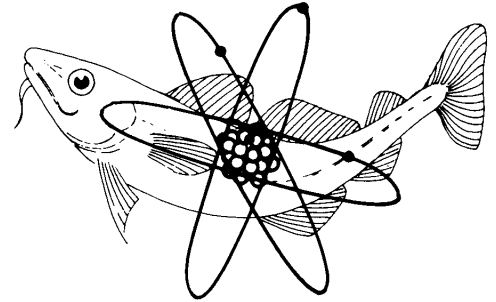


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MINISTRY OF AGRICULTURE FISHERIES AND FOOD

DIRECTORATE OF FISHERIES RESEARCH

**AQUATIC ENVIRONMENT
MONITORING REPORT**



Number 15

Radioactivity in surface and coastal waters of the British Isles.
Monitoring of fallout from the Chernobyl Reactor Accident

W.C. Camplin, N.T. Mitchell,
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LOWESTOFT 1986

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LOWESTOFT, 1986

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Foreword

This report, an interim one in the Directorate's annual Aquatic Environment Monitoring Report series, has been prepared in response to widespread interest in the impact of the Chernobyl reactor accident on the aquatic environment of the United Kingdom. It deals with the situation over a defined period, from the first documented arrival of Chernobyl fallout in the UK on 2 May until, in the case of the marine environment, 31 July when levels of radioactivity due to Chernobyl were already rapidly declining and, in the case of the freshwater environment, 31 August when levels in freshwater fish appeared to be levelling out.

The report is a reassuring one reflecting, as it does, a very minor impact on the marine environment whilst in the freshwater environment radioactivity levels of any remark have only been found in fish from acid upland lakes in areas of high deposition. Fish from these freshwater situations will continue to be closely monitored until levels have declined to negligible proportions. A full report of the result of all our 1986 monitoring will be published as usual next year in the normal annual publication.



A Preston
Director of Fisheries Research
24 September 1986

1. Introduction

In support of the Minister's responsibilities for the control of radioactive waste disposal (Radioactive Substances Act Great Britain - Parliament, 1960) an intensive environmental monitoring programme is undertaken to verify that liquid radioactive waste discharges from major nuclear sites to the aquatic environment are being satisfactorily controlled. This monitoring, conducted independently of similar programmes carried out by nuclear site operators as a condition of their authorisations to discharge radioactive wastes, is undertaken by the Directorate of Fisheries Research operating from Lowestoft. It includes not only monitoring throughout England but extends to the rest of the UK with programmes undertaken on behalf of departments of the Scottish Office, the Welsh Office, the Department of the Environment for Northern Ireland (DOE (NI)) and the Channel Islands States. The results are published annually by the Directorate in the Aquatic Environment Monitoring Report series (e.g. Hunt, 1986).

In order to assess the possible consequences to the aquatic environment of fallout from the reactor accident at Chernobyl, USSR, the Directorate adapted these normal monitoring activities to provide a basis for an assessment. This report presents the results of this special programme up to the end of July 1986 for marine samples and to the end of August 1986 for the special case of freshwater fish. The report, which does not replace the normal annual report, is in response to the great interest being shown in Chernobyl-related environmental monitoring data and is being published in advance of the normal, annual, schedule to meet that need. Data on further samples of environmental materials that continue to show evidence of activity from the Chernobyl reactor accident will be published in due course in the report relating to 1986.

2. Aims and objectives

The underlying purpose of this programme has been to determine the significance of the radioactivity found in terms of public radiation exposure, thus providing a basis for decisions on countermeasures if required. The principal objectives to be served by the monitoring programme were therefore to determine:

firstly, the concentrations and geographical distribution of radioactivity from Chernobyl in (or levels of external dose from) appropriate environmental materials. In the process, the levels of man-made activity already present were also determined; the latter arise principally from controlled discharges of radioactive waste from UK nuclear sites;

secondly, concentration/dose variations with time. This is an important factor in evaluating how quickly a possibly significant concentration or dose might subside to negligible levels, or, in an increasing regime, how long it might be before the peak concentration/dose is reached and thereafter begins to decline.

Environmental monitoring is of course only part of the work on radioactivity conducted within the Aquatic Environment Protection Division of the Directorate; there is also a substantial research programme. However, in current circumstances the monitoring must take priority since the first requirement is to determine the levels of radioactivity in the environment and from these measurements to calculate the possible doses being received

by members of the public. This provides a basis on which to determine the need for countermeasures, such as the banning of foodstuffs. However the presence of radioactivity from Chernobyl does also provide research opportunities some of which are being exploited.

3. Design of the monitoring programme

Because radioactivity from the reactor accident spread quickly via the atmosphere to much of the UK it was necessary to monitor widely and as quickly as possible to determine the extent to which the aquatic environment might be affected. It was thus very convenient that the major nuclear establishments, whose environments are normally monitored by the Directorate, are spread widely over the UK coastline and, also, that the monitoring programmes carried out there generally encompass the aquatic pathways through which possibly significant radiation exposure of the public might occur. The normal programme thus provided an ideal framework for the special programme, though of course much extra sampling was also done. In particular, the frequency of sampling was increased and in some respects, especially in the freshwater environment, the spatial distribution was also extended. Samples of fresh water were analysed to a limited extent to help understand and interpret the likely future pattern of levels in freshwater fish. However, the quality of drinking water is a responsibility of the Environment Departments (DOE, SO, WO, DOE(NI)) and the bulk of measurements have already been reported in a separate publication (DANI et al., 1986).

Although use was made of the regular monitoring programme it should be noted that the results presented here do not encompass all samples from the whole of the programme conducted during the period in question. The complete set of results for the whole programme will be assessed with those for the rest of the year when the Aquatic Environment Monitoring Report for 1986 is prepared. Nevertheless, sufficient analysis has been undertaken to assess the effect of the Chernobyl-derived fallout: the further data are needed only in relation to the effect of authorised UK discharges.

The principal environmental materials involved have been foodstuffs and these are grouped for convenience into five broad classifications: marine fish, freshwater fish, crustaceans, molluscs and seaweed. Seawater, fresh water and marine and freshwater indicator materials have also been sampled to contribute to our understanding of environmental distribution and behaviour. The detailed design of each of these programmes is explained in Section 5.

4. Methods of analysis and of presentation and interpretation of the data

4.1 Analytical procedures

In the circumstances prevailing immediately after arrival of the Chernobyl-derived fallout, speed of analysis was of paramount importance. The methods of analysis discussed in the Aquatic Environment Monitoring Report (e.g. Hunt, 1986) were therefore adapted in order to provide data as quickly as possible. Thus, samples that were analysed by gamma spectrometry (the principal procedure used) have generally been counted in the wet state whereas they are normally dried beforehand to ensure better reproducibility. Drying does however slow up the production of results and can lead to loss of potentially volatile radionuclides such as iodine-131.

Another part of the normal analytical procedure that had to be modified was the period of counting, a factor that influences the accuracy of results. The normal Directorate procedure is to count for long enough to keep the standard deviation to no more than a few per cent. This procedure has been followed wherever possible, though in some low-level samples the data are less accurate than usual, the counting period being curtailed in the interests of producing rapid results.

The predominant radionuclides in the Chernobyl fallout were gamma emitters; the principal analytical procedure used was therefore high-resolution gamma spectrometry using Germanium detectors. Few pure beta emitters were present, none at levels that would have been significant in the aquatic environment and few specific beta analyses or gross beta measurements have been made. Similarly, though several alpha emitters in the transuranic series of elements were detected, none reached concentrations of significance in aquatic materials and no extensive programme was necessary.

4.2 Presentation of results

SI units have been used throughout. In contrast to the annual reports, however, the data tabulated include individual samples because of the importance of time-dependence in demonstrating the build up and decline of the radionuclide content in some materials.

The measured concentrations include contributions from Chernobyl fallout and other sources such as nuclear industry routine discharges. However, no attempt has been made to subtract the latter when presenting the concentration data, though pre-Chernobyl levels have been considered in calculating doses. This point is discussed further in Section 6.

4.3 Interpretation of results

The basic principles of radiological protection for routine situations are fully discussed in the annual reports in this series. In the circumstances after the Chernobyl release, the initial need in interpreting results was to determine whether aquatic foodstuffs remained safe or whether restrictions should be considered. A rapid means of assessing the situation was thus required and to this end a system of indices, termed 'reference levels', was set up against which peak concentrations could be compared. These reference levels of concentrations were related to annual doses of 5 mSv (effective) or 50 mSv (limiting organ) as suggested by the ICRP (ICRP, 1984) and the NRPB (NRPB, 1986) as levels of dose at which a foodstuff ban may be considered following an accidental release of radioactivity. Conservative assumptions were used in their derivation so that they showed whether there was any likelihood of a problem, and thus guided the development of advice at an early stage regarding the need for restrictions.

In this report, doses have been calculated on a more realistic basis by taking into account the changes in concentrations or external dose with time (see Section 6). The levels of annual dose of 5 mSv (effective) or 50 mSv (limiting organ) have, however, been retained as an appropriate yardstick for judging estimated dose rates to individuals. Collective dose commitments have also been derived from preliminary estimates of deposition into the aquatic environment.

5. The monitoring programme and results

5.1 The early phase

News from Sweden of the discovery of high environmental levels of radioactivity on 28 April 1986, prompted the first investigations to detect the arrival of contaminated air in the UK. Initially this depended on the use of the dry cloth collectors operated routinely by the Directorate on behalf of the Ministry's Food Science Division. These are set up in the vicinity of most of the UK nuclear establishments to detect airborne releases in normal operation (McHugh *et al.*, 1986). The cloths were changed on 29 April at selected sites but analyses proved negative. The dry cloth from a reference location at Lowestoft was changed daily from 30 April and analysed immediately. The first activity attributable to Chernobyl was found on the cloth exposed up to 0830 h on Friday 2 May. This showed the presence of a number of radionuclides characteristic of those to be expected shortly after a reactor accident, e.g. iodine-131, tellurium-132/iodine-132, ruthenium-103, etc. A sample of local grass cut at 1000 h on 2 May, from a lawn mown the day before, confirmed the findings on the cloth. Both this and the quantity of activity on the dry cloth can only be roughly equated with air concentrations because of variable meteorological factors. Nevertheless, they did suggest that the concentration in air might be substantial and a sample of particulate material in air was therefore collected on the afternoon of Friday 2 May with a high flow air sampler. It showed a concentration of 5.9 Bq m^{-3} of iodine-131 and other nuclides; details are shown in Table 1. The local dry cloth continued to be changed daily and the sample collected on 3 May showed a substantial increase over the sample from the previous day. By 4 May the activity concentrations in air were already in decline; this was confirmed with a further air filter sample during the following week. Full data from analysis of the 2 May air filter are shown in Tables 1 and 2. Figure 1 illustrates the trend for iodine-131 based on data from the dry cloths. There was a slight reversal in the reducing trend on 12-13 May when a Chernobyl-contaminated air mass returned temporarily to the UK. However, it carried much less significance than the radioactivity which was present at the beginning of the month and concentrations then continued to decrease until by early June virtually no iodine-131 could be detected at all.

An immediate assessment was made based on the information from air/grass sampling, together with data mainly from events in Scandinavia. This indicated that activity would be detectable in certain sectors of the aquatic environment but that the concentrations that might be found in foodstuffs from such affected environments were unlikely to reach levels where countermeasures would need to be considered. Two members of the Directorate staff, undertaking a routine monitoring survey on the north bank of the Solway Firth on 3 May, found elevated gamma dose rates over shoreline terrain close to the beaches which they were about to monitor and subsequently on the beaches themselves. This and other information on high deposition in certain parts of the country reinforced the need for a precautionary programme. A widespread programme of aquatic monitoring was then sustained throughout the weeks that followed. The scope of the programme is discussed in the following sub-section. The results for marine fish, crustaceans, molluscs, seaweeds, freshwater fish and other materials are presented in Sub-sections 5.3-5.9.

5.2 Scope

The programme of foodstuff monitoring was devised with three major objectives in mind:

(i) to provide sufficient geographical coverage to encompass the higher concentrations expected in areas of high deposition and to include some low deposition samples for comparison;

(ii) to sample representative species of fish, crustaceans, molluscs and seaweed with a focus on edible materials and those expected to give rise to the highest levels of dose;

(iii) to develop a time series of observations for the important species and locations.

For ease of reference, the locations of sampling points for marine and freshwater fish, crustaceans, molluscs and seaweed are given in Figures 2-6. The locations are concentrated in Wales, Cumbria and southern Scotland - those areas where the highest deposition has occurred. Other areas such as the Channel Islands, Northern Ireland and the Isle of Man are also included.

More sampling was carried out on molluscs, seaweed and freshwater fish than on marine fish and crustaceans because the former contained higher radioactivity concentrations. The most intensive part of the programme was in May; it was then reduced progressively so that by the end of July only freshwater fish were being sampled extensively. These continued to be sampled because, as expected from the known biological half lives, the levels of radioactivity in fish had not yet stabilised.

Samples of non-edible materials were also obtained to add to the picture of fallout. These were primarily seawater, indicator seaweeds such as Fucus spp., freshwater plants and sediments. Some results from this set of samples are reported and further data will be given in the full 1986 report. The locations of sampling for water and sediments are shown in Figures 7 and 8.

5.3 Marine fish

Radionuclide concentrations in marine fish are shown in Table 3. The levels of activity are low and few radionuclides were detected. The clearest evidence for Chernobyl fallout comes from positive values for ruthenium-103 and iodine-131 which are not normally found in the marine environment. However, even these nuclides are present at very low levels, no more than 7 Bq kg⁻¹, barely above the minimum detection level. Higher levels of caesium-137 were found but only in Irish Sea fish, where the influence of liquid effluent discharges from BNFL, Sellafield predominated. When the effect of Sellafield discharges is subtracted, the maximum observed radiocaesium concentrations due to Chernobyl, are about 6 and 11 Bq kg⁻¹ for caesium-134 and caesium-137 respectively. This can be compared with the pre-Chernobyl levels of radiocaesium, typically of the order of 100 Bq kg⁻¹ in the eastern Irish Sea.

There do not seem to be gross differences between the species sampled, though the evidence is difficult to interpret in view of the low levels measured. For the same reason, it is not possible to make a definite

statement on the time trend of concentrations, other than to say that there is no evidence for significantly increasing levels.

5.4 Crustaceans

The marine crustaceans sampled were lobsters, crabs, shrimps and Nephrops. A similar picture to that of marine fish was found (Table 4) with low levels of all radionuclides attributable to Chernobyl. Up to 17, 13 and 9 Bq kg⁻¹ of iodine-131, silver-110m and ruthenium-103, respectively, were detected, the highest samples being shrimps from Annan and lobsters from Dounreay. The radiocaesium concentrations due to Chernobyl were no more than about 10 Bq kg⁻¹.

5.5 Molluscs

This class of shellfish represents, with seaweed and freshwater fish, the bulk of the samples collected. As would be expected, littoral species contained the highest levels of fallout. This is partly due to the well-known propensity of molluscs to concentrate certain elements, but also to the water concentration pattern after the deposition had taken place, where shoreline water concentrations were relatively high at the beginning of May but quickly declined. As a result the total concentrations of radionuclides rapidly reached of the order of 10 000 Bq kg⁻¹, with the highest values in a sample of winkles collected on 3 May on the north Solway coast (Table 5). However, this was a very short-lived phenomenon involving radionuclides of short half-life and low radiological significance. At this time, the dominant radionuclides in activity terms were the short-lived ruthenium-103, tellurium-129m, iodine-131, and tellurium-132, with the longer-lived ruthenium-106, silver-110m, caesium-134, -136 and -137 and barium-140 of secondary importance. The concentrations as percentages of the total activity are shown in Text table A for two early winkle and mussel samples alongside the air filter data for Lowestoft.

Text table A Radionuclide contributions to total activity concentrations in molluscs and in air

	Rockcliffe mussels 3 May	Southernness winkles 3 May	Lowestoft air-filter 2 May
¹⁰³ Ru	17	13	9
¹⁰⁶ Ru	10	4	6
^{110m} Ag	1	< 1	0
^{129m} Te	14	16	13
¹³¹ I	6	9	15
¹³² Te	46	46	37
¹³⁴ Cs	1	3	5
¹³⁷ Cs	3	5	8
¹⁴⁰ Ba	2	2	6

These data demonstrate little differentiation between the uptake of these radionuclides relative to air, assuming that the activity in air in the Solway area was similar to that in Lowestoft on 2 May. This is in sharp contrast to the situation that would be expected if concentrations in molluscs were measured at equilibrium and compared with ambient water concentrations. In the latter case mollusc concentrations relative to

seawater of 2 000, 1 000, 10, 30 and 20 would be expected for ruthenium, tellurium, iodine, caesium and barium respectively (IAEA, 1985). The reason for this difference is not self-evident, but it is likely that the mechanisms responsible include atmospheric washout and particle scavenging in seawater. Both processes can affect different elements or physico-chemical forms to a different degree.

Concentrations of Chernobyl radionuclides in low deposition areas, such as the English Channel and the North Sea, were not observed at more than 10 Bq kg⁻¹. The highest concentrations were found on the coastlines of the Irish Sea and northern Caithness. It has not been possible to correlate levels in molluscs with precipitation; however, limited evidence from rainfall stations on 2 and 3 May at Rockcliffe on the north Solway coast and Ravenglass on the Cumbrian coast (18.4 mm and 11 mm, respectively) (Heasman, 1986) suggests that there may be an effect of this kind.

The time dependence of concentrations of selected nuclides in winkles are shown in Figures 9-12. The iodine-131 concentrations show a steady decline with a half-life of about 3-5 days (iodine-131 has a radioactive half-life of 8 days) indicating that it was being removed by metabolic processes as well as by radioactive decay. A similar decline in concentrations was observed for ruthenium-103 (radioactive half-life 40 days) at Nethertown and Ravenglass with a half-life of 10-20 days again demonstrating the influence of a relatively fast biological loss mechanism. In contrast, the concentrations of silver-110m were maintained for some time after the initial depositing event.

The winkle data for Southerness exhibit peak concentrations at about 15 and 40 days for ruthenium-103, silver-110m and tellurium-129m. The reason for the different behaviour at this location is not clear but could simply be due to the natural variability of environmental sampling.

Mussel concentrations are shown in Figures 13 and 14. Both ruthenium-103 and silver-110m concentrations steadily reduced from the beginning of May and there is no evidence of late peaks in levels. Concentrations of these radionuclides in mussels decayed faster than in winkles and this could be due to physiological differences or to feeding habits of the species. Winkles take in radioactivity by feeding on the layer of organic material on surfaces between tide marks whilst mussels filter food directly from water. However, without more detailed environmental data, it is not possible to decide whether these mechanisms are the major cause of the observed differences.

5.6 Seaweed

The most important seaweed was considered to be Porphyra, being an edible species used for the manufacture of laverbread in South Wales. Nevertheless, other species, principally Fucus spp., have been sampled as indicator materials. Data on each of these materials has been included in Table 6. A similar mix of radionuclides has been detected in seaweeds as in molluscs. The percentage contributions to the peak concentrations of three species, corrected for radioactive decay to 2 May, are shown in Text table B.

Text table B

Radionuclide contributions to total activity concentrations in seaweeds

	Seascale	Ravenglass	Dounreay
	<u>Porphyra</u>	<u>Fucus vesiculosus</u>	<u>Cladophora</u>
	4 May	6 May	14 May
^{103}Ru	21	3	13
^{106}Ru	9	2	9
$^{110\text{m}}\text{Ag}$	< 1	< 1	< 1
$^{129\text{m}}\text{Te}$	8	5	NA
^{131}I	27	67	20
^{132}Te	31	17	48
^{134}Cs	< 1	1	2
^{137}Cs	2	3	4
^{140}Ba	< 1	3	2

The highest levels in seaweeds, due to Chernobyl, were found in samples around the Irish Sea. The peak concentrations in Porphyra were of the order of 1 000 Bq kg⁻¹ for ruthenium-103, iodine-131, tellurium-129m, and tellurium-132. Concentrations of other radionuclides were generally less than 100 Bq kg⁻¹. A sample of Fucus vesiculosus collected on 6 May contained higher concentrations, of the order of 3 000 Bq kg⁻¹ of iodine-131, suggesting that the concentration (sum of all radionuclides) might have been as high as 10 000 Bq kg⁻¹ at the time of deposition. However, as this seaweed is not a human foodstuff, such concentrations have no direct radiological significance.

The time series of concentrations show that these high levels quickly decayed away (Figure 15) and by the end of June levels were no more than about a 100 Bq kg⁻¹.

The sampling programme included laverbread. Concentrations in this foodstuff were much lower than the peak values found in Porphyra even after allowing for the fact that laverbread contains twice as much water as does the Porphyra from which it is made. This is because the peak levels in Porphyra were found at locations where the seaweed is not generally harvested for manufacture into laverbread. Peak concentrations in laverbread have been of the order of 100 Bq kg⁻¹ of ruthenium, and a few tens of Bq kg⁻¹ (or less) for other radionuclides.

5.7 Freshwater fish

As with other species, the sampling programme has focussed on areas of high deposition, notably Cumbria, North Wales and the Isle of Man. Brown and rainbow trout account for the majority of samples but a variety of other species have been analysed including char, sea trout, salmon, perch and eels. Iodine-131 was found in several of the early samples, but at a maximum of less than 7 Bq kg⁻¹. Initially, little or no other activity was found in freshwater fish, other than low concentrations of caesium-134 and -137. More recently and as expected, higher concentrations of caesium have been detected, notably in brown trout from impounded waters (up to 1 000 Bq kg⁻¹), but also in perch and other, mainly sport, fish (up to 2 000 Bq kg⁻¹) which are not eaten in large amounts and thus, compared with trout, have little or no significance as a source of potential radiation exposure. The higher concentrations are confined to soft water areas but are not general even there; the measurements cover a wide range with only a

small proportion of fish showing high values. Data on fish are shown in Table 3. Analyses have also been made of the concentrations of radiocaesium in water in order to provide a guide for the fish sampling programme and data are shown in Table 7.

This slowly developing caesium situation in certain freshwater fish is most likely due to a combination of mechanisms including delay in run off, turnover time of the water body, build-up via the food chain and slow turnover of these radionuclides in fish, the biological half-time of caesium in fish being about 100 days (Hewett and Jefferies, 1976). However, probably the most significant factor is that high deposition occurred in very soft water areas in which it has already been established (Preston, Jefferies and Dutton, 1968) that very high concentration factors occur for caesium.

The reason for placing emphasis on brown trout is that this is the most important edible species of freshwater fish in radiological terms. Higher concentrations have been found in some perch, notably in North Wales at Lake Trawsfynydd, but the much lower consumption rates more than offset this difference. The very wide range in concentrations that has been found in individual fish, even of the same species and at the same location, makes a full and detailed evaluation very complex. A further complication in evaluating results from Lake Trawsfynydd is the presence of radiocaesium of power station origin. Fortunately, this radiocaesium can be distinguished from that due to Chernobyl fallout because of the very different caesium-137:caesium-134 ratio associated with caesium of reactor origin. This shows that most of the radiocaesium in the more heavily contaminated Lake Trawnsfynydd fish, both trout and perch, is due to power station discharges, a typical value being 80 to 85 per cent. The Chernobyl-related values so derived are consistent with the higher values found elsewhere where there are no other sources to complicate the issue.

The sampling programme has been designed to ensure that stocks containing the highest concentration of radioactivity have so far as possible been adequately covered. Despite this, measurements at the top of the concentration-range are sparse. This raises doubt as to whether the caesium levels in such fish should be regarded as constituting anything of radiological significance, even to the extent that an uncritical examination of their radioactivity content might otherwise suggest. This is because it is very unlikely that such high-concentration fish will have been available to the public in sufficient numbers for them to sustain a significant radionuclide intake. This matter is taken up again in Section 6.

The fish that are most readily available for regular consumption in large quantities, hatchery reared and farmed trout, have a generally low radioactivity content which poses no radiological problem. This difference in concentrations between wild and other trout is shown, for example, in the results for Trawsfynydd Lake (Table 3) where both brown and rainbow trout are stocked. Nevertheless, in view of the continuing presence of Chernobyl radioactivity, an extended sampling programme is being maintained and will continue until such time as a general decline in concentrations has been clearly established.

5.8 Seawater

Seawater is regularly sampled, mainly as a research tool, to develop our understanding of water movements and concentration factors and this programme has been enhanced to cover radioactivity from Chernobyl.

Initially, effort was concentrated at shoreline stations in the Irish Sea but samples have also been taken from other areas around the UK and as part of the MAFF cruise programme (Figure 7). Neither the sampling programme nor the analysis is complete but some preliminary findings can be reported.

Samples from the southern North Sea and the Bristol and English Channels show very low levels of the caesium radionuclides; they are of the order of 0.1 Bq l^{-1} or less and not significantly greater than before the accident. Concentrations at northern Scottish stations are slightly higher, and the presence of some Chernobyl fallout is suggested by the caesium-137:caesium-134 ratio which is lower than before the accident.

Samples from the Irish Sea show the highest levels of Chernobyl fallout, the peak values being a few Bq l^{-1} of caesium-137 in the northern Irish Sea in early May. Again, the Chernobyl 'label' is clearly distinguishable by the caesium-137:caesium-134 ratio. The ratio fell in shoreline water at Southerness from the norm of 20-30 in early 1986 to less than 2 in early May immediately after the Chernobyl activity reached the UK.

Dispersion of the fallout from the shoreline area was however rapid. Figure 16 shows a time series of concentrations on the north Solway coast at Southerness. In a matter of days, water concentrations had fallen substantially, but levelled off at about 1 Bq l^{-1} (caesium-137) with a caesium-137:caesium-134 ratio that suggests that there was some Chernobyl activity remaining.

5.9 Other analyses

5.9.1 Radiochemical analyses

Radiochemical analyses take longer than measurements by gamma spectrometry. However, the few results available to date do not show any evidence of transuranics from Chernobyl fallout in aquatic samples (Table 8). Measured concentrations in such samples are due to other sources such as routine discharges from the nuclear industry. Further analyses will be included in the annual monitoring report for 1986, but it is not expected that significant concentrations will be found.

5.9.2 Sediments

Sediments are well known as being strong adsorbers of many radionuclides in the aquatic environment. Samples have been obtained for indicator purposes from the Irish Sea and elsewhere and the effects of Chernobyl-derived fallout are self-evident (Table 9). Concentrations of several thousands of Bq kg^{-1} were observed in early May in coastal areas of the northern Irish Sea but by June these levels had fallen substantially.

5.9.3 Freshwater plants

Monitoring of freshwater plants has largely been confined to watercress which is grown in areas where Chernobyl fallout was low (Table 10). Being a fast-growing plant it was foreseen that it might concentrate activity to a significant degree but this did not prove to be so. Several nuclides were found but at concentrations that did not exceed 100 Bq kg^{-1} , a level which is not of radiological significance.

6. The radiological impact of Chernobyl fallout

6.1 Methodology for dose calculations

The procedure used to estimate doses at the individual (critical group) level from ingestion involves 3 steps: firstly, to take measured concentrations in edible fish, shellfish and seaweed typical of the locations where the highest levels were found; secondly, to calculate from them radionuclide intakes by individuals in the critical groups using estimates of likely consumption rates and thirdly, to convert these intakes to dose using conventional dosimetry. Critical group doses were also derived for external exposure over intertidal areas, though the evidence of increased gamma dose rates in such areas is less easy to interpret than are the data for aquatic foodstuffs. Inhalation doses have not been estimated for two reasons: they are unlikely to be significantly different from those already reported for inland sites and, more importantly, they will be much less than doses from other sources in areas of high deposition (Nair and Darley, 1986; Fry et al., 1986; Welsh Office, 1986).

As the aim of this assessment has been to evaluate the dose from Chernobyl fallout it has been necessary to subtract the contribution to radioactivity from UK radioactive waste discharges. (These will be assessed in the annual monitoring report for 1986.) Pre-Chernobyl concentrations of radionuclides have been assessed from measurements carried out in 1986 as part of the Directorate's statutory monitoring activities. Where such information is ambiguous, for example, as a result of natural or imposed fluctuations in concentrations, radionuclide ratios have helped to complete the pre-Chernobyl baseline. Values for particular species and their locations are shown in Table 11. The locations reflect areas where the highest concentrations due to Chernobyl were found. On the whole, ruthenium-106 and caesium-137 dominate the doses from Chernobyl though low levels of ruthenium-103, silver-110m and caesium-134 have also been taken into account. Pre-Chernobyl concentrations of other nuclides in the dose assessment (tellurium-129m, iodine-131, tellurium-132, caesium-136, barium-140 and short-lived daughter products) have been taken to be zero.

Whilst measurable concentrations of additional nuclides, in particular strontium-89, strontium-90 and several transuranium isotopes, were found in the course of high volume air sampling (see Section 5), their contributions to dose relative to the nuclides listed above do not warrant their inclusion in the assessment. Technetium-99 is another nuclide which would have been deposited, however, it is unlikely to be of radiological significance. This assumption will be confirmed when the results of further radiochemical analyses are available for the annual monitoring report for 1986.

The computation of radionuclide intakes is complex, being crucially dependent on correct identification of the appropriate radionuclide concentrations and selection of the appropriate foodstuff consumption rates. Some simplifying assumptions have been necessary but these have been of a cautious nature so that results will be overestimates of the actual dose. This especially applies to the fish consumption pathways.

The assessment of dose to critical groups has been principally based on the assumption of regular harvesting and consumption throughout the year. This reflects the most common consumption pattern for regular high rate consumers of aquatic foods and the Directorate has extensive experience of this kind of situation with a large body of data from 'Habits Surveys' undertaken in relation to control of radioactive waste disposals from major

nuclear establishments in the UK. A set of 'hypothetical' critical groups has thus been derived based on this collected experience, the consumption rates concerned being shown in Table 12 which includes separate values for adults and children. Use of these values is likely to lead to considerable overestimates of the true dose; this is not only because relatively high values have been chosen but also because it is unlikely that such a critical group really exists in the locations where the adopted, environmental concentrations have occurred.

In deciding which values of radionuclide concentrations should be used in dose calculations, simplifications have been introduced which will also lead to overestimates of dose. In the case of molluscs and seaweed, the time series of concentrations for most nuclides is well established and integrated intakes have been worked out by computer. However, the data for caesium-136 and barium-140 are not complete and concentrations in these species have been derived from evidence of relative concentrations in air.

In the case of marine fish and crustaceans the time series of concentrations is not complete, and a conservative assumption has been made that the peak concentration observed is representative of the annual average value. The effect of dispersal of radioactivity has not therefore been included, though its inclusion would have been more realistic and would have substantially reduced the dose.

The time series of concentrations is also incomplete for freshwater fish. There will thus be further contributions to dose from fish caught later in 1986 that cannot yet be fully assessed though it is not expected that these additions will materially alter the estimates of dose. The very use of data from the upper end of the range of observations made so far will in any case lead to considerable overestimates of dose which will more than compensate for possibly higher concentrations later in 1986.

As an additional precaution a purely hypothetical pathway has been considered to allow for the possibility of a harvest and subsequent regular consumption of an unusually large amount of food. This may occur in certain favourable conditions resulting in the greater availability of food. Such an assessment would cover the use of extended preservation and storage methods such as freezing, pickling, drying, salting and smoking. The peak concentrations used in the assessment for molluscs and seaweed have been determined by extrapolation from observed values back to 2 May. For fish and crustaceans, where no time series data exist, the highest observed concentrations have been used. In the case of freshwater fish, brown trout data have been used and for the reasons explained previously, the result is likely to be a gross overestimate.

There is no definitive procedure for determining the size of the discrete harvest of each foodstuff for the 'freezer' pathway. As an example, values have been adopted equivalent to two weeks' consumption at the average annual rates for critical groups. The consumption values are shown in Table 12. For molluscs and seaweed, when the peak concentrations would only have been maintained for a few days, the doses derived for this pathway can only be regarded as highly speculative and likely to be considerable overestimates of the doses actually received.

Data on the doses received from ingestion of unit activity have been taken from the NRPB Report R162 (Greenhalgh *et al.*, 1985) for all nuclides except tellurium-132, where the values in ICRP 30 (ICRP, 1979) are adopted on more recent advice from the NRPB (Fell, 1986). Integration periods of 69, 60 and 50 years are used for 1- and 10-year-old children and adults,

respectively, for calculations of committed dose. Where appropriate, doses from short-lived daughter products are included.

Collective dose commitments have been derived using models based on estimates of the deposition of nuclides directly into UK coastal waters. These data can only be regarded as being approximate since no direct data on deposition into the marine environment are available at the time of writing. Estimates have been made by extrapolation from observations over land. When measured concentrations over a sufficiently long period of time are available, it will be possible to refine the collective dose estimates from marine pathways and this will be attempted for the 1986 annual monitoring report. A tentative estimate of collective dose from ingestion of freshwater fish has also been derived.

6.2 Individual dose from continuous consumption

The calculated doses from marine and freshwater fish, crustaceans, molluscs and seaweed, assuming continuous consumption, are presented in Table 13. These are derived from data for Whitehaven cod, Ennerdale brown trout, Annan shrimps, Southernness winkles and Seascale Porphyra, respectively. These locations and species have been chosen as being reasonably representative of the highest levels of Chernobyl nuclides though in the case of brown trout still higher values in individual fish can be found. Data from the Lake District were preferred to those from Lake Trawsfynydd to provide an unambiguous basis for assessing the effect of Chernobyl fallout. Several possibilities exist from within the Lake District data set; Ennerdale was chosen as being the highest observation but, as a single value from only one fish, it is still likely to substantially overestimate the dose found in the aquatic environment. In all cases, doses are largest for the notional 10-year-old age group but only by a small margin over the dose for adults and 1-year-old children. Subsequent references to dose refer to children aged 10 years. The estimates of effective dose in a year range from about 1 μ Sv to 1 mSv. Doses to potentially critical organs span a range from 0.05 to 1 mSv. The limiting organ is, in most cases, the thyroid but for freshwater fish it is the lower large intestine.

Of the foodstuffs considered, crustacean consumption yields the lowest doses. Values of effective dose are approximately the same for marine fish, molluscs and seaweed consumption, despite the substantially higher concentrations found in the latter two species groups. This is because of the differing rates of consumption (Table 12). The radionuclides which dominate doses from these species are ruthenium-106, tellurium-129m, iodine-131, tellurium-132 and radiocaesium. Consumption of freshwater fish represents the highest potential exposure pathway to date. This is due to two factors: adoption of a relatively high consumption rate (150 g d⁻¹ for adults) and the assumption that the concentrations adopted for dose assessment are representative of the average concentration throughout the year of intake. Both are clearly pessimistic but serve to put an upper limit to the level of dose that might be expected. As further time series of freshwater fish concentrations are produced and a well defined downward trend established, it will be possible to refine the calculation which is expected to reflect a much lower estimate of dose.

6.3 Individual dose from a hypothetical harvest at peak concentrations

This potential route of exposure was included to guarantee that a hypothetical harvest, when concentrations were at their highest, would be catered for. Effective doses (Table 14) have been estimated to range from a small fraction of a μSv to $0.09 \mu\text{Sv}$ (10-year-old child). Organ doses are higher, spreading from $2 \mu\text{Sv}$ to 1.6 mSv (10-year-old child). For some foodstuffs (molluscs and seaweed) doses from the discrete harvest are higher than from continuous consumption reflecting the high levels observed in these foods for a short period of time after the beginning of May. Because monitored levels have not fallen sharply with time in marine and freshwater fish and crustaceans, the doses from continuous consumption are higher than those from the hypothetical harvest for these species.

The dominant nuclides for a discrete harvest are similar to those for continuous consumption.

6.4 External exposure

Dose meters have been used at predominantly coastal locations throughout the country. In areas such as Lowestoft, where deposition from the cloud was small, no detectable changes in external exposure above background were detected. However, in Cumbria and south-western Scotland the situation was different and a selection of results are shown to illustrate this in Table 15. At Kippford, on the north shore of the Solway, the ambient gamma dose rate on 3 May rose to $0.57 \mu\text{Gy hour}^{-1}$. (It had previously shown an average in 1986 of only $0.22 \mu\text{Gy hour}^{-1}$.) By 15 May, it had fallen to $0.34 \mu\text{Gy hour}^{-1}$. There was a similar effect in the Ravenglass estuary.

The rate of decline to background levels of gamma dose rate is difficult to establish precisely from the data in this report. However, an estimated dose to a critical group due to Chernobyl can be made assuming a linear decrease in dose rate over one month and an average occupancy during that period of about 170 hours equivalent to 2 000 hours in a complete year. On this basis, the extra dose from gamma radiation in intertidal areas would be about 0.025 mSv at most.

6.5 Collective dose from ingestion

A tentative prediction of collective dose commitment from Chernobyl fallout via aquatic foodstuffs can be obtained by considering catches of marine and freshwater fish. These species will contain the bulk of the Chernobyl activity ingested via aquatic food pathways.

Measurements of seawater concentrations in the northern Irish Sea and Scottish waters are consistent with a total input to these areas of about 500 TBq of caesium-137 and about 250 TBq of caesium-134. Taking data on dose commitments for discharges from BNFL, Sellafield (Camplin, 1982), a figure of 30 man Sv is estimated. This represents only a provisional figure for the population exposure from Chernobyl fallout into UK coastal waters.

Concentrations in freshwater fish are much more difficult to interpret for collective dose purposes because of the poor quality of fishery statistics in these areas, particularly for wild species such as brown trout. Since it is these species that contain the higher levels of

activity, an order of magnitude estimate of collective dose is the best that can be made. From the data in Table 3 it is reasonable to choose a value of 100 Bq kg⁻¹ of caesium-137 and 50 Bq kg⁻¹ of caesium-134 as upper estimates of the average concentrations in fish attributable to Chernobyl consumed in the areas of high deposition in the year ending April 1987. The size of freshwater fish catches are very difficult to estimate as no data are normally collated for wild fish such as brown trout. Nevertheless, using information such as the number of fishing licences issued, it has been estimated that the annual catch of wild fish in the area of high deposition could be a few hundred tonnes, and could not conceivably be more than a thousand tonnes. On the basis of the upper estimate, the collective dose would be no more than 0.7 man Sv in one year.

7. Summary and conclusions

7.1 Individual doses from foodstuffs

A summary of the highest estimated individual doses, that might arise due to Chernobyl fallout from the ingestion of aquatic foods, is given in Tables 13 and 14. In deriving these data, concentrations of radionuclides from sources other than Chernobyl have been subtracted.

The doses have also been expressed as a percentage of 5 mSv (effective) or 50 mSv (organ) whichever is the more restrictive. The highest percentage is 21% for freshwater fish consumption. In view of this, trout and other species will continue to be monitored until a clear trend of decreasing concentrations is established. Nevertheless, having regard to the scale of pessimism introduced in the dose calculations to ensure that the calculated dose was not underestimated, it is likely that the true doses are much lower and that the presence of Chernobyl activity presents no cause for concern. The percentage of the 5 mSv and 50 mSv levels for other pathways is significantly less and monitoring for these species will continue at a much reduced rate.

7.2 Individual doses via external exposure pathways

The incremental contribution to the gamma dose rate in intertidal areas from Chernobyl was highest in areas of high deposition but this did not persist and an upper estimate to the dose by this route was about 0.025 mSv. Levels in low deposition areas were much less, so that overall no significant exposure occurred due to beach occupancy.

7.3 Collective doses

The collective dose commitment from Chernobyl fallout in marine pathways is tentatively estimated to be 30 man Sv. Almost all of this is due to consumption of sea fish and to the caesium radionuclides, but due to maximising assumptions in the calculation this is likely to be an overestimate. The collective dose commitment via freshwater fish is very difficult to assess with confidence but can be conservatively set at less than 1 man Sv at which level it is of no significance.

For comparison, the value for the collective dose commitment from liquid effluent discharges from UK nuclear installations was provisionally estimated at 90 man Sv in 1985 (Hunt, 1986) and the collective dose from natural background to the population of the UK is about 100 000 man Sv annually.

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Appendix 1 Tables 1-15

Table 1 Gamma spectrometric analysis of air samples at Lowestoft

Sample type	Collection date (1986)	Activity per sample (Bq)									
		^{103}Ru	^{106}Ru	$^{129\text{m}}\text{Te}$	^{131}I	^{132}Te	^{134}Cs	^{136}Cs	^{137}Cs	^{140}Ba	^{141}Ce
Air filter ^a	2 May	$3.4 \cdot 10^3$ (3.5)	$2.3 \cdot 10^3$ (2.4)	$4.9 \cdot 10^3$ (5.1)	$5.7 \cdot 10^3$ (5.9)	$1.4 \cdot 10^4$ (15)	$1.8 \cdot 10^3$ (1.8)	$7.4 \cdot 10^2$ (0.77)	$3.2 \cdot 10^3$ (3.3)	$2.2 \cdot 10^3$ (2.3)	$3.7 \cdot 10^1$ (0.04)
Dry cloths ^b	2 May	8.7	ND	NA	$9.5 \cdot 10^1$	NA	4.0	NA	7.2	NA	ND
" "	3 May	$1.4 \cdot 10^2$	$1.3 \cdot 10^2$	"	$8.7 \cdot 10^2$	"	$6.5 \cdot 10^1$	"	$1.2 \cdot 10^2$	"	3.8
" "	4 May	$7.4 \cdot 10^1$	$6.0 \cdot 10^1$	"	$8.1 \cdot 10^1$	"	$2.7 \cdot 10^1$	"	$4.5 \cdot 10^1$	"	ND
" "	5 May	$2.6 \cdot 10^1$	ND	"	$3.6 \cdot 10^1$	"	7.0	"	$1.2 \cdot 10^1$	"	"

(a) Air filter contained particulate from 963 m^3 : air concentration (Bq m^{-3}) shown in brackets.

(b) Dry cloths exposed for 24 h to 0830 on date stated as collection.

NA = Not analysed.

ND = Not detected.

Table 2 Radiochemical analysis of particulate material on the Lowestoft air filter, 2 May 1986

Radionuclide	Activity concentration (Bq m^{-3})
^{89}Sr	$8.0 \cdot 10^{-1}$
^{90}Sr	$6.4 \cdot 10^{-2}$
^{238}Pu	$5.2 \cdot 10^{-6}$
^{239}Np	$2.0 \cdot 10^{-5}$
$^{239/240}\text{Pu}$	$1.2 \cdot 10^{-5}$
^{241}Am	$2.5 \cdot 10^{-6}$
^{242}Cm	$1.8 \cdot 10^{-4}$
^{244}Cm	$1.5 \cdot 10^{-6}$

Table 3 Radioactivity in fish

Material	Location [†]	Collection date (1986)	Radioactivity concentration (Bq kg ⁻¹ wet)			
			¹⁰³ Ru	¹³¹ I	¹³⁴ Cs	¹³⁷ Cs
Plaice	Whitehaven	16 May	ND	ND	3.9	63.7
"	Ravenglass	16 May	"	"	3.1	71.6
"	Poole	15 May	"	2.6	ND	ND
"	Fleetwood	19 May	"	3.7	2.7	57.9
"	Hastings	18 May	1.2	2.2	1.1	1.5
"	Northern North Sea	20 May	ND	ND	ND	3.4
"	Minch	23 May	"	"	1.5	21.3
"	Southern North Sea	7 May	"	3.5	ND	3.7
"	Southern North Sea	13 Jun	"	ND	"	3.8
"	Mid North Sea	14 May	"	"	"	2.9
Cod	Southern North Sea	7 May	1.0	3.6	"	2.6
"	Southern North Sea	13 Jun	ND	ND	1.2	6.9
"	Mid North Sea	13 May	"	"	0.2	10.2
"	Whitehaven	16 May	3.1	6.7	7.5	169
"	Whitehaven	19 May	ND	ND	4.4	112
"	Hartlepool	14 May	"	2.6	ND	5.4
"	Fleetwood	19 May	"	2.9	2.4	55.3
"	Northern North Sea	20 May	"	"	0.5	6.2
"	Minch	23 May	"	"	ND	18.2
Herring	Isle of Man	21 May	"	4.5	1.5	41.2
Sole	Hastings	18 May	0.6	1.3	ND	2.6
Flounder	Hinkley	13 May	ND	ND	"	1.9
"	Annan	5 May	"	"	3.9	161
Dogfish	Weymouth	15 May	"	"	ND	ND
Pollack	Poole	15 May	"	2.3	"	2.4
Skate	Bradwell	5 May	"	ND	1.1	6.7
Dab	Sellafield	19 May	"	"	4.5	101
Fish oil	Irish Sea	28 May	"	"	ND	ND
Salmon	Melvich	12 Jun	"	"	"	3.1
"	"	23 Jul	"	"	"	1.6
"	"	8 Aug	"	"	1.0	2.7
"	Culkein	12 Jun	"	"	ND	0.9
"	"	23 Jul	"	"	"	ND
"	"	7 Aug	"	"	"	"
"	Perth	13 Jun	"	"	4.7	8.8
"	"	24 Jul	"	"	ND	ND
"	"	14 Aug	"	"	"	1.1
"	River Wear, Wolsingham	11 Jul	"	"	"	2.8
Sea trout	River Calder	12 Aug	"	"	4.4	60.3
"	River Ehen	11 Aug	"	"	1.4	70.0
"	Culkein	23 Jul	"	"	ND	18.1
"	Melvich	12 Jun	"	"	1.9	7.0
"	Perth	13 Jun	"	"	1.9	10.1
"	"	24 Jul	"	"	ND	11.2
Brown trout	Trawsfynydd	8 May	1.1	4.8	3.2	16.7
"	"	23 May	ND	ND	105	598
"	"	6 Jun	"	"	116	655
"	"	14 Jun	"	"	40.0	252
"	"	15 Jun	"	"	64.5	448
"	"	15 Jul	"	"	3.9	14.5
"	"	7 Aug	"	"	111	638
"	"	22 Aug	"	"	ND	2.8
"	"	23 Aug	"	"	"	8.8

Table 3 continued

Material	Location ⁺	Collection date (1986)	Radioactivity concentration (Bq kg ⁻¹ wet)			
			¹⁰³ Ru	¹³¹ I	¹³⁴ Cs	¹³⁷ Cs
Brown trout	Afon Gwyrfai	10 Jul	ND	ND	56.5	117
"	Afon Merddwr	11 Jul	"	"	52.8	102
"	Llangefni	16 Jul	"	"	8.3	15.0
"	River Wear, Durham	12 May	"	6.6	ND	1.8
"	"	13 May	"	ND	"	ND
"	River Wear, Wolsingham	11 Jul	"	"	1.8	3.2
"	Loweswater	11 May	0.6	6.7	2.7	11.9
"	Windermere	15 May	ND	2.2	0.9	5.5
"	"	28 Jun	"	ND	8.4	18.0
"	"	16 Jul	"	"	14.4	31.9
"	"	5 Aug	"	"	20.8	38.4
"	"	21 Aug	"	"	13.8	29.4
"	River Eden	16 Jul	"	"	ND	2.5
"	River Derwent	16 Jul	"	"	38.4	70.7
"	River Petteril	13 Jul	"	"	5.5	8.1
"	Crummock Water	18 Jul	"	"	125	247
"	"	4 Aug	"	"	81.4	185
"	Ennerdale	19 Aug	"	"	315	657
"	Wastwater	20 Aug	"	"	112	247
"	River Ehen	11 Aug	"	"	49.1	96.3
"	River Calder	12 Aug	"	"	106	881
"	Loch a'Choire	15 Jun	"	"	19.0	40.2
"	"	24 Jul	"	"	28.1	80.3
"	"	18 Aug	"	"	26.9	54.7
"	Larne, NI	23 Jul	"	"	ND	2.1
"	Kilrea, NI	"	"	"	"	3.0
"	Newtownstewart, NI	"	"	"	1.4	3.3
"	River Grillagh, NI	21 Aug	"	"	22.3	42.9
"	River Bush, NI	21 Aug	"	"	114	305
"	Cornaa River, IOM	9 Jul	"	"	92.8	177
"	"	5 Aug	"	"	177	368
"	Laxey River, IOM	18 Jul	"	"	38.6	80.7
"	"	5 Aug	"	"	6.8	25.5
"	Silver Burn River, IOM	18 Jul	"	"	56.7	112
"	"	5 Aug	"	"	55.1	113
"	Glen Mona River, IOM	18 Jul	"	"	36.5	71.4
"	"	5 Aug	"	"	37.9	94.0
"	Jacky Goldsmiths River, IOM	18 Jul	"	"	57.4	112
"	"	5 Aug	"	"	62.2	123
"	River Druisdale, IOM	5 Aug	"	"	118	251
"	Glen Darragh, IOM	18 Jul	"	"	111	230
"	"	5 Aug	"	"	89.3	169
"	River Glass, IOM	18 Jul	"	"	53.9	108
"	"	5 Aug	"	"	111	221
Rainbow trout	Trawsfynydd	8 May	"	"	0.8	3.4
"	"	16 May	"	"	ND	1.7
"	"	17 May	"	"	2.0	6.8
"	"	24 May	"	"	1.2	2.9
"	"	30 May	"	"	ND	3.4
"	"	7 Jun	"	"	"	4.8
"	"	14 Jun	"	"	3.5	16.6
"	"	20 Jun	"	"	3.6	13.5
"	"	15 Jul	"	"	0.2	3.8
"	"	7 Aug	"	"	26.5	81.7
"	"	18 Aug	"	"	ND	ND
"	"	25 Aug	"	"	"	3.4
"	Hawkeshead	13 May	"	3.2	"	1.0
"	"	22 Jul	"	ND	"	3.2
"	Sacrewell	16 Jul	"	"	"	1.4
"	Bodelwyddan	10 Jul	"	"	1.2	5.8

Table 3 continued

Material	Location ⁺	Collection date (1986)	Radioactivity concentration (Bq kg ⁻¹ wet)			
			¹⁰³ Ru	¹³¹ I	¹³⁴ Cs	¹³⁷ Cs
Rainbow trout	River Ae, Dumfries	24 Jun	ND	ND	ND	3.0
"	River Nairn	13 Jun	"	"	"	3.4
"	Almondbank, Perth	13 Jun	"	"	"	2.9
"	Cornaa River, IOM	9 Jul	"	"	0.9	4.1
"	Glen Maye, IOM	18 Jul	"	"	2.8	7.0
"	Larne, NI	23 Jul	"	"	ND	2.5
"	Kilrea, NI	23 Jul	"	"	"	ND
"	Newtownstewart, NI	23 Jul	"	"	0.8	3.3
Char	Windermere	28 Jun	"	"	32.0	48.4
"	"	16 Jul	"	"	30.5	62.6
"	"	5 Aug	"	"	32.0	56.9
"	"	20 Aug	"	"	31.2	57.6
"	Ennerdale	19 Aug	"	"	61.7	137
"	Wastwater	11 Jun	"	"	35.3	63.0
"	"	15 Jun	"	"	25.1	66.6
"	Thirlmere	11 Jun	"	"	17.5	30.1
"	"	18 Jun	"	"	11.7	23.8
Perch	Windermere	15 May	"	"	ND	2.0
"	"	24 Jul	"	"	20.7	35.3
"	"	5 Aug	"	"	31.2	68.6
"	"	20 Aug	"	"	29.4	73.6
"	Loweswater	18 Jul	"	"	32.9	67.6
"	"	21 Aug	"	"	204	445
"	Crummock water	18 Jul	"	"	141	293
"	"	4 Aug	"	"	167	369
"	Trawsfynydd	4 Aug	"	"	312	1840
Pike	Windermere	17 Jul	"	"	9.0	30.2
"	"	22 Jul	"	"	17.2	36.6
"	"	24 Jul	"	"	8.6	29.0
"	"	5 Aug	"	"	17.5	37.0
"	"	20 Aug	"	"	17.6	41.9
Eel	Bridgwater	15 May	"	"	ND	6.3
"	River Derwent	16 Jul	"	"	5.3	11.9
"	Windermere	23 Jul	"	"	8.0	21.2
"	"	5 Aug	"	"	11.9	29.2
"	River Irt	11 Aug	"	"	33.0	70.6
"	River Mite	11 Aug	"	"	8.0	29.6
"	River Ehen	11 Aug	"	"	6.9	18.7
"	River Calder	12 Aug	"	"	17.3	269
"	River Esk	12 Aug	"	"	23.2	177
Rudd	Trawsfynydd	4 Aug	"	"	142	777
"	"	15 Aug	"	"	106	430
"	"	15 Aug	"	"	78.4	370

⁺ See Figure 2 for marine fish and fish oil; Figure 3 for freshwater fish (brown/rainbow trout, eel, pike, rudd, char and perch).

NA = not analysed

ND = not detected

Table 4 Radioactivity in crustaceans

Material	Location [†]	Collection date (1986)	Radioactivity concentration (Bq kg ⁻¹ wet)				
			¹⁰³ Ru	^{110m} Ag	¹³¹ I	¹³⁴ Cs	¹³⁷ Cs
Shrimp	Annan	5 May	ND	ND	ND	1.6	34.4
"	"	4 Jun	9.2	10.5	3.1	7.0	47.8
"	Flookburgh	19 May	ND	ND	ND	3.0	34.7
Crab	Hartlepool	14 May	ND	ND	ND	ND	ND
"	Dounreay	15 May	1.1	"	3.8	0.14	2.4
"	Ravenglass	2 Jun	3.3	9.3	ND	2.01	23.9
Lobster	St Bees	7 May	2.7	7.8	"	1.8	34.7
"	Dounreay	15 May	ND	13.0	16.9	ND	3.9
"	Ravenglass	21 Jun	"	9.1	ND	1.0	27.6
<u>Nephrops</u>	Ardglass	15 May	"	ND	"	ND	6.3
"	Whitehaven	21 May	"	"	"	1.0	28.6

NA = not analysed

ND = not detected

[†]See Figure 4

Table 5 Radioactivity in molluscs

Material	Location [†]	Collection date (1986)	Radioactivity concentration (Bq kg ⁻¹ wet)										
			¹⁰³ Ru	¹⁰⁶ Ru	^{110m} Ag	^{129m} Te	¹³¹ I	¹³² Te	¹³⁴ Cs	¹³⁶ Cs	¹³⁷ Cs	¹⁴⁰ Ba	¹⁴⁰ La
Winkles	Nethertown	7 May	468	412	24.8	NA	172	793	26.8	NA	97.7	NA	NA
"	"	7 "	757	552	38.2	"	180	1330	45.8	"	151	ND	27.5
"	"	13 "	643	627	63.5	"	60.3	360	12.0	"	59.4	"	8.4
"	"	19 "	401	393	58.7	"	38.8	74.0	10.5	"	75.0	"	5.6
"	"	27 "	294	326	57.0	"	13.0	7.9	6.1	"	50.5	"	ND
"	"	2 Jun	328	497	73.1	"	7.3	ND	8.1	"	92.0	"	"
"	"	9 "	158	367	66.7	266	ND	"	4.4	11.9	71.9	"	"
"	"	16 "	159	520	65.5	228	"	"	7.9	ND	93.3	"	"
"	"	23 "	103	486	69.1	133	"	"	6.8	13.6	67.0	"	"
"	"	30 "	80.0	517	71.5	137	"	"	3.5	ND	66.2	"	"
"	Ravenglass	6 May	1260	835	53.1	1950	370	3180	116	45	305	NA	114
"	"	13 "	1030	556	69.2	NA	147	568	35.0	NA	110	"	NA
"	"	19 "	789	473	89.1	132	98.1	142	26.0	23.0	94.8	ND	12.2
"	"	27 "	619	405	93.8	NA	40.3	25.0	18.1	NA	68.6	"	ND
"	"	3 Jun	356	331	86.3	547	13.8	ND	9.1	12.9	196	"	"
"	"	10 Jun	185	283	92.4	298	8.1	"	6.3	9.9	46.8	"	ND
"	"	16 "	157	272	81.8	250	ND	"	9.0	ND	43.9	"	5.9
"	Southernness	3 May	2060	608	63.0	2490	1340	7060	419	177	805	372	344
"	"	15 "	2730	1024	186	3084	215	938	54.4	38	128	ND	10.3
"	"	23 "	835	358	94.2	1330	136	71.0	13.6	11.7	52.1	"	7.2
"	"	29 "	1040	481	135	1250	47.4	ND	25.3	21.8	82.2	"	ND
"	"	4 Jun	1080	565	210	1480	22.0	"	29.7	20.5	93.2	"	4.2
"	"	11 "	538	330	277	865	10.6	"	19.1	8.5	76.6	"	2.9
"	"	17 "	252	190	125	391	3.8	"	7.3	ND	44.4	"	ND
"	"	1 Jul	179	198	241	364	ND	"	5.4	13.4	25.8	"	"
"	"	16 "	134	210	318	268	"	"	7.1	3.8	41.7	"	2.0
"	Tarn Bay	13 May	427	256	48.6	NA	22.6	259	5.3	NA	26.7	NA	NA
"	Sandside Bay	14 May	115	74.2	85.2	"	33.1	53.3	3.6	"	7.4	ND	5.3
"	Hartlepool	15 May	6.4	ND	ND	"	ND	ND	ND	NA	ND	ND	ND
"	St Bees	15 May	1010	547	82.6	"	112	386	16.0	"	50.8	NA	NA
Mussels	Rockcliffe	3 May	765	472	45.1	618	254	2100	67.0	ND	147	ND	101
"	"	15 "	356	148	13.7	220	80.8	77.9	12.5	NA	38.9	"	12.5
"	"	23 "	235	99.7	8.5	117	38.3	9.0	7.2	"	22.8	"	ND
"	"	29 "	192	112	7.4	155	17.5	ND	7.6	ND	29.5	"	3.0
"	"	4 Jun	112	72.7	4.1	99.8	8.8	"	5.4	"	23.8	"	ND
"	"	11 "	105	86.4	4.3	126	4.1	"	5.1	"	21.9	"	"
"	"	17 "	70.7	61.9	4.6	47.5	ND	"	4.3	"	18.7	"	"
"	Ravenglass	6 May	338	351	17.7	NA	70.3	547	11.0	NA	39.8	ND	20.4
"	"	13 "	203	241	10.0	"	31.3	99.3	5.6	"	18.7	"	10.3
"	"	19 "	135	222	9.9	"	11.2	24.6	4.2	"	16.2	"	ND
"	"	27 "	86.3	217	4.8	"	6.5	2.2	4.1	"	14.8	"	1.3
"	"	3 Jun	67.9	237	3.7	"	1.3	ND	2.2	"	13.4	"	ND
"	"	10 "	50.8	230	1.9	59.8	ND	"	ND	ND	12.8	"	"
"	"	16 "	46.4	244	2.3	77.5	"	"	1.4	"	10.7	"	"
"	Conwy	13 May	221	86.0	16.0	NA	27.1	152	7.0	NA	14.8	NA	NA
"	"	19 "	124	48.9	8.4	"	11.4	32.3	3.7	"	10.5	ND	ND
"	"	29 "	68.8	30.1	5.0	"	3.2	4.6	1.4	"	5.7	"	1.0
"	"	3 Jun	53.4	25.5	3.8	151	2.0	ND	2.1	ND	6.1	"	ND
"	"	9 "	57.7	31.8	4.2	147	1.5	"	2.0	"	5.4	"	"
"	"	16 "	36.1	19.4	4.2	64.3	ND	"	1.1	"	3.2	"	"
"	"	23 "	24.8	21.9	3.3	64.6	"	"	1.3	"	4.0	"	"
"	"	20 "	17.4	ND	2.9	45.6	"	"	2.6	"	5.7	"	"
"	"	14 Jul	10.5	"	2.7	29.8	"	"	ND	"	4.8	"	"
"	Poole	13 May	2.4	"	ND	NA	"	"	ND	NA	ND	NA	NA
"	Hastings	14 May	2.6	"	"	"	"	"	"	"	"	ND	ND
Cockles	Wirral	2 May	ND	ND	ND	NA	ND	ND	ND	NA	12.7	NA	NA
"	Swansea	10 May	4.3	"	"	"	5.6	"	2.2	"	1.8	"	"
"	The Wash	14 May	ND	8.3	"	"	ND	"	ND	"	2.7	"	"
"	"	14 Jun	5.1	ND	4.5	ND	"	"	"	ND	1.7	ND	ND
Limpets	Sellafield	10 May	ND	234	6.6	NA	"	"	1.7	NA	51.8	"	"
"	Sandside Bay	14 May	1150	430	62.5	1190	60.1	425	20.3	6.6	39.9	"	23.4
"	Dounreay	14 May	1400	471	64.7	1160	119	385	37.2	24.3	63.9	"	32.9
"	Castletown	14 May	1800	615	61.2	1840	160	635	90.2	13.9	149	ND	48.5
"	St Bees	28 May	514	343	51.9	921	19.7	19.7	6.3	10.3	48.4	ND	ND
"	"	2 Jun	388	354	55.8	763	9.8	ND	6.5	13.5	53.7	"	1.9
"	"	11 "	281	363	52.9	512	6.6	"	6.0	16.6	57.6	"	ND
"	"	16 "	230	292	55.6	480	ND	"	3.2	ND	27.1	"	"
"	"	30 "	122	235	51.9	280	"	"	3.4	5.8	35.3	"	"
Oysters	Poole	13 May	1.8	ND	ND	NA	2.9	0.8	ND	NA	1.4	NA	NA
Scallops	Hastings	19 May	ND	"	"	"	ND	ND	NA	"	ND	ND	ND
"	Isle of Man	17 Jul	1.7	"	8.9	ND	"	"	0.7	ND	5.1	"	"
Queens	Kirkcudbright	3 May	ND	2.2	0.3	"	"	"	ND	"	4.1	"	"

NA = not analysed
 ND = not detected
[†]See Figure 5

Table 6 Radioactivity in seaweed

Material	Location ⁺	Collection date (1986)	Radioactivity concentration (Bq kg ⁻¹ wet)										
			¹⁰³ Ru	¹⁰⁶ Ru	^{110m} Ag	^{129m} Te	¹³¹ I	¹³² Te	¹³⁴ Cs	¹³⁶ Cs	¹³⁷ Cs	¹⁴⁰ Ba	¹⁴⁰ La
Porphyra	St Bees	6 May	1151	480	30.1	456	321	746	16.3	6.7	42.2	ND	14.0
		13 "	454	178	5.3	NA	99.8	29.8	7.8	NA	19.2	NA	NA
		19 "	412	257	7.0	"	45.2	10.2	3.8	"	13.8	ND	ND
		28 "	188	215	ND	"	18.7	ND	3.5	"	15.2	"	"
		2 Jun	183	120	"	"	10.0	"	ND	"	8.6	"	"
	11 "	164	138	"	ND	7.0	"	3.4	ND	11.9	"	"	
	16 "	84.1	123	"	"	2.6	"	2.5	"	12.3	"	"	
	4 May	1170	498	32.7	455	1280	1160	39.5	14.5	89.1	ND	32.9	
	12 "	635	359	16.4	195	396	101	20.1	5.0	47.2	"	5.1	
	18 "	512	234	6.7	71.5	142	12.2	9.4	8.9	24.5	"	ND	
27 "	323	196	ND	74.0	44.2	1.5	6.2	NA	21.7	"	"		
1 Jun	278	202	"	NA	26.1	ND	6.8	"	34.4	"	"		
8 "	221	170	"	"	12.7	"	4.2	"	19.5	"	"		
15 "	137	164	3.0	ND	5.8	"	3.5	ND	17.2	"	"		
22 "	115	179	2.0	"	3.5	"	2.7	"	15.4	"	"		
1 Jul	73.5	147	3.6	"	ND	"	1.0	"	10.9	"	"		
8 "	86.7	258	1.7	21.5	"	"	1.9	"	22.9	"	"		
20 "	96.3	282	ND	ND	"	"	2.0	"	19.8	"	"		
Lowestoft	6 May	7.4	ND	ND	NA	73.0	ND	ND	NA	1.2	NA	NA	
	14 "	11.1	"	"	"	39.4	3.8	"	"	ND	"	"	
	19 "	6.6	"	"	"	18.2	ND	"	"	3.2	ND	ND	
	30 "	3.8	"	2.4	"	5.9	"	"	"	0.8	"	"	
	6 Jun	3.7	"	ND	"	3.8	"	"	"	1.0	"	"	
	14 "	2.9	"	1.8	ND	1.7	"	"	ND	0.7	"	"	
	20 "	2.5	"	1.7	"	1.5	"	"	"	0.9	"	"	
	1 Jul	1.3	"	ND	"	ND	"	"	"	1.0	"	"	
	15 "	1.7	"	"	"	"	"	"	"	1.1	"	"	
	13 May	48.8	16.6	2.5	NA	11.1	4.2	"	NA	0.8	NA	NA	
20 "	50.5	20.3	1.6	"	6.1	ND	"	"	1.9	ND	ND		
27 "	212	72.3	4.4	"	10.6	"	2.3	"	5.4	"	"		
2 Jun	42.3	35.2	ND	"	5.1	"	ND	"	5.3	"	"		
9 "	93.5	45.5	3.4	"	2.2	"	0.9	"	1.4	"	"		
17 "	27.9	ND	ND	ND	ND	"	ND	ND	ND	"	"		
23 "	17.0	11.1	2.0	"	"	"	"	"	0.9	"	"		
30 "	13.5	12.8	1.9	"	"	"	"	"	1.3	"	"		
14 Jul	12.2	8.3	1.1	"	"	"	"	"	1.0	"	"		
Knock Bay	6 May	9.6	7.5	ND	NA	46.0	20.4	4.8	NA	10.8	NA	NA	
	13 "	197	65.9	15.4	"	42.0	ND	2.8	"	4.5	ND	ND	
	21 "	102	30.7	8.3	"	13.4	"	ND	"	2.5	"	"	
	28 "	68.4	29.6	5.0	"	11.5	"	1.5	"	2.8	"	"	
	9 Jun	48.8	30.2	7.3	"	1.5	"	ND	"	1.7	"	"	
	11 "	34.8	18.7	8.3	ND	ND	"	"	ND	1.0	"	"	
	18 "	29.3	20.0	5.9	"	"	"	"	"	1.8	"	"	
	25 "	16.2	10.4	6.1	"	"	"	"	"	1.4	"	"	
9 Jul	23.5	ND	ND	"	"	"	"	"	ND	"	"		
Thurso	14 May	63.2	ND	8.5	NA	17.3	"	2.7	NA	4.0	"	"	
Guernsey	14 May	0.8	17.0	ND	"	4.5	"	ND	ND	NA	NA	NA	
Laverbread	Swansea (1)	3 May	52.3	26.6	5.0	"	30.9	18.3	"	NA	2.6	NA	NA
		22 "	73.8	34.9	6.2	"	10.1	ND	"	"	2.1	ND	ND
		29 "	59.6	28.0	4.6	"	3.7	"	"	"	1.2	"	"
		5 Jun	1.4	ND	ND	ND	ND	"	"	ND	ND	"	"
		26 "	26.1	21.3	4.6	15.8	0.7	"	"	"	1.0	"	"
	3 Jul	10.2	7.4	2.3	ND	ND	"	"	"	0.8	"	"	
	Swansea (2)	14 May	7.4	ND	ND	NA	9.1	ND	1.8	NA	3.3	"	"
		22 "	68.3	25.1	4.8	"	9.3	1.3	ND	"	1.7	"	"
		29 "	2.6	ND	ND	"	0.9	ND	0.9	"	ND	"	"
		5 Jun	47.2	24.1	6.3	"	5.2	"	ND	"	1.3	"	"
12 "		46.2	23.6	4.6	ND	2.5	"	"	ND	0.9	"	"	
26 "	25.3	15.2	4.6	"	0.8	"	"	"	ND	"	"		
3 Jul	22.8	22.7	3.5	"	ND	"	"	"	1.2	"	"		
Swansea (3)	29 May	105	51.2	5.6	NA	10.2	"	"	NA	1.6	"	"	
	5 Jun	55.4	24.8	3.8	"	4.0	"	"	"	2.0	"	"	
	12 "	49.3	33.4	5.6	ND	2.0	"	"	ND	1.6	"	"	
	19 "	16.2	9.8	2.7	"	ND	"	"	"	1.0	"	"	
	26 "	15.5	12.0	3.3	"	"	"	"	"	1.3	"	"	
3 Jul	0.9	ND	ND	"	"	"	"	"	ND	"	"		
Swansea (4)	3 May	11.5	ND	ND	NA	40.3	"	"	NA	4.6	NA	NA	
Swansea (5)	10 May	10.4	"	"	"	21.4	6.9	2.0	"	4.9	"	"	

Table 6 continued

Material	Location [†]	Collection date (1986)	Radioactivity concentration (Bq kg ⁻¹ wet)										
			¹⁰³ Ru	¹⁰⁶ Ru	^{110m} Ag	^{129m} Te	¹³¹ I	¹³² Te	¹³⁴ Cs	¹³⁶ Cs	¹³⁷ Cs	¹⁴⁰ Ba	¹⁴⁰ La
Laverbread	Swansea (6)	14 May	4.9	ND	ND	NA	11.8	ND	ND	NA	1.9	ND	1.6
"	"	14 "	ND	"	"	"	ND	"	"	ND	"	ND	
"	"	22 "	75.6	31.2	6.4	"	8.7	"	"	"	2.3	"	
"	"	19 Jun	21.1	17.6	4.3	ND	ND	"	"	ND	"	"	
"	"	19 "	20.1	14.2	3.0	"	"	"	"	0.6	"	"	
"	Swansea (7)	10 May	10.4	ND	ND	NA	21.4	6.9	2.0	NA	4.9	NA	NA
<u>Fucus spiralis</u>	Weymouth	13 May	2.7	ND	ND	NA	14.6	2.7	1.0	NA	1.7	NA	NA
"	Lowestoft	7 May	7.9	"	"	"	167	ND	2.8	NA	6.1	NA	NA
"	"	14 "	1.8	"	"	"	57.4	"	ND	"	2.2	"	"
"	"	19 "	3.8	"	"	"	55.6	"	1.7	"	4.1	ND	ND
"	"	30 "	1.1	"	"	"	20.1	"	1.2	"	2.6	"	"
"	"	6 Jun	1.7	"	"	"	15.8	"	ND	"	1.7	"	"
"	"	14 "	1.2	"	"	ND	6.7	"	"	ND	2.3	"	"
"	"	20 "	1.3	"	"	"	3.6	"	"	"	3.2	"	"
"	"	1 Jul	0.7	"	"	NA	2.7	"	"	"	2.5	"	"
"	"	15 "	ND	"	"	"	ND	"	"	"	ND	"	"
<u>Fucus serratus</u>	Lavernock Pt	11 May	2.8	"	"	NA	72.3	"	"	NA	2.2	NA	NA
"	Colwyn Bay	13 May	65.6	20.8	5.6	"	554	11.0	11.6	"	32.4	"	"
"	"	19 "	44.7	15.1	2.8	"	317	4.1	6.5	"	20.6	21.9	20.6
"	"	28 "	21.1	ND	6.4	"	121	ND	5.1	"	17.4	ND	4.4
"	"	3 Jun	16.1	8.1	6.2	"	83.2	"	5.2	"	16.9	"	ND
"	"	9 "	17.0	"	4.7	ND	57.8	"	6.0	ND	18.0	"	2.9
"	"	16 "	11.5	"	5.4	"	21.7	"	1.4	"	10.5	"	1.5
"	"	23 "	9.4	7.1	6.8	"	9.1	"	2.7	"	9.3	"	ND
"	"	30 "	5.8	ND	4.8	"	6.0	"	2.0	"	9.3	"	2.1
"	"	14 Jul	2.5	ND	3.4	"	1.9	"	2.7	"	10.8	"	ND
"	Weymouth	13 May	3.4	"	ND	NA	22.8	3.1	ND	NA	ND	NA	NA
"	Hartlepool	15 May	8.3	"	"	"	34.7	1.7	2.2	"	7.3	"	"
"	Sandside Bay	14 May	93.4	27.5	16.1	"	556	19.7	4.8	"	16.1	ND	25.0
"	"	14 "	43.6	22.3	14.4	"	256	7.7	4.4	"	13.3	"	ND
<u>Fucus vesiculosus</u>	"	14 "	65.5	27.5	11.8	"	275	10.8	5.7	"	16.2	"	"
"	Ravenglass*	6 May	204	82.1	17.1	"	3190	390	63.2	"	131	NA	NA
"	"	13 "	104	52.9	20.9	"	819	35.2	27.0	"	63.2	"	"
"	"	19 "	127	68.3	32.8	"	371	ND	37.1	"	86.2	ND	16.5
"	"	27 "	42.7	27.2	16.9	"	126	"	18.9	"	53.0	"	5.3
"	"	3 Jun	34.7	24.5	19.7	"	57.6	"	15.1	"	49.6	"	1.9
"	"	10 "	33.7	26.0	17.6	ND	33.5	"	10.3	ND	38.9	"	ND
"	"	16 "	33.1	53.0	20.7	"	23.3	"	12.4	"	52.6	"	2.8
"	"	30 "	15.9	23.5	13.9	"	6.6	"	8.5	"	44.2	"	ND
"	"	18 Jul	15.2	53.1	16.6	"	ND	"	7.7	"	67.3	"	"
"	Ravenglass ^x	6 May	164	88.8	12.6	244	2370	364	44.9	19.1	102	112	112
"	"	13 "	245	115	23.3	227	915	83.2	92.6	21.7	191	45.0	64.0
"	"	19 "	119	70.8	23.4	NA	566	33.1	29.1	NA	80.0	ND	29.0
"	"	27 "	58.4	40.1	16.1	187	192	2.7	17.9	"	56.3	"	9.1
"	"	3 Jun	47.7	45.5	16.6	110	97.8	ND	15.3	"	49.9	"	7.4
"	"	10 "	45.9	55.1	21.8	72.5	50.9	"	17.8	ND	62.0	"	2.2
"	"	16 "	46.8	72.4	19.9	85.7	30.0	"	18.4	"	71.7	"	ND
"	"	30 "	23.2	63.2	14.4	ND	9.5	"	12.0	"	61.7	"	"
"	Hastings	14 May	ND	ND	ND	NA	18.1	ND	ND	NA	ND	ND	ND
<u>Cladophora</u>	Dounreay	14 May	491	437	41.5	NA	334	177	97.3	NA	196	59.6	67.4

NA = not analysed

ND = not detected

[†]See Figure 6

Laverbread was obtained from several suppliers in Swansea

*Salmongarth

^xRailway Bridge, River Mite

Table 7 Radioactivity in water

Location [†]	Collection date (1986)	Radioactivity concentration (Bq l ⁻¹)			
		¹³¹ I	¹³⁴ Cs	¹³⁷ Cs	Ratio ¹³⁷ Cs/ ¹³⁴ Cs
(a) Sea water					
Cape Wrath	17 May	NA	0.014	0.114	8.1
" "	15 Jun	"	0.024	0.15	6.4
" "	2 Jul	"	0.026	0.15	5.8
Pentland Firth	17 May	"	0.023	0.094	4.1
" "	16 Jun	"	0.013	0.100	8.2
" "	2 Jul	"	0.016	0.095	6.1
Buckie	14 May	"	0.076	0.20	2.6
	16 Jun	"	0.035	0.12	3.4
Aberdeen	16 May	"	0.019	0.10	5.3
	3 Jul	"	0.032	0.11	3.5
Lowestoft	9 May	"	0.017	0.11	6.8
50°32'N 0°W	18 Jun	"	0.0016	0.0083	5.1
50°16'N 1°30'W	18 "	"	ND	0.0059	-
50°0' N 3°W	19 "	"	0.0017	0.0045	2.6
49°14'N 4°30'W	19 "	"	ND	0.0036	-
48°22'18"N 6°W	19 "	"	"	0.0029	-
47°26'N 8°W	19 "	"	0.0016	0.0014	0.90
Hinkley	15 May	"	ND	0.030	-
Oldbury	6 May	"	ND	0.033	-
52° 3'N 5°5' W	5 May	"	ND	0.0080	-
52°10'N 5°40'W	5 "	"	"	0.011	-
52°12'N 6°5' W	5 "	"	0.045	0.092	2
Church Bay	27 May	"	ND	0.068	-
" "	2 Jun	"	0.016	0.12	7.7
" "	9 "	"	ND	0.091	-
" "	17 "	"	"	0.080	-
" "	23 "	"	0.024	0.12	5.2
" "	30 "	"	0.021	0.14	6.7
53°18'N 4°47'W	15 Jul	"	0.019	0.094	4.9
53°37'N 4°36'W	15 "	"	0.012	0.091	7.6
53°47'N 4°39'W	15 "	"	0.014	0.11	7.7
53°59'N 4°41'W	15 "	"	0.019	0.13	6.9
54°19'N 4°14'W	16 "	"	0.024	0.17	7.2
54°30'N 4°22'W	16 "	"	0.041	0.31	7.4
54°35'N 4°24'W	16 "	"	0.042	0.30	7.2
54°39'N 4°22'W	16 "	"	0.048	0.37	7.7
53°59'N 4°40'W	16 "	"	0.034	0.21	6.0
New Brighton	27 May	"	0.12	0.71	5.8
Ainsdale	27 May	"	0.090	0.89	9.8
Half Moon Bay	29 May	"	0.088	1.4	15
Rossal	28 May	"	0.076	0.84	11

Table 7 continued

Location [†]	Collection date (1986)	Radioactivity concentration (Bq l ⁻¹)			
		¹³¹ I	¹³⁴ Cs	¹³⁷ Cs	Ratio ¹³⁷ Cs/ ¹³⁴ Cs
Walney Island	30 May	NA	0.086	1.06	12
Silecroft	30 May	"	0.077	0.93	12
Sellafield (1)*	19 May surface	"	0.094	0.85	9.0
"	19 " bottom	"	0.080	0.87	11
"	20 Jun surface	"	0.096	0.91	9.4
"	20 " bottom	"	0.077	0.90	12
" (2)*	19 May	"	0.063	0.77	12
" (3)*	19 May surface	"	0.092	0.81	8.9
"	19 " bottom	"	0.076	0.83	11
Seascale	1 May	ND	ND	0.52	-
"	8 "	2.5	0.87	2.4	2.7
"	15 "	NA	0.23	1.4	5.8
"	22 "	"	0.15	1.2	7.9
"	29 "	"	0.13	1.7	13
"	15 Jun	"	0.093	1.2	13
St Bees	1 May	ND	0.046	0.80	17
"	8 "	0.65	0.32	1.2	3.7
"	15 "	NA	0.14	1.1	7.8
"	22 "	"	0.11	1.01	8.8
"	29 "	"	0.085	0.84	9.8
"	15 Jun	"	0.10	0.93	9
Whitehaven	6 May	"	0.32	1.3	4.0
"	12 Jun	"	0.076	0.87	12
Maryport	5 May	"	1.9	4.03	2.1
"	12 Jun	"	0.083	0.94	11
Silloth	5 May	"	0.94	2.4	2.6
"	12 Jun	"	0.097	1.3	14
Southernness	4 May	"	2.9	5.4	1.9
"	15 "	"	0.40	1.8	4.5
"	23 "	"	0.23	1.4	5.8
"	29 "	ND	0.15	1.3	8.2
"	11 Jun	NA	0.12	1.2	9.9
"	17 "	"	0.11	1.2	12
"	1 Jul	"	0.094	1.2	13
"	16 "	"	0.12	1.3	11
Rockcliffe	15 May	"	0.40	0.73	1.8
Ross Bay	3 "	"	2.06	3.7	1.8
Isle of Whithorn	2 "	"	0.020	0.520	26
Drummore	2 "	"	ND	0.32	-
Portpatrick	1 "	"	0.0077	0.25	33

Table 7 continued

Location [†]	Collection date (1986)	Radioactivity concentration (Bq l ⁻¹)			
		¹³¹ I	¹³⁴ Cs	¹³⁷ Cs	Ratio ¹³⁷ Cs/ ¹³⁴ Cs
(b) Fresh water					
Trawsfynydd	7 May	NA	0.18	0.39	2.2
"	7 "	"	0.22	0.45	2.1
"	24 Jul	"	0.13	0.50	4.0
"	" "	"	0.10	0.48	4.7
Loweswater	14 Jul	"	0.19	0.30	1.5
Crummock Water	14 Jul	"	0.064	0.098	1.5
River Esk	3 Jul	"	0.024	0.059	2.5

ND = not detected

NA = not analysed

[†]See Figure 7.

*Three separate sampling locations are near to the Sellafield site.

Table 8 Radiochemical analyses

Material	Location	Collection date (1986)	Radioactivity concentration (Bq kg ⁻¹ wet)							
			⁸⁹ Sr	⁹⁰ Sr	⁹⁹ Tc	²³⁸ Pu	²³⁹ Pu	²⁴¹ Am	²⁴² Cm	²⁴⁴ Cm
Mussels	Wylfa	13 May	NA	NA	NA	0.21	1.0	1.1	0.0049	0.0027
Sediment	Hartlepool	15 May	"	"	"	0.39	2.0	0.41	0.005	ND
Brown trout	Trawsfynydd	8 May	2.8	4.4	< 0.21	NA	NA	NA	NA	NA
Rainbow trout	"	8 May	1.9	4.7	< 0.19	"	"	"	"	"

NA = Not analysed
 ND = Not detected

Table 9 Radioactivity in sediments

Material	Location [†]	Collection date (1986)	Radioactivity concentration (Bq kg ⁻¹ wet)										
			¹⁰³ Ru	¹⁰⁶ Ru	^{110m} Ag	^{129m} Te	¹³¹ I	¹³² Te	¹³⁴ Cs	¹³⁶ Cs	¹³⁷ Cs	¹⁴⁰ Ba	¹⁴⁰ La
Sediment	Hartlepool	15 May	13.2	7.7	ND	NA	9.5	4.8	2.4	ND	44.6	NA	NA
"	Kippford	3 May	1230	698	32.0	1610	2370	4120	719	299	2030	724	665
"	"	3 May	2120	898	60.4	2820	923	ND	519	129	1670	ND	596
"	"	11 Jun	302	369	12.8	426	10.3	"	111	16.8	682	"	13.0
"	Newbiggin	10 Jun	138	1120	8.0	189	13.5	"	65.4	37.0	999	"	6.7
"	"	16 Jun	141	1090	6.5	186	14.7	"	71.1	39.8	996	"	14.4
"	"	30 Jun	94.3	1190	4.9	194	ND	"	65.9	ND	1090	"	ND
"	Newport	12 May	30.0	20.6	ND	ND	"	"	7.6	"	83.8	"	"
"	Ravenglass	28 May	195	772	6.3	241	"	"	68.2	"	830	"	"
"	"	3 Jun	156	778	7.6	248	"	"	73.4	"	1120	"	15.7
"	Walney	30 May	240	265	7.24	275	"	"	70.7	"	602	"	ND
"	Millom	27 May	402	477	20.1	527	"	"	148	"	865	"	"

NA = not analysed
 ND = not detected
[†]See Figure 8

Table 10 Radioactivity in watercress

Material	Location [†]	Collection date (1986)	Radioactivity concentration (Bq kg ⁻¹ wet)										
			¹⁰³ Ru	¹⁰⁶ Ru	^{110m} Ag	^{129m} Te	¹³¹ I	¹³² Te	¹³⁴ Cs	¹³⁶ Cs	¹³⁷ Cs	¹⁴⁰ Ba	¹⁴⁰ La
Watercress	Hampshire	13 May	5.0	ND	ND	NA	22.2	1.34	3.25	NA	9.04	NA	NA
"	Lowestoft	12 May	14.2	"	"	"	57.8	7.0	7.9	"	10.4	"	"
"	"	22 Jul	ND	"	"	ND	ND	ND	ND	ND	ND	ND	ND

NA = not analysed
 ND = not detected

Table 11 Pre-Chenobyl concentrations in selected materials

Material	Location	Collection date (1986)	Radioactivity concentration (Bq kg ⁻¹ wet)				
			¹⁰³ Ru	¹⁰⁶ Ru	^{110m} Ag	¹³⁴ Cs	¹³⁷ Cs
Cod	Whitehaven	25 Feb				2	52
Shrimp	Annan	8 "		2		1	42
Winkles	Southernness	7 "		15			15
Cockles	Ravenglass	18 "		267			22
Winkles	Nethertown	30 Apr	2	325	13		80
Mussels	Ravenglass	13 Feb		307		0.3	13
"	Conwy	18 Mar					3
<u>Porphyra</u>	Seascale	27 Apr	1.7	125			11
"	Knock Bay	4 Feb		9		0.3	5
"	St Bees	28 "	0.6	82		0.4	10
Laverbread	Swansea	17 Jan					0.4
Brown trout	Trawsfynydd	22 Apr				41	339

Table 12 Consumption data

Food	Adult	10 years	1 year
Continuous consumption (kg year ⁻¹ (g d ⁻¹))			
Marine fish	110 (300)	73	11
Freshwater fish	55 (150)	37	5
Crustaceans	18 (50)	12	2
Molluscs	18 (50)	12	2
Seaweed	26 (70)	17	3
Discrete harvest (kg)			
Marine fish	4.2	2.8	0.4
Freshwater fish	2.2	1.4	0.2
Crustaceans	0.7	0.5	0.07
Molluscs	0.7	0.5	0.07
Seaweed	1.0	0.7	0.1

Table 13 Individual dose from continuous consumption for 1 year

Food	Effective dose in one year (mSv)	Limiting organ dose in one year (mSv)	Percentage of 5 mSv (effective) or 50 mSv (organ) dose levels
Marine fish	0.054	0.62	1.2
Freshwater fish	1.1	1.1	21
Crustaceans	0.0087	0.051	0.17
Molluscs	0.084	0.92	1.8
Seaweed	0.068	0.81	1.6

Note: Dose to the critical group in the area of highest observed concentrations. Dose quantities are committed dose equivalents based on concentration data for Whitehaven cod, Ennerdale brown trout, Annan shrimps, Southernness winkles and Seascale Porphyra.

Table 14 Individual dose from a hypothetical harvest at peak concentrations

Food	Effective dose (mSv)	Limiting organ dose (mSv)	Percentage of 5 mSv (effective) or 50 mSv (organ) dose levels
Marine fish	0.0021	0.024	0.048
Freshwater fish	0.041	0.043	0.82
Crustaceans	0.00034	0.002	0.0068
Molluscs	0.086	1.6	3.2
Seaweed	0.060	1.6	3.2

Note: Dose to the critical group in the area of highest observed concentrations. Dose quantities are committed dose equivalents based on concentration data for Whitehaven cod, Ennerdale brown trout, Annan shrimps, Southernness winkles and Seascale Porphyra

Table 15 Gamma dose rate over intertidal areas

Location	Date (1986)	Dose rate in air at 1 m [†] ($\mu\text{Gy h}^{-1}$)	
Kippford, salt marsh	6 Feb	0.22	0.22
" " "	3 May	0.57	0.57
" " "	15 "	0.33	0.35
Ravenglass, salt marsh	6 Jan	0.53	0.58
" " "	13 Feb	0.55	0.55
" " "	3 Mar	0.52	0.53
" " "	2 Apr	0.63	0.62
" " "	6 May	0.73	0.77
" " "	3 Jun	0.58	0.58
" " "	3 Jul	0.60	0.64
Ravenglass, silt	6 Jan	0.33	0.35
" " "	13 Feb	0.33	0.33
" " "	3 Mar	0.32	0.32
" " "	2 Apr	0.34	0.33
" " "	6 May	0.45	0.46
" " "	3 Jun	0.33	0.34
" " "	3 Jul	0.30	0.33
Ravenglass, mussel bed	6 Jan	0.20	0.21
" " "	13 Feb	0.22	0.22
" " "	3 Mar	0.20	0.19
" " "	2 Apr	0.20	0.21
" " "	6 May	0.36	0.35
" " "	3 Jun	0.19	0.19
" " "	3 Jul	0.16	0.18

[†]Measurements are made with two instruments

Appendix 2 Figures 1-16

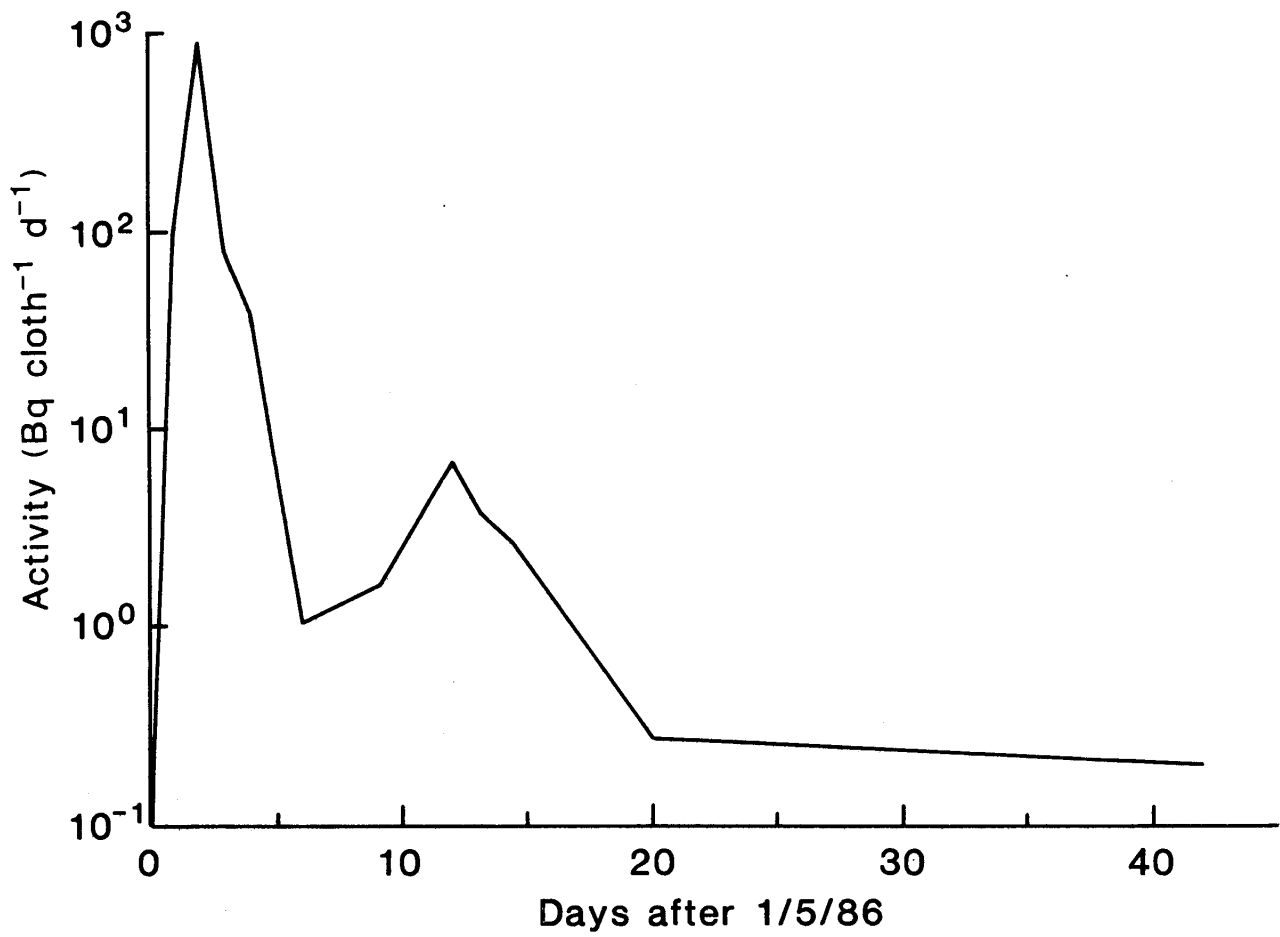


Figure 1 ^{131}I on dry cloths at Lowestoft

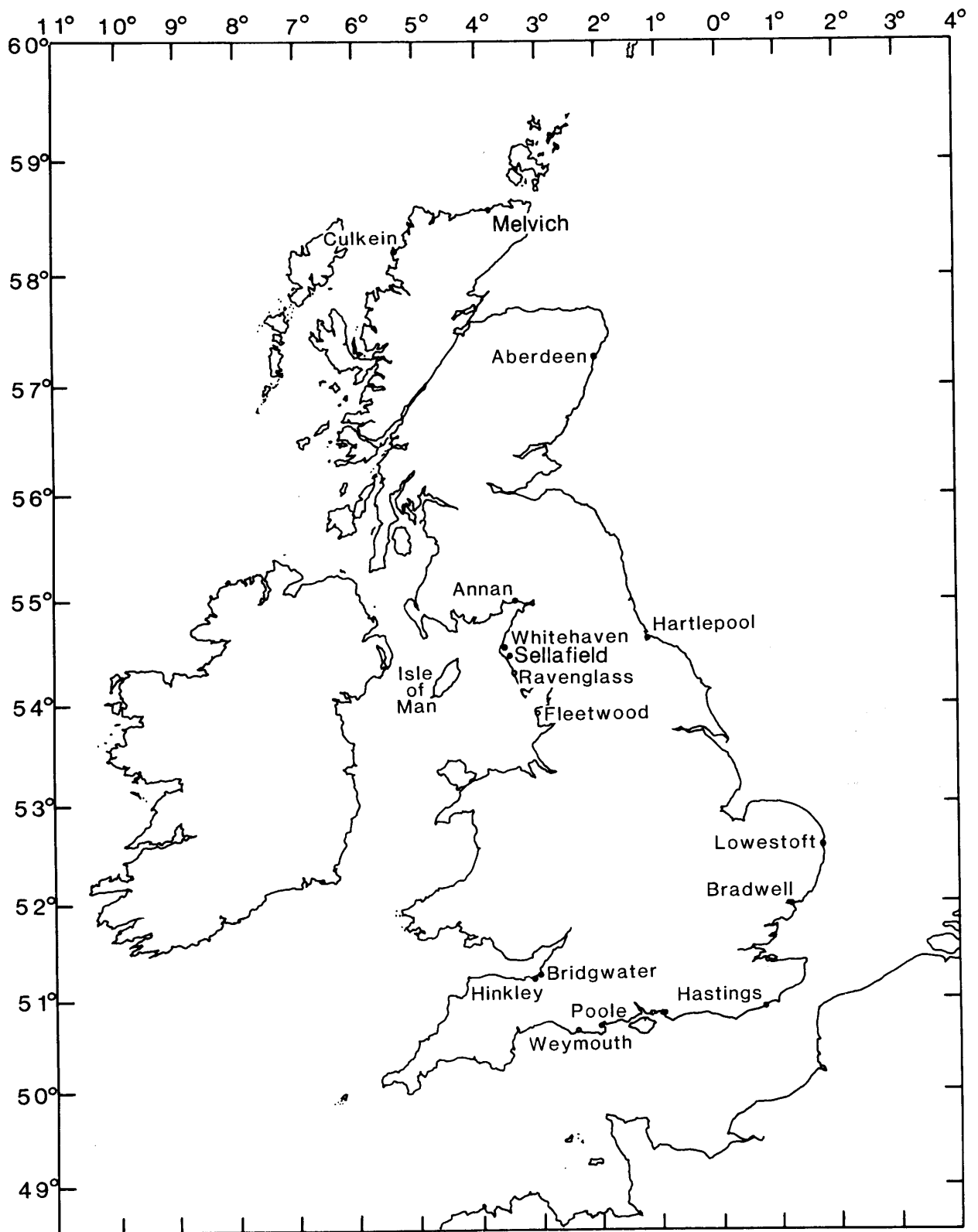


Figure 2 Sampling locations for marine fish

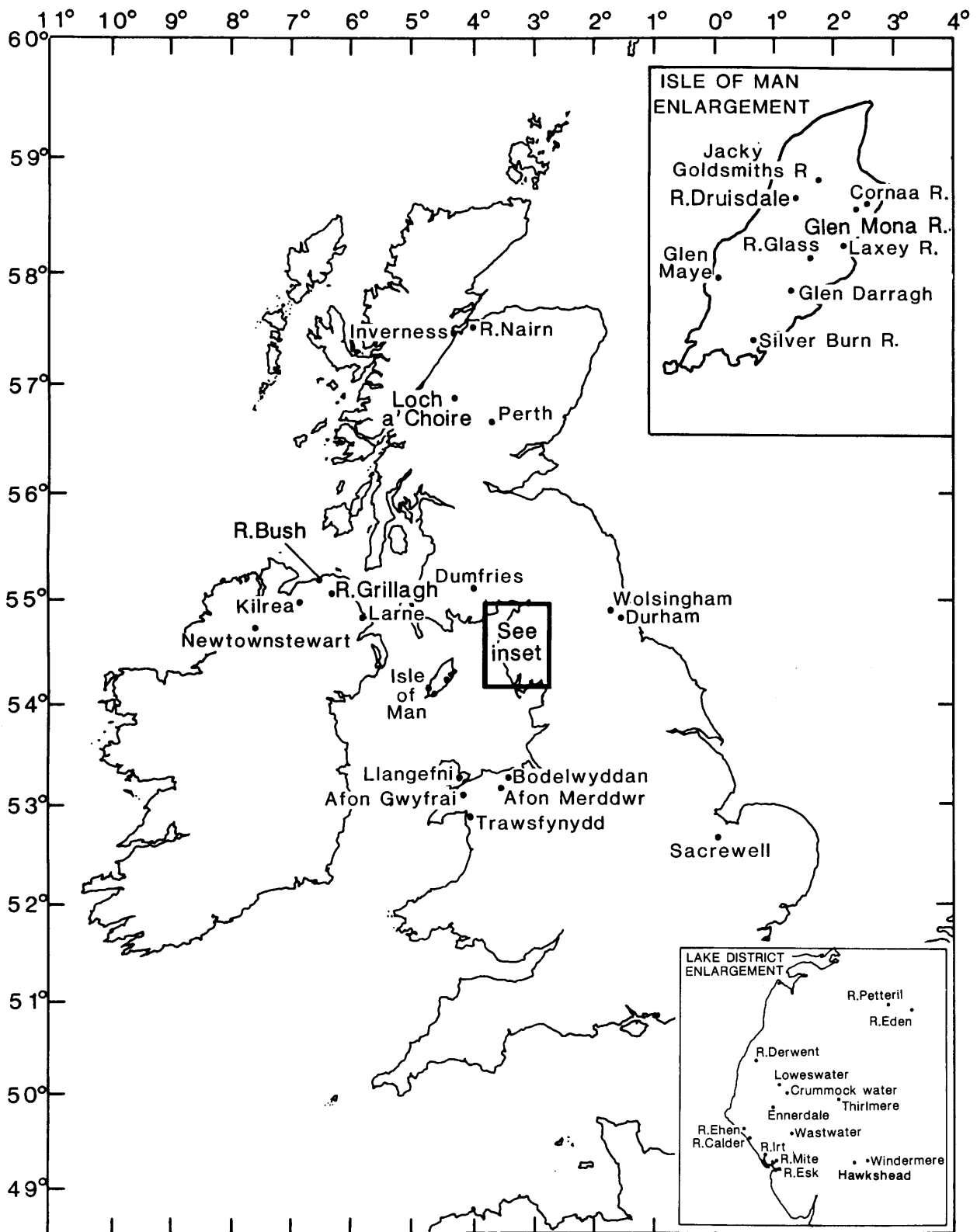


Figure 3 Sampling locations for freshwater fish

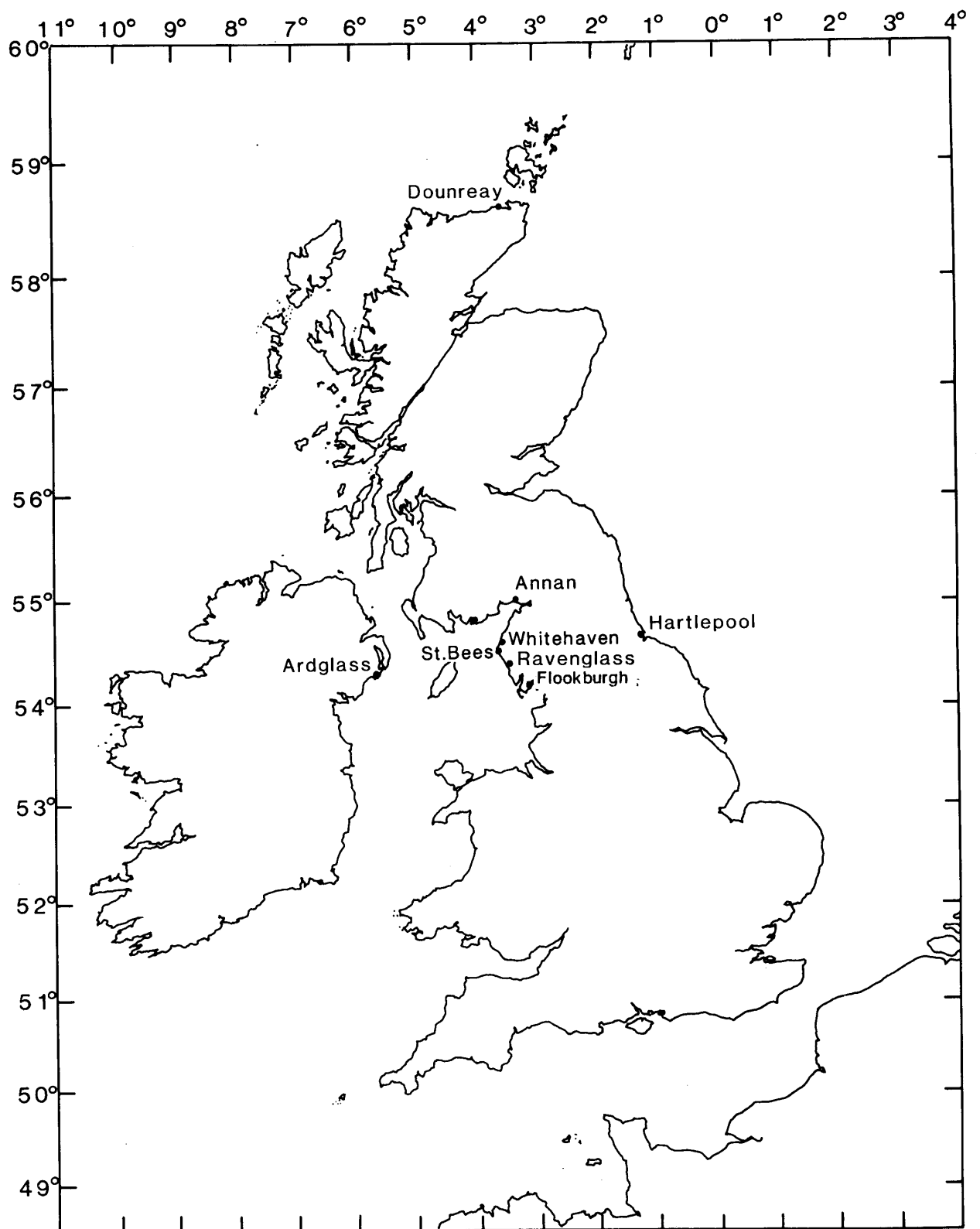


Figure 4 Sampling locations for crustaceans

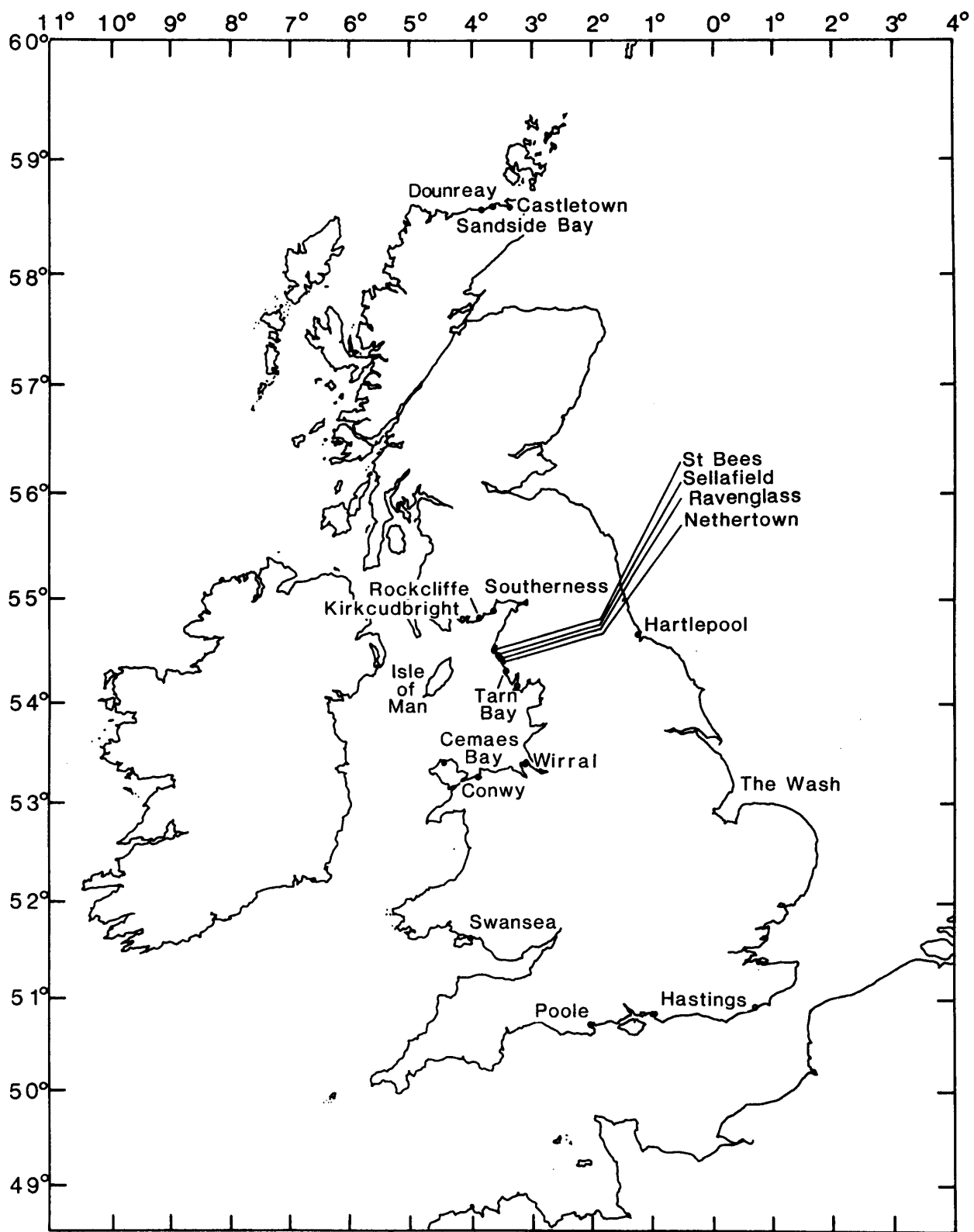


Figure 5 Sampling locations for molluscs

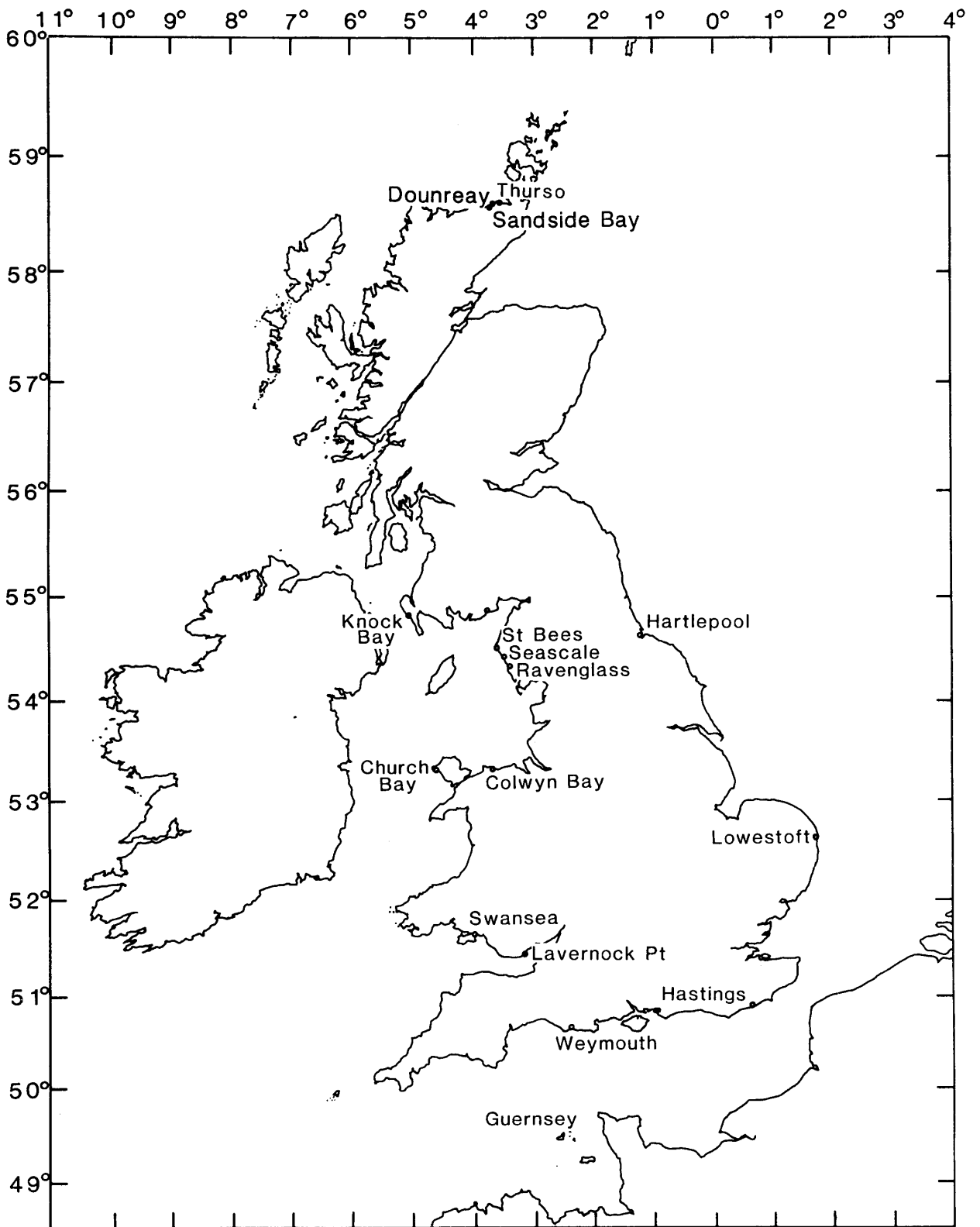


Figure 6 Sampling locations for seaweed

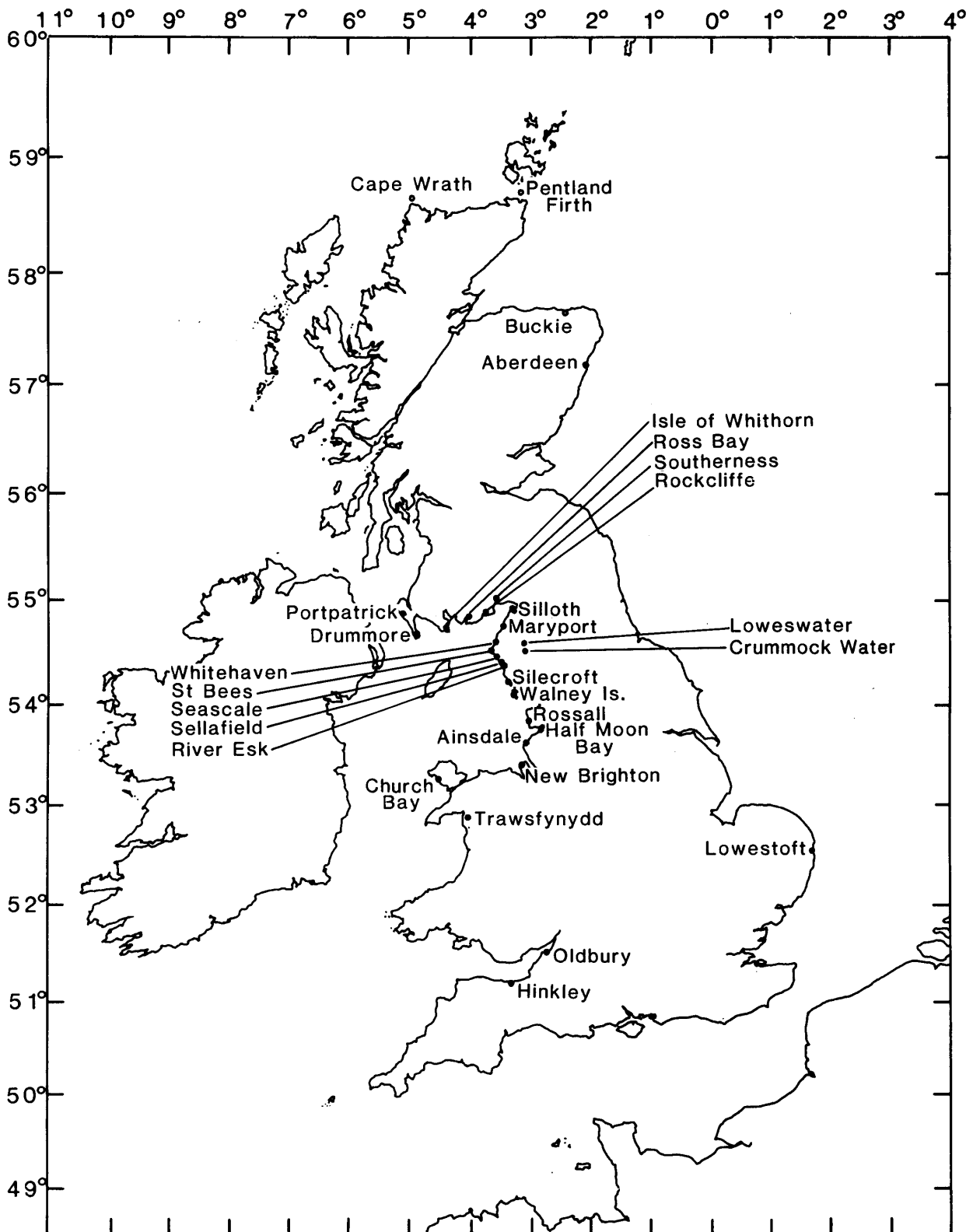


Figure 7 Sampling locations for water

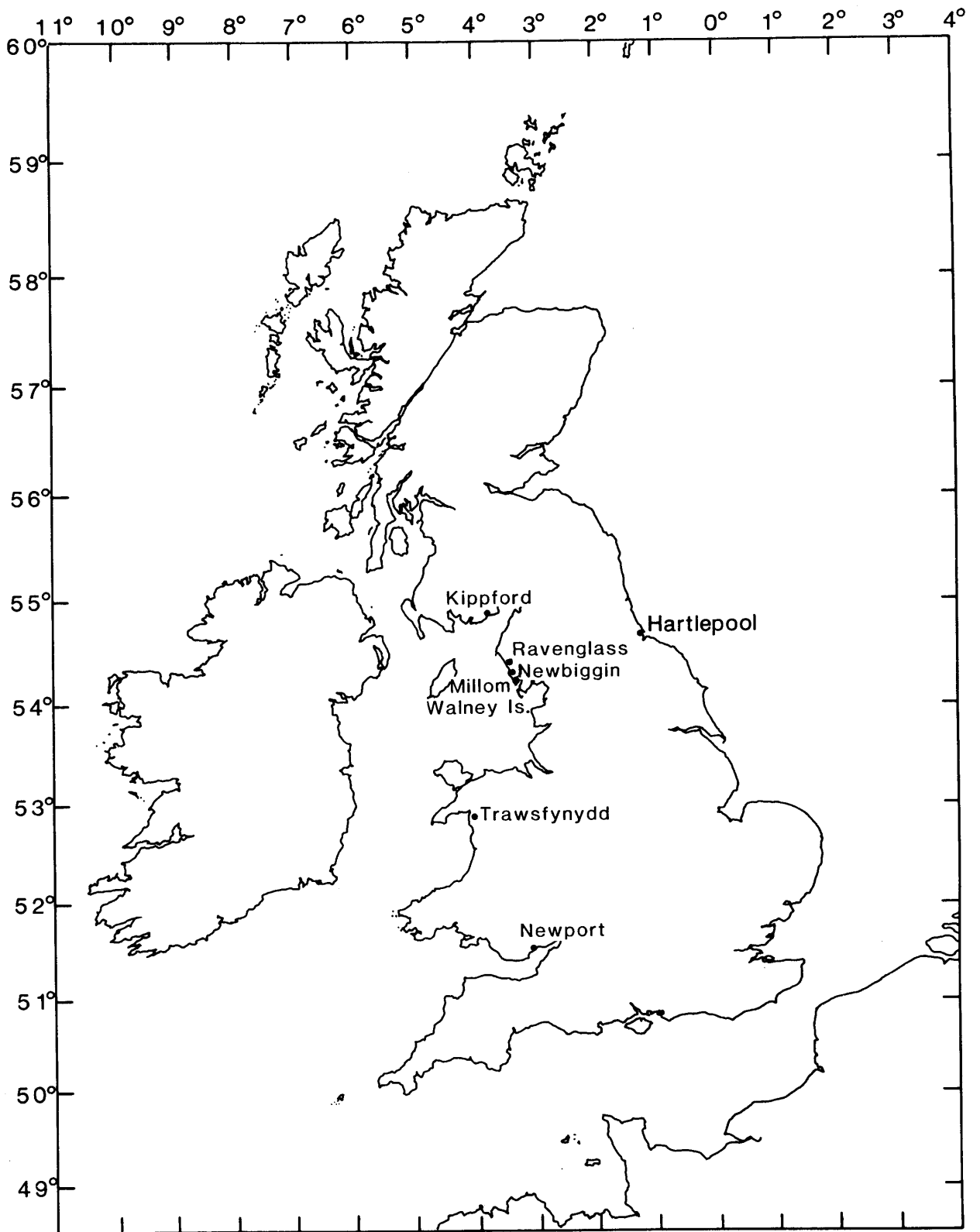


Figure 8 Sampling locations for sediments

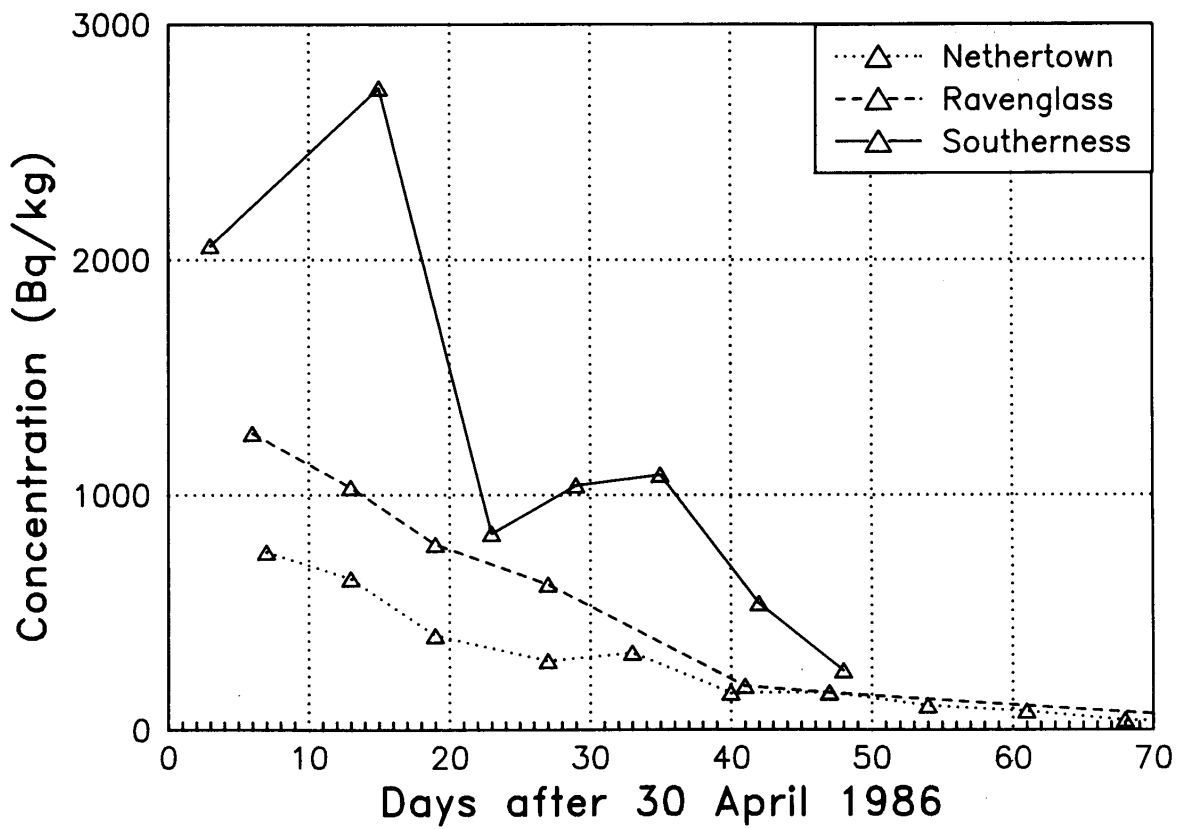


Figure 9 ^{103}Ru in winkles

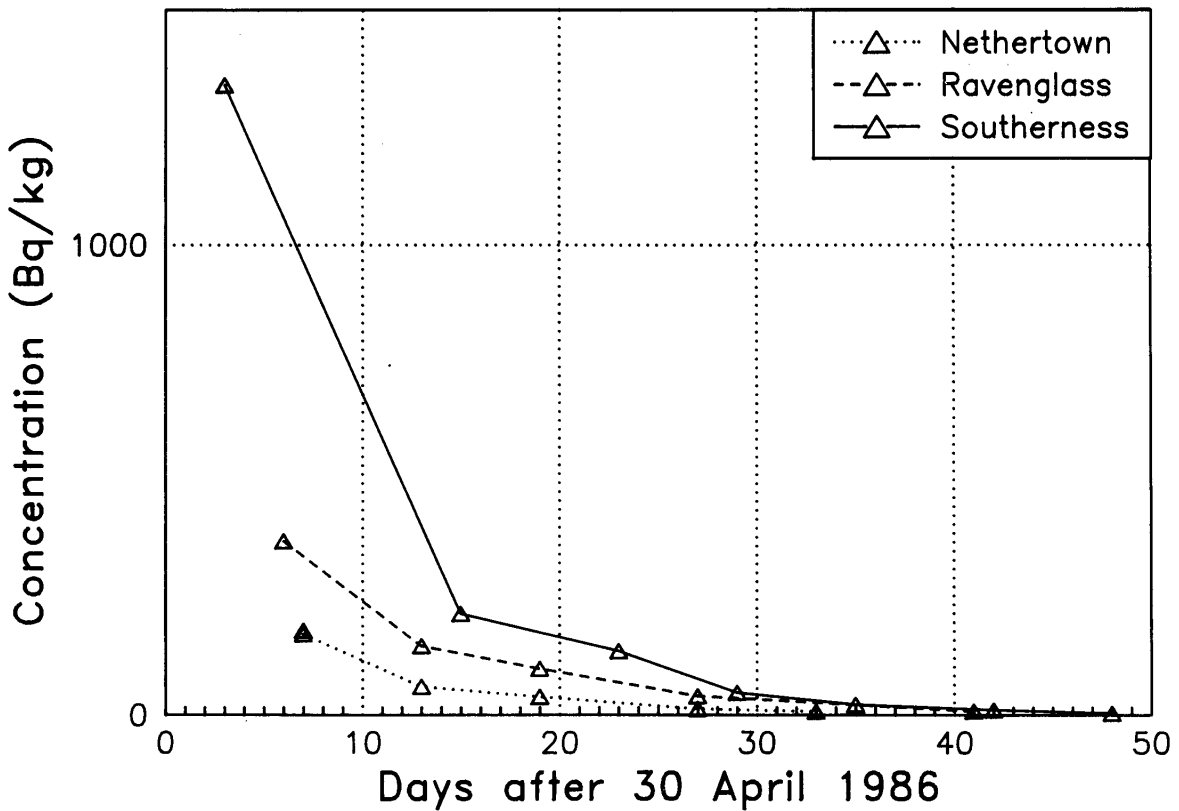


Figure 10 ^{131}I in winkles

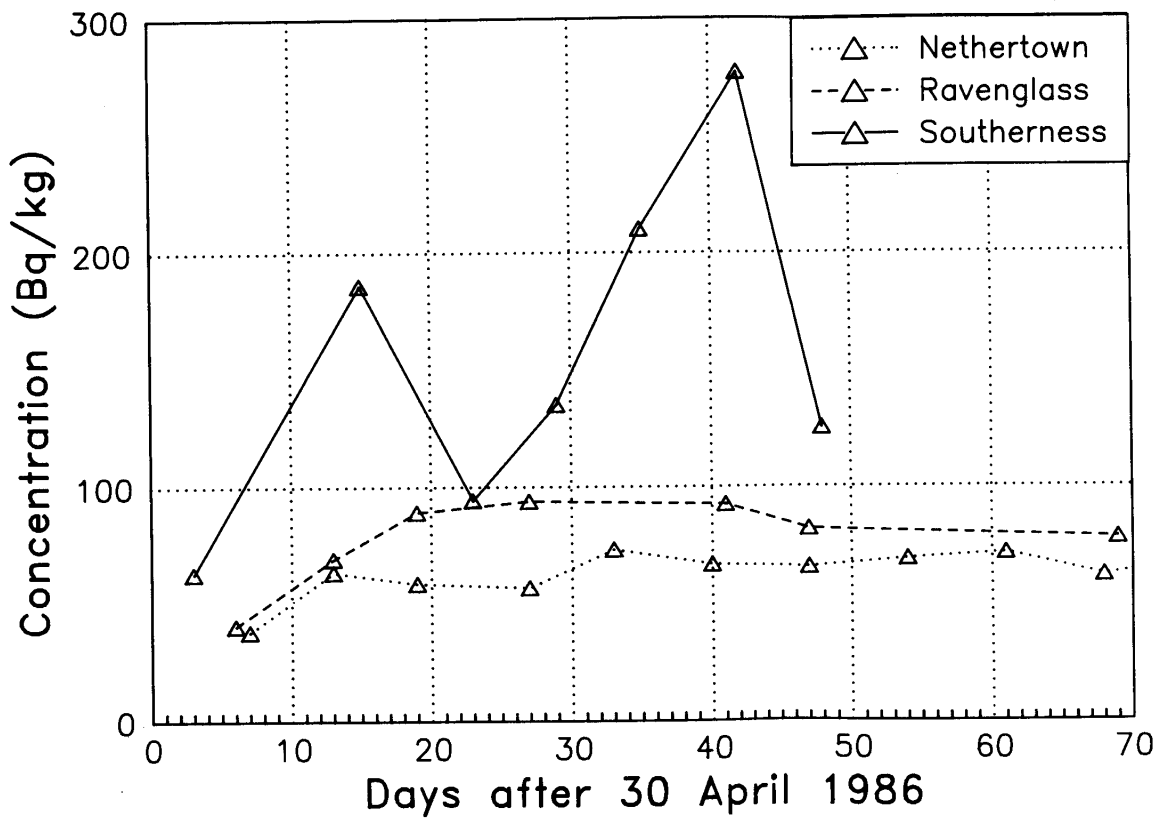


Figure 11 ^{110m}Ag in winkles

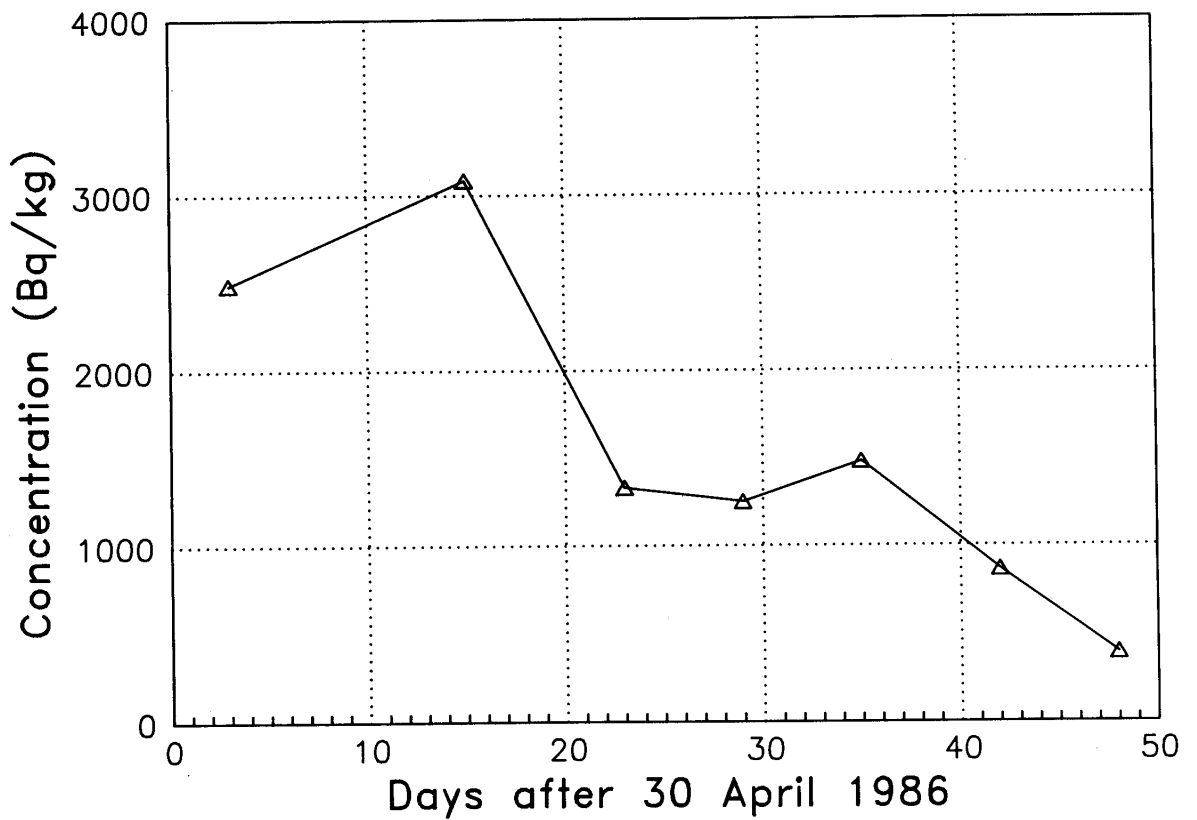


Figure 12 ^{129m}Te in winkles at Southernness

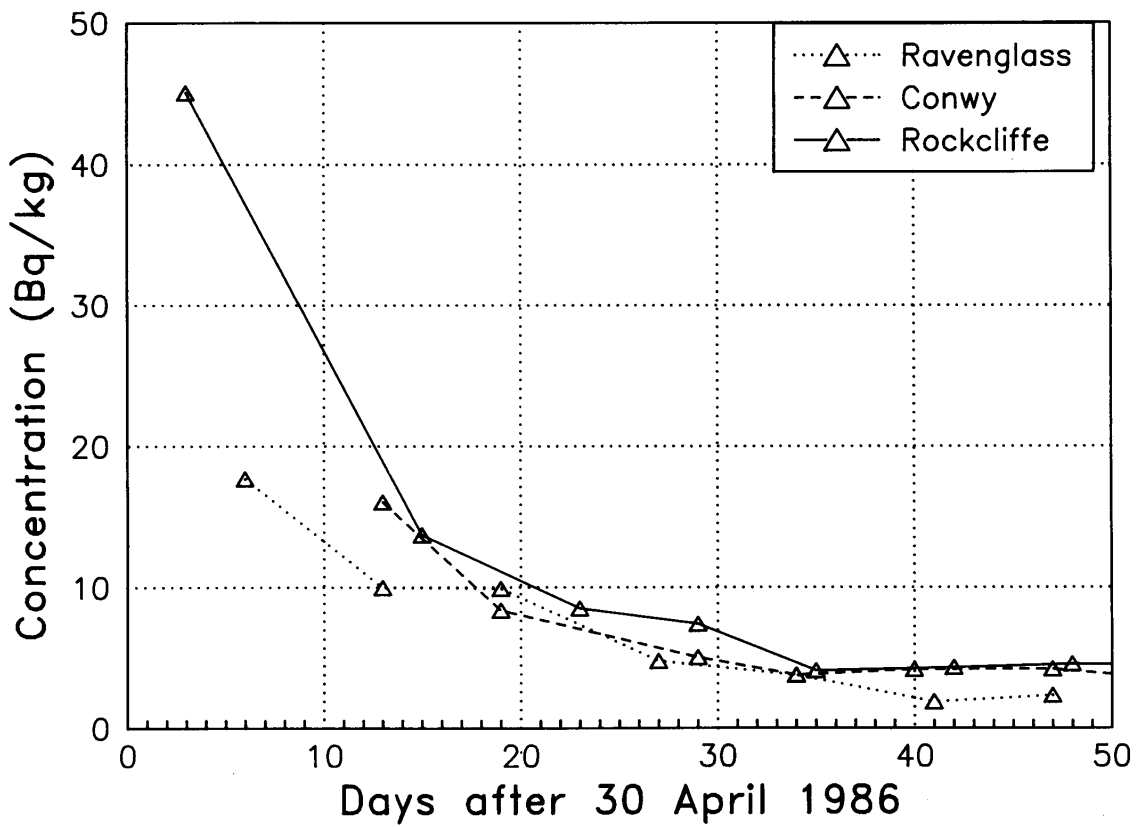


Figure 13 ^{110m}Ag in mussels

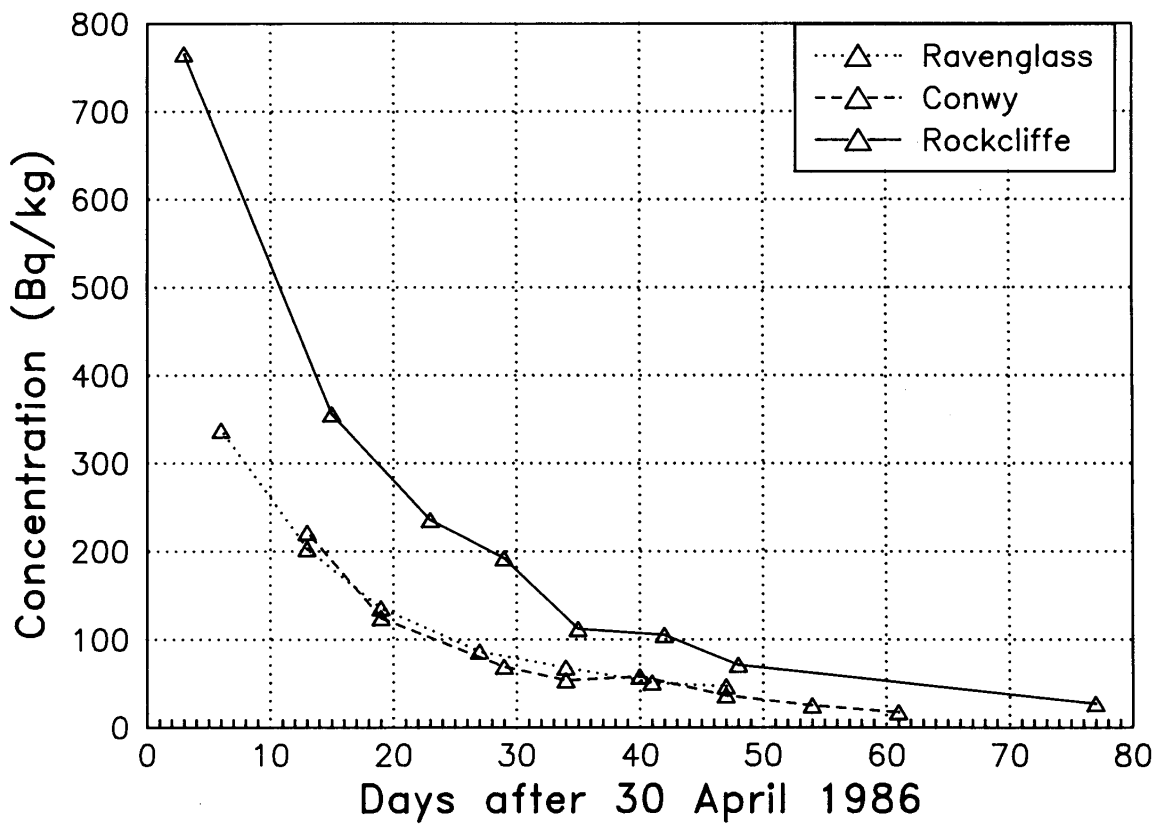


Figure 14 ^{103}Ru in mussels

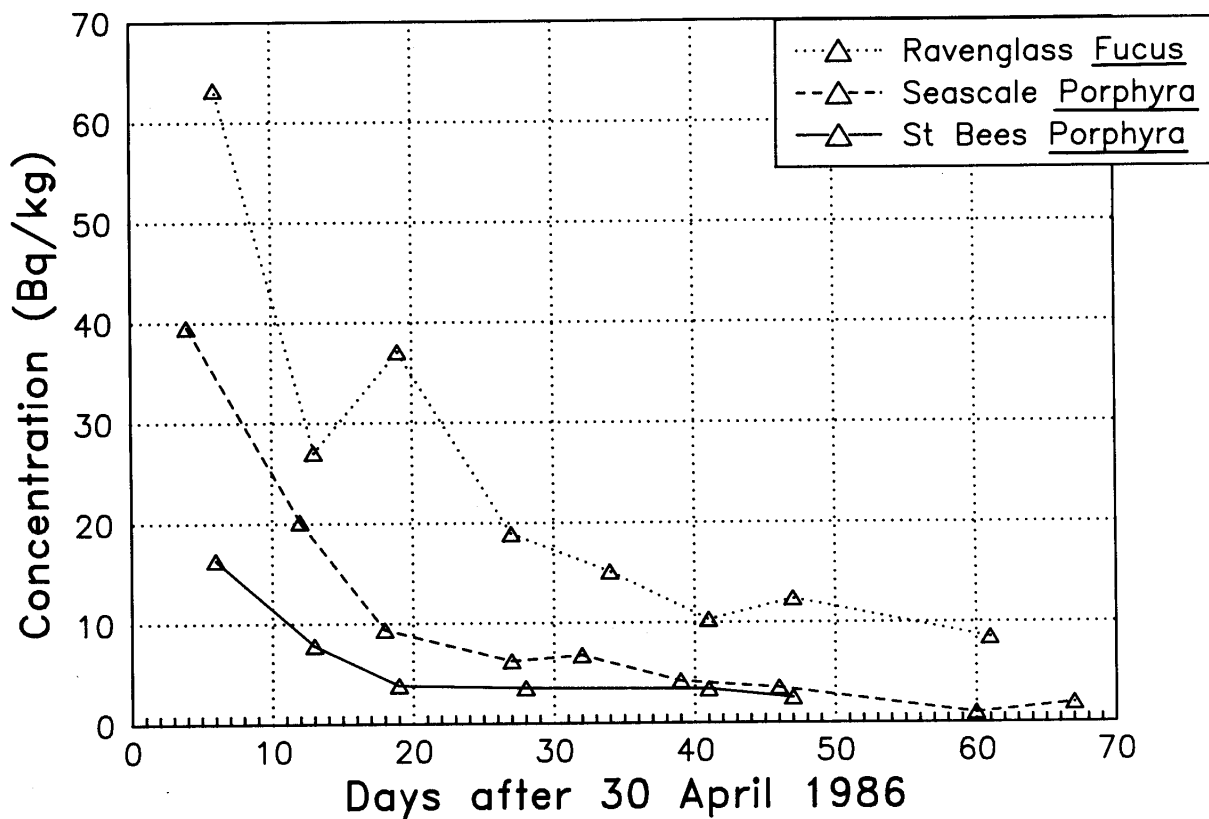


Figure 15 ^{134}Cs in seaweed

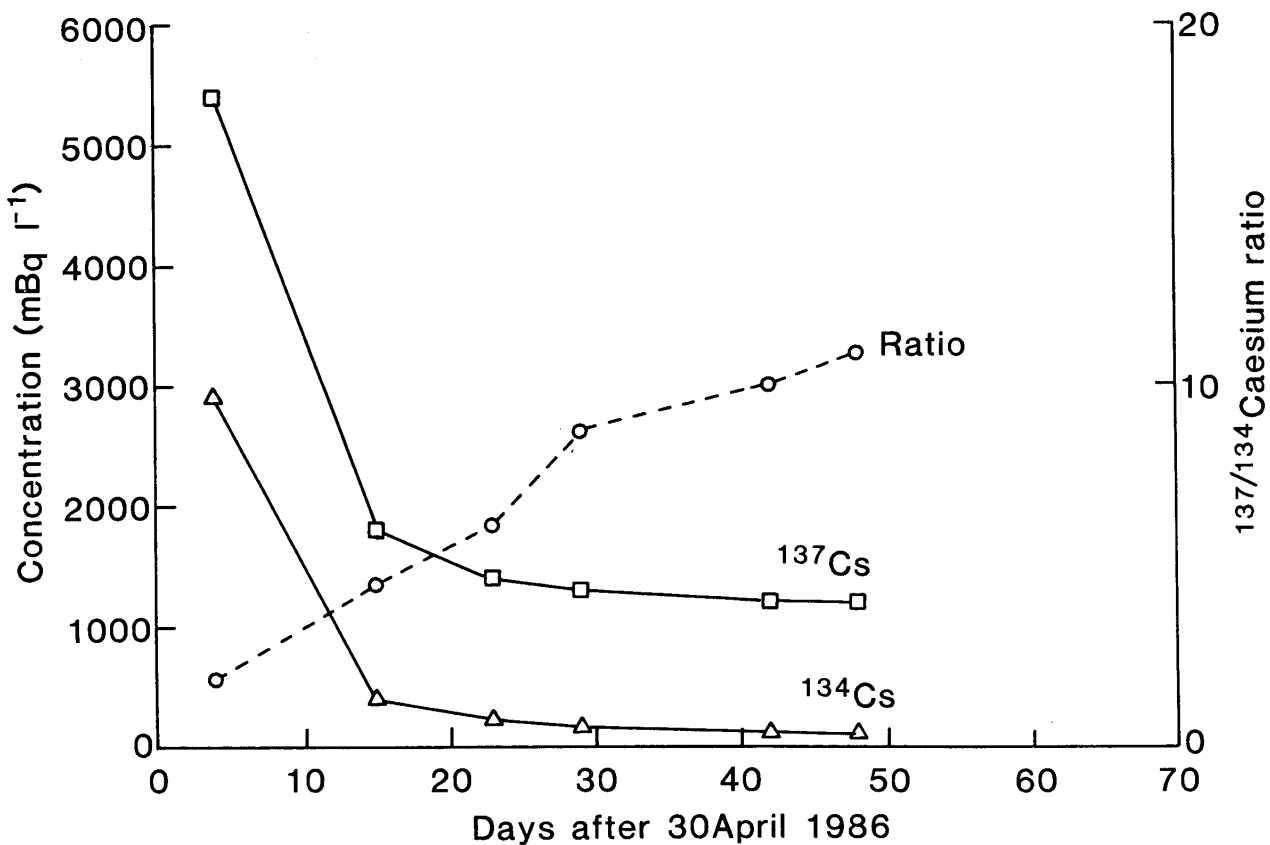


Figure 16 Radiocaesium in sea water at Southerness