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Radioactivity Monitoring of the Irish Marine Environment 1993 to 1995

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1. INTRODUCTION

This report presents the results of the marine radioactivity monitoring programme carried out by the Radiological Protection Institute of Ireland during the period 1993 to 1995. The principal objective of this programme is to assess the exposure to the Irish population arising from radioactive contamination in the Irish marine environment and to estimate the risks to human health arising from such exposure. In addition, the programme aims to assess the distribution of the significant contaminating radionuclides in the marine environment and to identify trends with a view to assessing possible future effects. The Institute is assisted in carrying out this programme by the Department of the Marine and the Marine Institute.

In recent decades, the concentrations of radioactivity in the Irish marine environment have been influenced by a number of sources of artificial radioactivity including atmospheric testing of nuclear weapons during the 1950s and 1960s, the Chernobyl nuclear accident and controlled discharges of radioactive effluent from nuclear installations. The principal source of artificial radioactivity in the Irish Sea, however, is the routine discharge of low-level liquid radioactive waste from the Sellafield nuclear fuel reprocessing plant on the Cumbrian coast of the north-west of England.

In addition to its routine monitoring activities, the Institute is actively involved in marine radioecology research aimed at providing a better understanding of the long term fate of radionuclides in the marine environment. Within the period covered by this report, the Institute collaborated with laboratories in six other European Union Member States on a project to assess the impact of non-nuclear industries on the concentrations of specific radionuclides in the marine environment. The Institute's work focused on polonium-210, which is considered to be the most radiologically significant naturally occurring radionuclide in the marine environment and which contributes a significant portion of the total radiation exposure arising from the consumption of seafood. This work, which was completed in 1995, was partially funded by the European Union.

2. SOURCES OF RADIOACTIVITY IN THE IRISH MARINE ENVIRONMENT

Discharges from Sellafield are controlled by the UK authorities by means of an authorisation issued jointly by Her Majesty's Inspectorate of Pollution (now incorporated into the Environment Agency) and the Ministry of Agriculture, Fisheries and Food. This authorisation stipulates that the best practical means be used to limit the activity of the waste discharged and that discharges do not exceed prescribed limits. The authorisation was revised in 1993 with the result that new limits were applicable in 1994 and 1995 [HMIP and MAFF, 1993]. The Sellafield marine discharge data for 1993 to 1995 and the discharge limits are presented in Table 1 [BNFL, 1994; BNFL, 1995; BNFL, 1996].

Discharges into the marine environment from the Sellafield site began in the early 1950s, reached a maximum in the mid 1970s and then declined steadily until the mid 1980s. The discharge was particularly high during the 1970s due to problems associated with wet storage of magnox fuel. The need to store fuel for longer periods at this time led to increased corrosion of the fuel rods [Manson, 1994]. Further improvements occurred in 1985 with the commissioning of the Site Ion Exchange Effluent and Salt Evaporator waste treatment plants. Since 1986, discharges of most radionuclides from the site have remained relatively constant. The discharges of the radionuclide caesium-137 between 1952 and 1994 are shown in Figure 1.

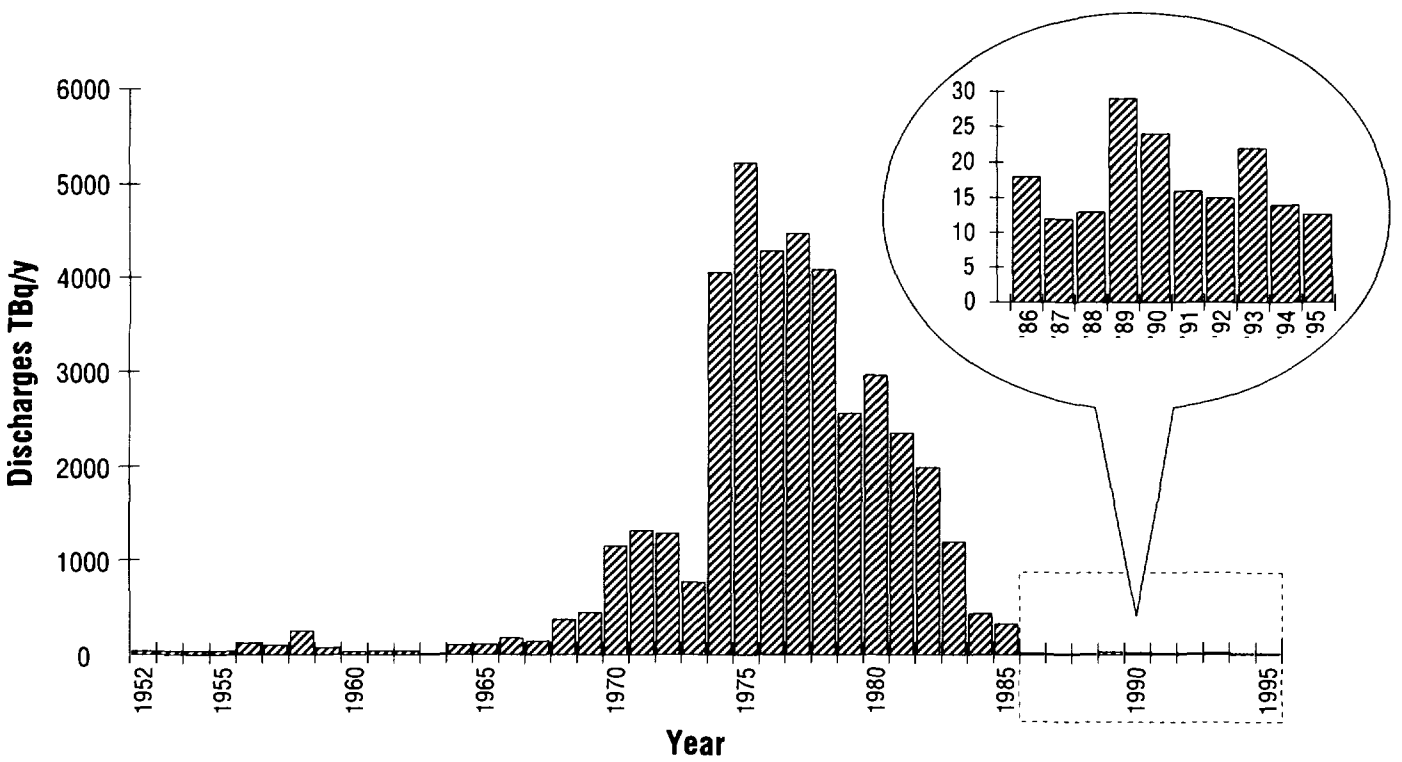

Figure 1 Marine Discharges of Caesium-137 from Sellafield, 1952 - 1995

During this reporting period, the Thermal Oxide Reprocessing Plant (THORP) and the Enhanced Actinide Removal Plant (EARP) commenced operation at the Sellafield site. Commissioning of THORP, which reprocesses oxide fuel from UK advanced gas cooled reactors and from light water reactors from Britain and abroad, commenced early in 1994. EARP, which is a waste treatment plant designed to reduce marine discharges of americium and plutonium, began operation in March 1994. As a result of these developments, the discharges of certain long lived beta emitting radionuclides, such as technetium-99 and carbon-14, have increased while the discharge of actinides has decreased.

Fallout from the atmosphere as a consequence of the testing of nuclear weapons in the 1950s and early 1960s is another source of radioactive contamination in the marine environment. These tests were largely suspended in 1963 and only intermittent tests have been carried out since then. Long lived fallout radionuclides such as tritium, carbon-14, strontium-90, caesium-137 and plutonium-239 continue to contribute to the inventory of artificial radioactivity in the Irish marine environment.

The discharge to the sewage system from some Irish hospitals of radionuclides used for medical purposes gives rise to traces of radioactive contamination in coastal waters in the vicinity of the outlet pipes. These tend to be radionuclides of short half-lives, such as iodine-131 and technetium-99m, with half-lives of 8 days and 6 hours, respectively. In a survey of radioactive waste disposal, O'Donovan *et al.* [1988] estimated that approximately 0.17 TBq of iodine-131 and 6.12 TBq of technetium-99m were discharged during 1987. The amounts discharged in subsequent years are expected to have been similar, as medical practices have not altered significantly in the interim.

In addition to artificial radioactivity, many naturally occurring radionuclides are also present in the marine environment [Walker and Rose, 1990]. These radionuclides include lead-210, polonium-210, radium-226, isotopes of uranium, carbon-14 and potassium-40. Of these polonium-210, because of the degree to which it is concentrated by certain species of fish and shellfish and of its relatively high radiotoxicity, is known to make the most significant contribution to radiation exposure through the consumption of marine foodstuffs [UNSCEAR, 1988, Pentreath and Allington, 1988; IAEA, 1995].

The concentration of polonium-210 in the environment may be locally enhanced by the discharge of radium-rich phosphogypsum which is a byproduct of certain industrial processes. In the Republic of Ireland phosphogypsum was discharged into the sea from phosphate fertiliser plants up until the early 1980s and in Northern Ireland until 1989 [O'Grady, 1992]. During the period covered by this report, the Institute completed a research project which aimed to identify local enhancement of this radionuclide around industrial sites where, formerly, phosphogypsum had been discharged into the sea. Additionally, the project aimed to estimate the dose from this radionuclide to Irish seafood consumers.

Potassium-40, although present in relatively large concentrations in the marine environment, is controlled by homeostatic processes in the human body and so its concentration in the body is normally independent of the amount consumed. Therefore, whilst the concentrations of potassium-40 in fish and shellfish are considerably higher than those of many other natural radionuclides, its presence in seafood does not result in an increased radiological hazard.

3. METHODS OF SAMPLING AND ANALYSIS

Sampling

Seawater, sediments, and seaweed were sampled from a number of coastal sites while fish and shellfish were sampled from commercial landings at major fishing ports. The range of sample types collected and the sampling frequency for each site are presented in Table 2. The locations of all coastal sites and fishing ports at which samples are collected are shown in Figure 2. The frequency of sampling at each coastal site for each sample type reflects the resolution judged to be necessary to assess the population dose and to identify important trends. Seawater and sediment samples were taken annually at a number of off-shore sites in the western Irish Sea using the Marine Institute's research vessel the Lough Beltra. Off-shore locations are shown in Figure 3 and their coordinates are listed in Table 3.

The fish species routinely monitored were whiting (*Merlangius merlangus*), cod (*Gadus morhua*), plaice (*Pleuronectus platessa*), herring (*Clupea harengus*), mackerel (*Scomber scombrus*), and ray (*Raja sp.*). These constitute the major proportion of the fish landings and are the more common

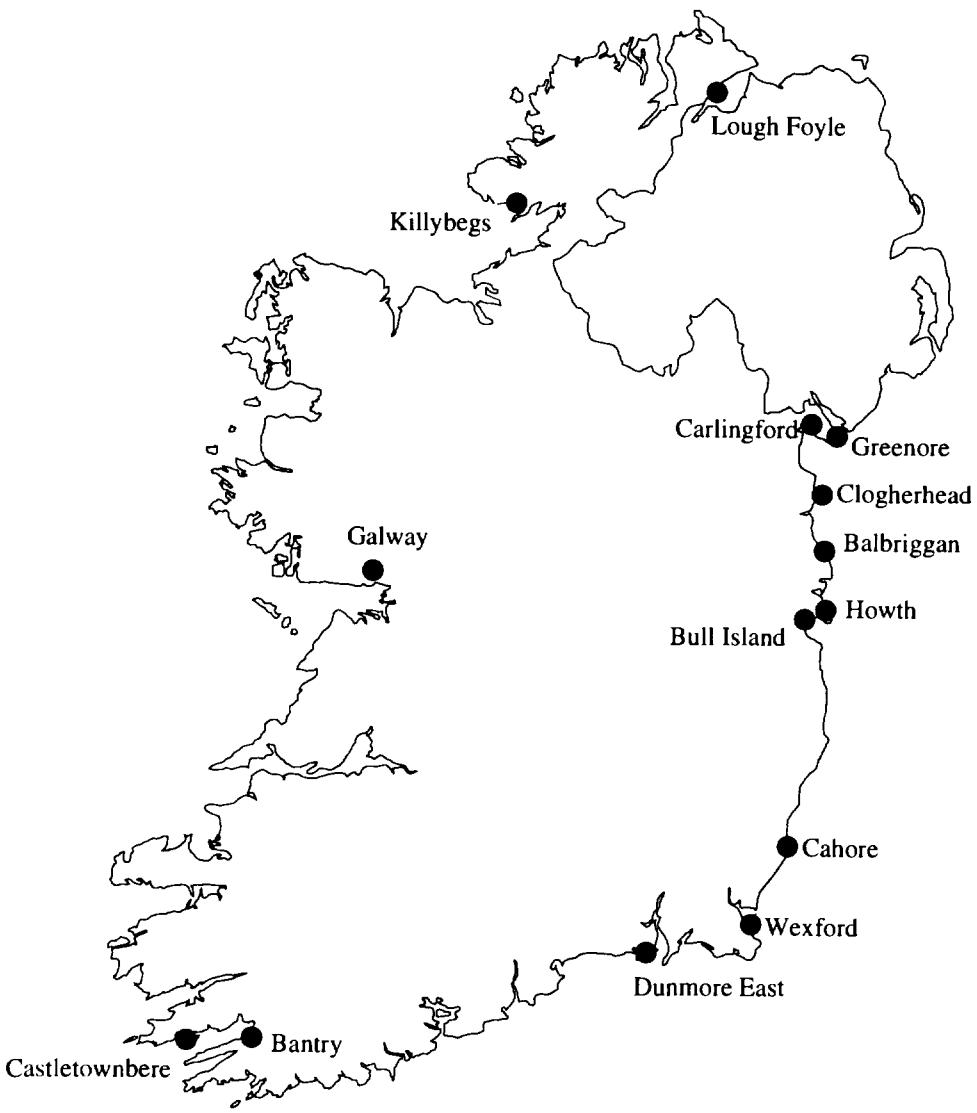

Figure 2 *Coastal Sampling Locations*

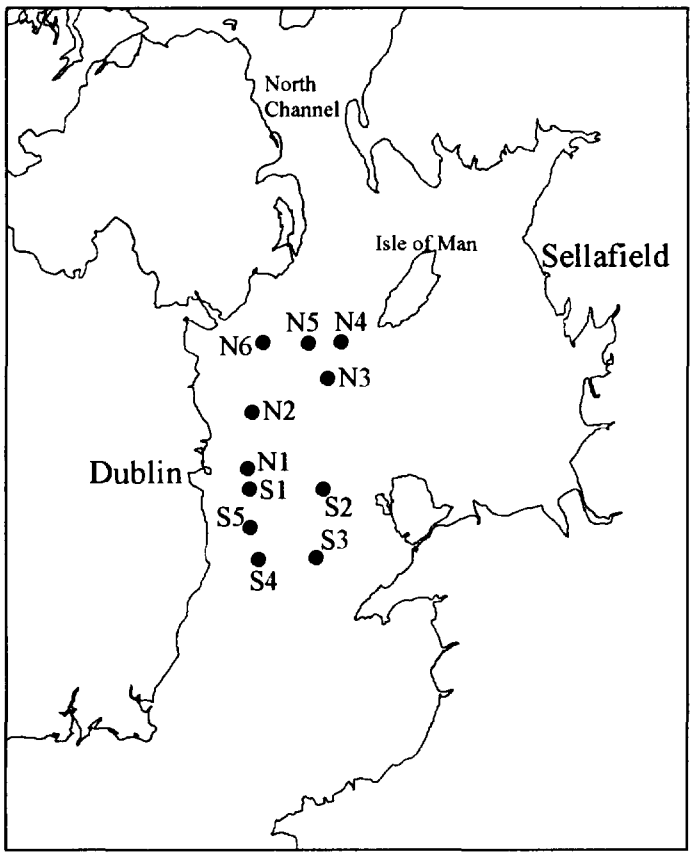

Figure 3 *Sampling Stations in the Western Irish Sea*

species consumed by members of the Irish public. The shellfish species routinely monitored were prawns (*nephrops*), mussels (*Mytilus edulis*) and oysters (*Ostrea edulis*).

Coastal sampling along the south and west coasts was carried out by the Department of the Marine regional fisheries officers. All other sampling was carried out by Institute staff.

Within the framework of the radioecology research project previously referred to, the variation in polonium-210 concentrations around the Irish coastline was studied using the common mussel, *Mytilus edulis*, as a bio-indicator. Mussels were sampled at a number of locations around the Irish coastline. The project focused on the phosphate fertiliser plants at Cork and Belfast Lough where formerly phosphogypsum waste was discharged into the sea. Sampling of mussels in Northern Ireland was carried out with the assistance of the Environment Service of the Department of the Environment for Northern Ireland.

Analysis

Fish and shellfish samples were first cleaned and the edible portion separated. All radionuclide determinations on fish and shellfish were made on the edible portion only. Seaweed samples were first washed to remove all sediment and other extraneous material. Fish, shellfish, seaweed and sediment samples were then dried to constant weight and homogenised prior to all radionuclide

determinations. Seawater samples were first filtered using a 0.45 micron membrane filter and radiocaesium and technetium-99 activity concentrations in the filtrate determined.

The activity concentrations of gamma emitting radionuclides in fish, shellfish, seaweed and sediments were determined by high resolution gamma spectroscopy using high purity germanium detectors. Two-sigma uncertainties on gamma spectroscopy measurements under typical counting conditions were ± 15% or better.

Radiocaesium concentrations in seawater were determined in accordance with the method described by Baker [1975]. Filtered seawater was passed through an ion-exchange resin which is then measured by high resolution gamma spectroscopy. Two-sigma uncertainties on seawater measurements under typical counting conditions were ± 20% or better.

Plutonium and americium activity concentrations were determined for composite fish and shellfish samples. Composites were prepared on a yearly basis for selected combinations of species and landing port. Plutonium and americium were chemically separated from the composite samples and measured by alpha spectroscopy using silicon surface barrier detectors.

In tables of results non detection of a particular radionuclide is indicated by ND. Approximate detection limits under typical analytical conditions are 1.0 Bq/kg for iodine-131, 0.3 Bq/kg for caesium-134 and caesium-137, 1.0 mBq/kg for plutonium-238 and plutonium-239,240 and 2.0 mBq/kg for americium-241.

Technetium-99 activity concentrations in seaweed and water were determined in accordance with the method described by Harvey *et al.* [1991]. Following chemical separation, the technetium-99 activity concentration was measured using a gas flow proportional counter. Two-sigma uncertainties on technetium-99 measurements under typical counting conditions were ± 10% or less.

Polonium-210 activity concentrations were determined using a variation of the method described by Flynn [1968]. Polonium-210 was separated from the samples using chemical techniques and measured by alpha spectroscopy using silicon surface barrier detectors.

All fish and shellfish results are quoted as activity concentrations, Bq/kg, based on the wet weight of the sample. Activity concentrations for seaweed are variously reported in the literature on either a wet or a dry weight basis. For this reason, both values are presented for seaweeds in this report. Activity concentrations for sediments are based on the dry weight of the sample. All results quoted are decay corrected to the date of sampling.

The Institute's environmental laboratory implements a comprehensive quality assurance system. All measurements are made by reference to certified radioactive sources traceable to international standards. All analytical techniques conform to current best international practice and are normally validated for each matrix both through participation in intercomparison exercises and by analysis of certified reference materials.

4. RADIOACTIVITY CONCENTRATIONS

Seawater

Radioactivity measurements in seawater samples are listed in Tables 4, 5 and 6 for the years 1993 to 1995. The annual mean caesium-137 activity concentrations in filtered coastal seawater at Greenore, the most northerly location sampled along the Irish Sea coastline, were 80 mBq/l in 1993, 59 mBq/l in 1994 and 48 mBq/l in 1995. At Cahore, on the south east coast, the measured activity concentrations were 36 mBq/l, 14 mBq/l and 16 mBq/l for each of the three years. Measured activity concentrations in all samples from west coast sampling stations were 6 mBq/l or less.

The results for 1993 to 1995 demonstrate that the slow but steady decline in radiocaesium concentrations in seawater in the Irish Sea, which has been observed since the mid to late eighties, continued during this period [McGarry *et al.*, 1994; O'Grady *et al.*, 1991; O'Grady and Currivan, 1990; Cunningham *et al.*, 1988]. This steady decline in activity concentrations in the Irish Sea is illustrated in Figure 4 which shows coastal caesium-137 activity concentrations at Balbriggan on the north east coast for the period 1988 to 1995. The results illustrate the decrease in concentrations with increasing distance from Sellafield. On the west coast the activity concentrations were essentially unchanged with respect to previous periods.

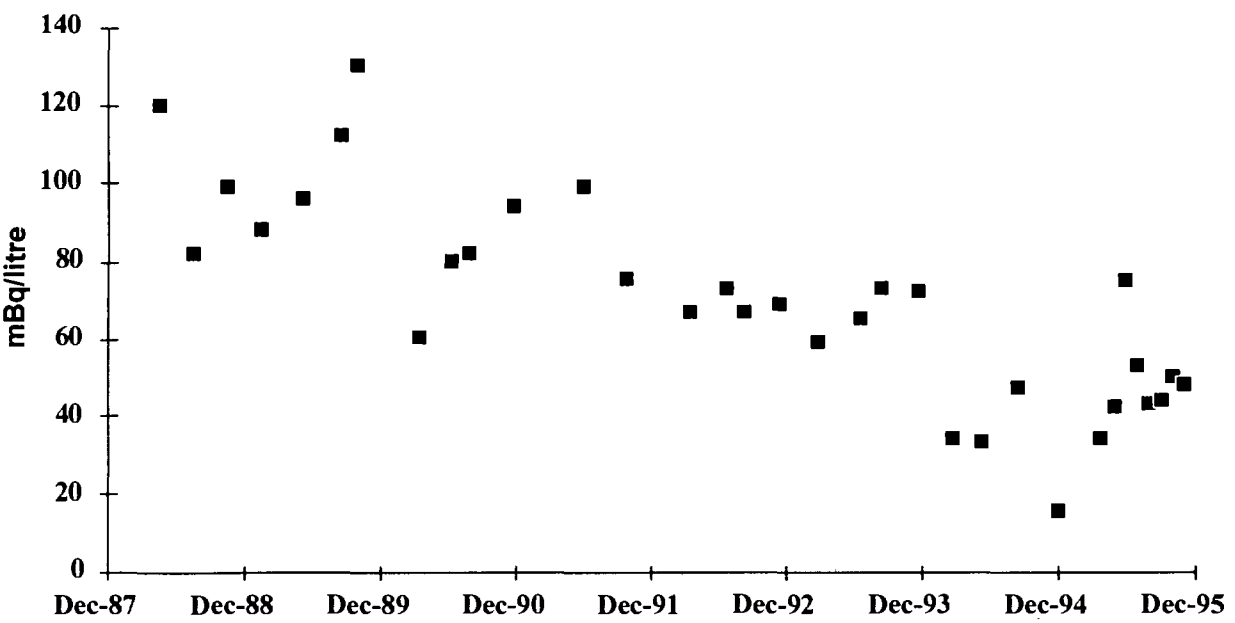

Figure 4 *Caesium-137 in Seawater at Balbriggan, 1988 - 1995*

During the reporting period the activity concentrations of caesium-137 in off-shore samples from the western Irish Sea ranged from a high of 73 mBq/l at station N1 during 1993 to 15 mBq/l at station S3 during 1995. No caesium-134 was detected in any of the coastal or off-shore samples measured.

As was discussed in section 2 of this report, it was anticipated that, due to the operation of new plant at the Sellafield site, the discharge of certain long lived beta emitting radionuclides would

increase during this reporting period. In particular, it was anticipated that, when the backlog of liquid wastes stored on site were processed through EARP, a significant increase in the discharge of the radionuclide technetium-99 would result. For this reason technetium-99 activity concentrations in seawater were measured at selected sites from 1995 (Table 6). The mean activity concentration for this radionuclide in seawater at Balbriggan during 1995 was 21 mBq/l. In off-shore samples the range observed for northerly sampling stations was 18 to 35 mBq/l.

Sediments

Radioactivity measurements on sediment are summarised in Tables 7 and 8 for intertidal and off-shore samples respectively. The results for 1993 to 1995 were broadly similar to those obtained at the same locations during the 1991-1992 reporting period. Caesium-134 was not detected in any of the coastal or off-shore samples measured.

The geographic pattern of caesium-137 in sediments was similar to that of caesium-137 in seawater. The highest levels were found in the north east, the lowest on the west coast and a steady decrease observed moving southwards along the east coast. With sediments, however, this pattern is complicated as the partitioning of radionuclides between the solid and solution phases can vary considerably with both water and sediment characteristics. Sediment grain size and composition and seawater characteristics, such as salinity and acidity, can affect this partitioning. A clear difference can be seen, for example, between the adjacent Carlingford and Greenore sampling sites where the mean caesium-137 activity concentrations over the reporting period were 41 and 12 Bq/kg (dry) respectively. The higher value at Carlingford is likely to reflect the finer sediment size within the estuary.

An area of mud and silt accumulation in the Irish Sea, where higher adsorption of radioactivity would be expected due to the fine particle size, extends south west of the Isle of Man towards Dundalk Bay. This would account for the significantly higher caesium-137 activity concentrations detected in the sediments in this area when compared with coastal sediments. The mean activity concentrations at the four stations in this area (N3, N4, N5 and N6) for the period 1993 to 1995 were 83, 69, 112 and 76 Bq/kg respectively, while in contrast the mean values for the two stations just north of Dublin (N1 and N2) were 11 and 20 Bq/kg respectively. Mean activity concentrations for all stations south of Dublin were less than 10 Bq/kg. The highest mean caesium-137 activity concentration south of Dublin was recorded for station S5. This station, which is located to the north of Wicklow Head, was identified in previous reports as having caesium activity concentrations in sediment higher than those found at neighbouring sites. This anomaly can be attributed to the sediment being of a finer grained texture. The activity concentrations at all off-shore stations were broadly similar to those for the previous reporting period.

Seaweed

Marine algae are known to accumulate radionuclides to activity concentrations considerably in excess of those in the surrounding seawater. Consequently seaweed is often a useful bioindicator for the distributions and trends of radionuclides in the marine environment. The seaweed sampled was *Fucus vesiculosus* which has been shown [McAulay and Pollard, 1987; Mitchell *et*

al., 1987] to be a good indicator of contaminating radionuclides. Radioactivity measurements in *Fucus vesiculosus* samples are presented in Tables 9 to 11 for the years 1993 to 1995 respectively.

The annual mean caesium-137 activity concentrations at Greenore were 15.4, 8.5 and 7.4 Bq/kg (dry weight) for each of the three years. As for seawater and sediment, caesium-137 activity concentrations were observed to decrease southwards along the east coast. During 1995 an activity concentration of 2.1 Bq/kg (dry weight) was measured at Cahore, the most southerly point sampled on the east coast, while on the west coast concentrations were typically 1 Bq/kg (dry weight). Mitchell *et al.* [1987] reported a value of 1 Bq/kg (dry weight) for the caesium-137 in *Fucus vesiculosus* due to nuclear weapons-test fallout at these latitudes. The measured caesium-137 activity concentrations in *Fucus vesiculosus* along the west coast are, therefore, indistinguishable from weapons-test fallout. The geographical variation in caesium-137 activity concentrations in *Fucus vesiculosus* is illustrated in Figure 5 in which the measured range is shown for each sampling point for the period 1993 to 1995.

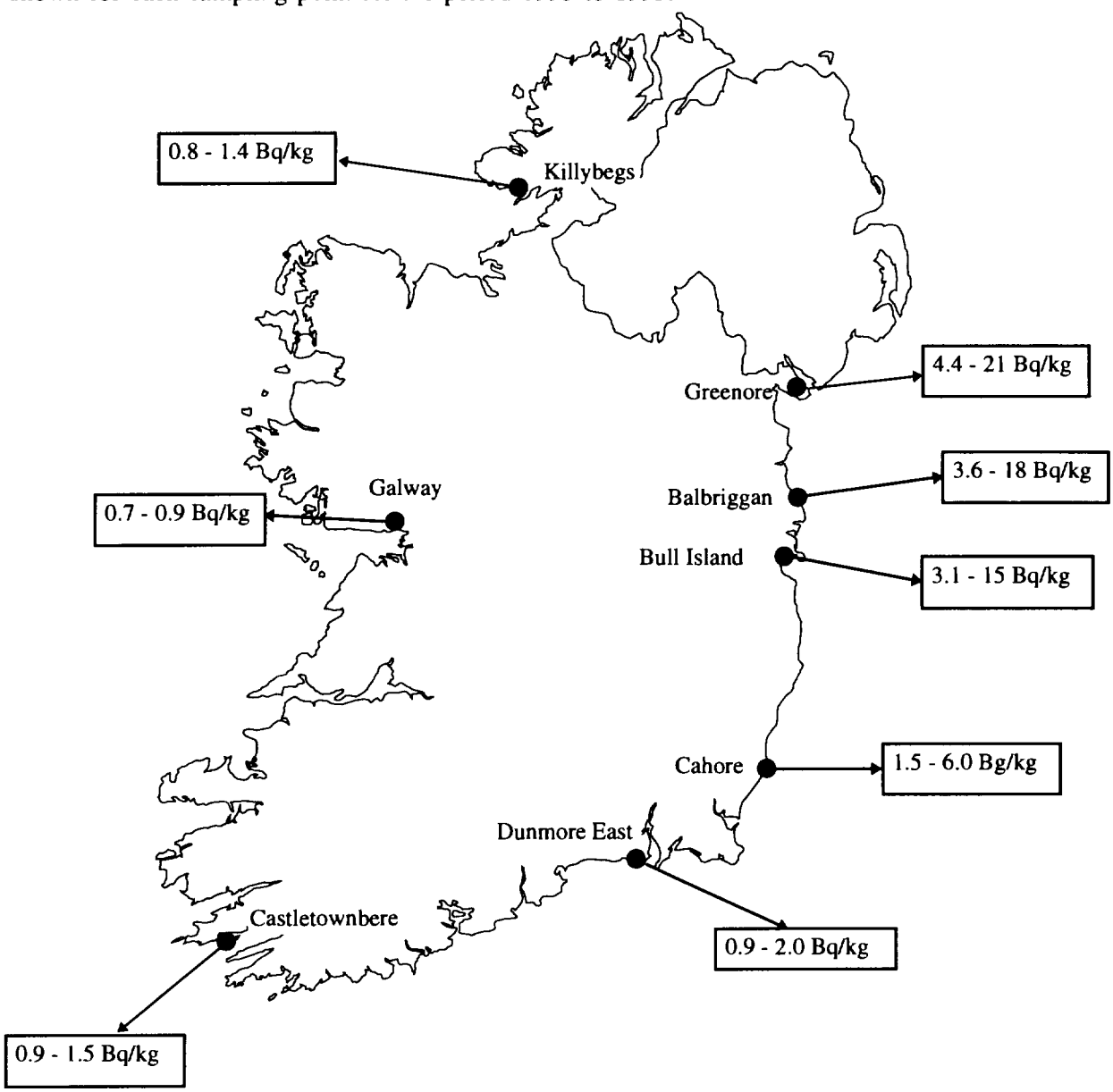

Figure 5 *Caesium-137 in Fucus vesiculosus, 1993- 1995*

The caesium-137 activity concentrations observed during the 1993 to 1995 period demonstrate a continuation of the downward trend which has been observed in the Irish Sea since the mid 1980s. No significant change was observed in west coast concentrations as compared to the previous reporting period. Caesium-134 was not detected in any of the *Fucus vesiculosus* samples measured during this reporting period. The annual mean caesium-137 activity concentrations in *Fucus vesiculosus* from Greenore and Balbriggan are shown in Figure 6 for the period, 1982 to 1995.

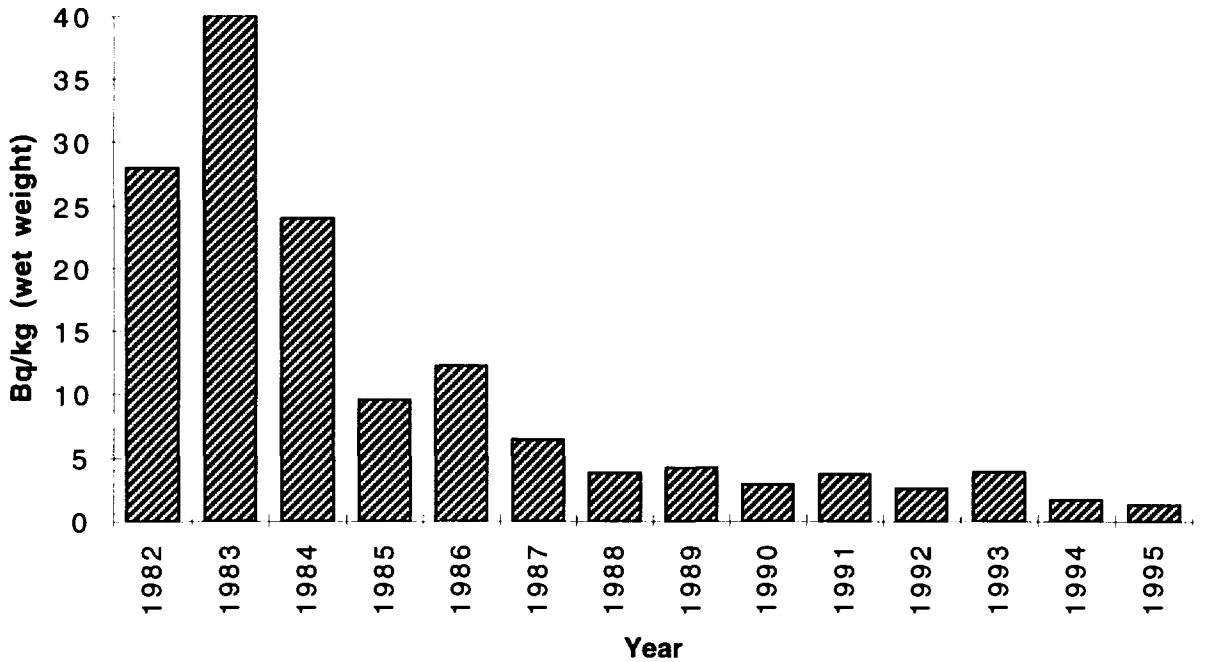

Figure 6 *Mean Caesium-137 in Fucus vesiculosus from North East Sampling Locations (Balbriggan and Greenore), 1982 - 1995*

Iodine-131 is discharged to sewage systems as a result of its use in medicine. A mean activity concentration for this radionuclide of 15 Bq/kg (wet weight) was measured in samples of *Fucus vesiculosus* from Bull Island during this reporting period with individual measurements ranging from <1 to 61 Bq/kg (wet weight). Variations of this nature would be expected due to the intermittent use of the radionuclide and the dilution of the radioactivity following discharge. These results are broadly similar to those reported for the period 1991 to 1992 [McGarry *et al.*, 1994].

As discussed earlier it was anticipated that the discharge of technetium-99 from Sellafield would increase significantly during 1994 and so from 1993 this radionuclide was measured in selected *Fucus vesiculosus* samples. Samples were selected for technetium-99 determination to establish the geographic variation around the coast line and to obtain time series measurements at a limited number of points commencing prior to the increase in discharges. EARP began active commissioning in March 1994 [BNFL, 1995] and, as can be seen from Table 1, discharges of this radionuclide increased during 1994 by a factor of approximately 10 as compared to the 1993 figure.

Technetium-99 activity concentrations in *Fucus vesiculosus* are given in Tables 9-11 and shown in Figure 7 for the period April 1993 to December 1995. Up to May 1994, the technetium-99 activity concentrations in *Fucus vesiculosus* at Balbriggan ranged from 317 Bq/kg to 553 Bq/kg (dry weight). During the latter part of 1994 this activity concentration increased to a range of 1030 Bq/kg to 1068 Bq/kg (dry weight). A further increase to a range of 1539 Bq/kg to 2530 Bq/kg was observed in 1995. It is likely that these increases corresponded to the commencement of operations involving EARP at Sellafield in March 1994. The results for 1994 show that the geographic distribution for technetium-99 in the Irish Sea is similar to that for caesium-137, i.e. a decrease in activity concentration with increasing distance from the point of discharge at Sellafield.

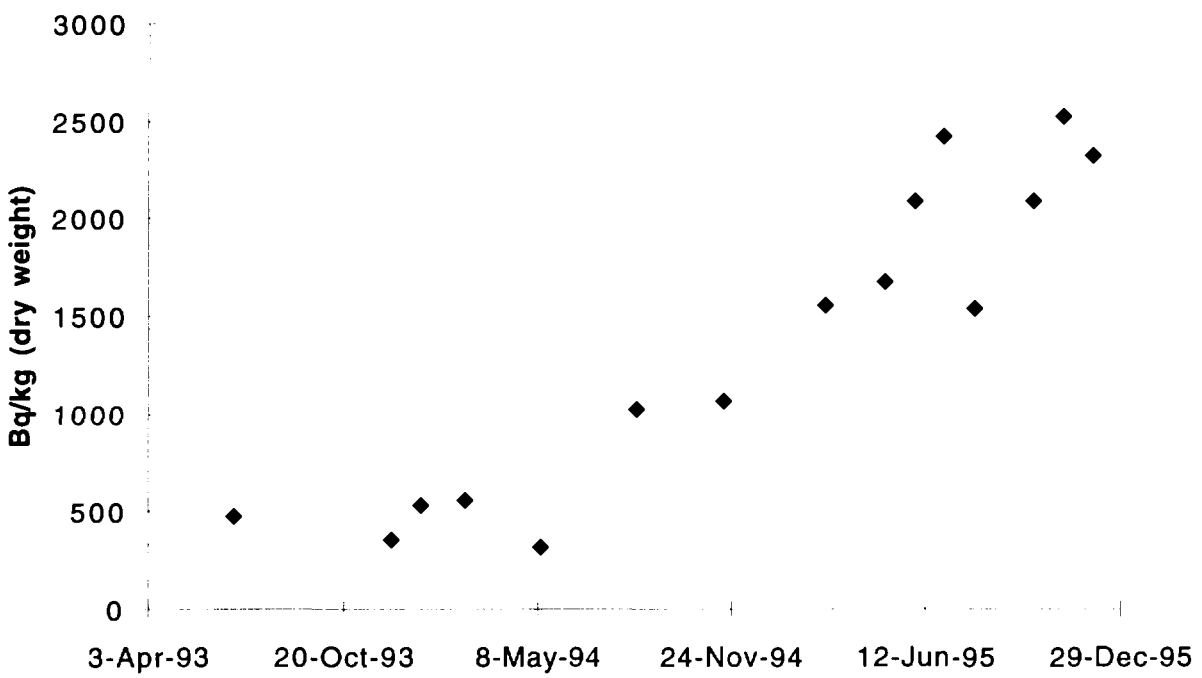

Figure 7 *Technetium-99 in Fucus vesiculosus at Balbriggan, 1993 - 1995*

Fish and Shellfish

Radioactivity measurements on whiting, cod, plaice, ray, herring, mackerel, prawns, mussels and oysters are presented in Tables 12 to 20. In addition, actinide measurements on samples collected during 1992 are presented in Table 21 as these data were not included in the 1991 to 1992 report [McGarry *et al.*, 1994].

The mean caesium-137 activity concentrations measured in whiting from Howth were 4.7, 3.8 and 1.7 Bq/kg (wet weight) for each of the three years respectively. The highest measured radiocaesium concentration in fish was 14.7 Bq/kg (wet weight) which was for a sample of cod from Howth in 1993 (Table 13). In shellfish the highest caesium-137 activity concentrations were found in prawns landed at Howth where the annual measured mean activity concentrations were 2.7, 1.8 and 1.3 Bq/kg (wet weight) for the three years respectively (Table 18). In general the radiocaesium concentrations measured in shellfish were lower than those measured in fish, reflecting differences in the concentration factors. Caesium-134 was not detected in any of the fish or shellfish samples measured.

The caesium-137 activity concentrations observed during the 1993 to 1995 period demonstrate a continuation of the downward trend which has been observed in the Irish Sea since the mid 1980s and which is reflected in all other compartments monitored. This trend can be seen from Table 22 in which the mean of individual radiocaesium measurements in fish and prawns from north east ports are given for the period 1979 to 1995.

A value of 0.3 Bq/kg (wet weight) for caesium-137 in cod has been reported as being typical of that due to weapons-test fallout [Camplin, 1995]. Caesium-137 activity concentrations in the fish landed along the south and west coasts are, therefore, only marginally greater than weapons-test fallout.

Plutonium-238, plutonium-239,240 and americium-241 were measured in selected composite fish and shellfish samples. For all fish samples the activity concentrations were less than 3 mBq/kg (wet weight) of plutonium-238 and 15 mBq/kg (wet weight) of plutonium-239,240. The ranges of activity concentrations measured in prawns, mussels and oysters were from less than 1 to 23 mBq/kg (wet weight) for plutonium-238, 0.6 to 125 mBq/kg (wet weight) for plutonium-239,240 and from less than 5 to 103 mBq/kg (wet weight) for americium-241. In general, the activity concentrations of transuranic elements in fish and prawns were similar to those reported for the 1991 to 1992 period [McGarry *et al.*, 1994].

Polonium-210 was measured in mussels sampled at 10 locations around Ireland and in a selection of fish samples taken from landings at Howth, Galway, Dunmore East and Killybegs. These measurements are summarised in Table 23 and the geographic variation in polonium-210 activity concentration observed in mussels is illustrated in Figure 8. Polonium-210 activity concentrations in mussels were found to range from 10 Bq/kg (wet weight) at Seapark near Belfast to 59 Bq/kg (wet weight) at Sutton near Dublin. Similar variations have been reported elsewhere [Rollo *et al.*, 1992]. The mean activity concentration of all samples for the sampling period was 25.5 Bq/kg (wet weight). No direct link was established between local concentrations of this radionuclide and the former discharges of phosphogypsum from fertiliser plants near Cork and Belfast.

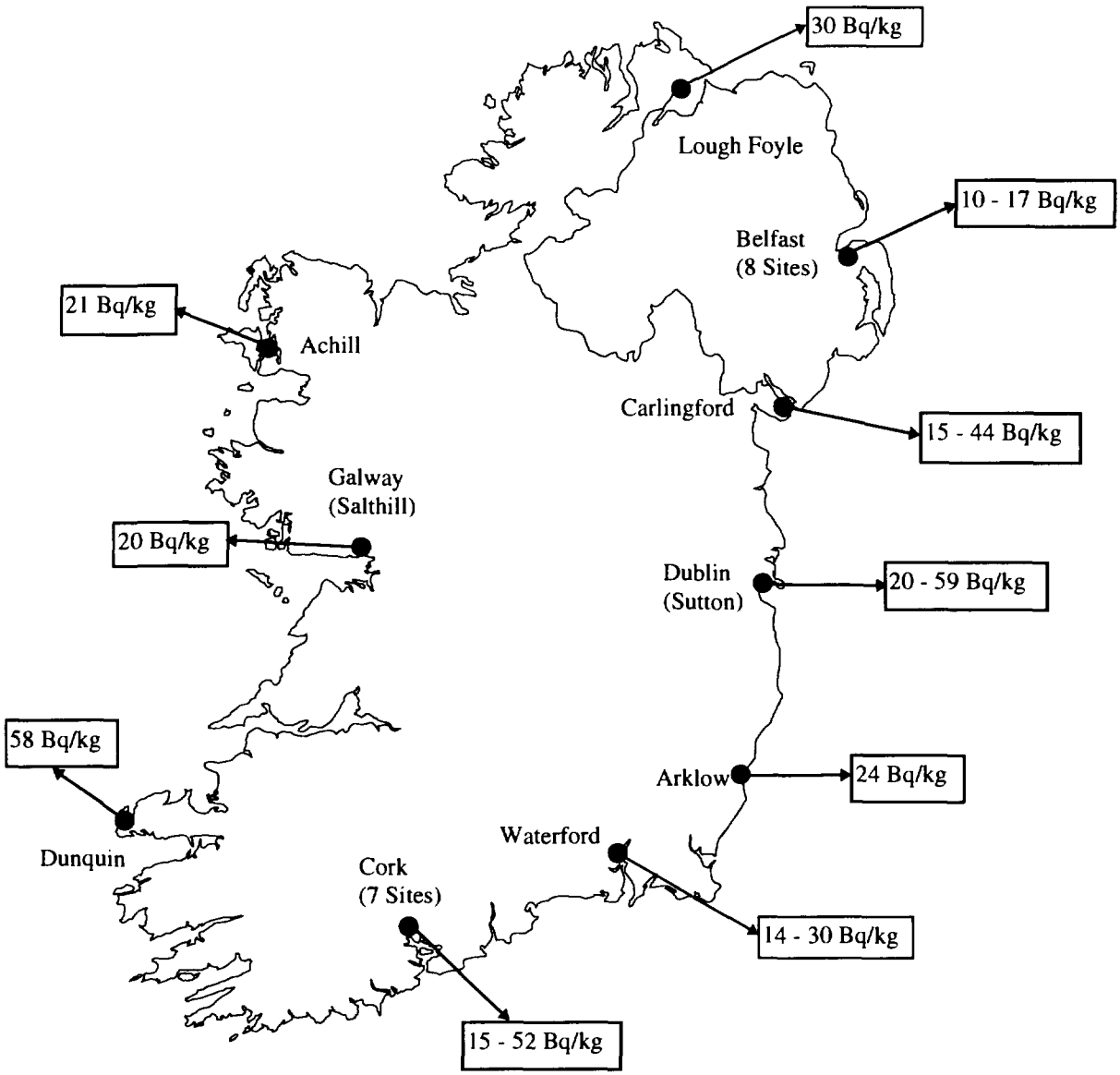

Figure 8 *Polonium-210 in Mussels (Bq/kg, wet weight), 1993-1995*

5. ASSESSMENT OF RADIATION EXPOSURE

The Ingestion Pathway

Committed Effective Dose

The committed effective dose due to the consumption of seafood was estimated in accordance with ICRP 60 [ICRP, 1991]. Annual doses for individual radionuclides were calculated by applying the appropriate dose per unit intake coefficient to the ingested activity. The intake was estimated by multiplying the assumed annual consumption rate by the mean activity concentration in samples from commercial landings. For artificial radionuclides the ingestion dose coefficients used are taken from Phipps *et al.* [1991] using the NRPB recommended gut transfer factors. The consumption rates used were considered to be representative of the quantities eaten daily by typical and heavy consumers of seafood and are 40 g of fish and 5 g of shellfish for a typical consumer and 200 g of fish and 20 g of shellfish for a heavy consumer.

The committed effective doses received through the consumption of fish and prawns landed at north-east ports are given in Table 24 for typical and heavy consumers. The doses estimated for each of the three years, 1993-1995, were 0.67 μSv, 0.51 μSv and 0.41 μSv to a typical consumer and 3.3 μSv, 2.5 μSv and 2.0 μSv to a heavy consumer. The corresponding doses for 1991 and 1992 were 1.1 μSv and 0.7 μSv to a typical consumer and 5.2 μSv and 3.6 μSv to a heavy consumer, respectively [McGarry *et al.*, 1994]. These doses are due to the radionuclides caesium-137, plutonium (alpha) and americum-241. The dose of 0.51 μSv to a typical consumer in 1994, for example, consisted of 0.47 μSv due to caesium-137 and 0.04 μSv to the plutonium (alpha) and americium-241 radionuclides.

The committed effective dose due to technetium-99 received through the ingestion of fish and shellfish was estimated for 1995 on the basis of the mean off-shore activity concentration in seawater and published concentration factors for marine fish and crustaceans. Using concentration factors of 10 and 100 [Coughtrey *et al.*, 1983], derived activity concentrations of 0.3 and 3.0 Bq/kg were obtained for fish and shellfish respectively. The estimated dose for 1995 was 0.007 μSv for a typical consumer and 0.03 μSv for a heavy consumer.

These ingestion doses can be compared with the annual dose limit for members of the public of 1000 μSv from practices involving controllable sources of radiation [ICRP, 1991]. During this reporting period, therefore, typical and heavy consumers would have received about 0.05% and 0.2% of this limit respectively.

The calculated doses can also be compared with the annual average dose of approximately 3000 μSv from all sources of radiation received by members of the Irish public. Of this 3000 μSv about 90% is due to naturally occurring radiation and the remainder is mainly due to medical uses of radiation. It can be seen, therefore, that the doses arising from the consumption of fish and shellfish, even by heavy consumers, are a very small fraction of the dose received from other sources.

The annual caesium-137 discharges from Sellafield and the estimated committed effective dose to typical consumers due to this radionuclide received through the ingestion pathway are shown in Figure 9 for the period 1983 to 1994. The correspondence between the patterns of discharge and dose can be clearly seen.

Calculation of the committed effective dose due to polonium-210 received through the ingestion

of fish and prawns was based on activity concentrations of 6.9 Bq/kg in prawns and 1.42 Bq/kg in fish (Table 23). The latter figure is the mean of the activity concentrations of all of the samples of the five fish species represented in Table 23. An ingestion dose coefficient of 1.2 μSv/Bq was used which is based on a gut transfer factor of 0.5 [ICRP, 1993]. In addition, a delay factor of 0.8 was used to allow for the decay occurring between catch and consumption because of the short half-life (138 days) of polonium-210 [IAEA, 1995]. This delay factor is based on statistical estimates, from global data, of the relative proportions of fish consumed fresh, frozen, smoked and canned and of the average delay between catch and consumption for each method. The doses due to the consumption of fish and prawns were then calculated as follows:

- dose due to consumption of fish = 1.42 x consumption rate x 1.2 x 0.8 μSv
- dose due to consumption of prawns = 6.9 x consumption rate x 1.2 x 0.8 μSv

The resulting annual dose estimates for typical and heavy consumers were 32 μSv and 148 μSv, respectively.

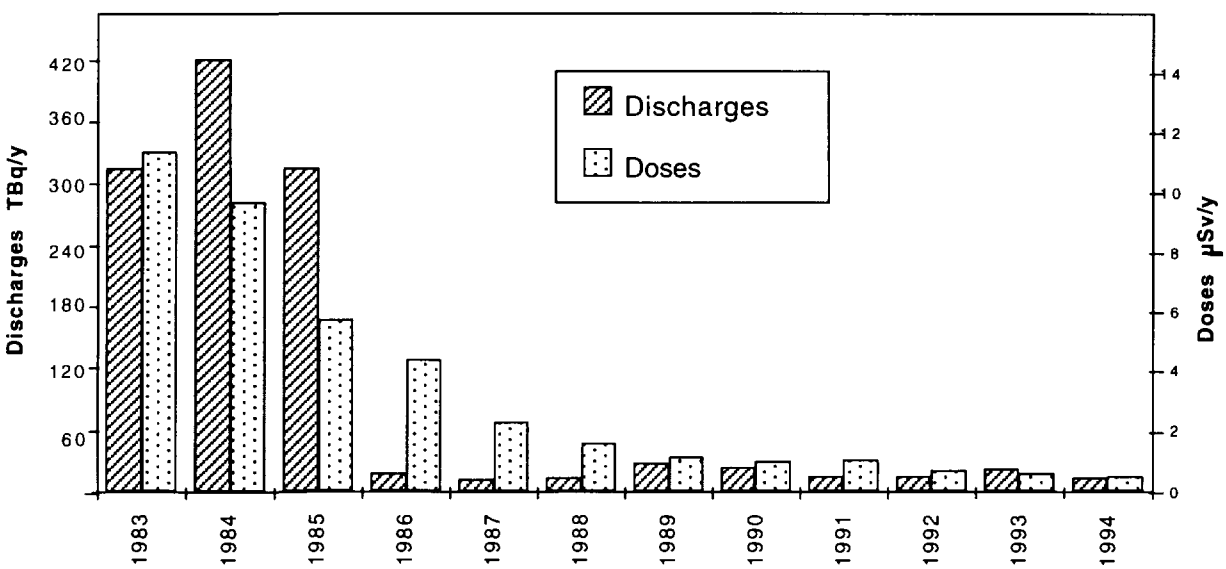

Figure 9 Sellafield Caesium-137 Discharges and Doses to Typical Seafood Consumers, 1983 - 1994

Collective Effective Dose

The committed collective effective dose (collective dose) provides a measure of the total detriment to the population. The collective dose to the Irish population due to caesium-137 resulting from the consumption of fish and shellfish landed at north-east ports was calculated by combining the quantities landed with their mean radiocaesium concentrations. Landing statistics for north-east ports were provided by the Department of the Marine (Table 25). It was assumed that 50% of the gross catch landed was discarded by cleaning and filleting and that 80% of the landings were exported. The collective doses to the Irish population for the years 1993 to 1995 were 0.017,

0.010 and 0.013 manSv respectively. The corresponding doses for 1991 and 1992 were 0.04 and 0.02 manSv [McGarry *et al.*, 1994]. The small increase in collective dose between 1994 and 1995 reflects an increase in the landing tonnage at the ports considered between these years. The collective dose to the Irish population from all sources of radiation is approximately 10,000 manSv per annum.

External Exposure

External exposure from beach occupancy was estimated from activity concentrations in intertidal sediments using the sandy beach model described by Hunt [1984]. The effective dose was calculated for an individual spending one hour per day in the intertidal zone based on the caesium-137 activity concentration in sediment. The activity concentration used in this calculation was the mean for the two sandy beach sampling locations in the north east, Balbriggan and Greenore, averaged over the reporting period. The estimated mean annual effective dose during the reporting period was 0.4 μSv/year.

In the absence of detailed habit survey data it is assumed that the actual number of people who spend 365 hours per year in the intertidal zone along the north east coast is small compared with the number of typical fish consumers. Therefore, while the estimates presented here for external dose and ingestion dose commitment are numerically similar, it is assumed that the number of people exposed via the external pathway is considerably smaller and so the ingestion pathway is still considered to be the dominant one affecting the Irish population. Other external exposure pathways such as swimming in the sea or boating are considered to be insignificant.

Risk Estimates

Evaluation of the risks associated with radiation exposures is based on the assumption that there is a linear relationship between radiation dose and the risk of a fatal cancer. The probability of a fatal cancer occurring in an exposed population is estimated to be 5×10^{-2} per sievert, i.e. a chance of 1 in 20 of developing a fatal cancer after exposure to a radiation dose of 1 Sv [ICRP, 1991]. The radiation induced risk for 1993 is, therefore, about one in thirty million to a typical Irish seafood consumer and about one in six million to a heavy consumer. In 1994 and 1995 the risks are marginally lower corresponding to the lower annual dose estimates. These compare with a risk in any year of death from cancer of 1 in 479 and from road accidents of 1 in 9232 [Central Statistics Office, 1996].

6. CONCLUSIONS

The consumption of fish and shellfish is the most important pathway contributing to exposure of the Irish public arising from artificial radioactivity in the marine environment. The major portion of the dose received via this pathway is due to the discharges from Sellafield of the radionuclide caesium-137.

The results in this report show that by 1995 the mean concentration of caesium-137 in fish landed at north-east ports had fallen to 1.6 Bq/kg, from a figure of 68 Bq/kg in 1979-82 and 3.0 Bq/kg in 1993. A similar decline is evident for seawater, sediment and seaweed. In addition, the Irish Sea data show the progressive dilution of artificial radioactivity with increasing distance from Sellafield.

When small contributions from plutonium and americium are added to the dose from caesium-137, the dose to a heavy consumer, from artificial radioactivity in fish and shellfish landed at north-east ports, was 3.3 μSv in 1993, 2.5 μSv in 1994 and 2.0 μSv in 1995. These figures may be compared with a dose of 3.6 μSv in 1992, and doses in the region of 70 μSv in the early 1980s [McAulay and Doyle, 1985; Cunningham and O'Grady, 1986], illustrating the steady decline in the dose from these sources in recent years.

To put the above doses in perspective, they may be compared with the dose of 148 μSv received by the heavy consumer of fish and prawns due to the naturally occurring radionuclide polonium-210. In addition, they may be compared with the annual dose from all sources of radioactivity which is estimated to be 3000 μSv.

While plutonium and americium make a relatively small contribution to the dose currently received by the Irish population, their significance arises from the fact that they will be present in the Irish Sea for a very long time. This is due both to their behaviour in the marine environment and their long physical half-lives.

Revised discharge authorisations for the Sellafield site which came into effect in 1994 provided for the operation of the new plants, known as THORP and EARP. The increase in the discharge of technetium-99 which followed was clearly reflected in the measured activity concentrations in seawater and seaweed in Irish coastal waters. However, as technetium-99 is a radionuclide of low radiotoxicity, its presence makes only a small contribution to the radiation dose to a fish consumer. The full effects of the operation of these new plants on the Irish marine environment will only become apparent over future years.

It is clearly objectionable from an Irish viewpoint that contamination of our marine environment should result from the operations of nuclear installations in other countries. Nonetheless, it is evident from the data in this report that the levels of radioactive contamination of the Irish Sea, which prevailed in the years 1993-'95, do not justify misgivings on health grounds about eating fish from the Irish Sea, or about swimming or engaging in any other activity in or near the sea along the east coast of Ireland.

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9. GLOSSARY OF TERMS

Activity
Quantity of a radionuclide. It describes the rate at which spontaneous emission occurs. The unit of activity is the becquerel (Bq). One Bq is equivalent to one disintegration per second.

Absorbed Dose
Quantity of energy imparted by the ionising radiation to unit mass of matter such as tissue. It is measured in grays (Gy). One Gy produces different biological effects on tissue depending on the type of radiation i.e. alpha, beta or gamma.

Equivalent Dose
The quantity obtained by multiplying the *absorbed dose* by a factor representing the different effectiveness of the various types of radiation in causing harm to tissues. It is measured in sieverts (Sv). One Sv produces the same biological effect irrespective of the type of the radiation.

Effective Dose
Weighted sum of the *equivalent doses* to the various organs and tissues. The weighting factor for each organ or tissue takes account of the fractional contribution of the risk of death or serious genetic defect from irradiation of that organ or tissue to the total risk from uniform irradiation of the whole body. The unit of effective dose is the sievert (Sv).

Collective Effective Dose
Total dose over a population group exposed to a given source. It is represented by the product of the average *equivalent dose* to the individuals in the group by the number of persons comprising the group. It is measured in man-sieverts (manSv).

Committed Effective Dose
Total dose gradually delivered to an individual over a given period of time by the decay of a radionuclide following its intake into the body. The integration time is usually taken as 50 years for adults and 70 years for children.

Half-life
The time taken for the activity of a radionuclide to lose half its value by decay.

Radionuclide
An unstable nuclide that emits ionising radiation. The emissions may be either alpha, beta or gamma radiation.

10. RADIATION QUANTITIES AND UNITS

QUANTITY	NAME and SYMBOL
Activity	becquerel (Bq)
Absorbed dose	gray (Gy)
Effective Dose Equivalent Dose	sievert (Sv)
Collective dose	man sievert (manSv)

In addition multiples and sub-multiples of the above units are frequently used. The most common ones are given below.

Activity:

1 millibecquerel (1 mBq) = 1×10^{-3} Bq

1 kilobecquerel (1 kBq) = 1×10^{3} Bq

1 megabecquerel (1 MBq) = 1×10^{6} Bq

1 terabecquerel (1 TBq) = 1×10^{12} Bq

Dose:

1 microsievert (1 μSv) = 1×10^{-6} Sv

1 millisievert (1 mSv) = 1×10^{-3} Sv

RADIONUCLIDE	SYMBOL	HALF-LIFE
Tritium	H-3	12.3 years
Carbon-14	C-14	5.73×10^{3} years
Potassium-40	K-40	1.28×10^{9} years
Strontium-90	Sr-90	29.1 years
Technetium-99m	Tc-99m	6.01 hours
Technetium-99	Tc-99	2.13×10^{5} years
Iodine-131	I-131	8.04 days
Caesium-134	Cs-134	2.06 years
Caesium-137	Cs-137	30.2 years
Polonium-210	Po-210	138 days
Plutonium-238	Pu-238	87.7 years
Plutonium-239	Pu-239	2.40×10^{4} years
Plutonium-240	Pu-240	6.50×10^{3} years
Americium-241	Am-241	433 years

TABLE 1
DISCHARGES OF RADIONUCLIDES FROM SELLAFIELD, 1993 - 1995

Radionuclide Category	1993		1994		1995	
	Discharge TBq	Limit TBq	Discharge TBq	Limit TBq	Discharge** TBq	Limit TBq
Total Beta*	97	500	125	400	190	400
Total Alpha	2.6	10	1.0	4.7	0.4	1.0
Tritium	2309	3500	1680	31000	2700	31000
Carbon-14	2.0	4	8.2	20.8	12	20.8
Cobalt-60	0.09	8	0.11	13	1.3	13
Strontium-90	17.1	35	28.9	30	28	48
Zirconium-95	6.3	}180	2.1	}50	0.34	}9
Niobium-95	3.4		1.1		0.40	
Technetium-99	6.1	10	72.0	200	190	200
Ruthenium-106	17.1	170	6.7	75	7.3	63
Iodine-129	0.16	0.4	0.16	2	0.25	2
Caesium-134	1.18	10	0.61	6.6	0.51	6.6
Caesium-137	21.9	110	13.8	75	12	75
Cerium-144	2.5	22	0.84	10	1.1	8
Americium-241	0.87	3	0.38	1.3	0.11	0.3
Plutonium Alpha	1.33	7	0.66	4	0.31	0.7
Plutonium-241	37.5	170	14.4	150	7.7	27
Uranium (kg)	653.7	NA	1388	2040	1300	2040

* Total beta does not include very low energy beta emitters such as tritium and plutonium-241.

** The 1995 discharge values are provisional.

NA = No limit was applied in 1992

TABLE 2
SAMPLING PROGRAMME, 1993 - 1995

Sampling Location	Samples Types
Carlingford	Shellfish
Greenore	Seawater, Sediment, Seaweed
Clogherhead	Fish, Shellfish
Balbriggan	Seawater, Sediment, Seaweed
Howth	Fish, Shellfish
Bull Island	Seawater, Sediment, Seaweed
Cahore	Seawater, Sediment, Seaweed
Wexford	Shellfish
Dunmore East	Fish, Shellfish, Seawater, Sediment, Seaweed
Bantry	Shellfish
Castletownbere	Fish, Shellfish, Seawater, Sediment, Seaweed
Galway	Fish, Shellfish, Seawater, Sediment, Seaweed
Killybegs	Fish, Shellfish, Seawater, Sediment, Seaweed
Lough Foyle	Shellfish
Western Irish Sea	Seawater, Sediment

TABLE 3
LOUGH BELTRA SAMPLING LOCATIONS IN THE IRISH SEA

Sampling Location	Location	
N1	53° 25′ N	6° 01′ W
N2	53° 36′ N	5° 56′ W
N3	53° 44′ N	5° 25′ W
N4	53° 52′ N	5° 14′ W
N5	53° 53′ N	5° 33′ W
N6	53° 52′ N	5° 53′ W
S1	53° 20′ N	6° 00′ W
S2	53° 20′ N	5° 22′ W
S3	53° 04′ N	5° 31′ W
S4	53° 00′ N	5° 55′ W
S5	53° 10′ N	6° 00′ W

TABLE 4
RADIOACTIVITY IN SEAWATER, 1993

Sampling Location	Month	Cs-137, mBq/l
Greenore [1]	Mar	60
	Jun	81
	Aug	94
	Nov	86
Balbriggan	Feb	59
	Jun	65
	Aug	73
	Nov	72
Bull Island	Feb	60
	Jun	62
	Aug	63
	Nov	50
Cahore	Sep	36
Castletownbere	Dec	5.4
Killybegs	Jun	ND
	Nov	4
Lough Beltra N1	Nov	73
Lough Beltra N2	Nov	65
Lough Beltra N3	Nov	33
Lough Beltra N4	Nov	37
Lough Beltra N5	Nov	30
Lough Beltra N6	Nov	55
Lough Beltra S1	Nov	69
Lough Beltra S2	Nov	25
Lough Beltra S3	Nov	51
Lough Beltra S4	Nov	53
Lough Beltra S5	Nov	65

Notes 1 Greenore was referred to as Carlingford in previous reports.
ND = not detected

TABLE 5
RADIOACTIVITY IN SEAWATER, 1994

Sampling Location	Month	Cs-137, mBq/l
Greenore [1]	Mar	62
	Apr	42
	Aug	84
	Dec	48
Balbriggan	Feb	35
	May	34
	Aug	48
Bull Island	May	35
	Nov	46
Cahore	Jul	14
Dunmore East	Jun	5
Galway	Aug	5
	Nov	5
Killybegs	Jul	5
	Dec	6
Lough Beltra N1	May	42
Lough Beltra N2	May	60
Lough Beltra N3	May	48
Lough Beltra N4	May	20
Lough Beltra N5	May	42
Lough Beltra N6	May	53
Lough Beltra S1	Jun	49
Lough Beltra S2	Oct	22
Lough Beltra S3	Oct	28
Lough Beltra S4	Jun	35
Lough Beltra S5	Jun	34

Notes 1 Greenore was referred to as Carlingford in previous reports.

TABLE 6
RADIOACTIVITY IN SEAWATER, 1995

Sampling Point	Month	Activity Concentration mBq/l	
		Cs-137	Tc-99
Greenore [1]	Mar	28	NM
	Jun	36	NM
	Aug	64	NM
	Nov	62	NM
Balbriggan	Mar	34	NM
	May	42	24
	Jun	75	22
	Jul	53	25
	Aug	43	21
	Sep	44	30
	Oct	50	12
	Nov	48	17
	Dec	60	15
Bull Island	Mar	33	NM
	Nov	39	NM
Cahore	Jun	16	NM
Dunmore East	Jul	7	NM
	Oct	10	NM
Galway	Apr	6	NM
Killybegs	May	6	NM
	Aug	5	NM
Lough Beltra N1	Apr	23	4
Lough Beltra N2	Apr	37	18
Lough Beltra N3	Apr	26	33
Lough Beltra N4	Apr	NM	35
Lough Beltra N5	Apr	55	34
Lough Beltra S2	Apr	42	NM
Lough Beltra S3	Apr	15	NM
Lough Beltra S5	Apr	27	NM

Notes 1 Greenore was referred to as Carlingford in previous reports.
NM = not measured

TABLE 7
RADIOACTIVITY IN IRISH COASTLINE SEDIMENTS, 1993 - 1995

Sampling Location	Year	Number of Samples	Mean (Range) Cs-137, Bq/kg, dry weight
Carlingford Harbour [1]	1993	3	47 (36-54)
	1994	3	34 (29-39)
Greenore [2]	1993	3	13 (9.9-16.4)
	1994	4	11 (8.3-13.9)
	1995	4	11 (10.4-12.3)
Balbriggan	1993	4	13 (8-17)
	1994	4	25 (9-39)
	1995	8	11 (10.2-18.4)
Bull Island	1993	6	6.4 (5.0-7.6)
	1994	4	4.6 (3.5-6.9)
	1995	4	3.6 (3.0-4.3)
Cahore	1993	1	1.6
	1994	1	1.2
	1995	1	0.9
Dunmore East	1993	1	1.6
	1994	2	4.6 (2.6;6.5)
	1995	1	3.0
Castletownbere	1993	1	1.2
	1994	1	1.0
	1995	1	0.8
Galway	1994	2	0.4 (0.3;0.5)
	1995	1	0.6
Killybegs	1993	2	1.1 (0.9;1.2)
	1994	2	0.6 (0.3;0.8)
	1995	2	0.6 (0.3;0.8)

Notes 1 Sampling at Carlingford Harbour discontinued after 1994.
2 Greenore was referred to as Carlingford in previous reports.

TABLE 8
RADIOACTIVITY IN WEST IRISH SEA SEDIMENTS, 1993 - 1995

Sampling Location	Year	Month	Cs-137, Bq/kg, dry weight
Lough Beltra N1	1993	Nov	12
	1994	May	9.7
	1995	Apr	10.2
Lough Beltra N2	1993	Nov	25
	1994	May	18
	1995	Apr	18
Lough Beltra N3	1993	Nov	78
	1994	May	73
	1995	Apr	98
Lough Beltra N4	1993	Nov	58
	1994	May	87
	1995	Apr	63
Lough Beltra N5	1993	Nov	115
	1994	May	128
	1995	Apr	93
Lough Beltra N6	1993	Nov	84
	1994	May	72
	1995	Apr	72
Lough Beltra S1	1993	Nov	8.5
	1994	Jun	7.7
	1995	Apr	2.3
Lough Beltra S2	1993	Nov	1.6
	1995	Apr	0.6
Lough Beltra S3	1993	Nov	0.9
	1994	Jun	1.6
	1995	Apr	0.5
Lough Beltra S4	1994	Jun	8.5
	1995	Apr	3.7
Lough Beltra S5	1993	Nov	11
	1994	Jun	2.3
	1995	Apr	8.1

TABLE 9
RADIOACTIVITY IN FUCUS VESICULOSUS, 1993

Sampling Location	Month	Activity Concentration Bq/kg, wet weight (dry weight)			
		Cs-137	I-131	K-40	Tc-99
Carlingford Harbour [1]	Mar	4.4 (18.0)	NM	413 (1677)	NM
	Jun	5.6 (18.6)	NM	348 (1161)	NM
	Aug	11.7 (30.2)	NM	518 (1357)	NM
	Nov	4.0 (18.7)	NM	313 (1476)	NM
Greenore [2]	Mar	2.9 (10.3)	NM	300 (1075)	NM
	Jun	5.8 (16.8)	NM	419 (1227)	NM
	Aug	4.5 (20.6)	NM	254 (1170)	NM
	Nov	3.4 (13.8)	NM	274 (1120)	NM
Balbriggan	Mar	2.2 (10.6)	0.8	261 (1262)	NM
	Jun	4.3 (13.4)	NM	354 (1098)	152 (472)
	Aug	4.1 (18.3)	NM	244 (1092)	78 (349)
	Nov	3.7 (12.6)	NM	352 (1188)	NM
Bull Island	Jan	1.8 (8.8)	1.3	255 (1273)	NM
	Mar	2.0 (11.0)	53	217 (1222)	NM
	Apr	2.5 (12.5)	2.4	224 (1141)	NM
	May	2.2 (15.0)	4.3	182 (1236)	NM
	Jul	3.2 (12.7)	1.6	302 (1226)	NM
	Sep	3.6 (14.7)	42	332 (1361)	NM
	Oct	2.8 (12.8)	23	289 (1333)	NM
	Nov	2.7 (12.1)	2.5	332 (1505)	NM
	Dec	2.0 (10.9)	1.5	242 (1352)	NM
Cahore	Sep	1.7 (6.0)	NM	235 (835)	NM
Dunmore East	Jun	0.4 (2.0)	NM	NM	NM
Castletownbere	Dec	0.4 (1.5)	NM	274 (1054)	NM
Killybegs	Jun	0.3 (1.0)	NM	233 (774)	0.7 (2.2)
Killybegs	Dec	ND	NM	234 (907)	NM

Notes 1 Sampling at Carlingford Harbour discontinued after 1994.
2 Greenore was referred to as Carlingford in previous reports.
NM = not measured
ND = not detected

TABLE 10
RADIOACTIVITY IN FUCUS VESICULOSUS, 1994

Sampling Location	Month	Activity Concentration Bq/kg, wet weight (dry weight)			
		Cs-137	I-131	K-40	Tc-99
Carlingford Harbour [1]	Jan	NM	NM	NM	59 (379)
	Mar	3.9 (15.1)	NM	253 (983)	86 (333)
	Apr	2.5 (13.5)	NM	158 (845)	60 (322)
	Aug	4.6 (19.3)	NM	288 (1200)	203 (862)
Greenore [2]	Mar	1.8 (9.0)	NM	173 (842)	NM
	Apr	1.4 (7.5)	NM	82 (784)	NM
	Aug	1.8 (12.8)	NM	78 (566)	NM
	Nov	1.1 (4.5)	NM	147 (590)	NM
Balbriggan	Jan	NM	NM	NM	102 (528)
	Feb	2.2 (8.5)	NM	295 (1191)	137 (553)
	May	1.3 (6.3)	NM	118 (898)	63 (317)
	Aug	2.6 (8.3)	NM	291 (919)	327 (1030)
	Nov	1.2 (3.9)	NM	314 (990)	339 (1068)
Bull Island	Jan	1.5 (7.7)	1.7	246 (1229)	53 (316)
	Feb	1.2 (7.1)	18.9	202 (1215)	NM
	Apr	1.4 (6.8)	61.2	244 (1167)	NM
	May	1.1 (6.8)	ND	177 (1081)	NM
	Jun	1.6 (6.8)	6.4	243 (1026)	NM
	Jul	1.9 (7.9)	7.3	257 (1085)	NM
	Aug	1.3 (7.9)	ND	190 (1132)	NM
	Sep	1.1 (6.0)	4.1	145 (795)	NM
	Oct	1.1 (5.7)	ND	205 (1001)	NM
	Nov	1.6 (9.1)	4.7	258 (1480)	NM
	Dec	1.4 (6.8)	2.5	298 (1511)	NM
Cahore	Jul	0.4 (1.5)	NM	249 (910)	NM
Rosslare	Jan	NM	NM	NM	32 (142)
Craden Point	Jan	NM	NM	NM	5.5 (31.8)
Dunmore East	Dec	0.33 (1.2)	NM	288 (1015)	10 (45.9)
Ringaskiddy	Jan	NM	NM	NM	4.1 (19.5)
Castletownbere	Oct	0.2 (0.9)	NM	270 (1318)	NM
Dunquin	Jan	NM	NM	NM	0.9 (7.9)
Galway	Jan	NM	NM	NM	2.6 (17.7)
	Aug	0.2 (0.7)	NM	238 (953)	1.7 (6.9)
	Nov	0.2 (0.7)	NM	200 (883)	13.7 (60.4)
Killybegs	Feb	NM	NM	NM	4.0 (22.7)
	Jun	0.4 (1.4)	NM	239 (842)	1.7 (6.0)
	Dec	0.2 (0.9)	NM	179 (713)	1.4 (5.4)

Notes
1 Sampling at Carlingford Harbour discontinued after 1994.
2 Greenore was referred to as Carlingford in previous reports.
ND = not detected
NM = not measured

TABLE 11
RADIOACTIVITY IN FUCUS VESICULOSUS, 1995

Sampling Location	Month	Activity Concentration Bq/kg, wet weight (dry weight)			
		Cs-137	I-131	K-40	Tc-99
Greenore [1]	Mar	0.7 (4.4)	NM	129 (856)	187 (1230)
	Jun	1.1 (7.0)	NM	138 (872)	328 (2074)
	Aug	2.1 (12.2)	NM	124 (711)	416 (2380)
	Nov	1.8 (6.1)	NM	314 (1082)	1351 (4641)
Balbriggan	Mar	1.0 (5.0)	NM	194 (953)	317 (1554)
	May	1.0 (5.7)	NM	173 (1020)	286 (1675)
	Jun	1.3 (7.5)	NM	216 (1263)	359 (2089)
	Jul	1.3 (8.1)	NM	178 (1103)	390 (2424)
	Aug	1.2 (7.2)	NM	164 (1013)	271 (1824)
	Oct	0.8 (3.6)	NM	162 (746)	454 (2094)
	Nov	2.2 (7.5)	NM	294 (1012)	741 (2530)
	Dec	1.3 (5.1)	NM	237 (912)	616 (2323)
Bull Island	Jan	1.0 (6.9)	ND	231 (1626)	NM
	Feb	0.9 (4.8)	2.2	247 (1385)	NM
	Mar	0.4 (3.1)	0.6	157 (1104)	NM
	Apr	0.5 (3.7)	2.2	130 (976)	NM
	May	0.6 (5.9)	1.8	123 (1152)	NM
	Jun	0.9 (7.6)	0.6	129 (1086)	NM
	Jul	1.0 (8.1)	45.4	134 (1128)	NM
	Aug	1.2 (6.3)	1.5	164 (1013)	NM
	Sep	1.1 (8.3)	6.6	156 (1217)	NM
	Oct	0.9 (4.2)	NM	162 (784)	NM
	Nov	NM	2.5	NM	NM
	Dec	0.8 (3.9)	2.0	150 (745)	NM
Cahore	Jun	0.4 (2.1)	NM	209 (1238)	NM
Dunmore East	Jul	0.1 (0.9)	NM	137 (929)	NM
Castletownbere	Aug	0.2 (0.9)	NM	151 (766)	NM
Galway	Apr	0.1 (0.9)	NM	147 (966)	NM
Killybegs	May	0.2 (1.1)	NM	125 (854)	1.5 (10.0)
	Aug	0.2 (0.8)	NM	154 (710)	1.1 (4.8)

Notes 1 Greenore was referred to as Carlingford in previous reports.
ND = not detected
NM = not measured

TABLE 12
RADIOACTIVITY IN WHITING, 1993 - 1995

Sampling Location	Year	Number of Samples	Mean (Range) Activity Concentration Bq/kg, wet weight			
			Cs-137	Pu-238	Pu-239,240	Am-241
Clogherhead	1993	4	4.6 (0.4-10.5)	ND	ND	ND
	1994	4	3.5 (0.6-5.5)	ND	0.0008	ND
	1995	4	2.0 (1.3-3.9)	ND	0.0009	ND
Howth	1993	12	4.7 (2.0-10.6)	ND	0.0009	ND
	1994	12	3.8 (0.6-14.3)	ND	0.001	ND
	1995	12	1.7 (0.4-5.4)	NM	NM	ND
Dunmore East	1993	1	1.8	NM	NM	NM
	1994	2	0.8 (0.7;0.8)	NM	NM	NM
	1995	2	0.9 (0.7;1.0)	NM	NM	NM
Castletownbere	1993	1	1.2	NM	NM	NM
	1994	2	0.6 (ND;1.0)	NM	NM	NM
	1995	1	0.5	NM	NM	NM
Galway	1994	1	ND	NM	NM	NM
	1995	1	0.3	NM	NM	NM
Killybegs	1993	2	1.0 (0.9;1.0)	ND	ND	ND
	1994	1	1.0	ND	ND	ND
	1995	2	0.7 (0.4;1.0)	ND	ND	NM

Notes ND = not detected
NM = not measured

TABLE 13
RADIOACTIVITY IN COD, 1993 - 1995

Sampling Location	Year	Number of Samples	Mean (Range) Activity Concentration Bq/kg, wet weight			
			Cs-137	Pu-238	Pu-239,240	Am-241
Clogherhead	1993	4	3.3 (2.1-5.0)	0.00023	0.00057	ND
	1994	4	4.1 (1.0-7.8)	ND	ND	ND
	1995	4	2.2 (0.4-4.0)	ND	ND	NM
Howth	1993	11	5.8 (0.7-14.7)	ND	ND	ND
	1994	12	3.7 (1.3-5.2)	ND	ND	ND
	1995	12	2.7 (0.4-5.6)	NM	NM	ND
Dunmore East	1993	1	1.3	NM	NM	NM
	1994	2	0.9 (0.7;1.1)	NM	NM	NM
	1995	2	1.5 (0.9;2.0)	NM	NM	NM
Castletownbere	1993	1	0.5	NM	NM	NM
	1994	1	0.5	NM	NM	NM
	1995	1	0.3	NM	NM	NM
Galway	1994	2	0.8 (0.7;0.8)	NM	NM	NM
	1995	1	0.5	NM	NM	NM
Killybegs	1993	2	0.4 (ND;0.4)	ND	ND	ND
	1994	2	0.7 (0.4;1.0)	ND	ND	0.026
	1995	2	0.75 (0.6;0.9)	ND	ND	ND

Notes ND = not detected
NM = not measured

TABLE 14
RADIOACTIVITY IN PLAICE, 1993 - 1995

Sampling Location	Year	Number of Samples	Mean (Range) Activity Concentration Bq/kg, wet weight			
			Cs-137	Pu-238	Pu-239,240	Am-241
Clogherhead	1993	4	1.8 (0.8-2.7)	0.0006	0.00078	ND
	1994	3	1.1 (0.2-1.7)	ND	ND	ND
	1995	3	1.0 (0.3-1.5)	ND	ND	ND
Howth	1993	12	2.4 (0.8-3.8)	ND	ND	ND
	1994	12	1.6 (0.7-2.7)	ND	ND	ND
	1995	12	1.6 (1.1-2.8)	NM	NM	0.008
Dunmore East	1993	1	1.1	NM	NM	NM
	1994	1	1.1	NM	NM	NM
	1995	2	0.3 (0.3;0.3)	NM	NM	NM
Castletownbere	1993	1	ND	NM	NM	NM
	1994	1	ND	NM	NM	NM
	1995	1	ND	NM	NM	NM
Galway	1994	2	0.4 (<0.3;0.5)	NM	NM	NM
	1995	1	0.3	ND	ND	0.008
Killybegs	1993	2	0.3 (ND;.4)	ND	ND	ND
	1994	1	ND	0.0029	0.013	0.028
	1995	2	0.5 (0.2;0.7)	NM	NM	NM

Notes ND = not detected
NM = not measured

TABLE 15
RADIOACTIVITY IN RAY, 1993 - 1995

Sampling Location	Year	Number of Samples	Mean (Range) Cs-137 Bq/kg, wet weight
Clogherhead	1994	1	3.1
Howth	1993	11	3.2 (0.7-5.4)
	1994	12	2.2 (0.8-3.3)
	1995	12	2.3 (0.3-4.7)
Dunmore East	1993	1	0.6
	1994	1	ND
	1995	2	1.2 (0.3;2.1)
Castletownbere	1994	1	0.3
	1995	1	0.3
Galway	1994	2	0.3 (ND;0.3)
	1995	1	0.4
Killybegs	1993	2	0.6 (0.1;1.0)
	1994	1	0.3
	1995	1	ND

Notes ND = not detected

TABLE 16
RADIOACTIVITY IN HERRING, 1993 - 1995

Sampling Location	Year	Number of Samples	Mean (Range) Cs-137 Bq/kg, wet weight
Clogherhead	1993	4	0.5 (0.4-0.6)
	1994	2	2.8 (1.7;3.8)
	1995	3	0.8 (0.5-1.4)
Howth	1993	6	0.9 (0.4-1.7)
	1994	5	0.6 (ND-0.9)
	1995	5	0.8 (0.5-1.5)
Dunmore East	1994	1	0.8
Galway	1995	2	0.5 (ND;0.5)
Killybegs	1993	3	0.6 (ND-0.8)
	1994	1	0.5

TABLE 17
RADIOACTIVITY IN MACKEREL, 1993 - 1995

Sampling Location	Year	Number of Samples	Mean (Range) Cs-137 Bq/kg, wet weight
Clogherhead	1993	4	2.2 (0.3-4.1)
	1994	3	0.5 (ND-0.6)
	1995	3	0.3 (ND- 0.3)
Howth	1993	11	1.8 (0.3-4.9)
	1994	12	0.7 (ND-3.2)
	1995	10	0.5 (0.3-0.8)
Dunmore East	1993	1	0.8
Castletownbere	1993	1	ND
	1995	1	ND
Galway	1994	1	ND
	1995	1	ND
Killybegs	1993	2	0.4 (ND;0.4)
	1994	1	0.2

Notes ND = not detected

TABLE 18
RADIOACTIVITY IN PRAWNS, 1993 - 1995

Sampling Location	Year	Number of Samples	Mean (Range) Activity Concentration Bq/kg, wet weight			
			Cs-137	Pu-238	Pu-239,240	Am-241
Clogherhead	1993	1	0.2	NM	NM	NM
	1994	3	2.1 (1.7-2.5)	0.0071	0.042	0.103
	1995	2	1.1 (0.5;1.7)	0.0015	0.008	0.138
Howth	1993	9	2.7 (0.8-3.8)	0.0024	0.012	0.012
	1994	11	1.8 (0.3-2.9)	0.0021	0.013	0.02
	1995	7	1.3 (0.1-2.0)	0.0013	0.008	0.027
Dunmore East	1994	1	ND	NM	NM	NM
	1995	1	0.3	NM	NM	NM
Castletownbere	1994	1	0.8	NM	NM	NM
	1995	1	ND	NM	NM	NM
Galway	1994	2	<0.3 (ND;ND)	NM	NM	NM
	1995	1	<0.2	0.0003	0.002	ND

TABLE 19
RADIOACTIVITY IN MUSSELS, 1993 - 1995

Sampling Location	Year	Number of Samples	Mean (Range) Activity Concentration Bq/kg, wet weight			
			Cs-137	Pu-238	Pu-239,240	Am-241
Carlingford	1993	4	1.6 (0.7-2.6)	0.015	0.067	0.012
	1994	4	0.7 (0.5-1.0)	0.023	0.125	ND
	1995	4	0.9 (0.3-1.5)	0.024	0.139	0.069
Sutton	1994	1	0.3	NM	NM	NM
Bantry	1993	1	ND	NM	NM	NM
	1994	1	0.1	NM	NM	NM
	1995	1	ND	NM	NM	NM
Galway	1994	2	0.2 (ND;0.2)	NM	NM	NM
	1995	1	ND	NM	NM	NM
Killybegs	1993	2	0.2 (ND;0.1)	ND	0.0006	ND
	1994	2	0.1 (ND;0.05)	ND	0.006	0.082
	1995	2	0.5 (0.08;ND)	NM	NM	NM
Lough Foyle	1993	1	ND	NM	NM	NM
	1994	2	0.3 (0.1;0.4)	NM	NM	NM
	1995	1	0.3	NM	NM	NM

Notes ND = not detected
NM = not measured

TABLE 20
RADIOACTIVITY IN OYSTERS, 1993 - 1995

Sampling Location	Year	Number of Samples	Mean (Range) Activity Concentration Bq/kg, wet weight			
			Cs-137	Pu-238	Pu-239,240	Am-241
Carlingford	1993	4	0.5 (0.4-0.7)	0.0064	0.051	NM
	1994	4	0.3 (0.3-0.5)	0.0088	0.053	0.027
	1995	3	0.3 (0.2-0.3)	0.012	0.062	0.014
Galway	1994	1	ND	NM	NM	NM
	1995	1	0.1	NM	NM	NM

TABLE 21
PLUTONIUM AND AMERICIUM IN FISH AND SHELLFISH, 1992

Species	Number of Samples	Landing Port	Activity Concentration Bq/kg, wet weight		
			Pu-238	Pu-239,240	Am-241
Plaice	4	Clogherhead	ND	ND	ND
	12	Howth	ND	ND	NM
	1	Killybegs	ND	ND	ND
Whiting	4	Clogherhead	ND	ND	0.0011
	11	Howth	ND	ND	ND
	1	Killybegs	ND	ND	ND
Cod	4	Clogherhead	ND	ND	ND
	12	Howth	ND	ND	ND
	1	Killybegs	ND	ND	ND
Prawns	1	Clogherhead	0.0033	0.0153	0.026
	6	Howth	0.0037	0.014	0.017
	1	Dunmore East	ND	ND	0.0038
Mussels	4	Carlingford	0.038	0.173	0.087
Oysters	4	Carlingford	0.017	0.076	0.026

Notes ND = not detected
NM = not measured

TABLE 22
RADIOCAESIUM IN FISH AND PRAWNS LANDED AT THE NORTH-EAST PORTS, 1979 - 1995

Sampling Period	Number of Samples	Mean Concentration Bq/kg, wet weight	
		Cs-137	Cs-134
1979-82[1]	60	68.0	3.0
1982-83	32	62.0	2.2
1982	28	55.4	2.2
1983	57	49.6	2.4
1984	58	42.4	2.0
1985	72	25.6	0.7
1986	42	19.5	0.7
1987	57	9.8	0.6
1988	126	6.4	0.8
1989	107	5.1	0.2
1990	117	4.2	0.3
1991	83	4.5	0.3
1992	90	3.0	0.2
1993	93	3.0	ND
1994	96	2.3	ND
1995	89	1.6	ND

Notes 1 Taken from McAulay and Doyle [1985]
ND = not detected

TABLE 23
POLONIUM-210 IN FISH AND SHELLFISH, 1993 - 1995

Species	Number of Samples	Mean Po-210 Activity Concentration Bq/kg (wet weight)
Whiting	4	0.9
Cod	3	1.3
Plaice	3	3.0
Ray	4	0.8
Mackerel	1	1.6
Prawns	3	6.9
Mussels	68	25.5

TABLE 24
COMMITTED EFFECTIVE DOSES, FROM ARTIFICIAL RADIONUCLIDES, DUE TO THE CONSUMPTION OF FISH AND SHELLFISH LANDED AT NORTH-EAST PORTS, 1993 - 1995

Type of Consumer	Consumption Rates of Fish and Shellfish (grammes per day)	Committed Effective Dose (μSv)[1]		
		1993	1994	1995
Heavy	200 g fish + 20 g shellfish	3.3	2.5	2.0
Typical	40 g fish + 5 g shellfish	0.67	0.51	0.41

1 Dose due to caesium, plutonium and americium

TABLE 25
FISH AND SHELLFISH LANDINGS AT NORTH-EAST PORTS, 1993 - 1995

Landing Port	Year	Fish Landed (kg)		
		Demersal	Pelagic	Shellfish
Clogherhead	1993	624,200	5,000	317,200
	1994	119,100	200	223,600
	1995	150,700	300	263,300
Balbriggan*	1993	102,500	5,800	174,800
Skerries	1993	260,100	6,700	477,500
	1994	192,300	900	585,800
	1995	164,600	0	600,300
Howth	1993	1,624,800	11,500	763,300
	1994	1,334,600	5,400	1,268,500
	1995	1,705,800	700	5,142,100

* After 1993 Balbriggan landings are included in the Skerries data.