"	5.9 (0.16)	48 (1.3)
St Helens	1	310 (8.5)	"	ND	7.4 (0.20)
Dunmore	1	370 (9.9)	"	"	ND
Carlingford	2	410 (11)	"	8.1 (0.22)	59 (1.6)
Laminaria					
Skerries	2	560 (15)	"	6.3 (0.17)	52 (1.4)
Colliemore	1	480 (13)	"	3.5 (0.10)	37 (1.0)
St Helens	1	370 (10)	"	2.1 (0.06)	11 (0.31)
Dunmore	1	560 (15)	"	ND	3.4 (0.09)
Carlingford	2	700 (19)	"	4.4 (0.12)	35 (0.94)

ND = not detected.

4.1.4 Other surveys

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

Seaweeds are useful indicator materials; they may concentrate certain radionuclides so that they greatly facilitate measurement and assist in the tracing of these radionuclides in the environment. Table 13 presents the results of measurements in 1977 on *Porphyra* and *Fucus vesiculosus*. Radioactivity concentrations in *Porphyra* are reported in this section for areas relatively remote from Windscale because of the value of this seaweed as an indicator, particularly for ruthenium–106. Although small quantities of *Porphyra* from these locations may be eaten, radioactivity concentrations are of negligible radiological significance. *Fucus* seaweeds are also useful indicators particularly of fission product radioactivity other than from ruthenium–106; samples of *Fucus vesiculosus* are collected both in the Windscale vicinity and further afield, and the results are presented here. Monitoring in Scotland is carried out on behalf of departments of the Scottish Office. Analyses of samples collected in Northern Ireland are carried out on behalf of DOE(NI).

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

Table 15 Radioactivity in mud and gamma dose rates near the Springfields pipeline, 1977

Location	No. of observations	Mean radioactivity concentration (dry), mBq g^{-1} (pCi g^{-1})					
		Total beta	^{60}Co	^{106}Ru	^{134}Cs	^{137}Cs	^{144}Ce
Pipeline outlet	4	15 000 (420)	5.1 (0.14)	780 (21)	300 (8.0)	2 200 (60)	100 (2.7)
Upstream							
90 metres	4	21 000 (560)	15 (0.41)	1 000 (27)	410 (11)	2 900 (79)	ND
460 metres	4	19 000 (520)	12 (0.32)	810 (22)	320 (8.6)	2 400 (65)	37 (1.0)
Downstream							
90 metres	4	22 000 (600)	8.2 (0.22)	960 (26)	360 (9.7)	2 700 (72)	ND

Location	No. of observations	Mean radioactivity concentration (dry), mBq g^{-1} (pCi g^{-1})				Mean gamma dose rate in air at 1 m, µGy h^{-1} (µrad h^{-1})
		^{234m}Pa	^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am	
Pipeline outlet	4	13 000 (360)	50 (1.4)	170 (4.5)	NA	0.34 (34)
Upstream						
90 metres	4	26 000 (710)	46 (1.3)	210 (5.7)	"	0.37 (37)
460 metres	4	19 000 (520)	44 (1.2)	190 (5.2)	"	0.36 (36)
Downstream						
90 metres	4	20 000 (550)	54 (1.5)	240 (6.5)	260 (7.0)	0.34 (34)

NA = not analysed.
ND = not detected.

4.2 Springfields, Lancashire

This establishment is mainly concerned with manufacture of fuel elements for nuclear reactors. Radioactive waste arisings are small and consist mainly of uranium and its daughter products; liquid discharges are made by pipeline to the Ribble estuary. Public radiation exposure as a result of these discharges is very low. The critical pathway is by way of adsorption of the radioactivity on the muddy areas of river banks near the outfall; this gives rise to slightly increased dose rates in these areas, which are visited by members of the public. Dredgermen constitute the critical group. FRL regularly monitors dose rates near the outfall, and samples mud at the same points. The mud is analysed for total beta radioactivity, beta/gamma emitting nuclides and transuranics. Results for 1977 are presented in Table 15. The only detectable radionuclide due to Springfields discharges is protactinium–234m; other radionuclides present are mainly from Windscale. Exposure of critical individuals in 1977, including the Windscale component, amounted to about 2% of the ICRP-recommended dose limit; the contribution due to Springfields discharges would have been but a small fraction of this.

4.3 Capenhurst, Cheshire

The main function of the Capenhurst Works is enrichment of uranium. Radioactive waste arisings, mainly of uranium and its daughter products, are very small; the Works have an authorisation to dispose of liquid wastes to the Rivacre Brook. Recently, uranium recovered from irradiated fuel has been recycled; this may contain small quantities of fission products, of which technetium–99 is the only significant component. Waste arisings in this second category are again very low; an authorisation was issued in September 1977 for their disposal to the Liverpool Bay from the North Wirral outfall at Meols. No disposals were made, however, in 1977. It is expected that the environmental consequences of these disposals, when made, will be

Table 16 Radioactivity in environmental materials and gamma dose rates in the vicinity of the Wirral, 1977

Material	Sampling point	No. of observations	Mean radioactivity concentration (wet), mBq g^{-1} (pCi g^{-1})			
			Total beta	^{60}Co	^{99}Tc	^{106}Ru
Plaice	Wirral	1	240 (6.4)	ND	1.5 (0.04)	ND
Shrimp	"	1	290 (7.8)	"	1.1 (0.03)	"
Cockles	Southport	1	260 (6.9)	2.6 (0.70)	4.1 (0.11)	52 (1.4)
Fucus vesiculosus	Hoylake	1	810 (22)	ND	120 (3.1)	270 (7.4)
Fucus spiralis	"	1	560 (15)	"	48 (1.3)	ND

Material	Sampling point	No. of observations	Mean radioactivity concentration (wet), mBq g^{-1} (pCi g^{-1})			
			^{110m}Ag	^{134}Cs	^{137}Cs	^{144}Ce
Plaice	Wirral	1	ND	16 (0.44)	140 (3.9)	ND
Shrimp	"	1	"	17 (0.47)	130 (3.6)	"
Cockles	Southport	1	3.3 (0.09)	13 (0.35)	100 (2.8)	"
Fucus vesiculosus	Hoylake	1	ND	74 (2.0)	590 (16)	12 (0.32)
Fucus spiralis	"	1	"	20 (0.54)	170 (4.6)	ND

ND = not detected.

extremely small and difficult to detect above background levels due both to natural sources of radioactivity and to Windscale discharges. However, in 1977 FRL began an environmental monitoring programme in order to establish background levels and reliable sources of samples. The programme reflects the potentially critical pathway due to consumption of locally-caught fish and shellfish. *Fucus vesiculosus* is also sampled, being a particularly good indicator for technetium–99. It is to be noted, however, that the size of the programme is unrelated to the potential radiological hazard. Results for 1977 are presented in Table 16. The concentrations of radioactivity are consistent with values to be expected at this distance from Windscale.

4.4 Chapelcross, Dumfriesshire

At this establishment BNFL operates a magnox-type nuclear power station. Liquid waste arisings are discharged to the Solway Firth under authorisation of the Scottish Development Department. There are two pathways of potential importance leading to public radiation exposure. External exposure from use of intertidal areas by fishermen is likely to be of somewhat greater significance, owing to occupancy rates. The second pathway is internal irradiation following consumption of locally-caught fish and shellfish, mainly shrimps. Monitoring by FRL, on behalf of departments of the Scottish Office, reflects

Table 17(a) Radioactivity in environmental materials in the vicinity of Chapelcross, 1977

Material	Sampling point	No. of observations	Mean radioactivity concentration (wet)*, mBq g^{-1} (pCi g^{-1})				
			Total beta	^{60}Co	^{95}Zr + ^{95}Nb	^{106}Ru	^{134}Cs
Flounder	Seafield	1	430 (12)	ND	ND	ND	29 (0.79)
Salmon	"	1	160 (4.3)	"	"	"	ND
Shrimps	"	4	230 (6.3)	"	"	"	22 (0.60)
Fucus vesiculosus	Waterfoot	4	780 (21)	"	"	21 (0.57)	31 (0.83)
"	Seafield	4	930 (25)	"	"	33 (0.88)	37 (1.0)
Sediment	"	5	10 000 (280)	18 (0.49)	85 (2.3)	1 400 (37)	280 (7.5)
"	Browhouses	1	9 400 (250)	15 (0.40)	ND	1 400 (37)	300 (8.2)
"	Waterfoot	1	3 100 (84)	ND	"	520 (14)	110 (3.0)

Material	Sampling point	No. of observations	Mean radioactivity concentration (wet)*, mBq g^{-1} (pCi g^{-1})				
			^{137}Cs	^{144}Ce	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am
Flounder	Seafield	1	290 (7.8)	ND	NA	NA	NA
Salmon	"	1	7.0 (0.19)	"	"	"	"
Shrimps	"	4	200 (0.54)	"	"	"	"
Fucus vesiculosus	Waterfoot	4	240 (6.5)	"	"	"	"
"	Seafield	4	290 (7.7)	"	"	"	"
Sediment	"	5	2 100 (57)	290 (7.8)	50 (1.3)	210 (5.8)	190 (5.2)
"	Browhouses	1	2 100 (56)	410 (11)	NA	NA	NA
"	Waterfoot	1	960 (26)	96 (2.6)	"	"	"

ND = not detected.
NA = not analysed.
*Except for sediment where dry concentrations apply.

Table 17(b) Gamma dose rates in air at 1 m over intertidal areas in the vicinity of Chapelcross, 1977

Location	No. of observations	μGy h^{-1}	μrad h^{-1}
Seafield	4	0.21	21
Browhouses	4	0.16	16
Waterfoot	4	0.17	17
Torduff Point	4	0.16	16
Battle Hill	4	0.16	16

these pathways. Samples of *Fucus vesiculosus*, as a useful indicator, are also analysed. The results of monitoring in 1977 are presented in Table 17.

Concentrations of artificial radionuclides in the Chapelcross vicinity are mostly due to Windscale discharges, and the general levels given in Table 17 are consistent with values to be expected at this distance from Windscale. Exposure of critical individuals in 1977, making the maximising assumption of additivity of the two pathways, amounted to less than 4% of the ICRP-recommended dose limit. The effects of Chapelcross discharges are not detectable above the Windscale-derived background; the magnitude of the discharges indicate that the local contribution would have been a tiny fraction of this exposure.

5 United Kingdom Atomic Energy Authority

FRL regularly monitors the environmental impact of liquid radioactive discharges from two UKAEA sites. These are the Atomic Energy Establishment, Winfrith and the Dounreay Nuclear Power Development Establishment. Liquid radioactive wastes also arise at the Atomic Energy Research Establishment, Harwell. In common with such wastes from other nuclear establishments in the Thames Valley area, these are discharged into the River Thames, and the critical exposure pathway is from drinking water. Monitoring in respect of these discharges is therefore carried out by the Department of the Environment rather than this Ministry. However, comment on the implications of discharges of tritium to the Thames in terms of collective dose has been included in section 9.

5.1 Atomic Energy Establishment, Winfrith, Dorset

The principal installation at which liquid radioactive wastes arise at this establishment is the Steam Generating Heavy Water Reactor. Most of the activity is due to tritium from the moderator and coolant, but small amounts of activation products, including manganese–54, cobalt–60 and zinc–65, are removed during decontamination of the reactor pressure circuit. These wastes are disposed of under authorisation to deep water in Weymouth Bay. It is the activation products rather than tritium which are of greater, but still small, environmental significance. Reconcentration of activation products by shellfish, followed by local consumption, constitutes the critical exposure pathway; this is reflected in the FRL monitoring programme. Fish are also sampled. Monitoring of the indicator materials, limpets and *Fucus serratus*, provides additional information on the distribution of activation products. Data for 1977 are presented in Table 18. The impact of Winfrith discharges is, as in previous years, mainly observed in the activation product concentrations. Radiocaesium levels in fish are not substantially in excess of those to be expected from fall-out; local discharges are likely to give rise to a negligible contribution. In 1977 the total radiation dose to critical consumers near this establishment was low, at less than 0.2% of the ICRP-recommended limit.

5.2 Dounreay Nuclear Power Development Establishment, Caithness

Liquid radioactive waste discharges from this establishment are made to the Pentland Firth under authorisation of the Scottish Development Department. Discharges include a minor contribution from the adjoining reactor site (HMS Vulcan) operated by the Ministry of Defence (Procurement Executive). Monitoring by FRL near Dounreay is carried out on behalf of departments of the Scottish Office. There are two critical exposure pathways, both involving external radiation. The first pathway is due to radioactivity adsorbed mainly on fine sediments becoming entrained on fishing gear which is regularly handled. This results in skin dose, mainly from beta particles, to the hands and forearms of fishermen. The critical group is a small number of people who operate a salmon fishery from Sandside Bay, close to Dounreay. Regular measurements throughout the 1977 fishing season showed that their exposure was low, at less than 1% of the ICRP-recommended dose limit. The second critical pathway is due to adsorption of radioactivity on sediments trapped in rocky clefts on the foreshore. This leads to exposure mainly to gamma radiation of those who frequent these areas; winkle picking accounts for the highest occupancies. Monitoring of foreshore dose rates is not carried out by FRL; the UKAEA have published the results of their surveys of these areas in their 1977 monitoring report (Flew, 1978). Public radiation exposure via this pathway was also very low, at less than 1% of the ICRP-recommended dose limit.

In addition to the above monitoring, FRL analyses limpets, winkles and *Fucus vesiculosus* as indicator materials. Results for 1977 are presented in Table 19. Radiocaesium levels are mostly due to discharges from Windscale. Other radionuclides detected (including transuranics) mainly reflect Dounreay discharges. In addition to giving information on the local behaviour of these radionuclides, the measurements enable sub-critical exposure pathways, such as that of fish and shellfish consumption, to be kept under review.

Table 18 Radioactivity in environmental materials from the vicinity of Winfrith, 1977

Material	Sampling point	No. of observations	Mean radioactivity concentration (wet), mBq g^{-1} (pCi g^{-1})			
			Total beta	^{54}Mn	^{60}Co	^{65}Zn
Gurnard	Poole	1	120 (3.2)	ND	ND	ND
Ray	"	1	96 (2.6)	"	2.0 (0.05)	"
Crab	Lulworth	2	130 (3.6)	2.5 (0.07)	78 (2.1)	59 (1.6)
Oysters	Poole	2	100 (2.7)	ND	8.9 (0.24)	250 (6.8)
Limpets	Chapman's Pool	2	100 (2.7)	3.8 (0.10)	48 (1.3)	14 (0.38)
	Osmington Mill	2	92 (2.5)	ND	14 (0.39)	13 (0.34)
Fucus serratus	Chapman's Pool	2	520 (14)	74 (2.0)	480 (13)	ND
	Osmington Mill	2	360 (9.8)	31 (0.83)	210 (5.5)	"
	Weymouth	2	370 (9.9)	33 (0.88)	200 (5.4)	"
	Swanage	2	360 (9.6)	14 (0.39)	150 (4.1)	"
	Portland	2	350 (9.4)	24 (0.66)	120 (3.3)	"

Material	Sampling point	No. of observations	Mean radioactivity concentration (wet), mBq g^{-1} (pCi g^{-1})			
			^{106}Ru	^{110m}Ag	^{134}Cs	^{137}Cs
Gurnard	Poole	1	ND	ND	ND	3.2 (0.09)
Ray	"	1	"	"	"	3.3 (0.09)
Crab	Lulworth	2	"	1.6 (0.04)	"	ND
Oysters	Poole	2	"	2.6 (0.07)	"	"
Limpets	Chapman's Pool	2	9.6 (0.26)	ND	"	"
	Osmington Mill	2	ND	"	"	"
Fucus serratus	Chapman's Pool	2	28 (0.75)	"	"	"
	Osmington Mill	2	17 (0.46)	"	"	"
	Weymouth	2	ND	"	"	"
	Swanage	2	"	"	"	"
	Portland	2	"	"	"	"

ND = not detected.

Table 19 Radioactivity in environmental materials from the vicinity of Dounreay, 1977

Sampling point and material	No. of observations	Mean radioactivity concentration (wet), mBq g^{-1} (pCi g^{-1})					
		Total beta	^{60}Co	$^{95}Zr + ^{95}Nb$	^{106}Ru	^{110m}Ag	^{134}Cs
Sandside Bay							
Limpets	8	200 (5.5)	1.8 (0.05)	5.2 (0.14)	25 (0.68)	ND	ND
Winkles	3	160 (4.2)	2.5 (0.07)	4.6 (0.12)	44 (1.2)	1.4 (0.04)	0.33 (0.01)
Fucus vesiculosus	8	560 (15)	11 (0.03)	8.9 (0.24)	3.0 (0.08)	ND	2.7 (0.07)

Sampling point and material	No. of observations	Mean radioactivity concentration (wet), mBq g^{-1} (pCi g^{-1})				
		^{137}Cs	^{144}Ce	^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am
Sandside Bay						
Limpets	8	8.1 (0.22)	3.3 (0.09)	0.27 (0.0073)	1.0 (0.027)	0.48 (0.013)
Winkles	3	5.1 (0.14)	6.5 (0.18)	0.38 (0.010)	0.96 (0.026)	0.56 (0.015)
Fucus vesiculosus	8	34 (0.92)	12 (0.33)	0.33 (0.0090)	1.3 (0.034)	0.27 (0.0073)

ND = not detected.

Table 20 Radioactivity in environmental materials and gamma dose rates near Berkeley and Oldbury nuclear power stations, 1977

Material	No. of observations	Mean radioactivity concentration (wet)*, mBq g^{-1} (pCi g^{-1})		
		Total beta	^{134}Cs	^{137}Cs
Flounder	1	81 (2.2)	ND	4.0 (0.11)
Mixed fish	1	85 (2.3)	"	2.1 (0.06)
Shrimp	1	70 (1.9)	"	2.0 (0.054)
Fucus vesiculosus	2	210 (5.6)	4.1 (0.11)	18 (0.49)
Mud: area of outfalls	4	960 (26)	28 (0.77)	160 (4.2)
area upstream	2	960 (26)	14 (0.39)	89 (2.4)

Mean gamma dose rate in air at 1 m over intertidal mud (6 observations):
0.072 μGy h^{-1} (7.2 μrad h^{-1})

ND = not detected.
*Except for mud where dry concentrations apply.

6. Nuclear power stations operated by the electricity boards

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

6.1 Berkeley, Gloucestershire and Oldbury, Avon

Liquid radioactive wastes from both of these stations are generally similar in composition and are discharged to the same stretch of the Severn estuary. The stations are therefore considered together for the purposes of environmental monitoring by FRL. The two critical pathways for public radiation exposure are internal irradiation from consumption of locally-caught fish and shellfish, and external exposure from occupancy of muddy intertidal areas. FRL therefore analyses samples of fish and shellfish and monitors beach gamma dose rates. In addition, measurements of external exposure are supported by analyses of intertidal mud, and *Fucus vesiculosus* is collected as an indicator material. Data for 1977 are presented in Table 20. The only artificial radioactivity detected was due to radiocaesium; apportionment is difficult at the low levels detected but concentrations represent the combined effect of discharges from the stations and fallout, and possibly include a small Windscale-derived component. Public radiation exposure, however, was very low, at less than 0.1% of the ICRP-recommended limit to the critical group of fish and shellfish consumers. Directly measured gamma dose rates over intertidal mud continued to be indistinguishable from the natural background.

6.2 Bradwell, Essex

Radioactive liquid effluent from this power station is discharged to the estuary of the River Blackwater. Environmental monitoring by FRL reflects the critical internal radiation exposure pathway from consumption of locally-caught fish. Oysters also continue to be sampled and analysed, though their consumption no longer constitutes the critical pathway (Mitchell, 1978). Gamma dose rate measurements over intertidal mud are also carried out, as well as analyses of intertidal mud and the indicator *Fucus vesiculosus*. Measurements for 1977 are summarised in Table 21.

Table 21 Radioactivity in environmental materials and gamma dose rates near Bradwell nuclear power station, 1977

Material	No. of observations	Mean radioactivity concentration (wet)*, $mBq\ g^{-1}$ ($pCi\ g^{-1}$)					
		Total beta	^{60}Co	^{65}Zn	$^{95}Zr + {}^{95}Nb$	^{110m}Ag	^{134}Cs
Mullet	1	NA	ND	ND	ND	ND	1.3 (0.036)
Oysters	4	92 (2.5)	"	19 (0.51)	"	1.6 (0.04)	ND
Mud	6	1 100 (30)	1.6 (0.04)	ND	1.8 (0.05)	7.4 (0.20)	20 (0.54)
Fucus vesiculosus	2	300 (8.2)	ND	"	ND	1.7 (0.05)	3.8 (0.10)

Material	No. of observations	Mean radioactivity concentration (wet)*, $mBq\ g^{-1}$ ($pCi\ g^{-1}$)			
		^{137}Cs	^{238}Pu	$^{239}Pu + {}^{240}Pu$	^{241}Am
Mullet	1	8.9 (0.24)	NA	NA	NA
Oysters	4	3.8 (0.10)	0.0032 (0.000086)	0.014 (0.00037)	0.025 (0.00068)
Mud	6	81 (2.2)	NA	NA	NA
Fucus vesiculosus	2	13 (0.35)	"	"	"

Mean gamma dose rate in air at 1 m over intertidal mud (6 observations): 0.065 $\mu Gy\ h^{-1}$ (6.5 $\mu rad\ h^{-1}$)

NA = not analysed.
ND = not detected.
*Except for mud where dry concentrations apply.

In fish, the only artificial radioactivity detected was due to radiocaesium, for which concentrations represent the combined effects of discharges from the station, of Windscale discharges, and of fallout. Apportionment is difficult because of the low levels detected. The radiological significance of radiocaesium here, however, is low, totalling less than 0.3% of the ICRP-recommended dose limit to members of the critical group of fish consumers. The levels of ^{65}Zn and ^{110m}Ag in oysters continued to decline in 1977, confirming that the exposure pathway involving these nuclides remains of small importance. The concentrations in oysters of transuranic nuclides, from local discharges and from Windscale, are of negligible radiological significance. Gamma dose rates, as directly measured, were indistinguishable from the natural background.

6.3 Dungeness, Kent

The two critical radiation exposure pathways as a result of liquid radioactive waste discharges from this station are internal irradiation due to consumption of locally-caught fish, and external exposure from occupancy of the foreshore. The FRL monitoring programme therefore includes analyses of fish (of which plaice is the most representative local species) and gamma dose rate surveys of the generally sandy beach. Samples of sand are also collected and analysed. Local shrimps and whelks have been analysed mainly for their value as indicator materials. The results for 1977 are given in Table 22.

Concentrations of caesium-137 in plaice were not significantly above the levels to be expected as a result of fallout. The radiation dose to members of the critical group of fish consumers was very low, at less than 0.1% of the ICRP-recommended limit in 1977. Gamma dose rates over sand were indistinguishable from natural background levels. Both whelks and sand samples appeared to show trace levels of cobalt-60; however, the concentrations were of negligible radiological significance.

6.4 Hartlepool, Cleveland

This station is not yet operational; its two Advanced Gas-cooled Reactors (AGRs) are under construction. However, monitoring by FRL has already begun in order to investigate background levels and to establish reliable sources of environmental materials. Potential critical pathways for radiation exposure of the public near this station likely to be associated with future liquid discharges are internal irradiation from consumption of local fish and shellfish, and external exposure from occupancy of intertidal areas. Collectors of small coal, which is washed ashore along this stretch of coast, account for the highest beach occupancies, but the highest external exposures are likely to be of fishermen who operate in muddy areas near the mouth of the Tees. In 1977 the FRL monitoring programme consisted of analyses of silt and coal samples. The results are shown in Table 23. Concentrations of radiocaesium were due to fallout and Windscale discharges, but were of very low radiological significance.

Table 22 Radioactivity in environmental materials and gamma dose rates near Dungeness nuclear power station, 1977

Material	No. of observations	Mean radioactivity concentration (wet)*, mBq g^{-1} (pCi g^{-1})				
		Total beta	^{60}Co	^{134}Cs	^{137}Cs	^{144}Ce
Plaice	4	110 (3.0)	ND	ND	1.7 (0.05)	ND
Shrimps	1	85 (2.3)	"	"	ND	"
Whelks	1	126 (3.4)	1.3 (0.03)	"	"	"
Sand	2	925 (25)	3.5 (0.09)	0.63 (0.02)	3.3 (0.09)	1.9 (0.05)

Mean gamma dose rate in air at 1 m over intertidal sand (10 observations):
0.044 μGy h^{-1} (4.4 μrad h^{-1})

ND = not detected.
*Except for sand where dry concentrations apply.

Table 23 Radioactivity in environmental materials near Hartlepool nuclear power station, 1977

Material	No. of observations	Mean radioactivity concentration (dry), mBq g^{-1} (pCi g^{-1})		
		Total beta	^{134}Cs	^{137}Cs
Silt	3	590 (16)	2.4 (0.07)	16 (0.43)
Coal	1	11 (0.30)	ND	3.0 (0.08)

ND = not detected.

Table 24 Radioactivity in environmental materials and gamma dose rates near Heysham nuclear power station, 1977

Material	No. of observations	Mean radioactivity concentration (wet)*, mBq g^{-1} (pCi g^{-1})				
		Total beta	^{60}Co	$^{95}Zr + ^{95}Nb$	^{106}Ru	^{134}Cs
Flounder	3	700 (19)	ND	ND	ND	67 (1.8)
Shrimps	3	480 (13)	"	"	20 (0.53)	26 (0.71)
Cockles	3	480 (13)	4.1 (0.11)	"	200 (5.5)	21 (0.57)
Fucus vesiculosus	4	1 100 (29)	ND	"	41 (1.1)	56 (1.5)
Silt	4	5 000 (130)	"	67 (1.8)	520 (14)	160 (4.4)

Material	No. of observations	Mean radioactivity concentration (wet)*, mBq g^{-1} (pCi g^{-1})				
		^{137}Cs	^{144}Ce	^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am
Flounder	3	630 (17)	ND	NA	NA	NA
Shrimps	3	230 (6.3)	"	"	"	"
Cockles	3	160 (4.3)	2.1 (0.06)	"	"	"
Fucus vesiculosus	4	440 (12)	ND	"	"	"
Silt	4	1 300 (35)	180 (4.8)	21 (0.57)	93 (2.5)	140 (3.7)

Mean gamma dose rate in air at 1 m over intertidal sand (8 observations):

0.16 μGy h^{-1} (16 μrad h^{-1})

NA = not analysed.
ND = not detected.
*Except for silt for which dry concentrations apply.

6.5 Heysham, Lancashire

This twin-AGR station is also under construction at present. Monitoring has begun by FRL for similar reasons as for the station at Hartlepool; in addition, information on radiation exposures and on the distribution of a range of radionuclides as a result of Windscale discharges is to be gained. The potential critical radiation exposure pathways from future liquid radioactive discharges from Heysham are judged to be internal irradiation following consumption of locally-caught fish and shellfish (mainly shrimps and cockles), and external exposure from occupancy of intertidal areas. The FRL monitoring programme includes analyses of fish and shellfish, and measurements of beach gamma dose rates. Samples of sediment are also analysed, and *Fucus vesiculosus* is monitored as an indicator material. The results for 1977 are given in Table 24. These mainly reflect discharges from Windscale; it is unlikely that the effect of future discharges from Heysham will be detectable above the Windscale-derived background. Estimates of the radiation exposure in 1977 of members of the critical group of fish and shellfish consumers associated with commercial fisheries (which include the Morecambe Bay area) were given in section 4.1.1. External exposure of members of the public was at most 1% of the ICRP-recommended dose limit.

Table 25 Radioactivity in environmental materials and gamma dose rates near Hinkley Point nuclear power station, 1977

Material	No. of observations	Mean radioactivity concentration (wet)*, mBq g^{-1} (pCi g^{-1})				
		Total beta	^{95}Zr + ^{95}Nb	^{106}Ru	^{134}Cs	^{137}Cs
Flatfish	3	110 (3.0)	ND	ND	0.33 (0.01)	5.2 (0.14)
Shrimps	3	120 (3.1)	"	"	1.0 (0.03)	4.4 (0.12)
Fucus vesiculosus						
Outfall	2	330 (8.8)	5.2 (0.14)	17 (0.46)	4.8 (0.13)	18 (0.48)
Elsewhere	6	320 (8.6)	ND	2.7 (0.07)	2.4 (0.06)	7.4 (0.20)
Mud	2	1 500 (41)	"	74 (2.0)	41 (1.1)	160 (4.4)

Material	No. of observations	Mean radioactivity concentration (wet)*, mBq g^{-1} (pCi g^{-1})			
		^{144}Ce	^{238}Pu	^{239}Pu + ^{240}Pu	^{241}Am
Flatfish	3	ND	NA	NA	NA
Shrimps	3	"	0.0066 (0.00018)	0.013 (0.00036)	0.019 (0.00052)
Fucus vesiculosus					
Outfall	2	1.0 (0.028)	NA	NA	NA
Elsewhere	6	ND	"	"	"
Mud	2	150 (4.0)	"	"	"

Mean gamma dose rate in air at 1 m over intertidal mud (6 observations): 0.077 μGy h^{-1} (7.7 μrad h^{-1})

NA = not analysed.
ND = not detected.
*Except for mud where dry concentrations apply.

6.6 Hinkley Point, Somerset

At this establishment there are two, essentially separate "A" and "B" nuclear power stations; the "A" station is powered by magnox-type reactors and the "B" station, which has been operational since 1976, by AGRs. Liquid radioactive discharges are made via the same outfall and for the purposes of FRL environmental monitoring are considered together. There are two critical radiation exposure pathways associated with liquid radioactive waste discharges. Consumption of locally-caught fish and shrimps gives rise to internal irradiation, while external exposure results from occupancy of the foreshore. The FRL monitoring programme includes analyses of locally-caught fish (of which plaice and flounder for 1977 have been grouped together as flatfish) and of shrimps. External exposure is monitored by means of gamma dose rate measurements, supported by analyses of mud. In addition, *Fucus vesiculosus* is monitored as an indicator.

The results for 1977, presented in Table 25, indicate concentrations of radiocaesium representing the combined effect of discharges from the station and from Windscale, in addition to fallout. Apportionment is difficult in view of the low levels detected. The total radiation exposure of members of the critical group through this pathway was low, at less than 0.2% of the ICRP-recommended dose limit. The concentrations in shrimps of transuranic nuclides from the station and from Windscale were of negligible radiological significance. Gamma radiation dose rates over the mud flats close to the station were indistinguishable from the natural background. Small quantities of fission products due to discharges from the station could be detected in mud and *Fucus vesiculosus*. The effects of the discharges may be observed in radioactivity concentrations in this seaweed from close to the outfall as compared with values in weed obtained some distance away; the results were of no radiological significance. No effect attributable to "B" station operation was observed.

6.7 Hunterston, Ayrshire

This establishment also comprises "A" and "B" stations, of which the latter is power by AGRs. Liquid radioactive waste discharges are made under authorisation of the Scottish Development Department to the Firth of Clyde. There are two critical radiation exposure pathways, of fish and shellfish (mainly winkle) consumption leading to internal irradiation, and occupancy of intertidal areas leading to external exposure. FRL regularly monitors, on behalf of departments of the Scottish Office, samples of fish and winkles, and carries out gamma dose rate measurements on the foreshore. Samples of sand are analysed, together with limpets and *Fucus spiralis* as indicators. The results of monitoring in 1977 are shown in Table 26.

The concentrations of artificial radioactivity in this area are predominantly due to Windscale discharges, the general values being consistent with those to be expected at this distance from Windscale. However, the resulting public radiation exposure in 1977 was low, at less than 2% of the ICRP-recommended dose limit to members of the critical group of fish and shellfish consumers. The effects of Hunterston discharges were not observable above the prevailing background; the magnitude of the local discharges indicate that the stations' contribution would have been a small fraction of this exposure.

6.8 Sizewell, Suffolk

FRL monitoring near this station reflects the two critical radiation exposure pathways of fish and shellfish consumption leading to internal irradiation, and of occupancy of intertidal areas giving rise to external exposure. Shellfish were not sampled in 1977, but their concentrations of caesium–137 as the nuclide of main radiological significance here are likely to be similar to the values measured in skate, which was the species of fish sampled. Gamma dose rates were also measured over sandy intertidal areas, where dose rates may be expected to be higher than on the rest of the beach which is mainly shingle. Results for 1977 are shown in Table 27.

The caesium–137 concentration in fish represents the combined effect of discharges from the station and from Windscale, as well as of fallout. Apportionment is difficult in view of the low levels detected. The total radiation exposure to local consumers was low, at less than 0.2% of the ICRP-recommended dose limit. Gamma dose rates continued to be indistinguishable above the natural background.

6.9 Trawsfynydd, Gwynedd

Discharges from this station are made to the freshwater Lake Trawsfynydd, and because of the limited volume flow for dispersion are of greater radiological significance than those from the other UK nuclear power stations which discharge to estuarine or coastal waters. The critical radiation exposure pathway here is from consumption of fish caught in the lake, leading to internal irradiation; the important nuclides are those of radiocaesium and, to a lesser extent, strontium–90. Species of fish in the lake include the indigenous brown trout, perch and, more recently, rudd; the lake is also regularly stocked with hatchery-reared rainbow trout. The last of these species now accounts for the highest consumption rates but, because artifical radioactivity concentrations in rainbow trout are considerably lower than in indigenous fish as a result of the limited time spent in the lake, consumption of brown trout still accounts for a large proportion of the radiation exposure. Perch are also consumed, but at still lower rates; rudd are hardly eaten, if at all. FRL regularly analyses samples of each of these fish. As part of FRL's research programme, mud and peat from the lake bed are

Table 26 Radioactivity in environmental materials and gamma dose rates near Hunterston nuclear power station, 1977

Material	No. of observations	Mean radioactivity concentration (wet)*, mBq g^{-1} (pCi g^{-1})					
		Total beta	^{60}Co	$^{95}Zr + ^{95}Nb$	^{106}Ru	^{134}Cs	^{137}Cs
Fish	5	NA	ND	ND	ND	6.7 (0.18)	69 (1.9)
Cockles	4	96 (2.6)	"	"	"	3.8 (0.10)	27 (0.73)
Winkles	4	560 (15)	1.0 (0.03)	"	140 (3.7)	14 (0.38)	66 (1.8)
Limpets	3	520 (14)	ND	"	120 (3.1)	14 (0.37)	74 (2.0)
Fucus spiralis	4	480 (13)	2.4 (0.06)	2.3 (0.06)	17 (0.45)	26 (0.71)	130 (3.6)
Sand	4	670 (18)	0.2 (0.01)	ND	4.4 (0.12)	7.8 (0.21)	59 (1.6)

Material	No. of observations	Mean radioactivity concentration (wet)*, mBq g^{-1} (pCi g^{-1})			
		^{144}Ce	^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am
Fish	5	ND	0.00024 (0.000006)	0.0013 (0.000035)	0.00048 (0.000013)
Cockles	4	"	NA	NA	NA
Winkles	4	"	"	"	"
Limpets	3	1.8 (0.05)	"	"	"
Fucus spiralis	4	ND	"	"	"
Sand	4	14 (0.39)	"	"	"

Mean gamma dose rate in air at 1 m over intertidal sand (4 observations): 0.12 µGy h^{-1} (12 µrad h^{-1})

NA = not analysed.
ND = not detected.
*Except for sand where dry concentrations apply.

Table 27 Radioactivity in environmental materials and gamma dose rates near Sizewell nuclear power station, 1977

Material	No. of observations	Mean radioactivity concentration (wet), mBq g^{-1} (pCi g^{-1})	
		Total beta	^{137}Cs
Skate	1	78 (2.1)	5.3 (0.14)

Mean gamma dose rate in air at 1 m over intertidal sand (10 observations): 0.037 µGy h^{-1} (3.7 µrad h^{-1})

also analysed; these materials contribute to the fishes' diet. Additional information is gained from analyses of the moss *Fontinalis* which is a sensitive indicator for a number of radionuclides, and from analyses of lake water. The results of these measurements for 1977 are shown in Table 28.

As compared with 1976, radiocaesium concentrations in fish showed a small increase (from 1 800 mBq g^{-1} (48 pCi g^{-1}) for ^{137}Cs in brown trout) despite the reduction in discharges for 1977 and the presence of a larger volume of lake water since the drought conditions of 1976. This

Table 28 Radioactivity in environmental materials near Trawsfynydd nuclear power station, 1977

Material	No. of observations	Mean radioactivity concentration (wet)*, mBq g^{-1} (pCi g^{-1})					
		Total beta	^{60}Co	^{90}Sr	^{95}Zr + ^{95}Nb	^{106}Ru	^{125}Sb
Rainbow trout	1	NA	ND	NA	ND	ND	ND
Brown trout	24	1 900 (52)	"	"	"	"	"
Perch	13	3 400 (93)	"	"	"	"	"
Rudd	16	1 600 (44)	"	"	"	"	"
Mud	3	3 900 (110)	11 (0.29)	"	"	"	1 000 (28)
Peat	3	3 100 (83)	7.8 (0.21)	"	"	"	1 000 (27)
Fontinalis							
Afon Prysor	4	290 (7.8)	ND	"	34 (0.91)	44 (1.2)	ND
Gwylan Stream	4	3 700 (100)	89 (2.4)	"	41 (1.1)	59 (1.6)	1 100 (29)
Water							
Hot Lagoon	12	NA	NA	0.99 (0.027)	NA	NA	NA
Cold Lagoon	12	"	"	0.97 (0.026)	"	"	"

Material	No. of observations	Mean radioactivity concentration (wet)*, mBq g^{-1} (pCi g^{-1})				
		^{134}Cs	^{137}Cs	^{144}Ce	^{239}Pu + ^{240}Pu	^{241}Am
Rainbow trout	1	2.0 (0.05)	22 (0.60)	ND	NA	NA
Brown trout	24	310 (8.3)	2 300 (61)	"	0.0063 (0.00017)	0.0067 (0.00018)
Perch	13	480 (13)	3 700 (100)	"	0.0069 (0.00019)	0.0048 (0.00013)
Rudd	16	220 (5.8)	1 700 (46)	"	0.0043 (0.00012)	0.0052 (0.00014)
Mud	3	110 (2.9)	1 700 (46)	"	NA	NA
Peat	3	30 (0.81)	480 (13)	"	"	"
Fontinalis						
Afon Prysor	4	ND	3.8 (0.10)	24 (0.66)	"	"
Gwylan Stream	4	44 (1.2)	520 (14)	250 (6.8)	"	"
Water						
Hot Lagoon	12	0.10 (0.0028)	0.74 (0.020)	ND	"	"
Cold Lagoon	12	0.10 (0.0028)	0.74 (0.020)	"	"	"

NA = not analysed.
ND = not detected.
*Except mud and peat for which dry concentrations apply.

observation may be explained on the basis of the delay to be expected before equilibrium is established between caesium in lake water and in fish. It is to be noted that concentrations of radiocaesium in lake water had reduced by about 40% since 1976.

The estimate of radiation exposure in 1977 of the members of the critical group of fish consumers is based on revised data on consumption rates, supplemented by values for recorded catches of the different fish species. It is estimated that members of the critical group received 3% of the ICRP-recommended dose limit in 1977. The reduction from the estimate of 21% for 1976, despite the small increase in activity concentrations in fish noted above, reflects the substantial reduction in the proportion of brown trout consumed since local habits were last surveyed. Consumption data will continue to be kept under review, however, in case the rates for indigenous fish should return to their former levels.

6.10 Wylfa, Gwynedd

Liquid radioactive wastes from this station are discharged to the Irish Sea. Monitoring is carried out by FRL in respect of the two critical pathways, of local fish and shellfish consumption leading to internal irradiation and of occupancy of intertidal areas resulting in external exposure. Pollack is sampled as representative of locally-caught fish: for shellfish the appropriate species are lobster, crab and winkles. Gamma dose rate measurements over intertidal mud are carried out and, in support, samples of mud are analysed. The indicator seaweed *Fucus vesiculosus* is also sampled. The results of monitoring in 1977 are presented in Table 29.

The effects of discharges from this station are masked by Windscale-derived radioactivity. Concentrations of artificial radionuclides in environmental materials were consistent with those to be expected at this distance from Windscale. The total radiation exposure of members of the critical group in 1977 was less than 3% of the ICRP-recommended dose limit. The magnitude of discharges from the station indicate that the local contribution will have been a small fraction of this.

7. Naval establishments

Liquid wastes containing relatively small quantities of radioactivity are discharged from the following establishments: Chatham, Devonport, Faslane and Rosyth, all of which are operated by the Ministry of Defence (Navy Department). The US naval base at Holy Loch also discharges small quantities of radioactive waste. Monitoring of the effects of all these discharges is carried out by FRL, in the case of Faslane and Rosyth on behalf of departments of the Scottish Office.

The critical pathway for public radiation exposure due to these discharges is via external exposure from occupancy of intertidal areas, the nuclide of main importance being cobalt–60. FRL therefore regularly carries out measurements of gamma dose rates; these are supported by analyses of sediments. Indicator seaweeds are also analysed. Results of monitoring in 1977 are presented in Table 30. The small concentrations of cobalt–60 mainly reflect discharges from the establishments; levels of other artificial nuclides are largely due to fallout and to discharges from Windscale. Gamma dose rates over intertidal sediments in 1977 remained indistinguishable from the natural background, such that public radiation exposure was very low, at less than 0.1% of the ICRP-recommended dose limit.

Table 29 Radioactivity in environmental materials and gamma dose rates near Wylfa nuclear power station, 1977

Material	No. of observations	Mean radioactivity concentration (wet)*, mBq g^{-1} (pCi g^{-1})						
		Total beta	^{106}Ru	^{134}Cs	^{137}Cs	^{238}Pu	$^{239}Pu + ^{240}Pu$	^{241}Am
Pollack	3	340 (9.1)	ND	20 (0.55)	170 (4.7)	NA	NA	NA
Lobster	1	170 (4.5)	"	4.8 (0.13)	37 (0.99)	"	"	"
Crab	1	130 (3.4)	"	3.0 (0.082)	27 (0.72)	"	"	"
Winkles	3	170 (4.6)	18 (0.48)	2.0 (0.053)	26 (0.71)	"	"	"
Fucus vesiculosus	5	440 (12)	ND	6.7 (0.18)	56 (1.5)	"	"	"
Mud	3	2 400 (65)	"	140 (3.8)	1 200 (33)	10 (0.27)	42 (1.1)	45 (1.2)

Mean gamma dose rate in air at 1 m over intertidal mud (8 observations): 0.12 μGy h^{-1} (12 μrad h^{-1})

NA = not analysed.
ND = not detected.
*Except for mud where dry concentrations apply.

Table 30 Radioactivity in environmental materials and gamma dose rates near naval establishments, 1977

Establishment	Material	No. of observations	Mean radioactivity concentration (wet)*, mBq g^{-1} (pCi g^{-1})			
			Total beta	^{54}Mn	^{60}Co	$^{95}Zr + ^{95}Nb$
Chatham	Sediment	6	1 000 (27)	4.4 (0.12)	18 (0.50)	26 (0.71)
Devonport	Sediment	6	960 (26)	2.8 (0.08)	2.1 (0.06)	27 (0.73)
	Winkles	2	130 (3.5)	ND	ND	ND
	Fucus vesiculosus	2	220 (6.0)	"	"	"
Faslane	Sediment	4	1 600 (42)	7.5 (0.20)	2.9 (0.08)	"
Rosyth	Sediment	1	590 (16)	0.92 (0.03)	ND	"
Holy Loch	Sediment	3	1 100 (29)	2.7 (0.07)	8.5 (0.23)	14 (0.37)
	Fucus spiralis	4	280 (7.5)	ND	ND	ND

Establishment	Material	No. of observations	Mean radioactivity concentration (wet)*, mBq g^{-1} (pCi g^{-1})			Mean gamma dose rate in air at 1 m	
			^{134}Cs	^{137}Cs	^{144}Ce	μGy h^{-1}	μrad h^{-1}
Chatham	Sediment	6	1.4 (0.04)	41 (1.1)	3.9 (0.11)	0.071	7.1
Devonport	Sediment	6	ND	11 (0.30)	8.3 (0.22)	0.087	8.7
	Winkles	2	"	1.6 (0.04)	ND	NA	NA
	Fucus vesiculosus	2	"	ND	"	NA	NA
Faslane	Sediment	4	35 (0.94)	320 (8.7)	"	0.096	9.6
Rosyth	Sediment	1	ND	8.1 (0.22)	"	0.10	10
Holy Loch	Sediment	3	"	59 (1.6)	11 (0.31)	0.10	10
	Fucus spiralis	4	12 (0.32)	100 (2.7)	ND	NA	NA

NA = not applicable.
ND = not detected.
*Except for sediment where dry concentrations apply.

8. Channel Islands monitoring

FRL has continued to analyse marine environmental samples provided by the Channel Islands States in surveillance of the effects of radioactive liquid discharges from the French reprocessing plant at Cap de la Hague. Fish and shellfish are monitored in relation to the internal irradiation pathway; sediment is analysed with relevance to external exposures. *Porphyra* is sampled as an indicator, particularly of ruthenium–106. The results for 1977 are given in Table 31. Concentrations of ^{137}Cs in fish and shellfish were not significantly in excess of those to be expected from fallout. However, the presence of transuranics in fish and shellfish, and of ruthenium–106 in shellfish, may be attributed to discharges from the plant at Cap de la Hague. The presence of ruthenium–106 may be more clearly observed in *Porphyra*. However, the concentrations of artificial radionuclides in each of these materials were of negligible radiological significance.

9. Summary and conclusions

A summary of estimated public radiation exposures in 1977 resulting from liquid radioactive waste discharges from nuclear establishments monitored by FRL, is presented in Table 32. The exposures are expressed in terms of the dose equivalent to members of the critical group or groups as percentages of the ICRP dose equivalent limit. For each of the exposures given, there is no substantial difference between results estimated on the basis of either ICRP Publication 9 or ICRP Publication 26 recommendations (ICRP, 1966; ICRP, 1977); if there is a difference, the higher value has been quoted.

All exposures were well within the ICRP-recommended limits. Discharges from Windscale have, as in previous years, given rise to the highest exposures. The most important contribution to this exposure was from radiocaesium which originated mainly from the fuel element storage ponds. The

Table 31 Radioactivity in marine environmental materials from the Channel Islands, 1977

Material	Sampling area		No. of observa-tions	Mean radioactivity concentration (wet)*, mBq g^{-1} (pCi g^{-1})				
				Total beta	$^{95}Zr + {}^{95}Nb$	^{106}Ru	^{137}Cs	^{144}Ce
Porphyra	Guernsey	Fort Doyle	4	220 (6.0)	1.6 (0.04)	13 (0.35)	ND	ND
		Fermain Bay	4	200 (5.4)	4.1 (0.11)	18 (0.49)	"	"
	Alderney	Telegraph Bay	2	330 (9.0)	ND	37 (1.0)	1.3 (0.04)	"
		Quenard Point	2	322 (8.7)	"	170 (4.6)	6.7 (0.18)	"
		Braye	2	260 (7.0)	13 (0.36)	48 (1.3)	ND	"
	Jersey	Greve de Lecq	4	260 (6.9)	4.4 (0.12)	30 (0.80)	"	"
		La Rozel	3	220 (5.9)	3.7 (0.10)	13 (0.34)	"	"
Ormers	Guernsey		1	120 (3.2)	ND	11 (0.31)	1.0 (0.03)	"
Skate	Guernsey		1	120 (3.3)	"	ND	1.5 (0.04)	"
Sediment	Jersey	St Helier	1	1 100 (31)	"	59 (1.6)	6.3 (0.17)	37 (1.0)
	Guernsey	Bordeaux Harbour	1	670 (18)	"	4.4 (0.12)	6.7 (0.18)	7.4 (0.20)

Material	Sampling area		No. of observa-tions	Mean radioactivity concentration (wet)*, mBq g^{-1} (pCi g^{-1})		
				^{238}Pu	$^{239}Pu + {}^{240}Pu$	^{241}Am
Porphyra	Guernsey	Fort Doyle	4	NA	NA	NA
		Fermain Bay	4	"	"	"
	Alderney	Telegraph Bay	2	"	"	"
		Quenard Point	2	"	"	"
		Braye	2	"	"	"
	Jersey	Greve de Lecq	4	"	"	"
		La Rozel	3	"	"	"
Ormers	Guernsey		1	0.010 (0.00028)	0.038 (0.0010)	0.015 (0.00040)
Skate	Guernsey		1	0.0019 (0.000050)	0.0078 (0.00021)	0.0087 (0.00024)
Sediment	Jersey	St Helier	1	NA	NA	NA
	Guernsey	Bordeaux Harbour	1	"	"	"

NA = not analysed.
ND = not detected.
*Except for sediment where dry concentrations apply.

reduction in 1977 to 31%, from the 1976 estimate of 44%, of the ICRP-recommended dose limit to the maximum local fish and shellfish consumer may be explained in terms of changes in dispersion in 1977; discharges of radiocaesium did not decrease. Contributions to exposures near many other nuclear establishments were also caused by radioactivity from Windscale. Since apportionment of exposure to radioactivity of local origin is often difficult, the exposure from all sources (including the small contribution due to fallout) is quoted in Table 32, with an appropriate footnote.

With the exception of Trawsfynydd, exposures near to nuclear establishments besides Windscale which were greater than 1% of the ICRP-recommended dose limit were also caused mainly by Windscale-derived radioactivity. Discharges from Trawsfynydd nuclear power station gave rise to doses to the critical group of fish consumers at a rate of 3% of the ICRP-recommended dose limit.

As in previous years, collective doses from UK liquid radioactive discharges have been considered. The most significant discharges giving rise to collective dose, compared with

Table 32 Summarised estimates of public radiation exposure from discharges of liquid radioactive waste in the UK, 1977

Establishment	Radiation exposure pathway	Critical group	Exposure[1] of individual members of critical group, 1977 (% of ICRP-recommended dose limit of 5 mSv y^{-1} (0.5 rem y^{-1}))
BRITISH NUCLEAR FUELS LIMITED			
Windscale and Calder	Fish and shellfish consumption	Local fishing community Commercial fishing community	31[2] 13
	External	Occupiers of intertidal areas	4.2[2]
	Porphyra/laverbread consumption	Consumers in South Wales	<0.2
Springfields	External	Dredgermen	2[3]
Capenhurst[5] (Meols outfall)	Shellfish consumption	Local fishing community	NA
Chapelcross	External Fish and shellfish consumption	Fishermen	<4[3]
UNITED KINGDOM ATOMIC ENERGY AUTHORITY			
Winfrith	Fish and shellfish consumption	Local fishing community	<0.2
Dounreay	External to hands: fishing gear External	Local fishermen Winkle pickers	<1[4] <1[4]
NUCLEAR POWER STATIONS OPERATED BY THE ELECTRICITY BOARDS			
Berkeley and Oldbury	Fish and shellfish consumption External	Local fishing community	<0.1[4]
Bradwell	Fish consumption	Local fishing community	<0.3[4]
Dungeness	Fish consumption External	Local fishing community	<0.1
Hartlepool[5]	Fish and shellfish consumption External	Local fishing community Coal collectors	NA
Heysham[5]	Fish and shellfish consumption External	Local fishing community	NA
Hinkley Point	Fish and shellfish consumption External	Local fishing community	<0.2[4]
Hunterston	Fish and shellfish consumption External	Local fishing community	<2[3]
Sizewell	Fish and shellfish consumption External	Local fishing community	<0.2[4]
Trawsfynydd	Fish consumption	Local fishing community	3
Wylfa	Fish and shellfish consumption External	Local fishing community	<3[3]
NAVAL ESTABLISHMENTS			
Chatham	External	Houseboat dwellers	<0.1
Devonport	External	Bait diggers	<0.1
Faslane	External	Boatyard workers	<0.1[4]
Rosyth	External	Dredgermen	<0.1[4]
Holy Loch	External	General public	<0.1[4]

NA = not applicable.
[1]On the basis of the higher of ICRP-9 (1966) or ICRP-26 (1977) procedures (see text).
[2]Based on extreme individual; see relevant section in text.
[3]Mainly due to discharges from Windscale.
[4]Partly due to discharges from Windscale.
[5]No radioactive discharges made in 1977; potential critical pathways given, but no result for exposure quoted.

which all other discharges may be disregarded, were those from Windscale, radiocaesium being the most significant component. Details were given in section 4.1.1. The collective dose to the UK population in 1977 was 89 man-Sv (8900 man-rem) as compared with 140 man-Sv (14 000 man-rem) in 1976. As before, the decrease was mainly due to different dispersion conditions rather than reductions in discharges.

An estimate is also given of the collective dose (small by comparison with the above) resulting from consumption of tritium in water derived from the River Thames, to whose catchment area discharges are made. In 1977 the estimated 7 million people who depend on this source of water received a total of approximately 1 man-Sv (100 man-rem), corresponding to less than 0.01% of the UK policy limit (Great Britain – Parliament, 1959) (see Section 3.4). The reduction from approximately 2 man-Sv (200 man-rem) for 1976 (Mitchell, 1978) is explained by the increase in mean flow rate of the Thames during 1977 compared with that during the drought conditions in 1976.

10. References

ADAMS, N., HUNT, B.W. and REISSLAND, J.A., 1978. Annual limits of intake of radionuclides for workers. HMSO, London, 42pp. (National Radiological Protection Board, Report NRPB-R82)

BRITISH COMMITTEE ON RADIATION UNITS and MEASUREMENTS, 1978. Draft recommendations on the introduction of the new SI Units for use with radioactivity and ionising radiations. National Physical Laboratory, Teddington, 8pp.

COMMISSION OF THE EUROPEAN COMMUNITIES, 1976. Council directive of 1 June 1976 laying down the revised basic safety standards for the health protection of the general public and workers against the dangers of ionising radiation. Off. J. Eur. Commun., 19 (L 187) 1–2.

DEPARTMENT OF THE ENVIRONMENT, SCOTTISH OFFICE and WELSH OFFICE, 1978. Annual survey of radioactive discharges in Great Britain, 1977. DOE, London, 42pp.

DUTTON, J.W.R., 1968. Gross beta counting of environmental materials. Tech. Rep. Fish. Radiobiol. Lab., MAFF Direct. Fish. Res., Lowestoft (FRL) (3) 13pp.

DUTTON, J.W.R., 1969. Gamma-spectrometric analysis of environmental materials. Tech. Rep. Fish. Radiobiol. Lab., MAFF Direct. Fish. Res., Lowestoft (FRL) (4) 18pp.

FLEW, E.M., 1978. Radioactive waste disposal by UKAEA establishments during 1977 and associated environmental monitoring results. Atomic Energy Research Establishment, Harwell, 24pp. (UKAEA/AERE-R 9049)

GREAT BRITAIN – PARLIAMENT, 1959 The Control of Radioactive Wastes. HMSO, London, 46pp. (Cmnd 884)

GREAT BRITAIN – PARLIAMENT, 1960. Radioactive Substances Act, 1960. HMSO, London, 28pp.

GREAT BRITAIN – PARLIAMENT, 1977. Nuclear Power and the Environment. HMSO, London, 21pp. (Cmnd 6820)

INTERNATIONAL ATOMIC ENERGY AGENCY, 1967. Basic safety standards for radiation protection. Saf. Ser. Int. Atom. En. Ag., (9) 79pp.

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1959. Report of Committee II on permissible dose for internal radiation. Pergamon Press, Oxford, 233pp. (ICRP, Publ. (2)).

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1966. Recommendations of The International Commission on Radiological Protection. Pergamon Press, Oxford, 27pp. (ICRP, Publ. (9)).

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1977. Recommendations of the International Commission on Radiological Protection. (Annal. ICRP 1 (3)). Pergamon Press, Oxford, 53pp. (ICRP, Publ. (26)).

MEDICAL RESEARCH COUNCIL, 1975. Criteria for controlling radiation doses to the public after an accidental escape of radioactive material. HMSO, London, 48pp.

MITCHELL, N.T., 1977. Radioactivity in surface and coastal waters of the British Isles, 1976. Part I: The Irish Sea and its environs. Tech. Rep. Fish. Radiobiol. Lab., MAFF Direct. Fish. Res., Lowestoft, (FRL) (13) 15pp.

MITCHELL, N.T., 1978. Radioactivity in surface and coastal waters of the British Isles, 1976. Part II: Areas other than The Irish Sea and its environs. Tech. Rep. Fish. Radiobiol. Lab., MAFF Direct. Fish. Res., Lowestoft, (FRL) (14) 20pp.

NATIONAL RADIOLOGICAL PROTECTION BOARD, 1978. Recommendations of The International Commission on Radiological Protection (ICRP Publication 26): statement by the National Radiological Protection Board on their acceptability in The U.K. HMSO, London, 2pp. (NRPB-ASP 1)

ROYAL COMMISSION ON ENVIRONMENTAL POLLUTION, 1976. Nuclear Power and the Environment, 6th Report of the Commission. HMSO, London, 237pp. (Cmnd 6618)

TAYLOR, F.E. and WEBB, G.A.M., 1978. Radiation exposure of the U.K. population. HMSO, London, 86pp. (National Radiological Protection Board, Report NRPB R–77)