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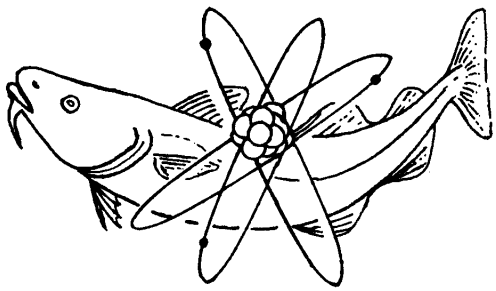

RADIOACTIVITY IN SURFACE AND COASTAL WATERS OF THE BRITISH ISLES 1967

N. T. MITCHELL

TECHNICAL REPORT FRL 2

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CONTENTS

Last year, in the first report in this series (FRL 1), Neil Mitchell reviewed the work done by the Fisheries Radiobiological Laboratory, Lowestoft, to ensure the safe disposal of radioactive waste to surface waters and the sea. In this second report, covering the work done in 1967, he records the changes which have occurred at the various sites where waste is discharged. The information supplied shows the care with which the interests of the public are protected and how the satisfactory situation of earlier years is being maintained.

H. A. Cole
Director of Fishery Research

Technical Report FRL 2

RADIOACTIVITY IN SURFACE AND COASTAL WATERS OF THE BRITISH ISLES, 1967

INTRODUCTION

The radiological control work of the Fisheries Radiobiological Laboratory of the Ministry of Agriculture, Fisheries and Food was described in the first report in this series[1], issued in 1967, which summarized monitoring information for the period 1963-66. In accordance with the laboratory's policy of publishing results of surveys, the present report contains data from similar work done in 1967. In addition to the results of monitoring situations in England and Wales where the Ministry is itself directly responsible, data are included for Scotland and the Channel Islands, where monitoring has been undertaken for the authorities responsible - Departments of the Scottish Office and the Channel Islands Governments respectively. In view of international interest in possible contamination of the high seas, measurements of radioactivity in waters of the open sea made in 1967 have been included, together with some for earlier years.

The surveys reported have covered essentially the same areas as in 1966, although the detailed design of monitoring programmes is subject to continual variation to satisfy particular demands. One new authorized site was added in 1967 - Oldbury-upon-Severn Nuclear Power Station, discharging to the River Severn near Bristol. Surveillance of this area added little to the laboratory's programme because discharges from Oldbury are made into essentially the same reach of the estuary as those from Berkeley (only four miles to the north), which has been monitored for the past seven years.

The most important factor in the design of monitoring programmes is information from surveys of the activities of those members of the public (critical groups) most closely concerned with the effects of each discharge. As the habits of the public tend to change, so, too, do the critical factors in determining public exposure. Thus these habits surveys must be brought up to date at regular intervals, which in turn leads to changes in monitoring surveys.

As in the previous report[1], data are recorded fulfilling two main purposes, the primary aim being to establish the degree of public radiation exposure from each discharge. The secondary objective is to produce information principally for use in long-term forward planning and though not essential for current radiological assessments is not without value in this respect. Contaminated environments provide data on such processes as dispersion and reconcentration,

which are often applied to environments other than the one from which they were collected, particularly in making pre-operational assessments of new sites and in estimating the capacity of those environments to accept discharges of radioactivity.

Rather more work than is scientifically necessary is done on occasions in some of the areas - particularly in environments where little or no contamination is measurable. This is done in order to demonstrate to the general public that the situation is entirely safe. Once the safety of such areas has been demonstrated over a period of years the extent of surveys can be reduced to a level which is more realistic in terms of the scientific needs of radiological assessment, and is at the same time still wholly adequate to confirm that discharges are being safely controlled.

Measurements of radioactivity are largely the result of laboratory work on samples, the exception being the measurement of dose-rate in the environment. In situ methods of measurement have not yet shown any clear advantage over the analysis of samples under controlled laboratory conditions, although analysis by gamma spectrometry in the field is feasible for certain purposes and is being developed. For instance, this is likely to be useful on silt banks, where estimation of the individual constituents of radioactive contamination is required in addition to a total beta or gamma dose-rate.

WORKING METHODS

Measurement of gamma dose-rates feature in many environmental monitoring programmes, a reflection of the frequency with which the exposure pathway of silt contamination in the working area of fishermen is found to be one of the critical routes. Such measurements are often, by laboratory standards, relatively imprecise, due to a number of factors. The values measured are frequently low and in many situations no more than natural background, so that there is a considerable statistical variation in making individual measurements. Efforts have been made to reduce this by averaging as many measurements as possible and the range collected indicates the degree of these random variations. In addition error arises due to the basic limitations of the system employed which, because of the need for portable and robust instruments, uses GM tubes. The energy response of these detectors is not linear and they considerably overestimate the dose from low energy gamma radiation. However, the error introduced in this way is only important in measurements at or near the natural background level, because it is only in these cases that a relatively large proportion is due to the low-energy component - essentially cosmic radiation. The true value of the cosmic component is about 3 μR/hour, but it is frequently overestimated by a factor of 2 unless particular efforts are made to avoid it by using energy-compensated GM tubes or by allowing for the effect in calibrating

the instruments. In most of the measurements collected for these reports a calibration correction has been applied so as largely to eliminate this error; hence the values collected are good approximations to a true gamma dose-rate. The only exceptions, where this correction has not been applied, are those areas of relatively high dose-rate where the cosmic component is only a small fraction of the total measured dose-rate and so is of no practical importance.

Total beta activity measurements have certain uses, particularly that of a basic screen to detect abnormal variations, although the method in current use up to the end of 1967, which involves the counting of infinitely thick sources, is only partially successful in this way. The main disadvantage is its inability to detect low-energy beta particles. This has now been largely overcome by the installation of equipment to count thin sources (200 milligrammes spread evenly over a 5 inch diameter tray). The operation of these two systems in this laboratory and their application are discussed in detail by Dutton[2]. All the 1967 results for total beta measurements are quoted for the infinitely thick source method, but this marks the end of routine use of this system by the laboratory.

A large proportion of the measurements of individual radionuclides is made by instrumental methods, which involve the minimum of preparative chemistry. However, some chemical separations are still necessary - for instance, for most pure beta emitters such as Strontium-90 - unless physical characteristics such as half-life can be used, as in the case of Phosphorus-32. With gamma-emitting radionuclides a great deal of use is made of their property of exhibiting an energy spectrum characteristic of the emitted gamma radiation and thus of the radionuclide itself. Most gamma-emitters can be measured by spectrometry even in relatively complex mixtures, unless interfering nuclides are present whose gamma photon energies effectively coincide. When this occurs resort is made to chemical separations, which are also necessary on some particularly important nuclides when they are at such low concentrations that their characteristic gamma peaks cannot be distinguished from the continuum resulting from other nuclides. Samples frequently contain several gamma-active contaminants in addition to the ubiquitous Potassium-40 and other natural radioactivity. In favourable circumstances, simultaneous identification and estimation of up to eight nuclides is being done using large, high-resolution, sodium iodide (thallium-activated) crystal assemblies. This is only possible because computer techniques are used for resolution of the complex spectra. The first method adopted by this laboratory, and still in current use, depends on the judicious selection of sections of the spectrum in each of which one radionuclide only will normally show a total absorption peak of a major gamma photon. Thus each of the nuclides making up the complex spectrum can be assigned an efficiency (determined by the use of standards) for any section of the spectrum. Standard solutions made up by The Radiochemical Centre, Amersham are used for this

purpose and are mixed with the appropriate environmental material or an accurate simulant of it. The amount of a radionuclide present in a mixture can be estimated from a series of simultaneous equations. Each equation relates to one section of the spectrum, and the solution of the series - a tedious arithmetical operation - is reduced to a simple routine by applying a computer to matrix inversion. The relative merits of this system and its application to the work of this laboratory are discussed by Dutton[3]. Much of the problem of interferences from overlapping gamma peaks will probably be overcome by the use of lithium-drifted germanium detectors, which are already showing promise for some purposes in which they may ultimately supersede the use of sodium iodide. Their detection efficiencies are at present relatively low, which is due to the limit on the size of detector available, but this is at least partially offset by their greatly superior resolution, which has already proved useful in samples from some of the more contaminated environments. Thus the 0.724 MeV peak of Zirconium-95 can be resolved from the complex at about 0.76 MeV due to this nuclide and Niobium-95, estimations which have previously required tedious chemistry. Similarly, the group of Iron-59, Zinc-65 and Cobalt-60, important isotopes in power station effluents, with peaks at 1.098, 1.116 and 1.173 MeV, can be resolved, so that this technique is already showing promise in environmental work as well as for research purposes.

SITES OPERATED BY THE UNITED KINGDOM ATOMIC ENERGY AUTHORITY

Windscale and Calder, Cumberland

Since the discharge from this site is the largest with which the laboratory is involved, it is not inappropriate that a large proportion of the monitoring effort should be related to it. Only part of this monitoring is essential for current radiological safety assessment; this is a reflection of the extensive opportunities which this environment offers for field research. A considerable range of important materials can be found, although the number of contaminating nuclides is limited to a few of the major fission nuclides.

Two groups of the public are important in relation to Windscale discharges - the laverbread consumers of South Wales, and a more local population in the Ravenglass Estuary for whom external exposure from contaminated silt is the critical pathway. The latter group is only slightly less important in terms of the proportion of the acceptable dose limit which is reached but involves only a small number of people, which is very much less than the total number of laverbread eaters.

Radiological control for laverbread consumption is effected by suitable monitoring of the seaweed concerned - Porphyra umbilicalis (Table 1). The critical nuclide is Ruthenium-106, which is normally responsible for more than 95 per cent of the dose to the critical organ - the gastro-intestinal tract of consumers. Cerium-144 makes a minor contribution to the G.I. tract dose, and that from Zirconium-95/Niobium-95 is almost negligible. This is so even though this pair of nuclides dominates the discharge, because they have lower concentration factors in the seaweed, and also lower radiotoxicities than either Ruthenium-106 or Cerium-144. However, the sources of radioactive waste at Windscale are so complex that the composition of discharges varies considerably; increases of cerium, in particular, could markedly change the relative radiological importance.

An accurate assessment of the dose-rate to laverbread eaters is not easily calculated since a number of factors are involved, and, in particular, a knowledge of the relative importance of different collection areas is necessary, receipts from which often vary in an unpredictable manner. Because of this, market dilution with weed from non-contaminated coastlines cannot be relied on in forward planning such as the setting of acceptable discharge limits in authorizations. During 1967 the product of the four main manufacturers of laverbread was sampled on a weekly basis and was analysed for Ruthenium-106 (Table 2). This demonstrated that a considerable market dilution does occur, though this

varies from one manufacturer to the next and, for the product of one manufacturer, is subject to quite wide fluctuations. Radiological assessment of this group of consumers has been discussed in detail by Preston and Jefferies[4, 5].

Monitoring for the sub-critical group in the Ravenglass Estuary requires regular measurements of gamma dose-rates at selected sites; an average of these measurements for 1967 will be found in Table 3, with analyses of the important constituents. Measurements are made on silt samples for fission nuclides, variations of which have been recently reported by Jefferies[6, 7]. For silt in this situation, unlike Porphyra, Zirconium-95 and Niobium-95 are the important nuclides, Ruthenium-106 being of secondary importance. Cerium-144 does not normally make any substantial contribution, although in any situation where the beta dose became important this nuclide could become critical, due to the high beta energy of its Praseodymium-144 daughter. Similar surveillance of silt dose-rates is made at other points on the coast where silt is extensive in areas visited by the public. The most important of these are Walney Island and Whitehaven Harbour (Table 3), though at neither of these points is contamination as important as in the Ravenglass Estuary.

Fish are monitored occasionally (Table 4) but are of relatively little importance as sources of exposure. Plaice, even in the vicinity of the pipeline, do not become contaminated to any important degree compared with Porphyra on the nearby seashore.

A variety of non-critical materials is sampled, particularly Fucus seaweeds (Table 5) which are useful indicator materials. Sea water has been sampled at selected points, particularly in relation to other monitoring efforts; it is not a factor in public exposure but is monitored to provide the basis for determining concentration factors, and in 1967 measurements were restricted to coastal waters. The samples as taken contain a variable amount of fresh water from run-off from the land, and correction is made for this before ultimate use of the results. However, the values presented here (Table 6) are as counted, and are therefore up to 10 or even 20 per cent lower than for undiluted sea water. Occasional seabed samples have been taken as opportunities arose, particularly in the vicinity of the pipeline area where the highest concentrations are likely to occur (Table 7). Sampling of seaweeds (Tables 8 and 9) and beach materials (Table 10) has again been extended beyond the limits where contamination leads to a significant degree of exposure. The areas covered are principally on the coastline of the Irish Sea and its approaches, particularly the St. George's Channel and the North Channel. In 1967 sand and silt were sampled at various points and show typical variations, the radioactivity in silt usually being much higher due to its greater natural content; in addition silt has a higher affinity for absorbing radionuclides such as the prominent fission products from Windscale discharges. The latter can be detected as far away as the Ribble Estuary (see Table 11, discussed under Springfields).

Table 1 Radioactivity in Porphyra in the immediate vicinity of Windscale, 1967

Sampling site	Distance from pipeline (miles)	Concentration of radioactivity, pCi/g (wet); mean and range				
		Total Beta	^{106}Ru	$^{95}Zr/^{95}Nb$	^{144}Ce	Total Alpha
Dubmill Point	32.0	8.5	3.8	1.1		
Maryport	25.5	22 (12-30)	10 (4-14)	2.1 (0.7-3.7)		
St. Bees	6.2	120 (25-207)	51 (11-88)	15 (0.8-41)	see Eskmeals	see Eskmeals
Nethertown	3.5	247 (78-388)	107 (28-163)	39 (1.8-157)		
Braystones North	2.3	268 (55-390)	114 (21-181)	35 (1.3-113)		
Braystones South	1.2	284 (44-491)	116 (18-199)	36 (1.2-133)		
Sellafield Pipeline	0	262 (42-516)	112 (20-210)	27 (1.6-77)	1.8 (1.0-3.2)	1.4 (0.9-1.7)
Sellafield Bailey Bridge	0.9	258 (30-556)	110 (14-186)	27 (1.0-114)		
Seascale	1.9	250 (59-408)	107 (29-173)	29 (1.6-87)		
Drigg Barnscar	3.5	232 (51-588)	98 (18-255)	16 (1.2-59)		
Drigg Rabbit Warren	5.0	175 (16-264)	72 (8-112)	24 (0.6-60)		
Eskmeals North	6.8	114 (77-143)	51 (30-65)	10 (1.0-22)	1.7 (0.2-2.8) (with St. Bees)	1.2 (0.3-1.9) (with St. Bees)
Eskmeals South	8.9	169 (29-365)	72 (13-159)	13 (1.5-49)		
Gutterby	12.5	133 (49-306)	56 (24-125)	16 (1.1-62)	1.8 (0.2-3.7)	1.5 (0.2-3.3)
Walney Island	24.0	67 (26-182)	29 (12-83)	7.2 (0.4-33)	2.2 (0.2-5.6)	3.3 (0.1-12)

NOTE: The mean concentration of natural radioactivity, ^{40}K, is 5.6 pCi/g (wet).

Table 2 Ruthenium-106 in laverbread manufactured in South Wales, 1967

Manufacturer	Concentration of ^{106}Ru, pCi/g (wet); mean and range
A	4.1 (0-29)
B	6.3 (0-32)
C	15 (0-56)
D	1.0 (0-19)

Table 3 Radioactivity in silt, and gamma dose-rates over silt banks in the vicinity of Windscale, 1967

Sampling site	Concentration of radioactivity, pCi/g (dry); mean and range			Gamma dose-rate, μR/hour
	$^{95}Zr/^{95}Nb$	^{106}Ru	^{144}Ce	
Eskmeals	1170 (114-7480)	746 (389-2880)	623 (170-4670)	134 (80-320)
Walney Island	417 (17-3100)	276 (74-1340)	271 (27-2400)	36 (18-60)
Whitehaven Harbour	225 (86-470)	293 (199-427)	124 (73-177)	65 (41-88)

Table 4 Radioactivity in plaice flesh in the vicinity of Windscale, 1967

Group	Concentration of radioactivity, pCi/g (wet); mean and range			
	^{106}Ru	^{134}Cs	^{137}Cs	^{40}K
I (0-1 years)	1.4	0.4 (0.3-0.5)	0.8 (0.7-0.8)	2.0
II (1-2 years)	1.9 (0.8-2.8)	0.3 (0.2-0.6)	0.7 (0.5-1.1)	2.1

Table 5 Radioactivity in Fucus vesiculosus in the vicinity of Windscale, 1967

Sampling site	Concentration of radioactivity, pCi/g (wet); mean and range					
	Total Beta	^{90}Sr	$^{95}Zr/^{95}Nb$	^{106}Ru	^{137}Cs	^{144}Ce
St. Bees	48 (25-75)	0.25	52 (5.7-99)	13 (5.4-27)	1.4	5.4
Nethertown	56 (46-65)	-	40 (8.8-80)	14 (9.1-16)	0.9	5.1
Sellafield Bailey Bridge	61 (24-95)	-	38 (5.5-88)	13 (6.6-18)	0.7	2.1
Seascale	66 (38-116)	0.25	63 (7.8-125)	20 (10-36)	1.0	5.2 (2.1-10)
Gutterby	30 (24-33)	0.19	25 (5.4-44)	6.6 (5.7-8.2)	0.5	1.8 (0.9-2.6)
Walney Island	18 (13-21)	0.19	10 (3.7-19)	3.2 (2.2-4.4)	0.6	1.1

Table 6 Radioactivity in coastal sea water in the vicinity of Windscale, 1967

Sampling site	Concentration of radioactivity, pCi/litre; mean and range			
	$^{95}Zr/^{95}Nb$	^{106}Ru	^{137}Cs	^{40}K
St. Bees	38 (1.7-119)	43 (1.2-161)	18 (2.0-63)	264
Braystones	65 (3.0-196)	66 (5.0-270)	30 (3.8-174)	257
Seascale	60 (1.9-393)	76 (6.8-827)	36 (5.5-546)	243

Table 7 Radioactivity in seabed samples in the vicinity of Windscale, 1967

Sampling position	Concentration of radioactivity, pCi/g (dry); mean and range		
	$^{95}Zr/^{95}Nb$	^{106}Ru	^{144}Ce
1 mile off Seascale	1260 (43-3770)	411 (136-1220)	260 (99-607)
2 miles off Braystones	4110 (640-7650)	1050 (574-2090)	771 (359-1250)

Table 8 Radioactivity in Porphyra around the British Isles, 1967

Sampling site	Concentration of radioactivity, pCi/g (wet); mean and range		
	Total Beta	$^{95}Zr/^{95}Nb$	^{106}Ru
Larbrax Bay	6.9 (6.0-9.5)	0.2	1.1 (0.4-1.5)
Port William	8.4 (7.8-8.8)	0.2 (0.2-0.3)	2.4 (2.3-2.5)
Garlieston	9.6 (6.9-15)	0.6 (0.4-0.7)	2.6 (2.0-3.6)
Bloody Foreland	5.8		
St. Helens	5.4 (4.7-7.0)		
Dunbar	6.0 (4.9-7.4)		
Lowestoft	3.5 (2.3-4.9)		

Table 9 Radioactivity in Fucus seaweeds around the British Isles, 1967

Seaweed and sampling site	Concentration of radioactivity, pCi/g (wet); mean and range				
	Total Beta	$^{95}Zr/^{95}Nb$	^{106}Ru	^{137}Cs	^{144}Ce
F. vesiculosus					
Port William	7.8 (6.6-8.8)	0.5 (0.3-0.8)	0.6 (0.3-0.7)	0.1	
Rascarrel Bay	9.4 (5.8-13)	2.7 (1.4-5.4)	1.3 (0.8-1.9)	0.1	0.4
Heysham	11 (9.0-14)	1.9 (1.3-3.7)	1.7 (0.8-2.7)	0.3	0.6
Bloody Foreland	6.4				
St. Helens	6.8 (6.0-7.4)				
F. serratus					
Millisle	8.0 (6.5-9.0)				
F. spiralis					
Lowestoft	5.6 (4.8-6.4)				

Table 10 Radioactivity in silt and sand around the British Isles, 1967

Material and sampling site	Concentration of radioactivity, pCi/g (dry); mean and range				
	Total Beta	$^{95}Zr/^{95}Nb$	^{106}Ru	^{137}Cs	^{144}Ce
Silt					
Garlieston	54 (30-94)	8.4 (1.6-16)	19 (8.2-34)	1.2 (0.9-1.4)	8.3 (5.6-14)
Cutters Pool	73 (25-93)	6.5 (0.9-12)	21 (4.4-30)	1.5 (1.0-2.1)	11 (3.0-16)
Sand					
Heysham	24 (17-32)				
Fleetwood	6.8 (6.3-7.5)				
Bloody Foreland	9.2				
St. Helens	4.4 (3.2-5.3)				
Lowestoft	3.2 (2.7-3.6)				

Springfields, Lancashire

Monitoring on a similar pattern to that of 1966 has shown that contamination has not changed significantly. The radioactivity in silt and the gamma dose-rate on silt banks in the Ribble Estuary (Table 11) are well within the acceptable limits, and the only nuclide attributable to Springfields discharges is Protactinium-234m.

Table 11 Radioactivity in silt and gamma dose-rate over silt banks in the Ribble Estuary, 1967

Sampling site	Concentration of radioactivity, pCi/g (dry); mean and range				Gamma dose-rate, μR/hour
	Total Beta	$^{95}Zr/^{95}Nb$	^{106}Ru	^{234m}Pa	
Pipeline outlet	181 (105-243)	10 (4.8-16)	40 (24-49)	535	18 (12-22)
Upstream*					
100 yards	364 (130-970)	12 (2.9-22)	40 (17-82)	323	18 (12-30)
500 yards	403 (151-563)	28 (8.4-49)	79 (42-134)	862	20 (12-32)
Downstream*					
100 yards	180 (134-216)	22 (4.8-53)	55 (26-77)	334	18 (11-23)

*from pipeline outlet.

Winfrith, Dorset

Discharges are still very small and, being discharged from a long pipeline into deep water which has good mixing and dispersion characteristics, there is no likelihood of measurable contamination of either critical or indicator materials. Because of this, monitoring programmes in this area are in abeyance.

Chapelcross, Dumfries-shire

Shrimps are still the critical material for this site; 1967 was a poor year for the local fishing grounds, and the measurements made are from samples collected further down the Solway Estuary from the discharge point than normal. However, these are still typical of the product normally fished from the vicinity of Annan in previous years, being the same species. Sea water and sand or silt were sampled nearer to the pipeline, and measurements of these materials are shown in Table 12 (together with those for shrimps). These results are a better indication of the degree of contamination of the Chapelcross environment than measurements in shrimps, and they show that operation of the site has little effect on the estuary and does not create any significant radiological exposure.

Table 12 Radioactivity in estuarine materials in the vicinity of Annan, 1967

Material	Sampling area	Concentration of radioactivity, pCi/g (wet)*; mean and range					
		Total Beta	^{90}Sr	$^{95}Zr/^{95}Nb$	^{106}Ru	^{137}Cs	^{144}Ce
F. vesiculosus	Waterfoot	9.1 (7.6-11)	-	2.5 (0.3-7.6)	1.2 (0.9-1.8)	0.3	0.7
	Seafield	8.9 (8.1-9.9)	-	1.1 (0.4-2.0)	1.5 (0.8-2.1)	0.9 (0.4-1.5)	1.1
Silt	Seafield	80 (37-132)	-	17 (3.0-33)	34 (14-54)	4.4 (1.5-7.8)	17 (5.4-33)
Sand	Seafield	30 (21-49)	-	6.3 (0.8-16)	6.0 (3.0-10)	1.5	5.0
Shrimp flesh	Estuary	2.6	0.014	-	-	0.2	-

*Except silt and sand - pCi/g (dry).

Dounreay, Caithness

A small amount of monitoring was done in the Dounreay area in 1967, being confined to measurements of total beta radioactivity on Fucus seaweed and in limpets (Table 13). Although this is the next largest discharge after Windscale and the environment is contaminated to an easily measured degree, the measurements indicate that the exposure is well within the acceptable limits.

Table 13 Total Beta radioactivity in the vicinity of Dounreay, 1967

Material	Sampling site	Concentration of Total Beta radioactivity, pCi/g (wet); mean and range
F. vesiculosus	Sandside Bay	123 (21-546)
Limpet flesh	Sandside Bay	144 (47-312)

NUCLEAR POWER STATION SITES OF THE CENTRAL ELECTRICITY GENERATING BOARD AND OF THE SOUTH OF SCOTLAND ELECTRICITY BOARD

Monitoring at these sites has continued in much the same way as in 1966, although minor variations in survey programmes have been made. Some important changes have been noted in the radioactivity measured, particularly in such areas as the Severn Estuary and Lake Trawsfynydd where the first indications of power station operation have been detected by environmental measurements. Although discharges from Trawsfynydd nuclear power station may ultimately become a significant source of exposure, it does not appear that the degree of environmental contamination at any of the coastal sites will become important and for some may not even reach measurable proportions. For instance no radioactivity of power station origin has as yet been detected in the Dungeness or Sizewell environments.

Environmental monitoring programmes are designed around radiological safety assessments, but some environments are beginning to show a considerable potential for field research. A range of nuclides can be found from the Bradwell discharges; apart from Caesium-137 and -134, they are all corrosion products from activation of the magnox fuel-element canning material. Thus the behaviour of many of these nuclides is providing new information, since in the United Kingdom they are normally found only in power station effluents and not to any significant degree in effluents from Windscale.

Bradwell, Essex

Here the basic monitoring programme for the assessment of radiological safety is the regular sampling of oysters, the only criticial material[8] (Table 14). Silt and seaweed close to the power station are also sampled and occasional measurements of dose-rate are made at similar locations (Table 15). None of these latter materials is important as a source of radiation exposure, but they do act as environmental indicators of the operation of the station.

Numerous oyster beds have been sampled from time to time, but the most important radiologically are the commercial beds nearest to the station, approximately 500 yards away downstream, at which the highest concentrations of radioactivity in marketable oysters are found. Temporary layings close to the point where the spent cooling water is discharged (the Barrier Wall) show higher values. Although oysters cannot be left long enough at this site for biological equilibrium to be reached, because the site is unsuitable for long-term cultivation, they do survive long enough to fulfil the purpose of indicating a "ceiling" concentration in any prevailing circumstances. The critical nuclide is Zinc-65 and, whilst this makes up most of the exposure resulting from consumption of oysters (as discussed in more detail later), several other nuclides

can be found, particularly in the Barrier Wall position. These are Cobalt-60, Iron-55, and Caesium-137, and, in addition, very recently, Silver-110m and Phosphorus-32. The identity of Silver-110m was established by chemical separations[9] and that of Phosphorus-32 (which, not being a gamma-emitter, cannot be identified by spectrometry) by repeated counts on the sample as it decayed, relying on a characteristic half-life. Although these numerous radionuclides can be detected in oysters their total effect is small and concentrations are well within acceptable, safe, limits.

Only a very limited programme of silt monitoring is carried out, since silt is not an important factor in exposure of the public in the vicinity of Bradwell, where no one makes extensive use of the foreshore, and thus external radiation exposure is of less importance than the internal exposure from consumption of oysters. The gamma dose-rates found close to the station are due to direct radiation from the power station itself and natural background radiation. Although traces of radioactivity attributable to discharges of liquid waste from the station are now being found in silt, particularly Caesium-137 and Zinc-65, measurements of the concentrations involved confirmed that such contamination of silt is not responsible for any measurable contribution to the total gamma dose-rate. Traces of radioactivity are found in locally-picked seaweeds and carry no more significance than the similar concentrations of these radionuclides detected in silt.

Table 14 Radioactivity in oysters in the Blackwater Estuary, 1967

Sampling area	Concentration of radioactivity, pCi/g (wet); mean and range						
	Total Beta	^{32}P	^{55}Fe	^{60}Co	^{65}Zn	^{110m}Ag	^{137}Cs
Native species							
Barrier Wall	4.9 (3.4-8.8)	≈1.8 (<0.5-2.8)	1.06 (0.51-2.15)	0.94 (0.41-1.9)	46 (10-78)	0.33	1.1 (0.5-1.4)
$\frac{1}{3}$ mile downstream*	-	≈0.3	0.11 (0.05-0.20)	0.052 (0.023-0.093)	4.7 (3.4-5.9)	0.07	0.2 (0.1-0.5)
1 mile upstream*	-	-	-	-	2.3 (1.6-2.7)	-	0.2 (0.1-0.3)
2 miles upstream*	-	-	-	-	2.0 (1.8-2.7)	-	0.2 (0.1-0.3)
Portuguese species							
Barrier Wall	3.4 (2.7-4.7)	≈1.3 (1.0-1.7)	-	0.31 (0.10-0.41)	24 (18-38)	-	0.8 (0.3-1.7)
Strood Channel	1.7 (1.7-1.7)	-	-	-	0.3 (0.2-0.3)	-	-

*Distance from Barrier Wall.

Table 15 Radioactivity in non-critical materials and gamma dose-rates over silt in the Blackwater Estuary, 1967

Material	Distance from Barrier Wall (miles)	Concentration of radioactivity, pCi/g (wet)*; mean and range					Gamma dose-rate, μR/hour
		Total Beta	^{60}Co	^{65}Zn	^{134}Cs	^{137}Cs	
F. vesiculosus	0	7.6	0.6	0.4	≈0.1	0.6	-
	1 (upstream)[x]	7.0	0.4	0.3	≈0.1	0.4	-
Porphyra	0	5.2	-	-	-	-	-
Silt	1 (downstream)	19 (17-21)	-	-	≈0.1	0.3 (0.2-0.4)	-
	0	20 (16-22)	-	-	≈0.4	0.5 (0.2-1.2)	21 (10-37)
	1 (upstream)	23 (22-24)	-	-	0.6 (0.1-1.7)	1.4 (0.2-3.4)	-

*Except silt - pCi/g (dry)

[x]Also shows traces of ^{106}Ru in first half of the year at about 0.3 pCi/g (wet).

Upper Severn Estuary

As previously mentioned, there are now two power stations, Oldbury-upon-Severn and Berkeley, discharging radioactive effluent to the Upper Severn Estuary. In designing monitoring programmes no distinction is at present drawn between the two sites, since it is obvious that any environmental contamination found during 1967 was due to the operation of Berkeley alone, negligible quantities of radioactivity having been discharged from Oldbury. Both are magnox stations, although Oldbury has a more advanced design and may ultimately discharge a waste of slightly different composition from that of Berkeley. When Oldbury reaches the stage of contributing waste at a significant rate some revision of the monitoring programme may be needed in respect of the particular nuclides to be looked for in the environment.

Silt, due to its ability to take up radioactivity - resulting in a source of external exposure - is potentially a more important critical factor than internal exposure from consumption of fish and shellfish. For this reason gamma dose-rates are measured over silt at some sixteen positions up to 15 miles from Berkeley (Table 16). These still show levels indistinguishable from background, with the exception of the area close to the station perimeter fence, which, however, includes some direct radiation from the power station. This situation is closely similar to that at Bradwell, and in the same way no significant proportion of this radiation dose-rate is due to silt contamination, which is confirmed by the concentrations of radioactivity found on analysis of samples. External exposure on the foreshore is a factor of some importance, extensive use being made of silt banks - particularly by salmon fishermen - but even the enhanced levels of gamma dose-rate found close to the station are well within safe limits.

Monitoring for the subsidiary critical factor of internal exposure involves regular measurements of fish, particularly flounders - the most common species - and shrimps, with occasional measurements on salmon and elvers when in season. The seaweed Fucus vesiculosus is sampled from the shore near Berkeley nuclear power station as an indicator material; the results are shown in Table 17, together with those for fish and shrimps.

Radioactivity of power station origin was detected in the estuary in 1967 for the first time, although the only nuclides found so far are Caesium-137 and -134, predominantly the former, which is the only measurement being quoted. It was found in silts over a wide range of the Severn Estuary (Table 16) though not without some difficulty, the concentrations being low and only a very small fraction of the natural radioactivity. These concentrations are too low to make any significant contribution to the measured gamma dose-rates, which are still effectively due to natural activity. These measurements are of very low significance, as will be seen by comparing the concentrations with those of the

natural radioactivities, Potassium-40 and Uranium; in addition, allowance must be made for further activity due to decay products in the natural uranium series which are not quoted.

Other materials - the seaweed Fucus vesiculosus and shrimps - showed very slightly higher concentrations of Caesium-137, though, as expected, the concentrations in salmon were not significantly different from the values expected from fallout. Concentrations of Caesium-137 in shrimps are only just in excess of fallout levels in Lowestoft shrimps of the same species - about 0.02 pCi/g (wet); at these concentrations they constitute no risk.

Table 16 Radioactivity in, and gamma dose-rate over, silt banks in the Upper Severn Estuary, 1967

Site	Distance from pipeline outlet (miles)	Concentration of radioactivity, pCi/g (dry); mean and range		Gamma dose-rate, μR/hour
		Total Beta	^{137}Cs	
East Bank	0	16 (13-22)	1.2 (0.2-2.4)	48 (21-65)
	1-3	-	1.2 (0.2-2.1)	6.9 (6.3-7.8)
	3-6	-	0.5 (0.2-0.8)	7.9 (6.8-11)
	6-10	-	0.6 (0.2-1.3)	7.3 (6.3-9.5)
	> 10	-	-	7.0 (6.6-7.2)
West Bank	1-3	-	0.6 (0.2-0.9)	6.9 (5.8-8.0)
	3-6	-	0.4 (0.2-0.5)	7.1 (6.7-7.3)
	6-10	-	0.6 (0.2-0.9)	6.5 (5.5-8.0)

NOTE: The mean concentrations of natural radioactivity are:
^{40}K - 11.6 pCi/g; ^{238}U - 3.6 pCi/g; ^{232}Th - 0.8 pCi/g.

Table 17 Radioactivity in fish, shrimps and seaweed in the Upper Severn Estuary, 1967

Material	Concentration of radioactivity, pCi/g (wet); mean and range		
	Total Beta	^{137}Cs	^{90}Sr
Flounder flesh	1.8 (1.4-2.1)	0.05 (0.04-0.06)	-
Salmon flesh	2.4 (1.6-2.9)	0.03 (0.02-0.03)	< 0.001
Shrimp (whole)	2.0	0.05	0.09
Elver	1.0	0.01	-
F. vesiculosus (pipeline outlet)	6.0 (4.3-7.1)	0.1 (0.1-0.2)	-

Dungeness, Kent

This power station is in such a favourable position to achieve a high dispersion of waste that any measurable effect in the marine environment is unlikely. Nonetheless, a limited programme of monitoring is conducted so as to be able to demonstrate that the situation is, in fact, as predicted (Table 18). Potential exposure pathways would lead to external dose to bait diggers by the contamination of silt and sand, and to internal dose to the local fishing population who are the most important consumers of locally-caught fish. Thus the monitoring programme includes measurements of gamma dose-rate on the beaches to the east of Dungeness Point, with analysis of samples of sand and plaice. No contamination of the environment attributable to the operation of the station has yet been detected from any of these measurements.

Table 18 Radioactivity in marine materials and gamma dose-rates over beaches in the vicinity of Dungeness, 1967

Material	Concentration of radioactivity, pCi/g (wet)*; mean and range		Gamma dose-rate, μR/hour
	Total Beta	^{137}Cs	
Plaice flesh	2.8 (2.8-2.9)	0.02 (0.01-0.04)	-
Sand	4.4 (1.7-6.5)	-	-
Sand and shingle	-	-	4.1 (3.0-5.8)

*Except sand - pCi/g (dry).

Hinkley Point, Somerset

Environmental monitoring for this discharge in 1967 consisted of the examination of silt, fish and shrimps, the critical materials, and of samples of Fucus vesiculosus taken at points close to the station (Table 19). Measurements on shrimps and fish, particularly the latter, were fewer than usual, due to a poor fishing season. However, this is not important from the radiological standpoint, particularly since no contamination was measurable in the critical materials. The seaweed, Fucus vesiculosus, always a good indicator for a number of nuclides, showed for the first time traces of radioactivity (Zinc-65) due to power station operation. Although analyses show this to be the first marine environmental indication of radioactivity discharged from Hinkley Point, no importance is attached to the very low concentrations found. None of the critical materials has any great affinity for Zinc-65, so it is not expected that it will appear in them.

Table 19 Radioactivity in marine materials and gamma dose-rates over silt in the vicinity of Hinkley Point, 1967

Material	Distance from pipeline outlet (miles)	Concentration of radioactivity, pCi/g (wet)*; mean and range			Gamma dose-rate, μR/hour
		Total Beta	^{65}Zn	^{137}Cs	
Shrimp flesh[/]	Bridgwater Bay	2.1 (1.9-2.2)	-	0.02 (0.01-0.02)	-
Whiting flesh	Bridgwater Bay	2.5 (2.3-2.6)	-	0.04 (0.02-0.06)	-
Silt	1 (east)	-	-	-	7.4 (5.0-8.5)
	0.5 (east)	-	-	-	
	0	11 (7.0-19)	-	-	
F. vesiculosus	1 (east)	7.3 (4.5-9.5)	0.2[x]	-	-
	0.5 (east)	7.6 (5.4-9.7)	0.1[x]	0.04[x]	-
	0	7.7 (3.7-9.7)	0.3 (0.1-0.7)	0.04[x]	-
	0.5 (west)	6.0 (4.1-7.0)	-	0.03[x]	-

*Except silt - pCi/g (dry)
[/]Also shows traces of ^{90}Sr - 0.004 pCi/g (wet)
[x]Single observations only.

Sizewell, Suffolk

This is another site where there are ample reserves of open sea water to aid dispersion, so it is not surprising that no radioactivity from the power station has yet been detected in any of the environmental measurements made. The critical group is the local fishing population who, in addition to consuming locally-caught fish, spend some time on the foreshore. The monitoring programme consists of measuring beach gamma dose-rates and examining a variety of fish and shellfish, particularly lobsters and crabs (Table 20).

Table 20 Radioactivity in fish and shellfish and gamma dose-rates over sand in the vicinity of Sizewell, 1967

Material	Concentration of radioactivity, pCi/g (wet); mean		Gamma dose-rate, μR/hour; mean and range
	Total Beta	^{137}Cs	
Cod flesh	3.3	0.05	-
Plaice flesh	2.0	0.03	-
Sole flesh	2.4	0.01	-
Crab flesh	1.0	-	-
Lobster flesh	1.3	0.02	-
Sand	-	-	3.6 (2.2-4.9)

Trawsfynydd, Merioneth

This power station uses fresh water from Lake Trawsfynydd for cooling purposes. The lake also receives low-level radioactive waste, and the situation of Trawsfynydd is thus quite different from that of all the other nuclear power stations with which the laboratory is concerned. However, in common with many other sites, the critical material is fish, particularly trout, but the critical group of the population is subject to internal exposure only, there being no potential source of external radiation. The importance of the critical nuclides Caesium-137 and -134 is accentuated by a particularly high concentration factor due to the very low Potassium content of the water, two factors which are inversely related[10]. Measurements made in lake water and in fish, particularly towards the end of 1967, are beginning to confirm the importance of this combination, which had been predicted as a result of fallout studies. So far the concentrations are only a small fraction of the acceptable working limits.

Various materials are sampled from the lake and local streams (Table 21) although of these only the moss Fontinalis has shown any useful capacity as an indicator for taking up radionuclides from power station operation. During the pre-operational phase, when fallout was more in evidence, the moss was found to be a good indicator of a number of fission nuclides which could still be detected. Although most of the radioactivity found in it during 1967 was still due to either fallout or natural Potassium-40, the nuclides Cobalt-60 and part of the Caesium-134 and -137 are believed to result from power station discharges. However, this material is not used in any way which would lead to public exposure, so it is of importance only as an indicator.

Table 21 Radioactivity in materials in Lake Trawsfynydd and local streams, and in the Glaslyn Estuary, 1967

Material	Sampling site	Concentration of radioactivity, pCi/g (wet)*; mean and range					
		Total Beta	^{54}Mn	^{60}Co	^{106}Ru	^{134}Cs	^{137}Cs
Water	Lake	-	-	-	-	-	3.1 (0.3-7.8)
Trout flesh	Lake	3.2 (2.6-3.7)	-	-	-	0.2 (0-0.4)	2.7 (1.6-4.4)
Perch flesh	Lake	4.0 (3.5-4.4)	-	-	-	0.1 (0-0.3)	2.8
Fontinalis	Afon Prysor[x]	5.7 (4.4-7.4)	1.8 (0.8-3.1)	-	2.9 (1.2-5.3)	-	0.4 (0.3-0.6)
	Gwylan Stream[x]	5.0 (3.0-8.1)	Present	0.4 (0.2-0.7)	2.5 (2.2-2.9)	-	2.2 (0.9-3.4)
Mud	Lake	44 (35-53)	-	-	-	-	-
Peat	Lake	16 (6-20)	-	-	-	-	-
Mussel flesh	Portmadoc	0.8 (0.5-1.3)	-	-	-	-	-

*Except mud and peat - pCi/g (dry); lake water - pCi/litre.

x ^{144}Ce was also qualitatively detected.

Hunterston, Ayrshire

Monitoring at this site (operated by the South of Scotland Electricity Board) is undertaken on behalf of Departments of the Scottish Office. The basic programme depends on the monitoring of Fucus seaweed and beach materials. Traces of Zinc-65 were detected in the seaweed during the latter half of 1967, though at trivial concentrations which are of no radiological significance. Apart from this, there is no indication of the power station's operation from monitoring of the environment, which otherwise shows only natural levels of radioactivity (Table 22).

Table 22 Radioactivity in materials in the vicinity of Hunterston, 1967

Material	Concentration of radioactivity, pCi/g*; mean and range				
	Total Beta	^{65}Zn	$^{95}Zr/^{95}Nb$	^{106}Ru	^{137}Cs
F. spiralis	6.5 (5.8-7.1)	0.1 (0-0.3)	0.1 (0.1-0.2)	0.4 (0.2-0.8)	0.1 (0.1-0.2)
Sand	5.6 (5.3-6.0)	-	-	-	-

*For F. spiralis - pCi/g (wet); for sand - pCi/g (dry).

CHANNEL ISLANDS

Monitoring has continued on behalf of the Channel Islands States to check for the possible effects of discharges from the fuel processing plant of the Commissariat à l'Energie Atomique at La Hague on the French coast. The main material chosen for monitoring was Porphyra, with particular emphasis on Alderney, the island nearest to the point of discharge, but occasional samples of Fucus serratus and sand are also included. Although discharges were being made from La Hague in 1967, no radioactivity has been detected that can be correlated with them, and traces of Ruthenium-106 found early in 1967 were consistent with the values found in other locations due to fallout from the testing of nuclear devices. For the first time samples of the flesh of ormer and brill were analysed in 1967 but showed no activity attributable to La Hague discharges, the levels of Caesium-137 being typical of concentrations due to fallout. The results of all these analyses are collected together in Table 23.

Table 23 Radioactivity in materials on the coasts of the Channel Islands, 1967

Material	Sampling area		Concentration of radioactivity, pCi/g (wet)*; mean and range	
			Total Beta	^{137}Cs
Porphyra	Guernsey	Fort Doyle	5.9 (5.2-6.3)	-
		Fermain Bay	5.2 (2.9-6.6)	-
	Alderney	Corbletts Bay	5.2 (3.6-6.5)	-
		Telegraph Bay	4.4	-
	Jersey	Greve de Lecq	4.8 (3.1-6.2)	-
F. serratus	Jersey	La Coupe	7.7	-
Sand	Guernsey	Bordeaux Harbour	9.9	-
Silt	Jersey	St. Helier	20	-
Ormer flesh	Guernsey		1.7	0.03
Brill flesh	Guernsey		3.5	0.08

*Except sand - pCi/g (dry).

DISCUSSION

In the United Kingdom considerable use is made of coasts and estuaries as sites for power stations, since such areas afford attractive opportunities for efficient dispersion of the waste-heat cooling water, and avoidance of thermal pollution. This practice is not confined to nuclear fuelled power stations, although for such units there is the added advantage of a safe means of disposal of low-level radioactivity. On British coasts there are now seven commercial nuclear power stations with a rated capacity of 3126 megawatts, which will increase to 7906 megawatts when the four further units under construction are in operation. The discharges resulting from the generation of electricity from nuclear energy, and even the larger discharges associated with re-processing of spent fuel, are conducted with complete safety. Nuclear power produces waste which involves a potential public health risk, but it is by no means unique as an industrial process in this respect; many others discharge potentially toxic wastes, usually to the atmosphere, for example, the combustion of conventional fuel.

For some years this laboratory has been measuring radioactivity in continental shelf waters round the United Kingdom, and a summary of the results for Strontium-90 will be found in Table 24; the sampling positions are shown in Figure 1. Strontium-90 was chosen for several reasons. It is among the more toxic nuclides discharged as waste from United Kingdom nuclear establishments and is also an important fission product. In addition, it is not held back in local environments close to the point of discharge due to removal on silt and by marine biota, as happens with many of the fission products; it therefore gives a true measure of the degree of dilution and dispersion of the effluent. In most of the waters sampled, the concentrations of Strontium-90 are entirely due to fallout - either direct to the sea or via run-off from the land - and the only areas where concentrations are in excess of these are the Irish Sea and waters in the immediately adjacent areas of south-west and western Scotland. Although this shows that an effect of the discharges from Windscale can be detected for a considerable distance, it is the magnitude of the concentrations which is important. These are of negligible significance, whether considered in absolute radiological terms or on a relative basis.

It is appropriate to consider the degree of radiation exposure from the consumption of fish caught in these areas. In discharges from Windscale the only radionuclides which persist are Strontium-90 and Caesium-137, for which the concentration factors in fish are well known. Thus the rate of exposure from the consumption of fish can be calculated from measurements of the activity in sea water. A man who eats fish caught from the fishing grounds nearest to Windscale at a rate of 1 kg per day - excessive by most standards though possible for fishermen themselves - would be subject to 0.7 per cent of the continuous working limits for Strontium-90 that is recommended by I. C. R. P.

as acceptable for continuous use over a lifetime. The degree of exposure from Caesium-137 is similar, so that even the most avid eater of fish is subjected to what is only an insignificant and entirely acceptable risk, equal to no more than that from the average background level of natural radiation.

A more realistic consumption rate of fish from the fishing grounds close to the Windscale pipeline, found from habits surveys, is 25 g per day. At this rate consumers are obviously subject to an even smaller risk. The next closest fishing grounds of international importance after the Irish Sea are the Stanton Banks off western Scotland; here concentrations of these radionuclides are smaller by a factor of about 50, and the attendant risk is correspondingly less. At these distances from Windscale the concentrations are indistinguishable from those due to fallout and are indeed less than the fallout concentrations found in coastal areas. They are also minute compared with the natural levels of radioactivity in sea water, a summary of which will be found in Table 25 for the more predominant radionuclides. This is based on the work of Mauchline and Templeton[11] and Libby[12], and this laboratory's Potassium-40 data.

At such low concentrations these radionuclides do not constitute any risk of substantial damage to marine resources such as fish; this is supported by recent work at this laboratory which has established concentration factors in the eggs of plaice (Pleuronectes platessa) for Strontium-90 and other nuclides. Thus concentrations of these radionuclides in the egg (the most radio-sensitive stage in the development of a fish) can now be calculated for any concentration of the radionuclide in sea water to which they may be exposed. This work shows that the concentration of Strontium-90 realized in plaice eggs in the Irish Sea is very much less than the concentration due to the naturally-occurring radionuclide Potassium-40, and the total effect of all artificial radionuclides is less than that of Potassium-40. Thus control of discharges of waste from Windscale is adequate to avoid radiation damage to marine resources.

Although radioactivity from the operation of nuclear sites is now detectable in a number of environments it has been kept well within the acceptable continuous working limits based on I. C. R. P. recommendations. In many of the instances where radioactivity has been detected it is no more than a reflection of the sensitivity of the techniques used, and does not indicate any radiological hazard. Although such measurements may appear to be academic, they do serve to put a quantitative verification on the degree of contamination, which is always more satisfactory than computed forecasts.

As the earlier-built power stations reach equilibrium on fuel turnover, the quantities of radioactivity to be discharged have risen, and two stations, Berkeley and Bradwell, have reached what may be expected to be an equilibrium discharge pattern. Due in large part to the unique combination of Zinc-65 and oysters, Bradwell is the more important radiologically. Although no measurable

change has been noted in gamma dose-rates on the silt banks of the Severn Estuary, the concentrations of Caesium-137 and -134 from the samples taken can be used to compute what the equivalent dose-rate would be if this could be measured in the presence of a much larger background. This shows that the risk from Berkeley discharges to users of the estuary does not exceed 0.07 per cent of the I.C.R.P. recommended dose limit for members of the general public, of which about one quarter is due to contamination from fallout. The risk will obviously be smaller still for the average member of the critical group and, although the exact degree cannot be calculated because the group is too small and too unhomogeneous, it is probably between two and three times less. Calculations of the radiation exposure to eaters of shrimps, based on current measurements of artificial radioactivity (essentially only Caesium-137), show that the hazard from this source is of a similar magnitude to the external hazard from silt contamination. This is equal to about 0.08 per cent of the acceptable limit, although almost half of this is due to Caesium-137 from fallout and is not a result of the operation of the power station.

Potential radiation exposure as a result of liquid waste discharges from nuclear power stations is higher for Bradwell than for any other such station, but even so is a very small fraction of the continuously acceptable limits. The largest degree of contamination of oysters sold for human consumption is found at the site nearest to the power station, and a number of nuclides can now be identified in these oysters. Although Phosphorus-32 has not yet been found in oysters from this area it is probably present at concentrations up to about 0.3 pCi/g (wet); this is inferred from the concentrations found at the "indicator" site near to the spent cooling water outfall. The concentration of the various nuclides found in oysters varies with distance from the outfall, and this, as discussed by Preston[8] and Preston, Dutton and Harvey[9], appears to be a function of the physical state of the radioactivity. The rate of attenuation is thus greater for Zinc, Cobalt and Iron, which are essentially in particulate form, than for nuclides such as Caesium and Silver which remain essentially in the dissolved phase in sea water.

Using these concentrations, the total radiation exposure to eaters of these oysters can be calculated (Table 26). The data are based on the maximum rate of consumption found in habits surveys (75 g of oyster flesh per day) since, as with the Berkeley critical group and for the same reasons, it is not possible to identify the average consumption rate. However, even the most avid eater of oysters is subject to negligible risk, at a total exposure of 0.23 per cent of the acceptable continuous working limit.

Table 24 Concentrations of Strontium-90 in estuarine, coastal and open sea waters around the British Isles

Sampling position	Reference (Figure 1)	Concentration of ^{90}Sr, pCi/litre			
		1964	1965	1966	1967
St. Georges Channel	1	0.42	-	-	-
S.W. Irish Sea	2	-	-	-	0.97
N.W. Irish Sea 3 miles off Seascale	3	-	19.5	-	-
North Channel	4	2.12	-	-	1.80
Off S.W. Scotland	5	-	-	-	1.49
" " "	6	-	-	-	1.05
" " "	7	-	-	-	0.90
" " "	8	-	-	-	0.41
N.W. North Sea	9	-	0.33	0.19	0.46
Dogger Bank	10	1.09	0.69	0.67	0.65
Borkum Outer Ground	11	0.56	-	-	-
Gabbard	12	-	-	-	0.41
Blackwater Estuary	13	-	0.72	-	0.60
Eastern English Channel	14	0.49	0.38	0.49	0.40
Hurd Deep	15	0.28	-	-	-

Table 25 Concentrations of the more important naturally-occurring radionuclides in sea water[11], [12]

Radionuclide	Concentration, pCi/litre	Radionuclide	Concentration, pCi/litre
Hydrogen-3 (Tritium)	16-33	Lead-210	0.05-0.13
Carbon-14	0.15	Radium-226	0.036-1.25
Potassium-40	280*	Uranium-234	1.17
Rubidium-87	2.8	Uranium-235	0.052
Bismuth-209	0.86	Uranium-238	1.15

*Referred to disintegrations yielding beta particles only. Determined at this laboratory.

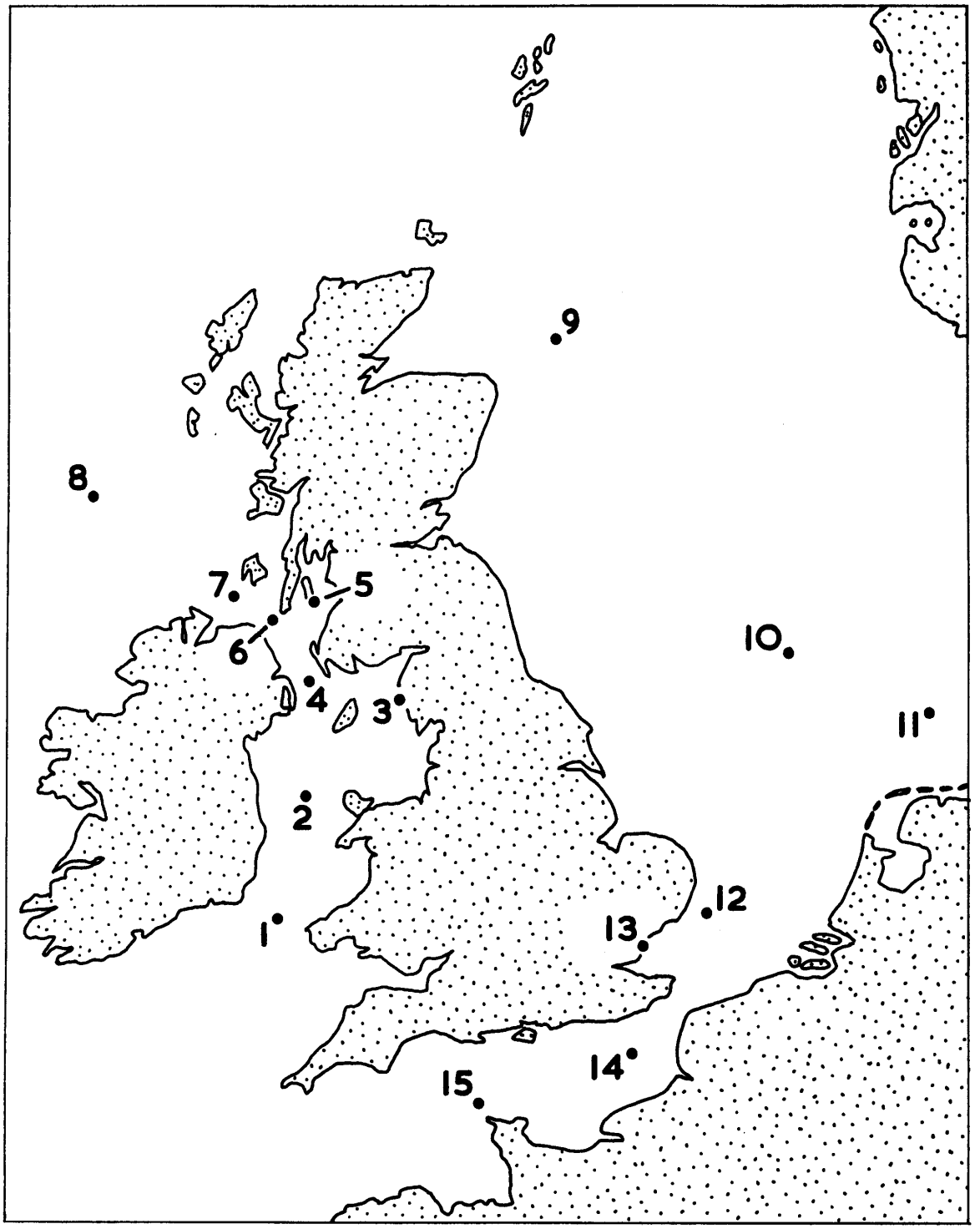

Figure 1 Sampling positions for Strontium-90 in surface sea water (see Table 24).

Table 26 Radioactivity in oysters (Ostrea edulis) at the nearest commercial oyster bed to Bradwell Power Station and their radiological importance in 1967

Radionuclide	Concentration, pCi/g (wet)	Radiological hazard*		
		Bone	G.I. tract	Total Body
Phosphorus-32	≈0.3	0.051	0.011	0.011
Iron-55	0.11	< 0.001	< 0.001	< 0.001
Cobalt-60	0.052	-	0.004	0.002
Zinc-65	4.70	0.016	0.080	0.160
Silver-110m	0.07	< 0.001	0.008	< 0.001
Caesium-134	≈0.05	0.014	0.001	0.034
Caesium-137	0.20	0.003	< 0.001	0.019
	Total	0.086	0.106	0.228

NOTE: The mean concentration of natural radioactivity, ^{40}K, is 2.2 pCi/g (wet)

*Expressed as a percentage of the acceptable working limit for a person consuming 75 g of oyster flesh per day - the maximum found from consumption surveys.

CONCLUSIONS

The information set out in this report shows that disposal into the aquatic environment of low-level liquid radioactive waste arising from the use of nuclear energy was safely carried out during 1967, maintaining the already satisfactory situation of previous years. Radiation exposure from such liquid waste operations was within internationally acceptable limits at all sites, and at many of these no contribution at all to radiation exposure of the public could be detected from waste disposal.

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