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RADIOACTIVITY IN SURFACE AND COASTAL WATERS OF THE BRITISH ISLES 1975

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FOREWORD

This is a further report in the series of Technical Reports on monitoring of the aquatic environment published by the Ministry of Agriculture, Fisheries and Food and summarizes the work done in 1975 within its Directorate of Fisheries Research by the Fisheries Radiobiological Laboratory in surveillance of the environmental consequences of disposal of liquid radioactive wastes. Most of the information published here has been produced to meet the Ministry's own statutory responsibilities in England and Wales. However, since the laboratory has continued to undertake similar monitoring on behalf of departments of the Scottish Office, the Channel Islands States and Ireland, the opportunity has been taken, with their agreement, to include summaries of these data and thus provide a comprehensive account of the state of the aquatic environment of the whole of the British Isles as regards radioactivity from major discharges of liquid radioactive waste.

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1. INTRODUCTION

The establishments from which these major discharges are made are listed in Tables 1 and 2 and comprise sites of British Nuclear Fuels Ltd (BNFL), the United Kingdom Atomic Energy Authority, The Radiochemical Centre and the Ministry of Defence, as well as nuclear power stations operated by the Central Electricity Generating Board and the South of Scotland Electricity Board. Much of the environmental data in this report is the direct result of the Fisheries Radiobiological Laboratory's (FRL) control monitoring activities in relation to these discharges - that is monitoring to verify that public radiation exposure from them remains within the prescribed limits laid down within national policy (Ref. 1). As such it is independent of the often similar environmental monitoring done by the operators as a condition of their authorizations. It is supplemented by some of the results of the Laboratory's extensive programme of environmental research where summaries of these data can be useful in providing a more comprehensive account of the situations being described.

2. DISCHARGES OF RADIOACTIVE WASTE

Although not essential to the basic purpose of these reports it has become customary to include data on discharges to give scale and perspective to the discussion of environmental data. Table 2 shows the amounts of radioactivity discharged during 1975 as a proportion of the limits set by authorization or interdepartmental agreement. These limits are generally lower (often very much lower) than the amounts which could be permitted without exceeding the dose limits recommended by the International Commission on Radiological Protection (ICRP) and embodied in national policy. In most entries in Table 2 discharges have been rounded off to the nearest curie and percentages to the nearest 1%.

In addition to receiving most of the liquid waste discharged by the major nuclear establishments in the UK, the marine environment also receives a quantity of low specific activity solid waste - to the deep Atlantic Ocean about 600 miles south-west of Land's End and not within coastal waters. Following previous practice the 1975 operation was carried out under the auspices of the Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development (OECD) and included waste from a number of other West European countries. Dumping of the UK solid waste, which came from several establishments, was coordinated by the Atomic Energy Research Establishment (AERE), Harwell according to the conditions laid down by this Ministry in addition to the overall surveillance of the NEA. The waste was dumped during July within an area defined by a circle of radius 35 nautical miles centred on the coordinates 46°15'N 17°25'W. The UK waste totalled 2 160 drums of 1 350 tonnes gross weight, and contained 704 Ci alpha-active material and 52 481 Ci of beta/gamma activity, much of it tritium or other low energy radionuclides.

An additional item for this 1975 report is information on Capenhurst, where fuel enrichment operations are carried out by BNFL (see Table 2). Data have not been included in previous reports because discharges are very small; indeed so small and with so negligible an environmental consequence that no environmental monitoring is necessary.

Table 1 Principal exposure pathways from the discharge of liquid radioactive wastes

Site	Critical material	Critical exposure category	Principal exposed group
BRITISH NUCLEAR FUELS LIMITED			
Windscale	Fish flesh	Beta/gamma dose to whole body	Fishermen
	Estuarine sediment	External gamma dose to whole body	Fishermen
	Porphyra/laverbread	Beta dose to GI tract*	General public (South Wales)
Springfields	Estuarine sediment	Gamma dose to whole body	Dredgermen
Chapelcross	Shrimp flesh	Beta/gamma dose to whole body	Local fishermen and families
	Estuarine sediment	Gamma dose to whole body	Salmon fishermen
UNITED KINGDOM ATOMIC ENERGY AUTHORITY			
Winfrith	Fish and shellfish	Beta dose to GI tract*	Local fishermen and families
Harwell	Drinking water	Beta/gamma dose to whole body (somatic and genetic hazard)	General public (Greater London)
Dounreay	Detritus associated with fishing gear	Beta dose to hands	Local fishermen
	Beach sludge	Gamma dose to whole body	Local fishermen and others
THE RADIOCHEMICAL CENTRE LIMITED			
Amersham	Drinking water	Beta/gamma dose to whole body (somatic and genetic hazard)	General public (Greater London)
CENTRAL ELECTRICITY GENERATING BOARD AND SOUTH OF SCOTLAND ELECTRICITY BOARD			
Berkeley	Estuarine sediment	Gamma dose to whole body	Salmon fishermen/river authority workers
	Shrimp and salmon flesh	Beta/gamma dose to whole body	Local fishermen and families
Bradwell	Oyster flesh	Gamma dose to whole body	Oyster fishermen and families
Dungeness	Fish flesh	Beta/gamma dose to whole body	Local fishermen and families
	Beach sediment	Gamma dose to whole body	Bait diggers
Hinkley Point	Fish and shrimp flesh	Beta/gamma dose to whole body	Local fishermen and families
	Beach sediment	Gamma dose to whole body	Local fishermen
Oldbury	Estuarine sediment	Gamma dose to whole body	Salmon fishermen/river authority workers
	Shrimp and salmon flesh	Beta/gamma dose to whole body	Local fishermen and families
Sizewell	Fish and shellfish flesh	Beta/gamma dose to whole body	Local fishermen and families
	Beach sediment	Gamma dose to whole body	Local fishermen
Trawsfynydd	Trout flesh	Beta/gamma dose to whole body	Local fishermen and families
Wylfa	Fish and shellfish flesh	Beta/gamma dose to whole body	Local fishermen and families
	Beach sediment	Gamma dose to whole body	Local fishermen
Hunterston	Fish flesh	Beta/gamma dose to whole body	Local fishermen and families
	Beach sediment	Gamma dose to whole body	Shellfish collectors
NAVAL ESTABLISHMENTS			
Chatham	Estuarine sediment	Gamma dose to whole body	General public (houseboat dwellers)
Devonport	Estuarine sediment	Gamma dose to whole body	General public
Faslane	Foreshore sediment	Gamma dose to whole body	Boatyard workers
Rosyth	Estuarine sediment	Gamma dose to whole body	Dredgermen
Holy Loch	Estuarine sediment	Gamma dose to whole body	General public
MINISTRY OF DEFENCE (PROCUREMENT EXECUTIVE)			
Aldermaston	Drinking water	Beta/gamma dose to whole body (somatic and genetic hazard)	General public (Greater London)

*Gastro-intestinal tract.

Table 2 Major discharges of liquid radioactive waste to surface and coastal waters during 1975

Site	Radioactivity	Authorized(1) discharge, curies/year	Discharge	
			In 1975, curies	As % of authorized limit
Windscale	Total beta	300 000*	245 151	82
	Ruthenium-106	60 000*	20 560	34
	Strontium-90	30 000*	12 635	42
	Total alpha	6 000	2 309	38
Springfields	Total alpha	360	52	14
	Total beta	12 000*	2 154	18
Chapelcross	Total activity†	700	17	2
	Tritium	150	7	5
Capenhurst	Total activity‡	0.04	0.018	46
Winfrith	Total activity	30 000*	1 436	5
	Ruthenium-106	9 000*	4	< 1
	Strontium-90	1 200*	6	< 1
	Total alpha	1 200*	2	< 1
Harwell	Total activity†(2)	240*	39	16
	Tritium	240*	98	41
Dounreay	Total alpha	240*	23	10
	Total activity	24 000*	5 540	23
	Strontium-90	2 400*	541	22
Amersham	Total activity†(2)	72*	20	28
	Tritium	400*	301	75
Berkeley	Total activity†	200	54	27
	Tritium	1 500	71	5
Bradwell	Total activity†	200	119	60
	Zinc-65	5	0.1	2
	Tritium	1 500	89	6
Dungeness	Total activity†	200	80	40
	Tritium	2 000	25	1
Hinkley Point	Total activity†	200	159	80
	Tritium	2 000	53	3
Oldbury	Total activity†	100	28	28
	Tritium	2 000	15	< 1
Sizewell	Total activity†	200	20	10
	Tritium	3 000	49	2

Table 2 (continued)

Site	Radioactivity	Authorized[1] discharge, curies/year	Discharge	
			In 1975, curies	As % of authorized limit
Trawsfynydd	Total activity†	40	18	45
	Tritium	2 000	90	5
	Caesium-137	7	4.8	68
Wylfa	Total activity†	65	3.5	6
	Tritium	4 000	129	3
Hunterston	Total activity†	200	116	58
	Tritium	1 200	55	5
Chatham	Total activity†	20	0.3	< 2
	Cobalt-60	10	0.3	3
	Tritium	20	< 0.1	< 1
Devonport	Total activity†	4	0.01	< 1
	Cobalt-60	1	0.01	1
	Tritium	10	0.1	1
Faslane	Total activity†	1	< 0.01	< 1
Rosyth	Total activity†	30	0.1	< 1
Aldermaston	Total activity[2]	156*	6	4
	Tritium	156	5	3

† Excluding tritium.
‡ Excluding uranium and its decay products.

Notes:

1. The authorized limits set out above are not all precisely as set down in the authorizations. This has occurred where there is no annual limit but only one which refers to a shorter period of time such as three consecutive months. In these circumstances the actual limit has been scaled up appropriately so as to provide a basis for direct comparison of the actual discharges made. The instances where this has been done are marked thus *.

2. The unit used for Aldermaston, Harwell and Amersham is not the curie but a derived unit computed from several components of the effluent and intended to compensate for differences in radiotoxicity. The unit is known as the 'equivalent curie'; the actual discharges in curies were somewhat lower than the figures indicated.

For completeness, mention may also be made of the very small discharges into Holy Loch from operation of the US Naval Submarine Base there. Radiological safety for the Holy Loch Base is the responsibility of the US Navy in association with the Ministry of

Defence (Navy Department) who have supplied the information that discharges in 1975 were less than

1 mCi of long-lived gamma-emmitting radionuclides, primarily cobalt-60;
1 mCi of short-lived radionuclides;
1 mCi of fission product radionuclides; and
10 mCi of tritium (^3H).

3. PRESENTATION OF RESULTS AND THEIR INTERPRETATION

The format of the tabular data in this report follows closely the revised arrangements introduced in the report for 1974 (Ref. 2).

Since the analytical data are mostly summaries, in many cases of quite a number of measurements which have been made on the species or in the location concerned throughout the year, a way of giving an indication of the variation found is required. This is done, wherever possible, by quoting the range in conventional statistical terminology, that is as ± one standard deviation. The range will thus contain about 70% of the data used to compute the mean, and refers to the spread of values found and not the counting statistics, which are generally very much more precise. Although the ranges of data are shown, it needs to be emphasized that it is the annual mean that is of importance when considering the significance of the measurements. Both national and international recommendations of acceptable public radiation exposure are set down as dose rates, the minimum time interval for which is one year. It may further be explained that in making surveys of, for instance, gamma dose rate on a beach, it is FRL practice to seek out the most highly contaminated area at the location being visited and achieve the most accurate estimate possible of this situation. The highest value in an annual range is thus due to one particular visit and does not indicate a situation which has been sustained throughout the year and to which any person could have been exposed for more than the interval between successive surveys.

Some of the tables are necessarily hybrid, combining for instance concentrations with dose rates, leading to a need to include a dash (-) in certain places. This does not indicate that a measurement has not been made but that it would not be applicable - for instance dose rate alongside seaweed or fish in a table which also includes measurements from gamma radiation surveys of the foreshore.

Units in which the results are expressed have been standardized as far as possible, all biota being quoted in pCi/g (wet), that is per gramme of the material in its normal condition as collected. Since the water content of sediment is variable, concentrations are quoted in units of pCi/g (dry), the dry state being more consistent for reference and comparative purposes. Concentrations for water are quoted in units of pCi/kg to avoid the problem of often having to include very small figures. Total beta radioactivity is estimated by a gross counting method (Ref. 3) which uses a thin source and is calibrated against a standard source of potassium-40. This reproduces the true sum total with reasonable accuracy because the system is nearly independent of beta energy over a wide range; however, it must not be expected that the total beta as quoted will always be exactly equal to the sum total of all individual radionuclides. Where the total of artificial radioactivity may be significant, standard FRL practice is to investigate the composition and estimate the more important component radionuclides by radiochemical analysis and/or spectrometry.

Both NaI(Tl) and Ge(Li) systems are employed at FRL for gamma spectrometry, and alpha emitters are analysed using silicon barrier layer detectors. Total beta data are not intended to be used directly in hazard assessment which requires a knowledge of the component radionuclides. The analyses are intended mainly as a prompt indication of the approximate activity; as total beta assays can be accomplished very quickly, they can give an early warning of change.

Because the principal aim of the work described here is the estimation of public radiation exposure, an index is included, where appropriate, by which the reader can make an approximate judgement of the significance of the data.

The primary standards for public radiation exposure, that is the ICRP-recommended dose limits, are not in a form which affords direct comparison and an intermediate, secondary standard to facilitate this is needed for rapid assessment of the importance of the data. This is the 'Derived Working Limit' (DWL) which relates public radiation exposure of the most highly exposed individual members of the population to the environmental quantity which is measured, such as the level of radioactivity in a foodstuff or dose rate. It is customary to set DWLs conservatively; in consequence compliance with them guarantees compliance with the ICRP-recommended dose limits and actual exposure may often be less than is indicated. The principal factors on which the DWL is based for an internal exposure pathway are the intakes of the contaminated foodstuff (taking the information on those who are the most highly exposed, i.e. the critical groups) and the metabolic data relating rates of intake of radioactivity to radiation exposure in humans. The latter are available through the work of Committee II of ICRP whilst the former are established by FRL surveys. The procedure for external exposure pathways requires information on the occupancy of the potentially contaminated areas which is provided by FRL surveys from which data appropriate to the critical groups are selected. In the strictest terms, data to relate environmental measurements to radiation exposure in humans are needed, since FRL measurements are dose rates in air; in practice these quantities are so nearly equal that they may be taken to be so in the majority of situations met by FRL.

For every discharge situation under FRL surveillance critical group(s) have been identified and their habits established by a direct survey of the populations concerned insofar as these habits affect exposure to radiation from environmental contamination. Major characteristics for all of the discharges for which monitoring is conducted by the laboratory are listed in Table 2. Rates of intake of potentially contaminated materials and the times spent in intertidal areas have been estimated by interviewing representative samples of the population. From this information, rates of intake and occupancy which are representative of the critical group, as defined by ICRP (Ref. 4), have been established for each exposure pathway, and these have been used to calculate the amount of radioactivity in the various materials (and the dose rates in the areas regularly frequented) which would cause doses just equal to the appropriate ICRP dose limits. Provided these levels are not exceeded it may be concluded that none of the dose limits has been exceeded; the difference between the measured contamination in any material and the DWL gives an indication of the margin between the situation as it exists and the maximum acceptable under the recommended standards of the ICRP, which have been endorsed for use in the UK by the Medical Research Council (MRC).

The proportion of the DWLs quoted in this report refer only to environmental materials which have a direct significance in terms of public radiation exposure, and values are not included for indicator materials. When more than one radionuclide is present the value refers to the whole of the contamination, a result which will usually have been reached by summation of the proportions of the DWL contributed by each individual radionuclide. It should be noted that the value cannot be deduced from data on total beta activity, where these are given, because they include a proportion of natural activity.

In many situations contamination is barely measurable or even below limits of detection; it is then important to know the levels of natural radioactivity and radiation because these will then make up most, perhaps the whole, of the measured values. In the laboratory it is possible to identify the contributions from natural sources by specific analysis such as spectrometry for potassium-40 and the heavy natural elements as well as by relying on collected experience; in field measurements knowledge of the natural background dose rate is provided by measurements in comparable environmental situations remote from nuclear activities, as well as from experience gained before the discharge began.

A summary of representative values is given in Table 3.

Table 3 Natural radioactivity of various materials

Material	Total beta activity	Comments
Fish	1 to 3 pCi/g (wet)	Mostly ^{40}K
Shellfish	1 to 3 pCi/g (wet)	"
Seaweed	5 to 15 pCi/g (wet)	"
Sand	5 to 10 pCi/g (dry)	^{40}K plus U, Th and their decay products
Mud	20 to 30 pCi/g (dry)	"
Sea water	300 pCi/kg	Mostly ^{40}K

The natural background dose rates over intertidal areas vary, according to the nature of the sediment. Over sand and shingle the dose rate is in the range 3 to 5 μR/h and a predominant component is cosmic. Over mud it is generally between 5 and 10 μR/h with more of the radiation being terrestrial in origin.

4. BRITISH NUCLEAR FUELS LIMITED

BNFL operates several establishments in the north of England and one in Scotland. It is associated with the production and reprocessing of fuel for nuclear reactors and also operates two sets of Magnox reactors and the prototype Advanced Gas-cooled Reactor (AGR). FRL monitors the consequences of liquid waste disposal from three of its establishments, Windscale and Calder, Springfields and Chapelcross, but not its fourth, Capenhurst, because of the negligible effect of the very small discharges made.

4.1. Windscale and Calder, Cumbria

The principal waste-producing operation at this establishment is the storage and reprocessing of irradiated fuel, negligible quantities being disposed of from either the Magnox reactors on the Calder part of the site or the AGR development. Almost the whole of the waste arising from fuel reprocessing activities remains on the Windscale site and is stored in high specific activity liquid form. By comparison with this, disposals through a 2.4 km long twin pipeline into the north-east Irish Sea are very small. During 1975 discharges of radioactivity made within the total beta clause of the authorization rose to 82%

of the authorized limit (from 69% in 1974), an increase due in large proportion to caesium-137 and -134 from fuel element storage, whilst discharges of alpha activity fell by half, from 76 to 38% of its authorized limit. Ruthenium-106 also showed a fall (49 to 34%); strontium-90 a small increase (35 to 42%). However, it is to be noted that all the discharges were within the authorized limits and that, since these limits are less than those which are equivalent to the ICRP-recommended dose limits, public radiation exposure stayed well within these dose limits.

The FRL environmental monitoring programme has concentrated on the two critical pathways - fish consumption and external exposure - but some effort has continued to be devoted to the Porphyra/laverbread pathway, even though it can only be described as one of potential importance as long as no local harvesting of the seaweed occurs. Reinforcing the basic monitoring there has been an extensive research programme which, inter alia, enables the laboratory to adjudge the importance of sub-critical pathways, i.e. those which lead to public radiation exposure at lower level than the critical pathways mentioned above. Part of the FRL research programme has been supported by contract from the European Atomic Energy Community (EURATOM) for investigation of the environmental behaviour of transuranics and fission products.

4.1.1. The fish/shellfish consumption pathway

This is currently the most important pathway to human radiation exposure, almost the whole of this exposure being due to the caesium radionuclides. Because of this and the rising rate of discharge of these radionuclides during 1974 and 1975, the FRL sampling programme has been enlarged and intensified.

The coastal zone around the pipeline extending from St Bees Head in the north to the Ravenglass Estuary in the south provides the fish and shellfish which are eaten by the most highly exposed group of the public associated with this pathway, the small local fishing population. Fish and shellfish from the immediate vicinity of the pipeline are sampled by the Laboratory's own surveys and regarded as representative of the intake of the local population. Monitoring to cover the wider areas of the Irish Sea and beyond is arranged by sampling commercial landings, chiefly at Whitehaven where FRL maintains a small out-station, but also at Fleetwood with the help of the Ministry's Sea Fisheries Inspectorate there. So as to facilitate the calculation of collective dose, samples have been collected from areas outside the Irish Sea, particularly the Minch and the northern North Sea. The species sampled have been those eaten in greatest quantity, particularly plaice. Salmon has now been included and shows a low level of radioactivity as was to be expected in view of this fish's migratory behaviour. The more important shellfish are Nephrops and crabs, mussels being sampled primarily for their value as an indicator and not for any direct public radiation exposure since those found on the Cumbrian coast are not eaten regularly.

All these samples were analysed for total beta radioactivity; they were then subjected to gamma spectrometry which showed that caesium-137 and -134 were present in all samples and that ruthenium-106 was present at detectable levels only in shellfish. Bulk samples representative of the whole year's sampling of northern Irish Sea plaice and coastal area Nephrops were analysed for strontium-90 and for the transuranic radionuclides plutonium-239/240 and americium-241. Results are summarized in Table 4.

The primary purpose of all these analyses is to provide information on which assessments may be made of the extent of public radiation exposure in terms of both individual and collective dose, the latter including the population of other Western European nations

Table 4 Radioactivity in fish and shellfish from the Irish Sea and other areas relevant to Windscale discharges, 1975

Species	Sampling area	Concentration of radioactivity, pCi/g (wet)					
		^{106}Ru	^{134}Cs	^{137}Cs	^{90}Sr	$^{239/240}Pu$	^{241}Am
Plaice flesh	Windscale area	not detected	5.0 ±1.1	30 ± 9	not analysed	0.0003	0.001
	North Irish Sea	<0.1	1.8 ±1.8	9.3 ± 8.4	0.04	0.0008	0.002
Dab flesh	Windscale area	not detected	3.0 ±1.7	18 ± 8	not analysed	not analysed	not analysed
Cod flesh	Windscale area	"	8.8	52	"	"	"
	North Irish Sea	"	2.8 ±1.3	14 ± 7	"	"	"
Herring edible parts	North Irish Sea	"	0.7 ±0.4	4.4 ± 2.0	"	"	"
Salmon	Windscale area	"	0.4 ±0.3	2.3 ± 1.9	"	"	"
Nephrops edible parts	North Irish Sea	0.3 ± 0.5	1.3 ±0.8	6.0 ± 3.9	0.08	0.0095	0.033
Crab edible parts	Windscale area	15 ±19	5.6 ±3.6	25 ±11	not analysed	not analysed	not analysed
Mussels	Windscale area	80 ± 2	3.0 ±0.3	12 ± 1	"	"	"
Plaice flesh	South Minch	not detected	not detected	0.19 ± 0.03	"	"	"
Cod flesh	South Minch	"	0.02 ±0.01	0.31 ± 0.05	0.0014	"	"
Herring flesh	South Minch	"	0.06 ±0.03	0.46 ± 0.21	0.006	"	"
Plaice flesh	Northern North Sea	"	not detected	0.04 ± 0.02	0.0008	"	"
Cod flesh	Northern North Sea	"	"	0.10 ± 0.03	0.0008	"	"

and not just the UK. The results of these calculations for individual members of the public are set out in Table 5. The most highly exposed 'organ' is the total body but data are

Table 5 Windscale discharges, 1975: estimates of exposure of individuals and critical groups exposed through the fish/shellfish consumption pathway

Population group and persons concerned	Assumed consumption rate and source	Radiation exposure (% of ICRP-recommended dose limit)	
		Total body	Bone
Coastal fishing community Maximum consumer	265 g/day Local supplies	34	11
Coastal fishing community Average consumer	57 g/day Local supplies	7	2
Other fish-eaters Critical group average	300 g/day Commercial Whitehaven landings	12	4
Public at large Average consumer	21 g/day Commerical Whitehaven landings	0.8	0.3

also included for bone since this is the organ in which exposure due to strontium-90 and the transuranics is potentially important. Even so almost all the exposure to bone is due to caesium radionuclides.

Beginning with those people subject to the highest degree of radiation, exposure values are first presented for the local Cumbrian coastal fishing community. Surveys of this group have shown that the mean and maximum consumption rates (fish and shellfish combined) are 57 and 265 g/day respectively. When these values are combined with data on the mean concentrations of radioactivity in the fish and shellfish from the immediate vicinity of Windscale in 1975, it is found that the maximum total body dose to any member of the public was 34% of the ICRP-recommended dose limit whilst to a person eating at the average rate for this community it was 7%. Turning attention to the more widespread fish-eating public for whose supplies the commercial landings at Whitehaven are considered to be representative, a value has been calculated for the higher rate consumers. Landings at Whitehaven come from a much wider area of the Irish Sea than that from which the Windscale-vicinity fishing community derives its fish and the mean concentrations of radioactivity are much lower. The mean consumption rate of the critical group eating Whitehaven-landed fish has been estimated at 300 g/day and leads to a value of 12% of the ICRP-recommended dose limit for exposure of total body. The average exposure of the general public at large will be much lower than this because of their smaller fish consumption rate. A value has been included for the typical individual who, according to national food statistics (Ref. 5), consumes at a rate of about 21 g/day. In 1975 this was 0.8% of the ICRP-recommended dose limit for total body. Reflecting higher rates of discharge of caesium-137 and -134, doses through fish consumption in 1975 were higher than in 1974, themselves slightly higher than those in preceding years. Though discharge rates had levelled out in 1975, the concentrations in fish (and hence doses) do not represent the equilibrium values because of the time it takes for caesium to work its way through the whole pathway including the food chain. However, 1975 values are close to the equilibrium for near-water stocks of fish from which the highest doses are derived.

Collective population exposure has been calculated and is due only to caesium-137 and -134, the other radionuclides not making a significant contribution. For this purpose use has been made of data on the distribution of these radionuclides in sea water around the British Isles: these data permit a value for radiocaesium levels in fish to be computed in order to supplement direct information from monitoring of the fish stocks themselves. The water sampling surveys have continued in a similar manner to those for 1974 which are discussed in detail in the report in this series for that year (Ref. 2). The 1975 results are summarized as concentration-contour diagrams in Figures 1 and 2. The assumption is again made that all the radiocaesium, apart from that attributable to fallout from nuclear-weapons testing, is due to Windscale, a reasonable approximation since other UK discharges to these waters are comparatively very small.

Results of the collective dose calculations are summarized in Table 6 for two separate population groups, first the population of the UK and second that of other Western European nations involved. The latter include Ireland, France, Belgium, the Netherlands, Denmark, the Federal Republic of Germany and Norway, statistics on whose catches of fish have been derived from the 1975 fish landing statistics to be published by the International Council for the Exploration of the Sea (Ref. 6). The values for 1975 in Table 6 are compared with data for 1974 and show an increase which, like the individual dose values referred to above, reflect higher discharge rates of caesium-137 and -134. The 1974 data in Table 6 differ slightly from those previously published, the opportunity having been taken to refine the original estimates by including data which have come to hand since the

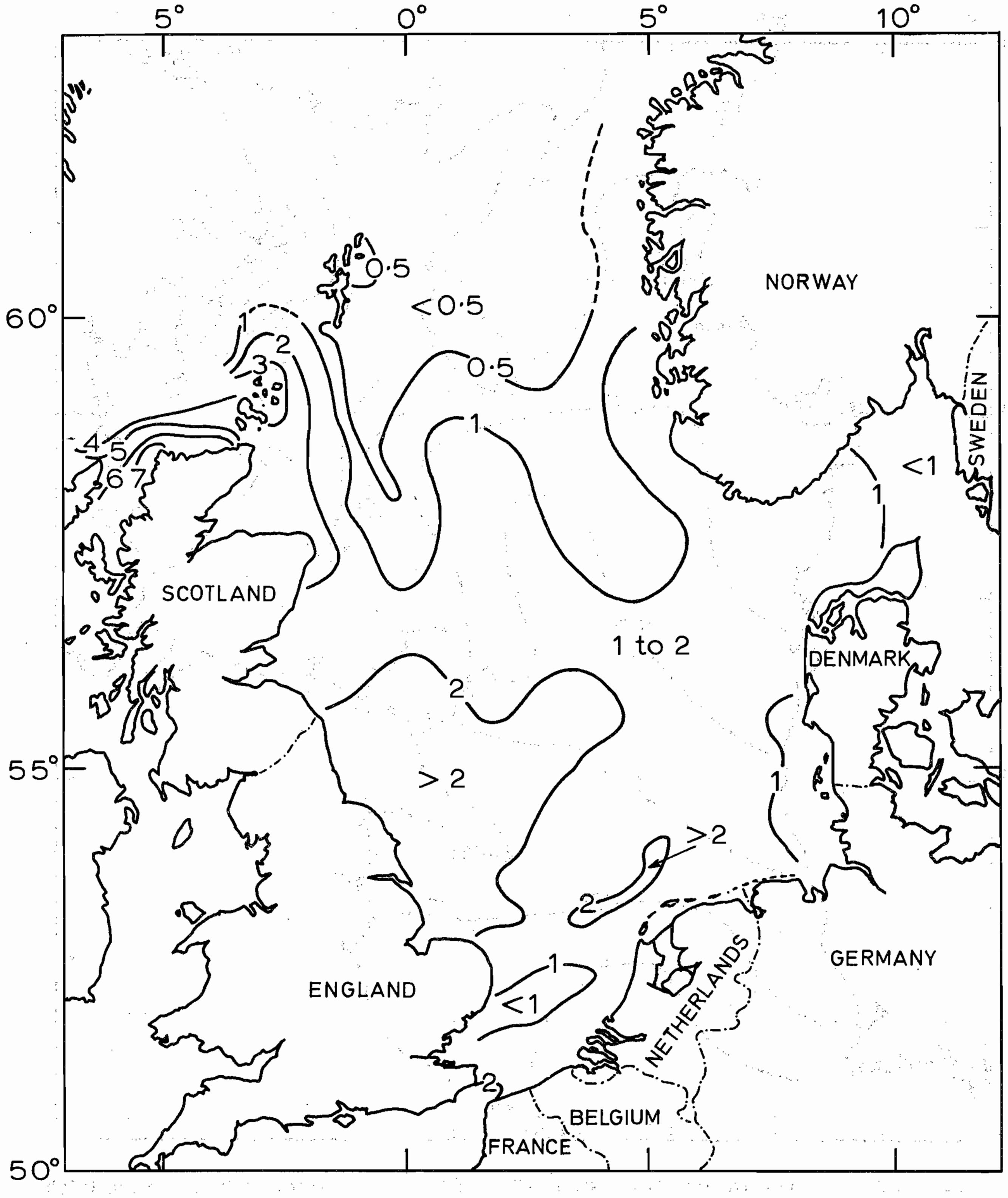

Figure 1 Concentrations of caesium-137 in filtered sea water (pCi/kg) from British Isles coastal and North Sea waters, August-October 1975.

1974 report was completed. The collective doses for 1975 to the UK and other Western European nations from fish which contain Windscale-derived radiocaesium were 8.3×10^3 and 5.7×10^3 man-rem respectively. The second objective of UK national radioactive waste disposal policy provides a yardstick against which to judge importance of these

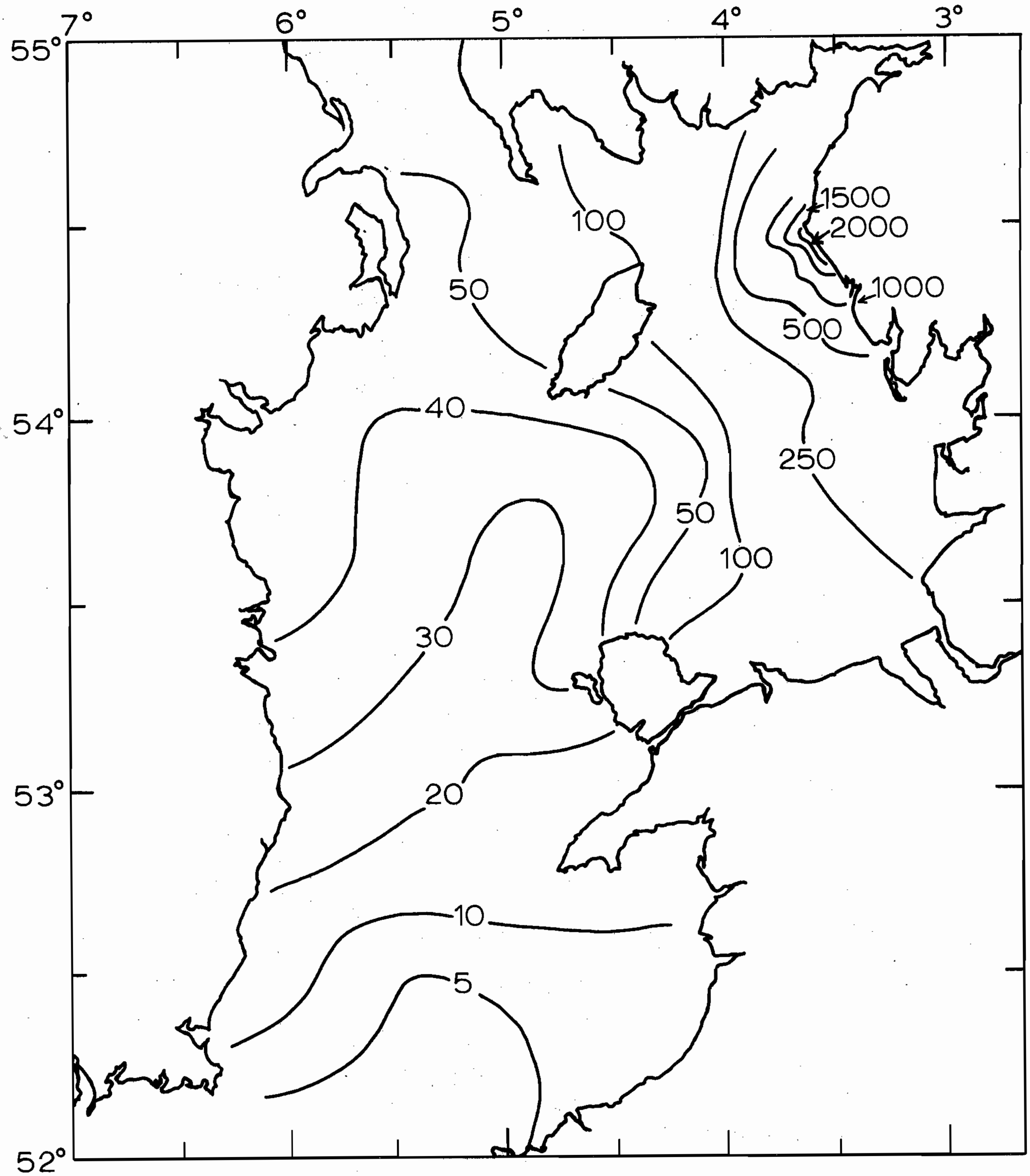

Figure 2 Concentrations of caesium-137 in filtered sea water (pCi/kg) in the Irish Sea, July 1975.

values, laying down that the population of the country must not on average be exposed to more than 1 rem per generation (30 years), equivalent to an annual limit of about 33 millirem. In 1975 exposures of the populations of the UK and other Western European nations were 0.45 and 0.12% of this limit respectively.

Table 6 Collective dose rates of Windscale radiocaesium discharges through the fish consumption pathway, 1974-75

Population (and size)	Collective dose rate, man-rem/year		Mean *per caput* dose			
			millirem/person/year		% of UK maximum	
	1974	1975	1974	1975	1974	1975
UK (5.5×10^7)	4.8×10^3	8.3×10^3	0.09	0.15	0.24	0.45
Other European nations (1.4×10^8)	3.8×10^3	5.7×10^3	0.03	0.04	0.08	0.12

4.1.2. External exposure pathway

This is currently the second most important radiation exposure pathway from liquid waste disposals from Windscale. It comes about due to the uptake of a number of gamma radiation-emitting fission products by marine sediments and the radiation field thus presented to the general public who frequent areas of the foreshore where these sediments are found. The degree of this uptake varies widely with sediment type, being greatest on fine particles making up the fine muds which are mainly found in estuaries and harbours, and least on the coarser particle sands which make up most of the local beaches. Backed up by more than a decade of experience of monitoring this pathway and supported by research, most of the FRL routine surveys are devoted to the areas where the highest dose rates are found, because assessment of the usage of the foreshore has shown that these are where the highest degree of radiation exposure is likely, the Ravenglass Estuary in particular. Although doses along the open sandy coastline are lower, surveys are made at some of the more frequently used points and the result for Seascale is included in Table 7 as a typical example of these areas.

In evaluating the significance of these data it is considered that the population who visit the Ravenglass Estuary for bait digging, repairing boats and the operation of salmon traps as well as recreation constitute the critical group. The value recorded in Table 7 for Eskmeals is typical of the highest dose rates found anywhere in the Ravenglass Estuary in 1975; in many parts where there is less mud or even none at all the dose rates are correspondingly lower. For the purposes of dose estimation it is considered reasonable to use the value for the mussel beds around the salmon garth to estimate the upper limit to exposure. When this is used in conjunction with occupancy data, maximum individual exposure in 1975 is found to be equivalent to about 9% of the ICRP-recommended dose limit.

Table 7 Gamma radiation dose rates over intertidal areas on the Cumbrian coast during 1975

Site	Sediment type	Gamma dose rate, μR/h
Maryport	Mud	70 ± 18
Workington Harbour	Mud	70 ± 10
Whitehaven Harbour	Mud	82 ± 8
Seascale	Coarse sand	30
Ravenglass Estuary (Eskmeals)	Mud	200 ± 10
Ravenglass Estuary (Salmon Garth area)	Mud/ mussel bed	165 ± 10
Walney	Mud	68 ± 5

Note: These values include background which is estimated at about 10 μR/h.

4.1.3. Porphyra/laverbread pathway

Since harvesting of Porphyra from Cumbrian beaches for manufacture into laverbread did not resume during 1975, this pathway remained one of potential importance only. However, since good quality Porphyra still grows plenteously on the Cumbrian beaches, a limited survey similar to that for 1974 was continued in case harvesting resumed and so that levels of public radiation exposure could be checked in order to confirm that they would still be within the intended limits. Samples were collected from three points, Braystones, Seascale and Walney Island, which together describe the range of concentrations along the local coastline over which most of the seaweed collection has gone on in the past. Samples were measured for total beta radioactivity then examined by gamma spectrometry to estimate the more important fission products, ruthenium-106 still being predominant.

Experience when there was regular harvesting of Porphyra showed that the material dispatched to South Wales was generally equivalent to a mixture of seaweed from the immediate area of Windscale and from Walney Island in approximately equal parts. On this basis and assuming a consumption rate for laverbread by the critical group of 130 g/day, radiation exposure of the most highly exposed in 1975 would have been equivalent to about 9% of the ICRP-recommended dose limit for the Gastro Intestinal (GI) Tract - the critical organ. In reality no such exposure occurred, as shown by measurements on the actual product of the South Wales laverbread manufacturers. Regular sampling continued during 1975 of the product of each of the five major manufacturers. Results of measurements for ruthenium-106 and the percentages of the DWL for GI Tract exposure are shown in Table 8. From this table it can be seen that Porphyra remained a pathway of potential significance only.

Table 8 Radioactivity in laverbread samples from the markets of South Wales during 1975

Manufacturer	^{106}Ru concentration, pCi/g (wet)	% of DWL
A	0.2	< 0.1
B	0.1 ± 0.2	< 0.1
C	0.3 ± 0.3	0.1
D	0.3 ± 0.3	0.1
E	0.2 ± 0.4	< 0.1

4.1.4. Other surveys

In addition to the basic programme of monitoring which is needed to assess public radiation exposure and to verify that adequate control is being achieved, research is undertaken by FRL the importance of which has been referred to earlier in this report. Surveys to establish the distribution of radiocaesium of Windscale origin in British Isles coastal waters are a special case in point. In addition to complementing data on fish consumption for assessment of dose via that pathway, this research also provides information on water dispersion and mixing patterns.

Mention has also been made in section 4.1.1 above of the use of indicator materials, analyses on which, together with the direct measurement of caesium in sea water, provide a framework on which the importance of other, albeit minor, pathways can be assessed. Seaweeds are particularly good indicators and each species has its own characteristics; for instance, Porphyra reconcentrates ruthenium to a higher degree than Fucus species whilst the reverse is true for most of the other fission products which are frequently encountered. Both of these seaweeds are sampled at various locations along the coastline of the north-eastern Irish Sea, and sediment at a few of them. Data are set out in Table 10 and should be read in conjunction with additional measurements on Cumbrian Porphyra in Table 9. The data in Table 10 referring to points in the south of Scotland are from surveys undertaken on behalf of departments of the Scottish Office. Some Porphyra from this coastline is used for human consumption but concentrations of radioactivity are very low and do not represent an important source of public radiation exposure.

Table 9 Radioactivity in Porphyra from Windscale vicinity, 1975

Sampling site	Concentration of radioactivity, pCi/g (wet)				
	Total beta	$^{95}Zr/^{95}Nb$	^{106}Ru	^{137}Cs	^{144}Ce
Braystones South	300 ± 130	21 ± 18	250 ± 90	20 ± 8	11 ± 11
Seascale	320 ± 150	21 ± 18	200 ± 70	20 ± 7	20 ± 17
Walney Island	47 ± 14	1.7 ± 1.2	34 ± 11	5.4 ± 1.9	1.5 ± 1.3

Table 10 Radioactivity in seaweed and sediment around the English and Scottish shoreline of the Irish Sea, 1975

Material and sampling site	Concentration of radioactivity, pCi/g (wet)*					
	Total beta	$^{95}Zr/^{95}Nb$	^{106}Ru	^{134}Cs	^{137}Cs	^{144}Ce
Fucus vesiculosus						
Port William	23 ± 7.0	<0.1	not detected	0.6 ± 0.3	3.4 ± 1.0	not detected
Garlieston	33 ± 9.0	0.5 ± 0.3	1.0 ± 0.6	1.2 ± 0.4	7.9 ± 1.7	"
Rascarrel Bay	31 ± 10	0.5 ± 0.4	1.8 ± 1.9	0.3 ± 0.4	7.7 ± 2.1	0.1 ± 0.2
Braystones South	400 ± 30	32 ± 5.0	77 ± 37	18 ± 2.0	92 ± 2.0	13 ± 10
Heysham	59 ± 26	0.4 ± 0.5	4.1 ± 4.7	2.8 ± 0.5	15 ± 4.0	0.3 ± 0.5
Porphyra						
Labrax Bay	7.6 ± 1.3	not detected	0.8 ± 0.3	<0.1	0.4 ± 0.1	not detected
Port William	9.1 ± 1.2	0.1 ± 0.1	2.8 ± 0.9	0.2 ± 0.1	1.0 ± 0.3	"
Garlieston	15 ± 8.5	0.6 ± 0.3	4.8 ± 3.2	0.4 ± 0.3	2.3 ± 1.5	0.2 ± 0.3
Sediment						
Garlieston (silt)	180 ± 150	1.9 ± 3.1	37 ± 62	4.2 ± 4.0	27 ± 27	14 ± 23
Heysham (sand)	130 ± 60	2.5 ± 2.0	16 ± 4.0	6.1 ± 2.4	33 ± 16	11 ± 2.4
Fleetwood (sand)	30 ± 3.4	not detected	0.5 ± 0.4	1.1 ± 0.2	5.9 ± 2.4	1.0 ± 0.2

*Except sediment, pCi/g (dry).

4.2. Springfields, Lancashire

This establishment fabricates fuel elements for the nuclear industry and only small amounts of naturally-occurring radionuclides accrue for disposal via pipeline into the tidal River Ribble. The waste has little radiological impact, with slightly enhanced radiation dose levels on the muddy banks of the river in the vicinity of the outfall. The FRL environmental monitoring programme is therefore only small, consisting of gamma dose rate measurements at four points in the near-vicinity of the outfall. Samples of mud were also taken and analysed for protactinium-234m, the only radionuclide present attributable to discharges from Springfields. Results are summarized in Table 11. Maximum radiation exposure of the public from these discharges via the critical pathway, external exposure of those who frequent the river banks near the outfall, is low, and was estimated at about 1% of the ICRP-recommended dose limit in 1975.

Table 11 Radioactivity in mud and the gamma dose rates over the mud banks in the River Ribble Estuary, 1975

Sampling site	^{234m}Pa, pCi/g (dry)	Gamma dose rate, μR/h
Pipeline outlet	1500 ± 2200	24 ± 11
Upstream		
90 metres	1700 ± 1600	30 ± 15
460 metres	2100 ± 1800	31 ± 14
Downstream		
90 metres	560 ± 310	26 ± 12

4.3. Chapelcross, Dumfriesshire

Discharges from this site are made into the Solway Firth under authorization of the Scottish Development Department. Monitoring by this laboratory (on behalf of departments of the Scottish Office) has concentrated on the two critical pathways, internal exposure due to consumption of local fish and shellfish, principally shrimps, and external exposure due to time spent in intertidal areas of the foreshore. In addition, samples of the seaweed Fucus vesiculosus are collected for their value as an indicator. The results of these surveys are shown in Table 12.

Table 12 Radioactivity in materials from the Solway estuary in the vicinity of Chapelcross, 1975

Material and sampling site	Concentration of radioactivity, pCi/g (wet)*					
	Total beta	$^{95}Zr/^{95}Nb$	^{106}Ru	^{134}Cs	^{137}Cs	^{144}Ce
Shrimps						
Seafield	6.8 ± 1.7	not detected	0.3 ± 0.3	1.0 ± 0.4	5.0 ± 1.4	not detected
Fucus vesiculosus						
Waterfoot	24 ± 6.3	0.1 ± 0.1	0.2 ± 0.3	1.1 ± 0.3	6.2 ± 2.0	"
Seafield	22 ± 5.8	0.3 ± 0.4	1.0 ± 0.5	1.0 ± 0.2	6.1 ± 2.2	"
Sediment						
Seafield	270 ± 200	2.5 ± 2.8	28 ± 17	5.5 ± 0.7	31 ± 8.0	12 ± 4.4
Gamma dose rate over intertidal area at Seafield = 12 ± 1 μR/h						

*Except sediment, pCi/g (dry).

The radiological impact of Chapelcross discharges on the Solway estuary cannot be assessed precisely because of the overriding effect of the much larger discharges from Windscale. The levels of radioactivity found in the area are consistent with those to be expected at this distance from Windscale and the contribution from Chapelcross has been judged to be no more than a very small fraction of 1% of the ICRP-recommended dose limit.

5. UNITED KINGDOM ATOMIC ENERGY AUTHORITY

The laboratory has monitored the environment of two establishments operated by the United Kingdom Atomic Energy Authority (UKAEA) which dispose of liquid wastes, the Atomic Energy Establishment at Winfrith in Dorset and the Dounreay Experimental Reactor Establishment at Dounreay in Caithness. A third major establishment of UKAEA also has liquid wastes to dispose of; this is the AERE, Harwell. Along with other establishments in the catchment area of the River Thames, the critical pathway is drinking water and the lead here is taken by the Department of the Environment rather than the Ministry of Agriculture, Fisheries and Food.

5.1. Atomic Energy Establishment, Winfrith, Dorset

Liquid wastes are released via pipeline into deep water in Weymouth Bay and most of the activity is due to tritium. However, this radionuclide is of no environmental significance and the much smaller amounts of some metallic activation products present in the effluents are the only radionuclides which can be detected in environmental materials. The critical pathway for these discharges is the consumption of crustacean shellfish, cobalt-60 and zinc-65 being the critical radionuclides. Because concentrations are extremely low, it has been found more effective to monitor indicator materials and these also afford an opportunity to study the environmental behaviour of cobalt-60 in particular. The materials chosen are Fucus serratus and the flesh of the limpet. Data from these surveys are summarized in Table 13 from which it is judged that public radiation exposure in 1975 was very low indeed, much less than 1% of the ICRP-recommended dose limit.

Table 13 Radioactivity in indicator materials from the vicinity of Winfrith, 1975

Material	Sampling site	Concentration of radioactivity, pCi/g (wet)		
		Total beta	^{60}Co	^{65}Zn
Limpet flesh	Chapman's Pool	2.6 ± 0.7	1.1 ± 0.3	0.2 ± 0.3
	Osmington Mills	2.1 ± 0.2	0.4 ± 0.1	0.2 ± 0.2
Fucus serratus	Chapman's Pool	15 ± 5.5	13 ± 5.4	not detected
	Osmington Mills	8.3 ± 1.7	5.6 ± 2.8	"
	Weymouth	9.2 ± 2.5	5.8 ± 0.6	"
	Swanage	10 ± 0.2	7.0 ± 1.2	"
	Portland	10 ± 2.9	4.0 ± 0.6	"

5.2. Dounreay Experimental Reactor Establishment, Dounreay, Caithness

Discharges are made from this site into the Pentland Firth under authorization of the Scottish Development Department and monitoring has been undertaken by FRL on behalf of departments of the Scottish Office. Discharges include a minor contribution from the adjoining reactor site of the Ministry of Defence, Procurement Executive (HMS VULCAN). The critical pathways both relate to external exposure; one is via salmon and lobster fishing operations for which a small number of people at nearby Sandside Bay constitute the critical group, the other is caused by stranding of radioactivity on sediment trapped in rocky clefts of the foreshore. The radiological significance of the fishing operations is the radiation exposure to fishermen's hands (primarily from beta radioactivity) incurred when fishermen handle their fishing gear. Regular measurements made throughout the fishing season showed that exposure of the critical group in 1975 was very low - less than 1% of the ICRP-recommended dose limit.

In addition to these measurements, FRL has analysed the indicator materials limpet, winkle and Fucus vesiculosus, data for which are summarized in Table 14. These show a range of fission products and provide the basis for evaluation of concentrations in sea water and hence the significance of Dounreay discharges through other, non-critical pathways such as fish consumption.

Monitoring of the shoreline exposure pathway has not been done by FRL but is carried out by the UKAEA who have published the data in their own monitoring report for 1975 (Ref. 7). Like the fishing gear pathway, public radiation exposure in 1975 was very low; it is estimated to be less than 2% of the ICRP-recommended dose limit.

Table 14 Radioactivity in environmental materials from the vicinity of Dounreay, 1975

Material and sampling site	Concentration of radioactivity, pCi/g (wet)				
	Total beta	$^{95}Zr/^{95}Nb$	^{106}Ru	^{137}Cs	^{144}Ce
Limpet flesh Sandside Bay	50 ± 43	9.4 ± 12	4.6 ± 3.4	0.1 ± 0.1	12 ± 10
Winkle flesh Sandside Bay	13 ± 2.4	0.3	1.4	0.1	6.6
Fucus vesiculosus Sandside Bay	36 ± 27	24 ± 39	0.5 ± 0.9	0.1 ± 0.1	5.0 ± 4.3

6. NUCLEAR POWER STATIONS

All but one of these establishments are in England and Wales and thus operated by the Central Electricity Generating Board, the exception being Hunterston, in Scotland, operated by the South of Scotland Electricity Board.

6.1. Berkeley, Gloucestershire and Oldbury, Avon

Since the liquid radioactive wastes from both of these power stations have similar characteristics and are released into the same stretch of the Severn Estuary it has long been the practice to combine monitoring effort and cover the consequences of both these discharges simultaneously. Two pathways are of potentially critical importance - internal exposure from consumption of estuarine fish and shellfish and external exposure from occupancy of the estuarine margins. Based on these, the most important elements of the environmental monitoring programme are sampling of flounders, eels and shrimps together with gamma dose rate surveys of selected points on the intertidal zone of the river banks. The latter are supported by analysis of samples of mud and the seaweed *Fucus vesiculosus* which is collected as an indicator.

The only artificial radionuclides found in these samples were those of caesium. In most cases the concentrations were indistinguishable from fallout levels and in the one sample where a trace attributable to the stations could be inferred (estuarine mud) it was far below the derived working limit. In consequence, public radiation exposure was very low indeed, less than 0.1% of the ICRP-recommended dose limit.

Results of these measurements are summarized in Table 15.

Table 15 Radioactivity in environmental materials around Berkeley and Oldbury nuclear power stations, 1975

Material	Concentration of radioactivity, pCi/g (wet)*			% of DWL
	Total beta	^{137}Cs	^{134}Cs	
Flounders	2.7	<0.1	not detected	<0.01
Elvers	2.1	<0.1	"	<0.01
Shrimps	2.2 ± 0.2	<0.1	<0.1	<0.01
Fucus vesiculosus	7.7 ± 0.6	0.2	not detected	-
Mud	28 ± 3.0	1.8 ± 1.0	0.1 ± 0.2	-
Background mud	23 ± 2.7	0.5 ± 0.2	not detected	-

Gamma dose rate over intertidal mud = 7.4 ± 0.4 μR/h

*Except mud, pCi/g (dry).

6.2. Bradwell, Essex

There is one critical pathway for discharges made from this power station into the Blackwater Estuary, that which results in internal exposure from the consumption of oysters. The critical radionuclides are zinc-65 and silver-110m, but due to the very low discharges of these radionuclides in recent years they were only just detectable in 1975. The principal component in discharges is caesium-137 but, because of its much lower concentration factor in oysters compared with both silver-110m and zinc-65, only a trace was to be found in oysters. All components taken together, the radiological significance of radioactivity of Bradwell origin was very low indeed at 0.07% of the ICRP-recommended dose limit.

In addition to sampling and analysis of oysters the monitoring programme includes the indicator seaweed Fucus vesiculosus, intertidal mud and a small survey of gamma dose rate measurements which have remained indistinguishable from natural background.

Results of these measurements are summarized in Table 16.

Table 16 Radioactivity in environmental materials around Bradwell nuclear power station in 1975

Material	Concentration of radioactivity, pCi/g (wet)*				% of DWL
	Total beta	^{137}Cs	^{65}Zn	^{110m}Ag	
Oysters	2.4 ± 0.9	0.1 ± 0.1	0.4 ± 0.1	0.3 ± 0.1	0.07
Fucus vesiculosus	7.1 ± 0.1	0.5 ± 0.2	<0.1	<0.1	-
Mud	28 ± 5.9	3.2 ± 2.2	<0.1	0.2 ± 0.3	-

Gamma dose rate over intertidal mud = 7.4 ± 0.4 μR/h

*Except mud, pCi/g (dry).

6.3. Dungeness, Essex

To cover the two critical pathways for discharges from this power station, those due to consumption of fish (internal exposure) and use of the foreshore (external exposure), the monitoring programme consists of sampling locally-caught fish (plaice) and gamma dose rate surveys on the beach. Sand is also sampled and analysed but like the plaice has not shown evidence of any radioactivity attributable to the power station, so that public radiation exposure is very low indeed, much less than 0.1% of the ICRP-recommended dose limit.

Results of these measurements are summarized in Table 17.

Table 17 Radioactivity in environmental materials around Dungeness nuclear power station in 1975

Material	Concentration of radioactivity, pCi/g (wet)*		% of DWL
	Total beta	^{137}Cs	
Plaice	3.0 ± 0.2	<0.1	<0.1
Sand	17 ± 11	<0.1	-

Gamma dose rates over intertidal sand = 5.7 ±1.3 μR/h

*Except sand, pCi/g (dry).

6.4. Hinkley Point, Somerset

The two critical pathways here are internal exposure through consumption of local fish and shrimps and external exposure due to use of the foreshore. Flatfish and shrimps were analysed without finding any radioactivity attributable to power station discharges. Though small amounts of fission products could be detected in mud, part of this is attributable to fallout. In toto the levels are such that the gamma dose rates measured over the mud flats near to the power station in surveillance of the external exposure pathway are not distinguishable from natural background levels. The negligible effect of the power station's discharges was further confirmed by sampling of the indicator seaweed Fucus vesiculosus and comparing analyses of local samples with those of the same seaweed growing at places which are remote from the power station.

Results are summarized in Table 18; radiation exposure of the public in 1975 was less than 0.1% of the ICRP-recommended dose limit.

Table 18 Radioactivity in environmental materials around Hinkley Point nuclear power station in 1975

Material	Concentration of radioactivity, pCi/g (wet)*				% of DWL
	Total beta	^{137}Cs	^{144}Ce	^{106}Ru	
Flatfish	2.9 ± 0.7	<0.1	not detected	not detected	<0.03
Shrimps	2.8 ± 0.8	<0.1	"	"	<0.1
Fucus vesiculosus (outfall)	8.7 ± 3.7	0.5 ± 0.4	"	"	-
Fucus vesiculosus (elsewhere)	8.2 ± 1.5	0.4 ± 0.1	"	"	-
Mud	26 ± 6.7	2.4 ± 1.1	0.2 ± 0.3	0.2 ± 0.3	-

Gamma dose rate over intertidal mud = 9.1 ± 1.2 μR/h

*Except mud, pCi/g (dry).

6.5. Sizewell, Suffolk

Here again there are two critical pathways - internal exposure from consumption of fish and crustaceans and external exposure from use of the foreshore, but due to the small discharges from the power station and to environmental factors the pathways are of potential importance only. Several species of fish are analysed and grouped for convenience according to type, into flatfish such as sole, plaice and skate, and round fish such as cod and whiting. Both crabs and lobsters have been analysed but, like the fish, they show no artificial radioactivity attributable to Sizewell, so with measurements from gamma dose surveys of the shore showing no distinguishable deviation from background, it is clear that public radiation exposure from Sizewell is very low indeed, much less than 0.1% of the ICRP-recommended dose limits.

Results of these measurements are summarized in Table 19.

Table 19 Radioactivity in environmental materials around Sizewell nuclear power station in 1975

Material	Concentration of radioactivity, pCi/g (wet)		% of DWL
	Total beta	^{137}Cs	
Roundfish	3.1 ± 0.4	0.1	<0.1 (Roundfish and Flatfish)
Flatfish	3.3 ± 0.4	0.1	
Crabs	2.0	<0.1	<0.01 (Crabs and Lobsters)
Lobsters	2.6	<0.1	

Gamma dose rate over intertidal sand = 3.6 ± 0.5 μR/h

6.6. Trawsfynydd, Gwynedd

The one critical pathway for discharges from this power station, unique in the UK in that they are made to a freshwater lake, is from the consumption of fish, the analysis of which forms the essential part of the FRL monitoring programme. There are several species of fish in the lake and though the most important in terms of public radiation exposure is trout, perch also live there and are therefore analysed.

The principal radionuclides in fish are caesium-137 and -134 together with a small amount of strontium-90. For the first time antimony-125 has been found in fish but only in perch (eaten in much less quantity than trout) and at such a small concentration, close to the limit of detection, that it is of negligible radiological significance. In the stocks of trout in the lake the artificially-reared rainbow trout are now predominant over the mainly indigenous brown trout. There is a considerable variation in the range of artificial radioactivity in these fish and in general the higher values are to be found in brown trout. However, in making dose estimates the cautious attitude is adopted of using only analyses on brown trout. In consequence, the FRL assessment of 8% of the ICRP-recommended dose limit for the maximum degree of public radiation exposure in 1975 may well be an overestimate, but even on this basis can be seen to be within acceptable limits with a wide margin in hand.

The other materials, for which analyses are quoted together with those for fish in Table 20, form part of the Laboratory's research programme in the lake. The moss Fontinalis is a particularly sensitive indicator for a number of radionuclides. The significance of the peat and mud of the lake bed is in the food chain to fish which derive most of their radioactivity through food.

Table 20 Radioactivity in environmental materials around Trawsfynydd nuclear power station in 1975

Material	Concentration of radioactivity, pCi/g (wet)*								% of DWL
	Total beta	^{60}Co	^{90}Sr	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce	
Brown trout	24 ± 11	not detected	0.06	not detected	not detected	1.6 ± 1.1	20 ± 14	not detected	8 (Brown trout and Perch)
Perch	34 ± 9.5	"	not analysed	"	"	3.6 ± 1.2	36 ± 11	"	
Mud	35 ± 4.3	<0.1	"	"	3.7 ± 2.0	0.3 ± 0.3	12 ± 1.1	"	-
Peat	110 ± 49	0.5 ± 0.3	"	"	50 ± 23	2.3 ± 0.9	24 ± 13	"	-
Fontinalis (Afon Prysor)	9.9 ± 4.7	not detected	"	1.2 ± 0.8	<0.1	not detected	0.2 ± 0.3	1.2 ± 0.9	-
Fontinalis (Gwylan Stream)	61 ± 20	3.6 ± 2.5	"	4.9 ± 2.2	22 ± 17	1.8 ± 0.6	11 ± 2.5	1.4 ± 1.7	-
Water (Hot Lagoon)	not analysed	not analysed	15 ± 5.8	not analysed	not analysed	3.5 ± 1.9	26 ± 14	not analysed	-
Water (Main Lagoon)	"	"	16 ± 6.3	"	"	3.5 ± 2.0	25 ± 15	"	-

*Except peat and mud, pCi/g (dry); and water, pCi/kg.

6.7. Wylfa, Gwynedd

There are two critical pathways for discharges from this power station, although the quantities of radioactivity which are released are so low as to be unlikely to lead to measurable levels of radiation exposure through either of them. The pathways involve internal exposure through consumption of fish and shellfish and external exposure through use of the foreshore. Samples of fish and shellfish are collected and surveys undertaken of the local foreshore to gather samples of mud and to measure the gamma dose rate there. These surveys are supplemented by sampling of the seaweeds Porphyra and Fucus vesiculosus, both in the role of indicators. Low concentrations of caesium-137 are present in fish and crustaceans and of several fission products in both molluscs and mud, but in all cases the levels are consistent with a concentration of fallout from nuclear weapon tests and of Windscale discharges. The gamma dose rates are indistinguishable from background and exposure via this pathway from all sources of artificial radioactivity is very low. Fish and shellfish consumption leads to a maximum degree of public radiation exposure of about 0.5% of the ICRP-recommended dose limit, a negligible component of this being due to the operation of Wylfa.

Results of these measurements are summarized in Table 21.

Table 21 Radioactivity in environmental materials around Wylfa nuclear power station in 1975

Material	Concentration of radioactivity, pCi/g (wet)*				% of DWL
	Total beta	^{137}Cs	^{106}Ru	^{144}Ce	
Pollack	6.6 ± 1.1	3.7 ± 0.3	not detected	not detected	0.5 (Pollack, Lobsters, Crabs)
Lobsters	5.3	1.1	"	"	
Crabs	4.2 ± 0.9	1.0 ± 0.2	"	"	
Winkles	5.9 ± 2.3	1.1 ± 0.5	1.5 ± 1.9	<0.1	-
Porphyra	7.0 ± 1.8	0.5 ± 0.1	<0.1	not detected	-
Fucus vesiculosus	20 ± 3.4	2.2 ± 0.6	<0.1	"	-
Mud	69 ± 7.0	31 ± 5.8	10 ± 6.6	1.7 ± 2.0	-
Gamma dose rates over intertidal mud = 12 ± 1.4 μR/h					

*Except mud, pCi/g (dry).

6.8. Hunterston, Ayrshire

Monitoring of the environment of this power station is undertaken on behalf of departments of the Scottish Office. The internal pathway is represented in the monitoring programme by sampling of cockles and winkles and the external pathway by surveys of the foreshore in the course of which gamma dose rates are measured and samples of sand collected. Seaweed is sampled as an indicator, in this area the species chosen being Fucus spiralis. Analyses of sea water do not form part of the essential monitoring programme but are included in Table 22 for interest, data being available from the FRL research programme which follows dispersion of water masses labelled with Windscale discharges of radiocaesium.

Table 22 Radioactivity in the vicinity of Hunterston nuclear power station in 1975

Material	Concentration of radioactivity, pCi/g (wet)*					% of DWL
	Total beta	^{106}Ru	^{134}Cs	^{137}Cs	^{144}Ce	
Cockle flesh	1.5 ± 1.3	0.2 ± 0.2	<0.1	0.2 ± 0.1	<0.1	<0.01
Winkles	8.4 ± 2.4	1.2 ± 0.6	0.6 ± 0.4	2.2 ± 1.3	0.4 ± 0.2	<0.01
Fucus spiralis	14 ± 0.9	<0.1	0.4 ± 0.3	2.2 ± 0.7	<0.1	-
Sand	17 ± 6.5	not detected	0.2 ± 0.1	1.0 ± 0.6	0.5 ± 0.1	-
Sea water	not analysed	not analysed	13 ± 2.4	66 ± 10	not analysed	-

*Except sand, pCi/g (dry); and water, pCi/kg.

Several radionuclides have been detected in the vicinity of Hunterston but public radiation exposure is very low, less than 0.1% of the ICRP-recommended dose limit. The contribution of Hunterston discharges is itself very small, with fallout from weapons testing and the Windscale discharge still accounting for most of it.

7. NAVAL ESTABLISHMENTS

Small amounts of radioactive waste were discharged during the year from each of four naval bases operated by the Ministry of Defence (Navy Department) - Chatham, Devonport, Faslane and Rosyth. Monitoring has been continued in each of these areas, in the case of Faslane and Rosyth on behalf of departments of the Scottish Office. The results of these surveys are set out in Table 23; also included is a summary of monitoring data related to discharges into the Holy Loch from the US Naval Submarine Base there.

Table 23 Monitoring surveys in the vicinity of naval establishments, 1975

Site and material	Concentration of radioactivity, pCi/g (wet)*			Gamma dose rate, μR/h
	Total beta	^{60}Co	^{137}Cs	
Chatham				
Foreshore sediment	22 ± 4.6	0.5 ± 0.3	0.9 ± 0.4	9.0 ± 1.4
Devonport				
Foreshore sediment	29 ± 3.8	<0.1	0.3 ± 0.2	12 ± 1.9
Winkle flesh	3.0 ± 0.9	not detected	not detected	-
Fucus vesiculosus	6.5 ± 0.4	"	"	-
Faslane				
Foreshore sediment	51 ± 19	0.4 ± 0.4	6.1 ± 5.6	10 ± 1
Sea-bed sediment	42 ± 4.2	1.3 ± 1.6	11 ± 2.6	-
Rosyth				
Foreshore sediment	20 ± 2.1	<0.1	0.5 ± 0.5	12
Sea-bed sediment	25 ± 2.2	0.3 ± 0.3	0.9 ± 0.6	-
Holy Loch				
Foreshore sediment	32 ± 7.6	0.4 ± 0.3	1.0 ± 0.7	9.4 ± 2.0
Fucus spiralis	6.7 ± 1.0	not detected	0.6 ± 0.4	-

*Except sediment, pCi/g (dry).

It so happens that the principal exposure pathway associated with all of these discharges is external exposure following the uptake of radioactivity by intertidal sediments. The monitoring is concentrated mainly on gamma dose measurement backed up by analyses of samples of sediment together with a small number of indicator materials. They show that the sediments contained traces of cobalt-60, as would be expected since this is the most important component of the discharges. The caesium-137 found from these surveys is not due to naval operations but is attributable to weapons testing fallout and the

Windscale discharge. The concentrations of both of these radionuclides were very small, however, and the resultant dose rates were not significantly different from those which are to be expected in these muddy areas from natural sources. Public radiation exposure has remained negligible, much less than 1% of the ICRP dose limit.

8. THE CHANNEL ISLANDS

The laboratory has continued its programme of analysis on environmental samples made available by the Channel Islands Governments. This has been in surveillance of possible effects of discharges from the fuel reprocessing plant operated by the Commissariat à l'Energie Atomique at Cap de La Hague on the mainland of France to the east of the Channel Islands. The range of materials for which measurements are quoted in Table 24 includes fish and shellfish chosen so as to be able to judge the possible significance of discharges from Cap de La Hague in terms of public radiation exposure; Porphyra seaweed is also included and fulfils an indicator role. Traces of caesium-137 are found in a few of these materials, in most cases at levels consistent with fallout from weapons testing. There is also evidence of ruthenium-106, especially in Porphyra, though again levels are low and of very little radiological significance. However, measurements suggest a contribution from a source additional to fallout, presumably the discharges from the plant at Cap de La Hague.

Table 24 Radioactivity in materials on the coasts of the Channel Islands, 1975

Material	Sampling area		Concentration of radioactivity, pCi/g (wet)		
			Total beta	^{106}Ru	^{137}Cs
Porphyra	Guernsey	Fort Doyle	8.0 ± 4.1	2.0 ± 0.2	not detected
		Fermain Bay	6.5 ± 2.7	0.9 ± 0.5	"
	Alderney	Telegraph Bay	12	4.2	"
		Hannain	7.7	1.9	"
		Quenard Point	20 ± 9.3	8.5 ± 4.0	0.2 ± 0.2
	Jersey	Greve de Lecq	7.0 ± 2.0	1.0 ± 0.6	not detected
		La Rozel	8.3 ± 2.1	1.2 ± 0.7	"
Ormer flesh	Guernsey		not analysed	0.3	<0.1
Ray wings	Guernsey		2.4	not detected	0.1

9. IRELAND

Monitoring has continued of seaweed indicator materials collected from a series of sites on the Irish Sea coast of the Republic of Ireland. A variety of seaweeds has been collected and the results of analysis are summarized in Table 25. Fission products have been found, primarily caesium-137, but concentrations are small and the radiological significance which they may imply through various pathways is very small.

Table 25 Radioactivity in seaweeds from the coastline of Ireland, 1975

Material and sampling site	Concentration of radioactivity, pCi/g (wet)			
	Total beta	$^{95}Zr/^{95}Nb$	^{106}Ru	^{137}Cs
<u>Porphyra</u>				
Skerries	4.7 ± 1.6	0.1 ± 0.1	0.3 ± 0.1	0.2 ± 0.1
Colliemore	4.4 ± 1.1	not detected	<0.1	0.1 ± 0.1
St Helens	5.2 ± 1.0	<0.1	0.1 ± 0.1	0.1
Dunmore	5.2 ± 0.4	not detected	not detected	not detected
Carlingford	6.4	"	"	0.3
<u>Fucus serratus</u>				
Skerries	17 ± 5.6	"	0.1 ± 0.1	1.1 ± 0.6
Colliemore	18 ± 3.8	"	not detected	1.0 ± 0.6
St Helens	9.5 ± 2.7	"	"	0.1 ± 0.1
Dunmore	7.7 ± 0.2	"	"	not detected
Carlingford	15 ± 2.2	"	"	1.5 ± 0.7
<u>Laminaria digitata</u>				
Skerries	14 ± 3.6	"	<0.1	1.1 ± 0.5
Colliemore	14 ± 3.8	"	not detected	1.0 ± 0.5
St Helens	8.2 ± 2.7	"	"	0.1 ± 0.1
Dunmore	12 ± 5.4	"	0.2 ± 0.3	not detected
Carlingford	14 ± 1.6	"	not detected	0.7 ± 0.3

10. MISCELLANEOUS SURVEYS

As in previous years, a limited programme of work has been undertaken to measure the concentrations of radioactivity in a selection of marine samples from areas remote from any controlled discharge of radioactive waste. This work has shown that traces of fission products such as ruthenium-106 and caesium-137 remain detectable in fish and seaweed at concentrations of the order of 0.1 pCi/g (wet).

11. SUMMARY AND CONCLUSIONS

The principal purpose of the environmental monitoring surveys summarized here is to ensure the adequacy of the procedures for controlling discharges of radioactive waste to coastal and surface waters, and in this report data have therefore been interpreted in terms of radiation exposure to members of the public. This has been achieved by the application of the conventional critical pathway approach and for each source of radioactive waste the dose to the critical group (or groups) has been calculated. Summarizing the values quoted in previous sections of this report, a full list is to be found in Table 26 where the doses are expressed as percentages of the appropriate ICRP dose limits.

As in previous years, the discharges from the BNFL reprocessing plant at Windscale in Cumbria have provided the largest source of public exposure. In the extreme case of local fishermen working close to the discharge area the doses received by the most highly exposed individuals were about 34% of the ICRP dose limit; in all other circumstances doses were much lower. Of the discharges from the nuclear power stations, only those from Trawsfynydd have led to public radiation exposure amounting to more than a small fraction of 1% of the ICRP dose limits; even in that case the maximum dose to any individual was no more than about 8% of the dose limit.

Table 26 Estimates of public radiation exposure from liquid radioactive waste disposal in the United Kingdom, 1975

Site	Pathway	Maximum exposure* of an individual (% of ICRP-recommended dose limit)	
BRITISH NUCLEAR FUELS LIMITED			
Windscale	Fish	34	(to critical group)
	External dose	9	
	Porphyra/laverbread	< 0.2	(to critical group)
Springfields	External dose	1	
Chapelcross	External dose	< 0.1	
	Shellfish	< 0.1	
UNITED KINGDOM ATOMIC ENERGY AUTHORITY			
Winfrith	Shellfish	< 1	
Harwell*	Drinking water	< 1	
Dounreay†	External dose (foreshore)	2	
	Beta dose (fishermen	< 1	
	Shellfish	< 1	
CENTRAL ELECTRICITY GENERATING BOARD			
Berkeley/ Oldbury	External dose	< 0.1	
	Fish/shellfish	< 0.1	
Bradwell	Oysters	0.07	
Dungeness	External dose	< 0.1	
	Fish	< 0.1	
Hinkley Point	External dose	< 0.1	
	Fish/shellfish	< 0.1	
Sizewell	External dose	< 0.1	
	Fish/shellfish	< 0.1	
Trawsfynydd	Lake fish	8	
Wylfa	Fish/shellfish	< 0.1	
	External dose	< 0.1	

Table 26 (continued)

Site	Pathway	Maximum exposure* of an individual (% of ICRP-recommended dose limit)
SOUTH OF SCOTLAND ELECTRICITY BOARD		
Hunterston	External dose	< 0.1
	Fish/shellfish	< 0.1
NAVAL ESTABLISHMENTS		
Chatham	External dose	< 0.1
Devonport	"	< 0.1
Faslane	"	< 0.1
Rosyth	"	< 0.1
Holy Loch	"	< 0.1

*Assessed for discharges from the site named only except Harwell where the entry includes an estimate for other discharges to the River Thames.
†Includes the effect of minor discharges from the adjoining site (HMS VULCAN) operated by MOD (Procurement Executive).

Although a primary consideration when assessing the impact of radioactive waste discharges is the dose received by individuals, it is necessary also to assess the collective population dose and so ensure that the objective of limiting average per caput dose is met. When this integration is done for most of the discharges from sites covered by this report it is found that their contribution to collective dose is negligible. Exceptions are the discharge of radionuclides from Windscale and that of tritium into the catchment area of the River Thames. Details have already been given of the FRL programme to measure the collective dose due to the contamination of fish by Windscale caesium (see section 4.1.1) and it has been shown that the dose to the UK population itself during 1975 was equivalent to 0.45% of the UK limit of 33 millirem per person per year whilst that to the other nations of western Europe was approximately 0.12% of the UK limit.

The collective dose from tritium released to the catchment of the River Thames is at a much lower level. In 1975 the collective dose, estimated from the mean flow rate of the river at the point at which water is extracted and the rate at which water is consumed by the estimated 7 million people who depend on this source, was about 100 man-rem, equivalent to less than 0.01% of the UK dose limit.

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