*RPII-03/3*

# *Radioactivity monitoring of the Irish marine environment 2000 and 2001*

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## Summary

*The safety of the food chain and the protection of the environment are prime concerns of the Irish public. The Institute responds to these concerns and to its legislative responsibilities in this area by undertaking monitoring programmes of radioactivity in foodstuffs and in the environment. This report presents the results of the marine radioactivity monitoring programme carried out by the Radiological Protection Institute of Ireland (RPII) during 2000 and 2001. The primary objective of the programme is to assess the exposure of the Irish population resulting from radioactive contamination of the Irish marine environment and to estimate the risks to health from this exposure.*

*Discharged radioactive waste from the British Nuclear Fuels plc (BNFL) reprocessing plant at Sellafield in Cumbria in the North West of England continues to be the dominant source of this contamination. In particular, the remobilisation from sediments of historic discharges makes an important contribution to the levels of radioactivity in the seawater of the western Irish Sea.*

*Approximately 300 samples of fish, shellfish, seaweed, seawater and sediment were collected in 2000 and again in 2001. Both the Marine Institute and the Department of Communications, Marine and Natural Resources assisted the Institute with this sampling. The samples were analysed for a range of radionuclides at the Institute's radio-analytical laboratory.*

*The results show that the artificial radionuclide of greatest dosimetric significance continues to be caesium-137. The activity concentration of this radionuclide in the Irish marine environment has remained relatively stable since the mid 1990s but at a lower level than that observed during the previous two decades. Along the Irish coastline the highest activity concentrations observed are in the north-east.*

*Since 1994 the commissioning and operation of new facilities at Sellafield have resulted in an increase in the discharges of technetium-99 to the Irish Sea. This has been reflected in an increase in the activity concentrations of this radionuclide at all east coast sampling sites. However, the low radiotoxicity of technetium-99 means that it is generally of lesser radiological significance than caesium-137.*

*The main pathway contributing to the exposure of the Irish public is the consumption of seafood. The committed effective dose to heavy consumers of seafood due to measured artificial radionuclides was 1.18 μSv in 2000 and 1.20 μSv in 2001. Caesium-137 is the dominant radionuclide, accounting for approximately 60-70% of the total dose. The dose to the Irish population due to this radionuclide has declined significantly over the last two decades. For example, in 1982 the dose due to caesium-137 to heavy consumers was estimated to be approximately 70 μSv. This had fallen to 0.73 and 0.81 μSv in 2000 and 2001, respectively.*

*These doses may be put into context by comparing them with the dose attributable to the presence of the naturally occurring radionuclide, polonium-210, in seafood. This has been estimated to be 148 μSv for heavy seafood consumers. The estimated doses may also be compared with the annual average dose of approximately 3620 μSv from all sources of radiation received by members of the Irish public. The dose received in 2000 and 2001 by a heavy seafood consumer corresponds to a risk of developing a fatal cancer of approximately 1 in 17 million.*

*The doses incurred by people living in Ireland today as a result of the routine operations at Sellafield are now very small and do not constitute a significant health risk. The Institute therefore advises that from a radiological perspective it is safe to eat seafood landed at Irish fishing ports and to enjoy the amenities of the Irish maritime area.*

*Further reductions in these doses are being pursued through the implementation of the OSPAR Strategy with regard to Radioactive Substances. All signatories to the Strategy are committed to progressive and substantial reductions in radioactive discharges from their facilities. Compliance with the objectives of the OSPAR Strategy should ensure that the radiation doses attributable to the operations at Sellafield and other nuclear facilities are even further reduced in future years. The rate of reduction in radiation doses will be influenced by the remobilisation of radionuclides bound to sediments in the Irish Sea. The Institute takes the view that the very highest possible standards of safety and waste management should apply to nuclear facilities including the implementation of best available techniques for the further reduction of discharges with a view to minimising their environmental impact.*

## 1. Introduction

This report presents the results of the marine radioactivity monitoring programme carried out by the Radiological Protection Institute of Ireland (RPII) during 2000 and 2001. The primary objective of the monitoring programme is to assess the exposure to the Irish population resulting from radioactive contamination of the Irish marine environment and to estimate the associated risks to health. In addition, the programme aims to assess the distribution of contaminating radionuclides and to identify long-term trends. The programme involves the routine sampling of and testing for radioactivity in fish, shellfish, seaweed, sediments and seawater. The Institute is assisted in the collection of samples by the Marine Institute and the Department of Communications, Marine and Natural Resources.

In recent decades Irish coastal waters have been influenced by a number of artificial sources. These include discharges from nuclear installations, fall-out from the Chernobyl accident in 1986, atmospheric nuclear weapons testing during the 1950s and 1960s and discharges to sewage from some hospitals of radionuclides used for medical purposes. The most significant of these sources is the discharge of low-level radioactive waste from the British Nuclear Fuels plc (BNFL) nuclear fuel reprocessing plant situated at Sellafield in Cumbria in 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. In 2001, the Institute completed work on a marine research project partially funded by European Union structural funds under the inter-regional provisions. The project title was *Atlantic Hydrology Modelling and Radionuclide Tracer Network*. The principal objective of the project was to bring together a number of groups with skills and expertise in oceanography, hydrodynamic modelling and marine radioecology to study water circulation and radionuclide distribution in the Irish Sea, Celtic Sea, western Channel and the adjacent Atlantic.

In 2000, the Institute commenced work on a project focusing on the remobilisation of radionuclides from the seabed. The project, which is called *REMOTRANS*, is partially funded by the European Union and involves 12 laboratories in eight countries. The results and conclusions of this project will provide a more precise description of the long-term implications of past and present radioactive discharges for the environment and for man. The results will be particularly valuable in providing an improved understanding of the consequences of past discharges from Sellafield to the Irish Sea, a significant proportion of which have accumulated on seabed sediments and are now being slowly released back into the water column.

## 2. Sources of Radioactivity in the Irish Marine Environment

The most significant source of radioactive contamination in the Irish Sea is the discharge of low-level liquid waste from BNFL's nuclear fuel reprocessing plant situated at Sellafield. Activities at Sellafield include reprocessing, spent fuel storage, vitrification of high-level radioactive wastes, decommissioning of obsolete plants, the generation of nuclear power, the fabrication of mixed oxide (MOX) fuel for nuclear reactors and the storage of reprocessed plutonium. Radioactive wastes resulting from these operations are treated to reduce their radioactivity concentration and are then discharged to the Irish Sea. These discharges are authorised within prescribed limits by the UK Environment Agency. The Sellafield marine discharge data including discharge limits for 1999, 2000 and 2001 are presented in Table 1 [MAFF and SEPA, 2000; MAFF and SEPA, 2001, MAFF and SEPA, 2002].

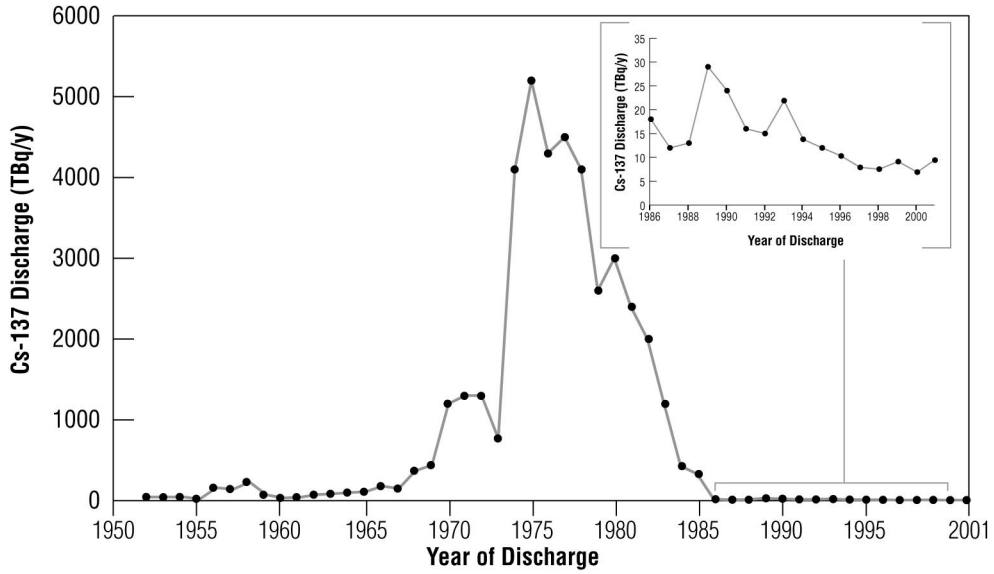


**Figure 1.** Marine Discharges of Caesium-137 from Sellafield, 1952-2001

Discharges from Sellafield to the marine environment began in the early 1950s and were relatively low until the early to mid-1970s, when considerably larger discharges occurred [Gray *et al.*, 1995]. Discharges then decreased during the late 1970s and early 1980s when the practice of discharging the so-called medium active concentrate (MAC) and cooling pond water directly to sea was halted. The commissioning of the Site Ion Exchange Effluent Plant (SIXEP) and the Salt Evaporator waste treatment facility resulted in a substantial reduction in discharges in the mid-1980s. The discharges of the radionuclide caesium-137 between 1952 and 2001 are illustrated in Figure 1. In addition to current discharges, the remobilisation from sediments of historic discharges is now an important source of caesium-137 particularly for the seawater of the western Irish Sea [MAFF and SEPA, 1998; Hunt and Kershaw, 1990].

Annual marine discharges of technetium-99 from the Sellafield site have increased significantly since 1994, peaking in 1995. This is clearly seen in Figure 2, which shows annual discharges of technetium-99 as compared with caesium-137 for the period 1990 to 2001. While it is convenient to represent such discharges averaged over a year, actual discharges vary throughout the year. The increased discharges of technetium-99 are due mainly to the processing of a backlog of liquid waste through the Enhanced Actinide Removal Plant (EARP) at Sellafield. This liquid waste had been accumulated in storage tanks on site since the early 1980s and contained a range of long-lived

radionuclides including technetium-99 and the isotopes of plutonium. EARP, which is designed to reduce the concentrations of nuclides such as the isotopes of plutonium in effluent discharged to the Irish Sea, is ineffective at removing technetium. Hence the processing of this waste backlog has resulted in a large increase in the quantities of technetium discharged.

Fall-out from nuclear weapons testing, most of which was carried out during the 1950s and 1960s, has also resulted in radioactive contamination of the marine environment. The longer lived radionuclides resulting from these tests, such as tritium (hydrogen-3), carbon-14, strontium-90, caesium-137 and plutonium-238,239,240, have contributed to the inventory of artificial radioactivity in the Irish marine environment.

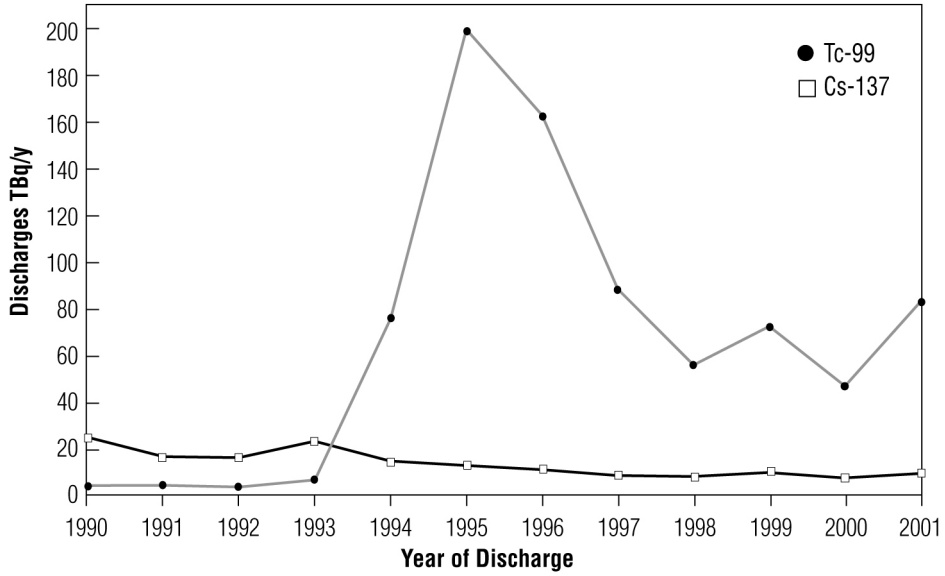


**Figure 2.** Marine Discharges of Technetium-99 and Caesium-137 from Sellafield, 1990-2001

Radionuclides such as iodine-131 are used for medical and scientific research purposes and give rise to discharges from hospitals to sewage. As these radionuclides are predominantly short-lived, their contribution to the inventory of artificial radionuclides in the marine environment is small.

Radioactivity in the marine environment is dominated by sources of natural origin. The activity concentrations of some of the naturally occurring radionuclides most commonly found in seawater are summarised in Table 2 [Walker and Rose, 1990]. Of these, polonium-210 is known to make the most significant contribution to radiation exposure through the consumption of marine foodstuffs [Pollard *et. al.,* 1998].

Potassium-40, a naturally occurring radionuclide, is present in relatively large activity concentrations in the marine environment. However it is controlled by homeostatic processes in the human body [Eisenbud and Gessell, 1997] and its equilibrium activity concentration in the body is normally independent of the amount consumed. Therefore, while the activity concentrations of this radionuclide in seafood are considerably higher than many other natural radionuclides, its presence does not result in an increased radiological hazard.

## The OSPAR Strategy

In July 1998 at Sintra, Portugal, the Contracting Parties to the Convention for the Protection of the Marine Environment of the North-East Atlantic (the OSPAR Convention) adopted the following objective strategy for the purposes of directing the future work of the Commission with regard to

radioactive substances. The objective is to prevent pollution of the maritime area from ionising radiation through progressive and substantial reductions of discharges, emissions and losses of radioactive substances, with the ultimate aim of concentrations in the environment near background values for naturally occurring radioactive substances and close to zero for artificial radioactive substances. In achieving this objective, the following issues should, *inter alia*, be taken into account: legitimate uses of the sea, technical feasibility and radiological impacts on man and biota.

It was agreed that the Strategy would be implemented in accordance with the following time frame:

- By the year 2000 the Commission will, for the whole maritime area, work towards achieving further substantial reductions or elimination of discharges, emissions and losses of radioactive substances.

- By the year 2020 the Commission will ensure that discharges, emissions and losses of radioactive substances are reduced to levels where additional concentrations in the marine environment above historic levels, resulting from such discharges, emissions and losses, are close to zero.

The Institute has assisted the Nuclear Safety Division of the Department of the Environment and Local Government to develop Ireland's 'National Implementation Plan' to deal with the implementation of the OSPAR Strategy in an Irish context. It is a requirement of all Contracting Parties to develop such national plans. While Ireland has no nuclear industry, small quantities of radioactive substances are discharged to the Irish marine environment, predominantly by the medical sector. The use of such unsealed sources is controlled by licence. Licences are issued by the Institute and have conditions attached which are specific to each licensee.

As part of a schedule for the implementation of the Strategy, the Institute has completed a review of the use of unsealed sources of radioactivity in Ireland. The radionuclides used in largest amounts and which are discharged to the marine environment are technetium-99m and iodine-131. As a consequence of the review, stricter conditions attaching to licences permitting the use and discharge of liquid radioactive waste are being implemented. The only radionuclide present in measurable amounts in the marine environment is iodine-131. Issues such as the possible installation of sewage holding tanks in hospitals have been identified as needing further evaluation. These have been scheduled for decision upon completion of the necessary scientific studies.

## 3. Methods of Sampling and Analysis

### Sampling

During 2000 and 2001 fish and shellfish were routinely collected from commercial landings at major Irish fishing ports. Particular attention was given to collecting samples from the 'north-east' ports of Carlingford, Clogherhead and Howth where the highest levels of contamination are usually found due mainly to the water circulation patterns in the Irish Sea. Sampling expeditions in 2001 were somewhat curtailed as a matter of good practice during the 'foot and mouth' alert. Seawater, sediment and seaweed were also collected from coastal sites and seawater and sediment samples were taken at offshore sites in the western Irish Sea. The Marine Institute's research vessel, the RV *Celtic Voyager*, together with the Commissioners of Irish Lights' vessel, ILV *Granuaile*, were used for offshore sample collection. The coastal sampling sites are shown in Figure 3 and offshore locations in Figure 4. The offshore location co-ordinates are listed in Table 3. Sampling locations together with the range of samples collected at each location are given in Table 4. The sampling frequency for each site reflects the resolution judged to be necessary to assess the population dose and to identify important trends.

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 fish landings and are the more common species consumed by members of the Irish public. The shellfish species routinely monitored were prawns (*Nephrops norvegicus*), mussels (*Mytilus edulis*), lobster (*Homarus gammarus)* and oysters (*Crassostrea gigas*). While Institute staff carried out most of the sampling operations, Sea Fisheries Officers of the Department of Communications, Marine and Natural Resources assisted in the sampling along the south and west coasts.

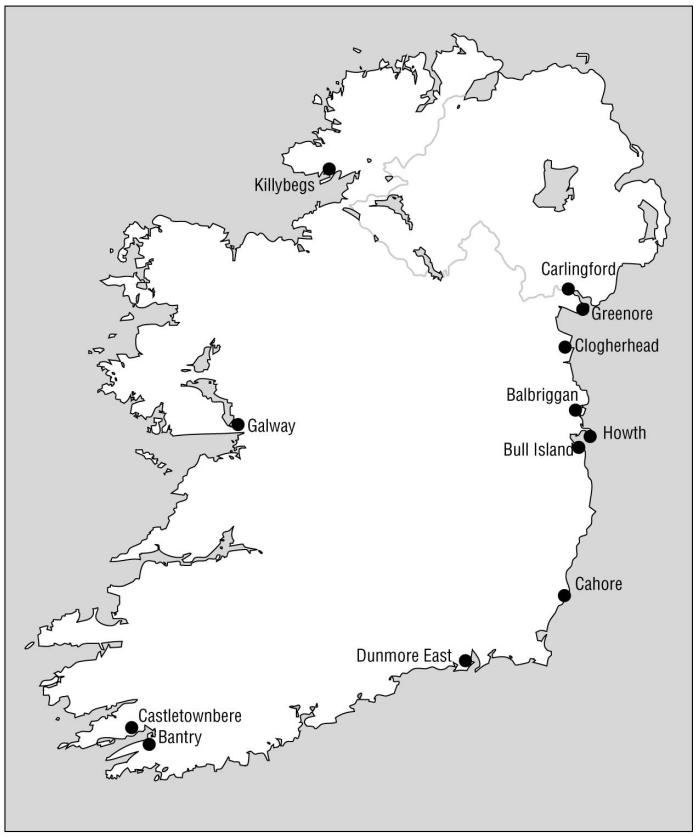


**Figure 3.** Main Coastal Sampling Locations

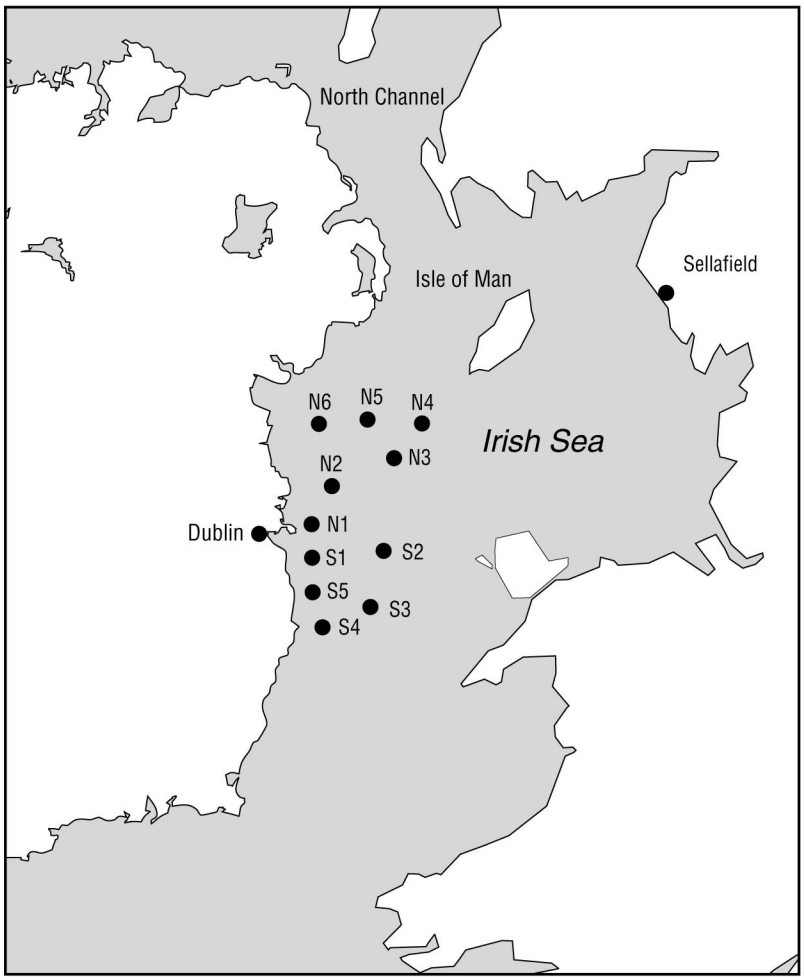


**Figure 4.** Sampling Locations in the Irish Sea

## Analysis

Initial preparation of samples included cleaning fish and shellfish and separation of the edible portion for analysis. Seaweed samples were washed to remove all sediment and other extraneous material. Fish, shellfish, seaweed and sediment samples were then dried to constant weight, pulverised and thoroughly mixed. Samples were analysed individually for caesium-137 and other gamma-emitting radionuclides. Selected individual and bulked samples were analysed for carbon-14, technetium-99, plutonium-238 and plutonium-239,240. Americum-241 activity concentrations were estimated using mean americium/plutonium ratios in fish, prawns and mussels [Ryan *et al*., 1999]. Radio-analytical measurement techniques are summarised in Table 5.

All results are quoted as activity concentrations in Bq/kg or mBq/l and are decay corrected to the date of sampling. Where activity concentrations are quoted as Bq/kg, they are expressed either on a wet weight (wet) or dry weight (dry) basis. Bulked samples are decay corrected to the middle of the bulking period. Approximate detection limits under typical analytical conditions are 0.1 Bq/kg for technetium-99, 1.0 Bq/kg for carbon-14 and iodine-131, 0.3 Bq/kg for caesium-137, 0.001 Bq/kg for plutonium-238 and plutonium-239,240. Under typical counting conditions, expanded uncertainties ($k$=2) on gamma and alpha spectrometry and carbon-14 measurements are 15% or better. The expanded uncertainties for technetium-99 measurements are 10% or better except in fish where they are typically 30%. Activity concentration ranges and means discussed in the text relate to samples where activities were actually detected.

The Institute's radio-analytical laboratory implements a comprehensive quality assurance system and holds accreditation from the Irish National Accreditation Board for a broad range of tests [NAB, 2002]. Analytical techniques are validated both through participation in intercomparison exercises and by analysis of certified reference materials.

## 4. Radioactivity Concentrations

### Seawater

All seawater samples were analysed for caesium-137 and a selected number were analysed for technetium-99. The results for coastline seawater are presented in Table 6 and the mean activity concentrations of caesium-137 are presented in Figure 5. In 2000 the mean annual activity concentrations of caesium-137 in coastline seawater samples ranged from 2 mBq/l at Killybegs to 32 mBq/l at Greenore. The maximum activity concentration recorded was 35 mBq/l in Greenore in November 2000. In 2001 the mean activity concentrations of caesium-137 in coastline seawater ranged between 4 mBq/l at Cahore to 16 mBq/l at Greenore. The maximum activity concentration recorded that year was 17 mBq/l in seawater from Greenore in February and September.

Caesium-137 activity concentrations in offshore samples from the western Irish Sea in 2000 ranged from 17 mBq/l at location S2, south-east of Dublin, to 35 mBq/l at locations N1 and N2 between Dundalk Bay and the Isle of Man (Table 7). In 2001 the activity concentrations in offshore seawater ranged from 9 mBq/l recorded at locations N1 and N6 to 15 mBq/l at location N5. The offshore locations south of Dublin were not sampled in 2001.

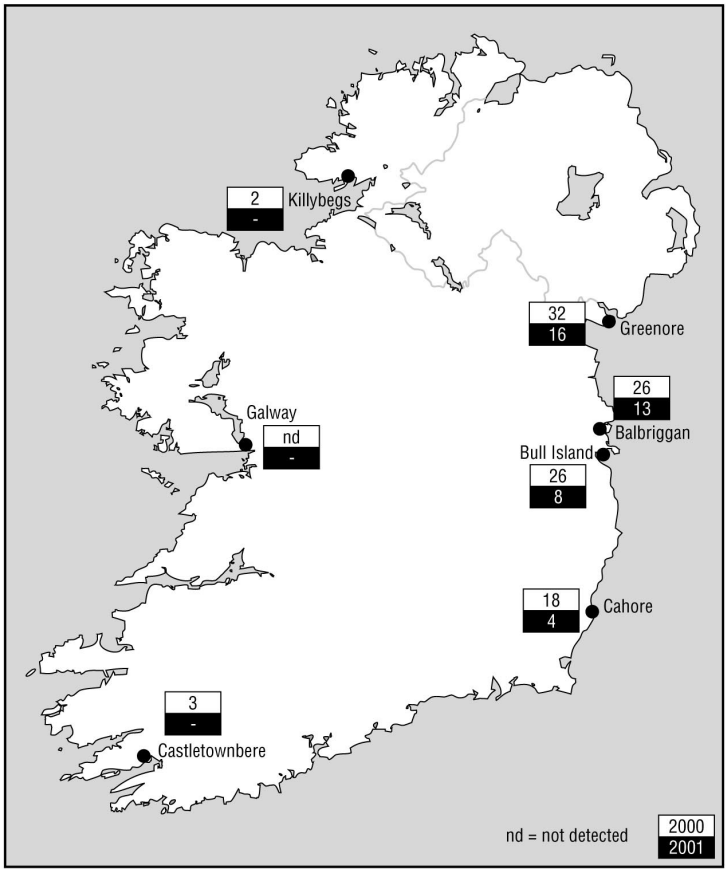


**Figure 5.** Mean Caesium-137 Activity Concentrations in Coastline Seawater (mBq/l), 2000 and 2001

Figure 6 illustrates the trend observed in caesium-137 activity concentrations in seawater at locations N1-N6 inclusive since 1985. Since the mid-1990s caesium-137 activity concentrations in the western Irish Sea had remained essentially stable until 2001 when a notable decrease was observed. Further work is required to clarify if this reduction is due to variations in discharge rates, remobilisation rates or other factors. It has been established that remobilisation from sediments of historic discharges is now an important source of caesium-137 in seawater from the western Irish Sea [MAFF and SEPA, 1998; Hunt and Kershaw, 1990]. As a consequence, the rate of reduction in caesium-137 activity concentrations in seawater has been slower than might have been expected. The caesium-137 activity concentrations measured along the south and west coasts in 2000 and 2001 were similar to those measured in the periods 1998 and 1999 [Ryan *et al*., 2000].

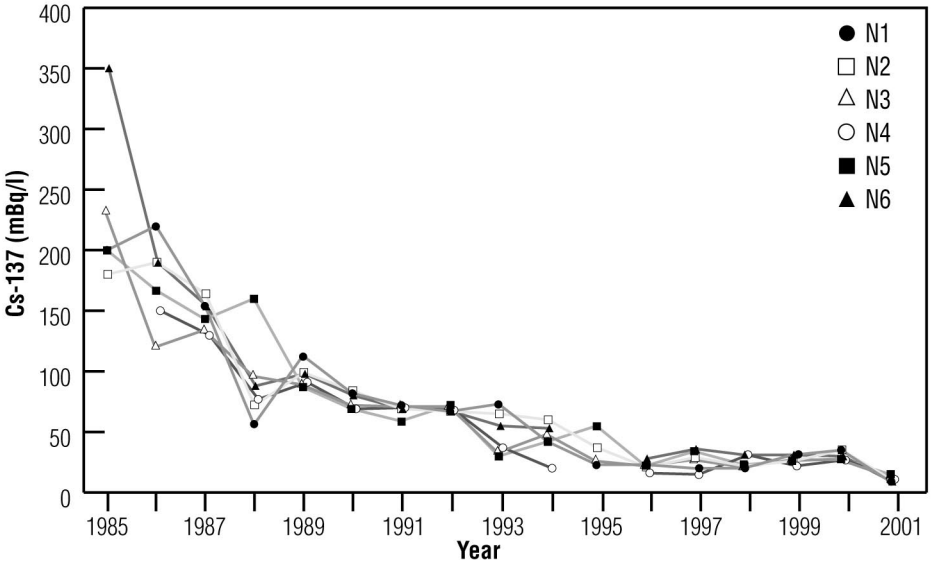


**Figure 6.** Caesium-137 in Seawater from Locations N1-N6 in the Irish Sea (mBq/l), 1985-2001

In 2000 the mean activity concentration of technetium-99 in coastline seawater samples ranged from 0.2 mBq/l at Castletownbere to 17 mBq/l at Balbriggan. The maximum activity concentration recorded in 2000 was 23 mBq/l at Balbriggan in August. The mean activity concentration measured in offshore samples from the western Irish Sea north of Dublin was 25 mBq/l. In 2001 the mean activity concentration of technetium-99 measured in coastline seawater samples from Balbriggan was 10 mBq/l with a maximum activity concentration of 14 mBq/l at Balbriggan in June. The mean activity concentration measured in offshore samples from the western Irish Sea north of Dublin was 16 mBq/l. The activity concentrations of technetium-99 measured in seawater samples from the south and west coasts remain close to the limit of detection.

## Sediment

Sediment samples were analysed for caesium-137 and other gamma emitting radionuclides. The results are presented in Tables 8 and 9 and the mean activity concentrations in coastline sediments for 2000 and 2001 are shown in Figure 7. In 2000, the mean activity concentrations of caesium-137 in east coast sediments ranged from 0.8 Bq/kg (dry) at Cahore to 10.0 Bq/kg (dry) at Balbriggan. The maximum activity concentration recorded was 11.7 Bq/kg (dry) at Balbriggan in March. In 2001 the mean activity concentrations of caesium-137 in east coast sediments ranged from 0.6 Bq/kg (dry) at Cahore to 9.3 Bq/kg (dry) at Balbriggan. The maximum activity concentration recorded was 11.7 Bq/kg (dry) at Balbriggan in March.

In 2000 the activity concentrations of caesium-137 in offshore sediment samples from the western Irish Sea ranged from 0.8 Bq/kg (dry) at location S3 south-east of Dublin to 96.7 Bq/kg (dry) at location N5 which is between Dundalk Bay and the Isle of Man. In 2001 the activity concentrations of caesium-137 in offshore samples from the western Irish Sea ranged from 39.2 Bq/kg (dry) at location N6 to 79.8 Bq/kg (dry) at location N5. The offshore locations south of Dublin were not sampled in 2001.

The activity concentrations of caesium-137 in sediment from the south and west coasts were all less than 1 Bq/kg (dry). These activity concentrations are similar to those measured during 1998 and 1999 [Ryan *et al.,* 2000]. All other artificial gamma emitting radionuclides were below the detection limit.

The relatively high activity concentrations of caesium-137 measured in sediments from locations between Dundalk Bay and the Isle of Man (N3 – N6 inclusive) are associated with areas of mud and silt accumulation which tend to concentrate radionuclides to a greater degree as has been previously observed in the Irish marine environment [Ryan *et al*., 1996].

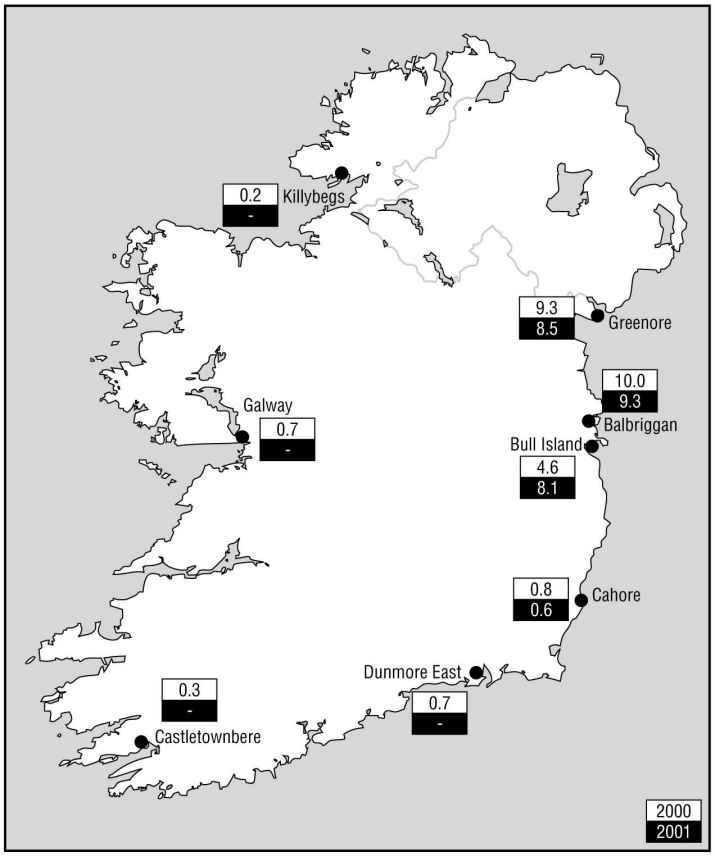


**Figure 7.** Mean Caesium-137 Activity Concentrations in Coastline Marine Sediments (Bq/kg, dry), 2000 and 2001

## Seaweed

The mean activity concentrations of caesium-137 and technetium-99 in seaweed for 2000 and 2001 are presented in Figures 8 and 9. The detailed results are given in Tables 10 and 11. All results are presented on a dry weight basis and an estimate of the wet weight activity concentration may be obtained using the mean dry to wet weight ratio of 0.19 established during 2000 and 2001.

In 2000, the mean caesium-137 activity concentration in seaweed (*Fucus vesiculosus*) from the Irish Sea coastline ranged from 1.2 Bq/kg (dry) at Cahore to 5.8 Bq/kg (dry) at Greenore. The maximum activity concentration recorded was 7.3 Bq/kg (dry) at Balbriggan in August. In 2001 the mean caesium-137 activity concentrations ranged from 2.4 Bq/kg (dry) at Bull Island to 4.0 Bq/kg (dry) at Greenore. The maximum activity concentration recorded was 4.5 Bq/kg (dry) at Greenore in June. Caesium-137 activity concentrations in seaweed sampled from Balbriggan, as with seawater, have remained relatively constant since the mid 1990s with slightly lower concentrations noted in 2001 (Figure 10).

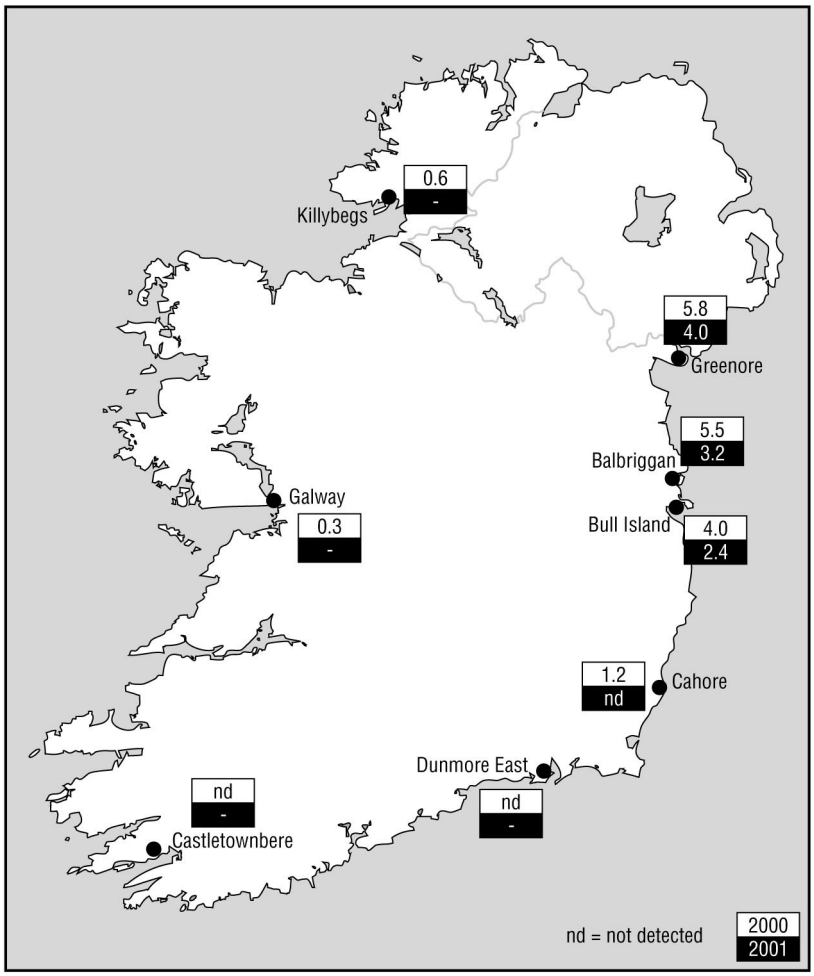


**Figure 8.** Mean Caesium-137 Activity Concentrations in *Fucus vesiculosus* (Bq/kg, dry), 2000 and 2001

During 2000 the mean activity concentration of technetium-99 measured in seaweed from the Irish Sea coastline ranged from 683 Bq/kg (dry) at Cahore to 3905 Bq/kg (dry) at Greenore. The maximum activity concentration recorded was 5613 Bq/kg (dry) at Greenore in February. In 2001 the mean activity concentration of technetium-99 in seaweed ranged between 264 Bq/kg (dry) at Cahore and 2772 Bq/kg (dry) at Greenore. The maximum activity concentration recorded was 3945 Bq/kg (dry) at Balbriggan in February. Activity concentrations measured in samples collected from the south and west coasts were significantly lower. Technetium-99 activity concentrations in seaweed from Balbriggan and Greenore for the period June 1988 to December 2001 are shown in Figure 11. These data demonstrate that technetium-99 activity concentrations in seaweed from the north-east coastline peaked between late 1997 and early 1998.

Iodine-131 is discharged to sewage systems primarily as a result of its use in medical procedures. In 2000 the mean activity concentration for this radionuclide in samples from Bull Island was 47 Bq/kg (dry) while individual measurements ranged from 29.6 Bq/kg (dry) to 82.9 Bq/kg (dry). In 2001 the activity concentrations of iodine-131 in seaweed from Bull Island ranged between 9.1 Bq/kg (dry) and 80.0 Bq/kg (dry). These data are presented in Tables 10 and 11.Variations of this nature are expected due to the intermittent use of the radionuclide in medical procedures and its dilution following discharge. Figure 12 clearly indicates this variability as observed in samples of *Fucus vesiculosus* collected from Bull Island between 1993 and 2001.

All other artificial gamma emitting radionuclides were below the detection limits

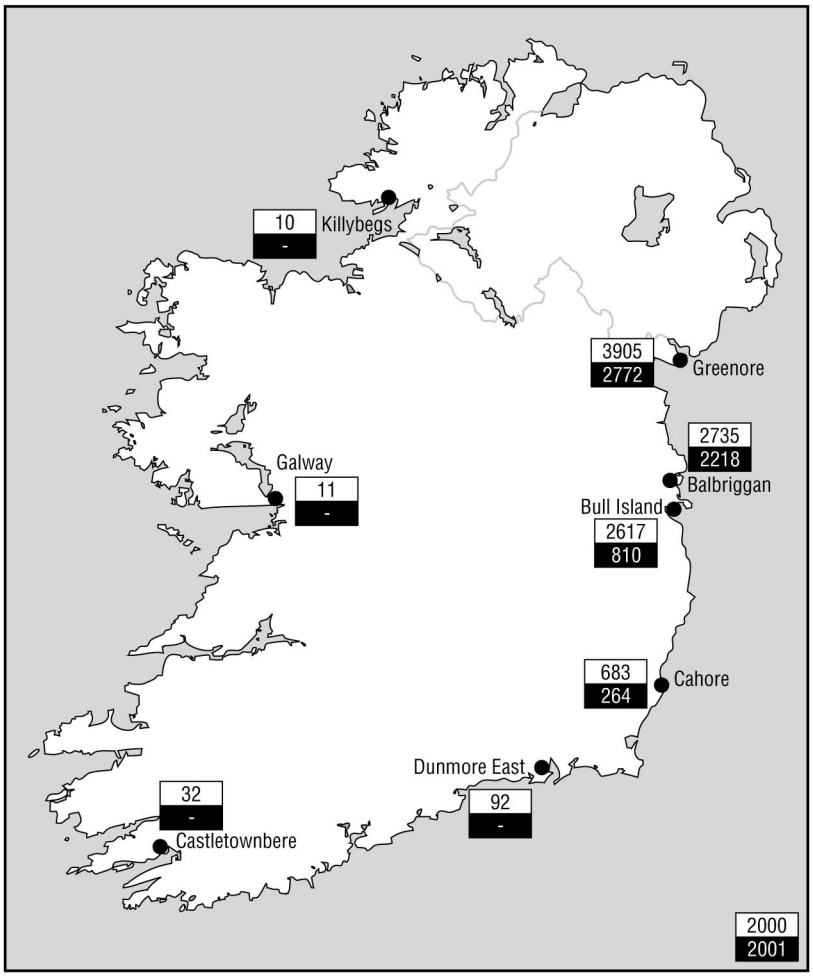


**Figure 9.** Mean Technetium-99 Activity Concentrations in *Fucus vesiculosus* (Bq/kg, dry), 2000 and 2001

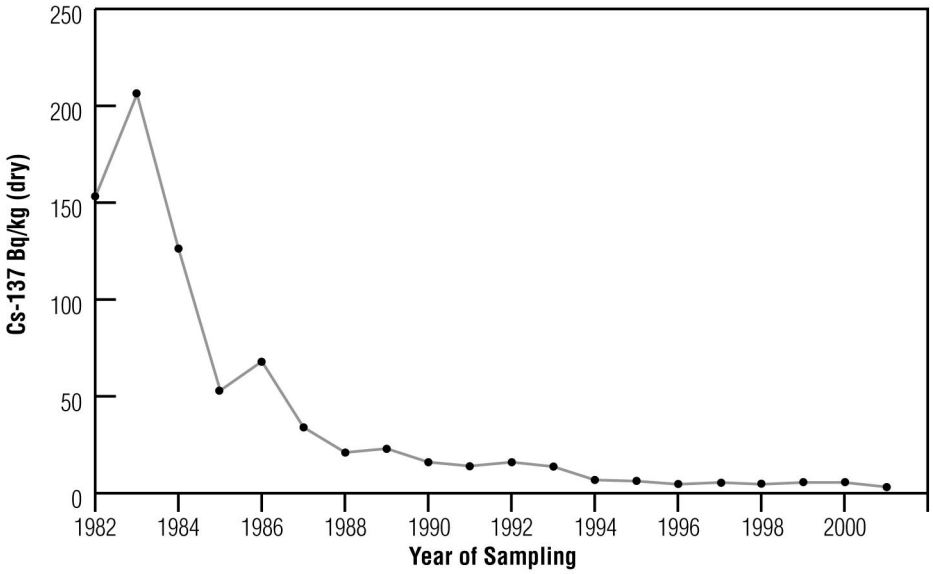


**Figure 10.** Mean Caesium-137 Activity Concentrations in *Fucus vesiculosus* at Balbriggan (Bq/kg, dry), 1982-2001

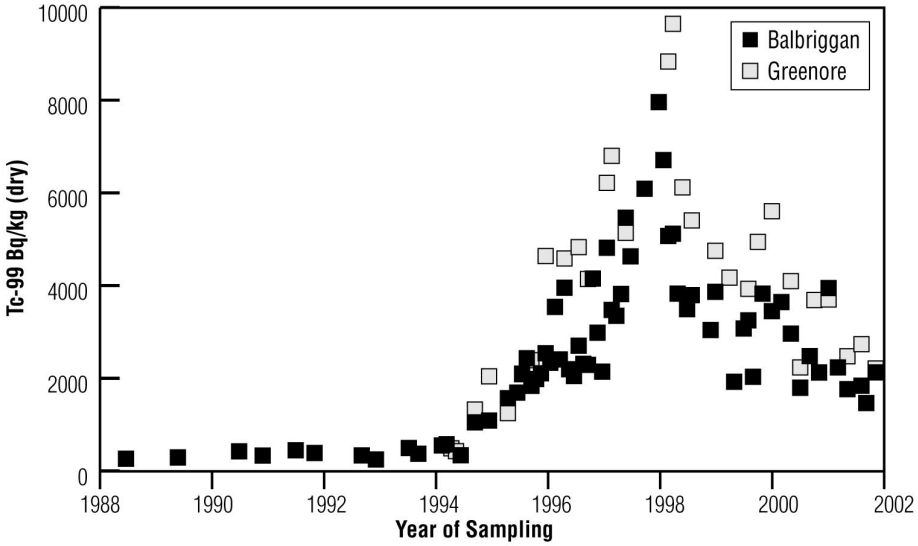


**Figure 11.** Technetium-99 Activity Concentrations in *Fucus vesiculosus* from Balbriggan and Greenore (Bq/kg, dry), 1988 - 2001

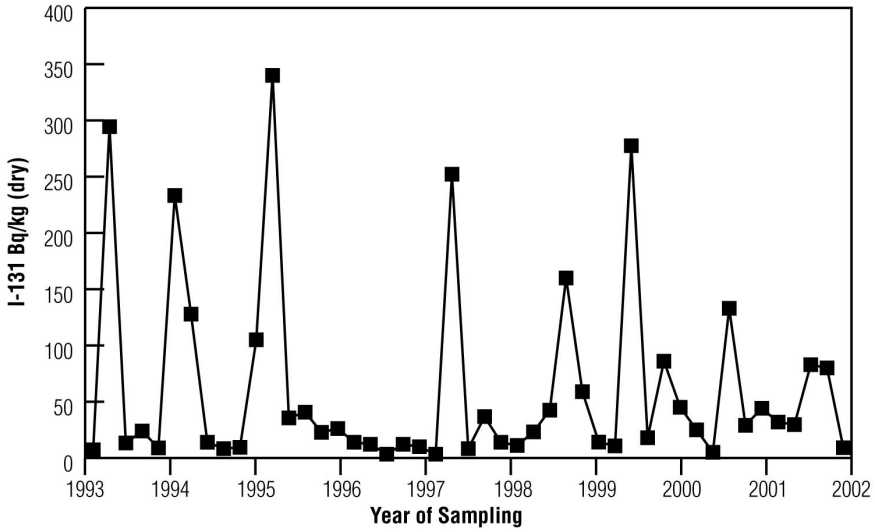


**Figure 12.** Iodine-131 Activity Concentration in *Fucus Vesiculosus* from Bull Island, 1993-2001

## Fish and Shellfish

Fish and shellfish samples were analysed for caesium-137 and other gamma emitting radionuclides and a selected number of individual and bulked samples were analysed for carbon-14, technetium-99, plutonium-238 and plutonium-239,240. The results of measurements on fish are presented in Tables 12 to 17 and those for shellfish in Tables 18 to 24. The mean caesium-137 activity concentrations in fish for 2000 and 2001 are presented in Figure 13.

The mean caesium-137 activity concentrations measured in fish landed at the north-east ports in 2000 and 2001 were 0.7 Bq/kg (wet) and 0.8 Bq/kg (wet) respectively. These concentrations are similar to the 1999 figure of 0.8 Bq/kg (wet). The mean caesium-137 activity concentrations measured in prawns landed at north-east coast ports in 2000 and 2001 were 1.0 Bq/kg (wet) and 0.8 Bq/kg (wet), respectively. The mean activity concentrations of caesium-137 measured in mussels from north-east ports in 2000 and 2001 were 0.4 Bq/kg (wet) and 0.3 Bq/kg (wet), respectively. Mean caesium-137 activity concentrations in oysters from Carlingford in 2000 and 2001 were 0.3 Bq/kg (wet) and 0.2 Bq/kg (wet), respectively.

All other artificial gamma emitting radionuclides were below detection limits.

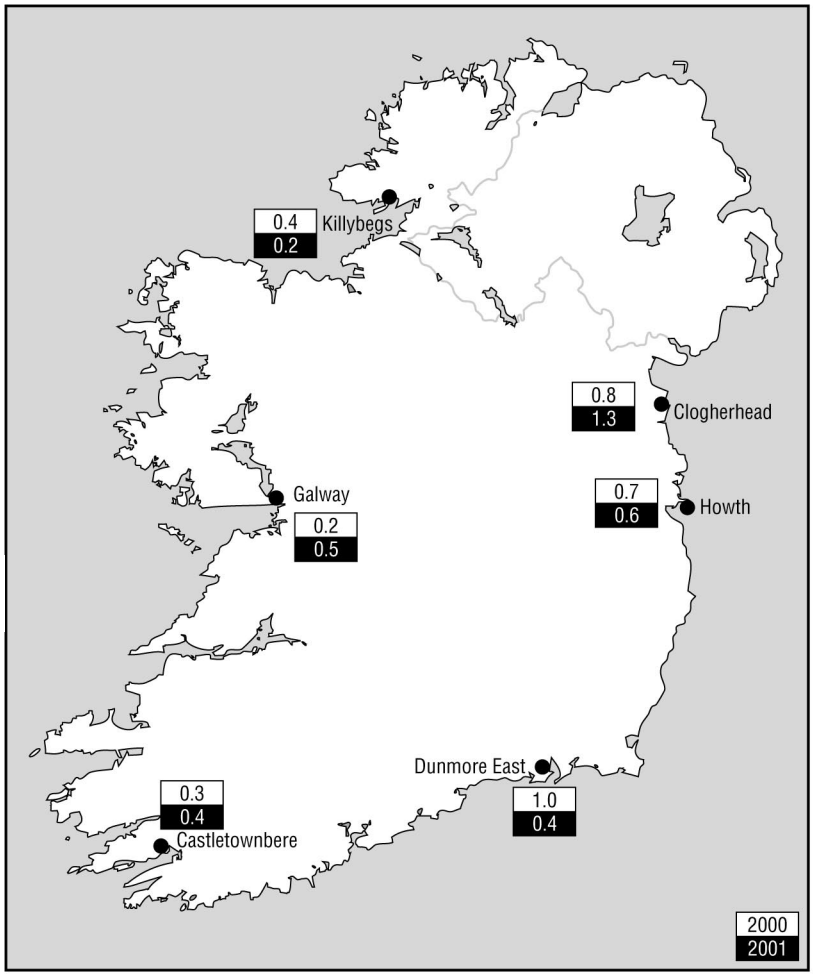


**Figure 13.** Mean Caesium-137 Activity Concentrations in Fish Landed at Irish Ports (Bq/kg, wet), 2000 and 2001

The mean measured activity concentrations of technetium-99 in fish, prawns and mussels landed at north-east ports during 2000 were 0.4 Bq/kg (wet), 85 Bq/kg (wet) and 24 Bq/kg (wet), respectively. In 2001 these mean activity concentrations were 0.5 Bq/kg (wet), 29 Bq/kg (wet) and 30 Bq/kg (wet) respectively. Activity concentrations were generally observed to be higher in lobsters and prawns than in mussels and higher in mussels than in fish which is consistent with the higher concentration factor reported for this radionuclide for shellfish [IAEA, 1985]. For lobster, the species with the highest concentration factor for technetium-99, the mean activity concentration measured in north-east coast landings was 42 Bq/kg (wet) in 2000 and 107 Bq/kg (wet) in 2001. The highest individual observation for lobster in 2000 was 47 Bq/kg (wet) for a sample landed at Carlingford in August. In 2001 the highest individual observation was 322 Bq/kg (wet) for a sample landed at Howth in March.

In 2000 total carbon-14 activity concentrations in fish ranged between 19.2 Bq/kg (wet) in a composite sample of whiting landed at Howth and 32.4 Bq/kg (wet) in a composite sample of plaice landed at Clogherhead. Mean activity concentrations of carbon-14 in mussels and oysters landed at Carlingford were 20.0 Bq/kg (wet) and 24.3 Bq/kg (wet), respectively. In 2001 total carbon-14 activity concentrations in fish ranged between 25.5 Bq/kg (wet) in a composite sample of whiting landed at Howth and 35.7 Bq/kg (wet) in a composite sample of plaice landed at Clogherhead. Mean activity concentrations in mussels and oysters landed at Carlingford were 27.3 Bq/kg (wet) and 22.6 Bq/kg (wet), respectively. The magnitude of the Sellafield contribution to these activities is masked by the presence of carbon-14 of natural origin and from weapons fall-out.

Plutonium-238 was below the detection limit in all but one of the fish samples analysed in 2000 and 2001. The mean measured activity concentration of plutonium-239,240 in fish landed at north-east Irish ports was 0.0002 Bq/kg (wet) in 2000 and 0.0005 Bq/kg (wet) in 2001. The corresponding plutonium-238 values were 0.0026 Bq/kg (wet) in prawns in 2000 and 0.010 Bq/kg (wet) in 2001, while mean activity concentrations of plutonium-239,240 in prawns were 0.014 Bq/kg (wet) in 2000 and 0.045 Bq/kg (wet) in 2001. The mean activity concentrations of plutonium-238 and plutonium-239,240 in mussels in 2000 were 0.016 Bq/kg (wet) and 0.095 Bq/kg (wet) respectively. In 2001 these were 0.015 Bq/kg (wet) and 0.076 Bq/kg (wet) respectively. In 2000, mean plutonium-238 and plutonium-239,240 activity concentrations in oysters from Carlingford were 0.011 Bq/kg (wet) and 0.059 Bq/kg (wet) respectively. In 2001 these were 0.008 Bq/kg (wet) and 0.045 Bq/kg (wet) respectively. The activity concentrations for these radionuclides in fish and shellfish are similar to those reported for the 1999 monitoring period [Ryan *et al*., 2000].

## External Dose rates

During 2000 and 2001, external ambient gamma dose rate readings were taken at 11 locations around the country and these data are presented in Table 25 with mean values presented in Figure 14. These measurements take account of all sources of ambient gamma radiation of which natural radionuclides and cosmic radiation are the dominant components. The mean dose rates were found to range between 0.052 μGy per hour at Bull Island in 2001 and 0.086 μGy per hour at Galway in 2000.

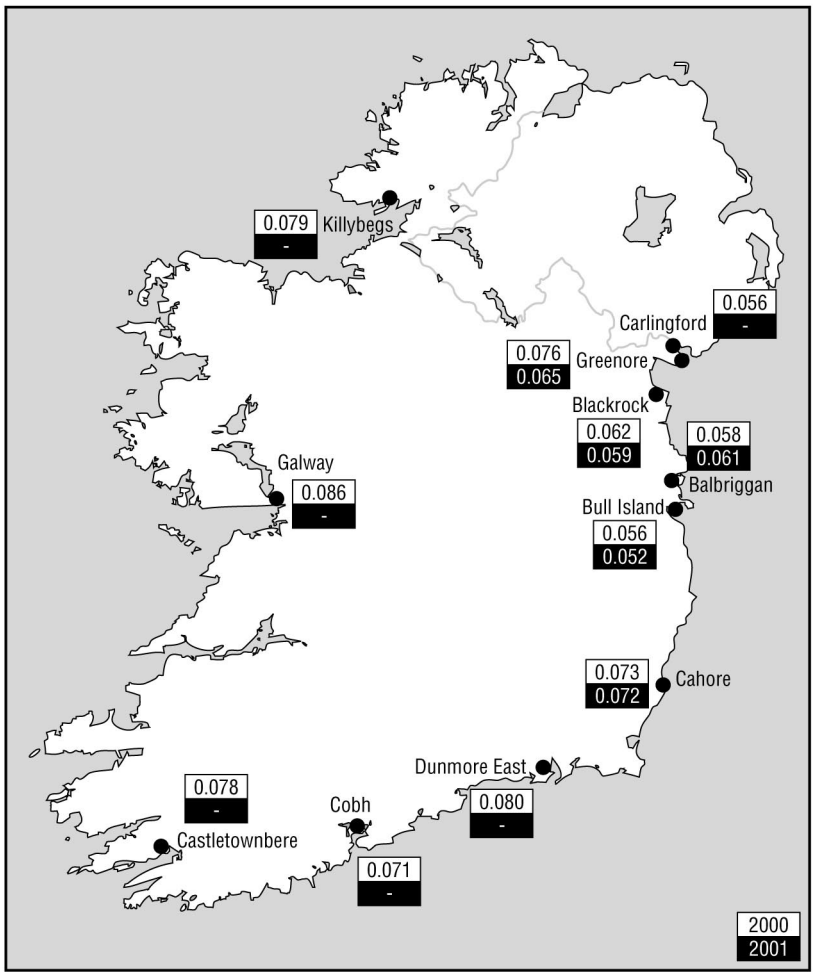


**Figure 14.** Mean External Dose Rate Measurements (μGy/h), 2000 and 2001

## 5. Assessment of Radiation Exposure

## The Ingestion Pathway

*Committed Effective Dose*

The committed effective dose due to the consumption of seafood was estimated for typical and heavy consumers using the following dose model:

$$dose = [mean\ activity\ concentration] \times [annual\ consumption\ rate] \times [dose\ conversion\ factor]$$

The mean activity concentrations for artificial radionuclides in fish, crustaceans and molluscs from north-east ports for 2000 and 2001 are presented in Tables 26 and 27. The consumption rates used were considered to be a conservative representation 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. Shellfish consumption was assumed to be divided equally between crustaceans and molluscs and activity concentrations in prawns and mussels were considered to be representative of crustaceans and molluscs, respectively. Dose conversion factors used were those recommended by ICRP 72 [ICRP, 1996(a)] as presented in Table 28.

The committed effective doses by radionuclide for typical and heavy consumers of seafood landed at north-east ports for 2000 and 2001 are given in Table 29. The total doses for 2000 were estimated to be 0.27 microsievert (μSv) and 1.17 μSv to typical and heavy consumers, respectively. Similarly in 2001 these doses were 0.26 and 1.20 μSv to typical and heavy consumers, respectively. These doses include contributions from technetium-99, caesium-137, plutonium-238,239,240 and americium-241. For example, the doses due to the ingestion of caesium-137 to typical and heavy consumers in 2000 were 0.15 μSv and 0.73 μSv, respectively and in 2001 were 0.16 μSv and 0.81 μSv, respectively.

These doses may be compared with those attributable to the presence in seafood of the naturally occurring radionuclide, polonium-210, which were estimated to be 32 μSv and 148 μSv for typical and heavy consumers, respectively [Pollard *et al.,* 1998]. The doses from artificial radionuclides may also be compared with the annual dose limit of 1000 μSv for members of the public from practices involving controllable sources of radiation [EC, 1996]. Thus, during 2000 and 2001, typical and heavy consumers would have received about 0.03% and 0.12% of this limit, respectively, in each year.

Comparison can also be made with the annual average dose of approximately 3620 μSv from all sources of radiation received by members of the Irish public. Of this, approximately 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 those received from other sources.

Caesium-137 continues to be the dominant radionuclide, accounting for approximately 60-70% of the total dose due to artificial radionuclides in the marine environment. Although there are significantly higher activity concentrations of technetium-99 than of caesium-137 in shellfish, technetium-99 accounts for less than 30% of the dose. This is mainly because the dose received per becquerel of technetium-99 ingested is approximately 20 times less than that received per becquerel of caesium-137 ingested.

Of the dose attributable to caesium-137, approximately 90% is due to the consumption of fish. This is in contrast to the dose due to technetium-99, where approximately 90% of the dose is attributable to

consumption of shellfish reflecting the significantly higher activity concentrations of this radionuclide in crustaceans and molluscs than in fish (Tables 26 and 27). The estimated committed effective dose to heavy consumers due to radiocaesium is shown in Figure 15 for the period 1982 to 2001. A downward trend is evident during the mid to late 1980s but in recent years the decrease in dose has been less pronounced and the dose has remained essentially unchanged since 1997.

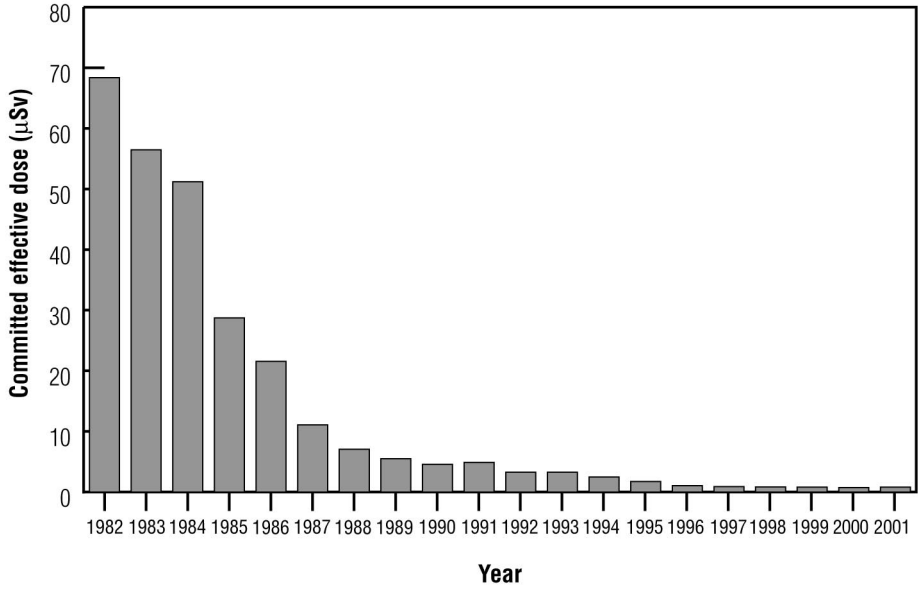


**Figure 15.** Doses to Heavy Seafood Consumers due to Radiocaesium (μSv), 1982-2001

*Collective Effective Dose*

The collective effective dose was calculated for the consumption of fish, crustaceans and molluscs landed at the north-east Irish Sea ports of Clogherhead, Skerries and Howth. The landing data were combined with the mean activity concentration for each radionuclide measured (Tables 26 and 27). The landing tonnages for fish, crustaceans and molluscs for 2000 were provided by the Department of Communications, Marine and Natural Resources [Personal Communication] and are presented in Table 30. The fractions of the landing weight consumed for fish, crustaceans and molluscs were taken to be 0.5, 0.35 and 0.15 respectively [Pentreath *et al*., 1989]. It was assumed that 20% of landings were consumed in Ireland and that the remainder was exported.

The total collective doses to the Irish population, due to caesium-137, technetium-99, plutonium-238,239,240 and americium-241, for 2000 arising from fish and shellfish landed at north-east ports was 0.017 manSv (Table 31). This dose may be compared to the collective dose to the Irish population from all sources of radiation of approximately 13 000 manSv per annum.

## External Exposure

The effective dose from beach occupancy was estimated from the caesium-137 activity concentration in inter-tidal sediments using the sandy beach model described by Hunt [1984]. It was calculated for an individual spending one hour per day in the inter-tidal zone and is based on the mean caesium-137 activity concentrations in sediments for the two sampling locations in the north-east, Balbriggan and Greenore. The dose was estimated to be approximately 0.3 μSv for both 2000 and 2001. These doses are similar in value to the annual committed dose to the typical seafood consumer from artificial radionuclides. However, in the absence of detailed habit surveys, it is assumed that the actual number

of people who spend 365 hours per year in the inter-tidal zone is considerably smaller than the number of typical seafood consumers. The ingestion pathway is therefore still considered to be the dominant one affecting the Irish public. Other external exposure pathways such as swimming in the sea or boating are considered to be of lesser significance.

The dose rate due to all radiation sources was also measured directly at locations along the coastline in 2000 and 2001 using an energy compensated Geiger Müller detector. These data are presented in Table 25. The mean dose rates measured at east coast locations during 2000 and 2001 were 0.065 μGy and 0.062 μGy per hour respectively. This is equivalent to an exposure of 0.055 μSv per hour in 2000 and 0.053μSv per hour in 2001 using a mean conversion factor of 0.85μSv per μGy for gamma rays in the energy range 0.05 MeV to 2 MeV [ICRP, 1996(b)]. This exposure is due predominantly to cosmic radiation and the presence of naturally occurring radionuclides in beach sediments and the earth's crust. An individual spending one hour per day on the beach would, therefore, have received a total dose from all radiation sources of 20 μSv in 2000 and 19 μSv in 2001 of which 0.3 μSv may be attributed to caesium-137 contamination, predominantly from Sellafield.

### Risk Estimates

Evaluation of the risks associated with radiation exposure 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 $5 \times 10^{-2}$ per sievert, i.e. there is 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 2000 and 2001 is, therefore, about 1 in 75 million to a typical Irish seafood consumer and about 1 in 17 million to a heavy consumer. These compare with a general risk of death from cancer of 1 in 479 in any year [Central Statistics Office, 1996].

## 6. Research

### Atlantic Hydrology Modelling and Radionuclide Tracer Network

The extent to which radioactivity released from the Sellafield Nuclear Fuel Reprocessing Plant into the Irish Sea is transported southwards towards the English Channel and around the south and west coasts of Ireland has not been fully studied. Similarly, much work remains to be done to evaluate the extent to which radionuclides from the La Hague reprocessing plant near Cherbourg may be transported to the south and west within the English Channel. It was in this context that the Atlantic Hydrology Modelling and Radionuclide Tracer Network was formed. The focus of the project was to bring together experts in key disciplines to discuss the issues and to share information and data. The Network was formed between the Institut de Radioprotection et de Sûreté Nucléaire (IRSN), the National University of Ireland, Galway (NUI, Galway) and the Institute. The objectives of the project were achieved through formal meetings and scientific exchanges. The formal work of the Network was completed in 2001.

## REMOTRANS

When radionuclides such as the isotopes of plutonium, caesium and technetium are discharged from nuclear facilities to the marine environment, each radionuclide behaves differently. The more soluble radionuclides such as technetium-99 are transported with the water circulation to the Irish coast and northwards out of the Irish Sea and have been detected along the Norwegian coast and in Arctic waters. Radionuclides such as plutonium-239, americium-241 and, to a lesser extent, radiocaesium tend to react with particles in the water column and are transported to the sediments of the seafloor. Once deposited on the seafloor these radionuclides may be subject to remobilisation that results in their re-introduction to the water column. The processes involved in such remobilisation are the focus of an international research project (REMOTRANS) that commenced in 2000 and runs until December 2003. The results of the project will be particularly valuable in providing an improved understanding of the consequences of the past discharges from Sellafield to the Irish Sea, a significant proportion of which have accumulated on seabed sediments and are now being slowly released back into the water column.

The Institute's main role within the project is to provide an improved estimate of the inventory of plutonium and radiocaesium in the sediments of the western Irish Sea. This is being achieved by analysis of sediment cores collected from the western Irish Sea mud patch. To date, 26 sediment cores have been collected from the western Irish Sea mud patch and analysis of them began in 2001. Initial results suggest that caesium-137 and plutonium isotopes tend to concentrate to a greater extent in areas of finer sediments (mud) compared to the surrounding sandy sediments. This can be clearly seen in Figure 16 where activity concentrations of caesium-137 in the top 2 cm of the seabed peak in the area off the north-east coast which corresponds to fine sediments.

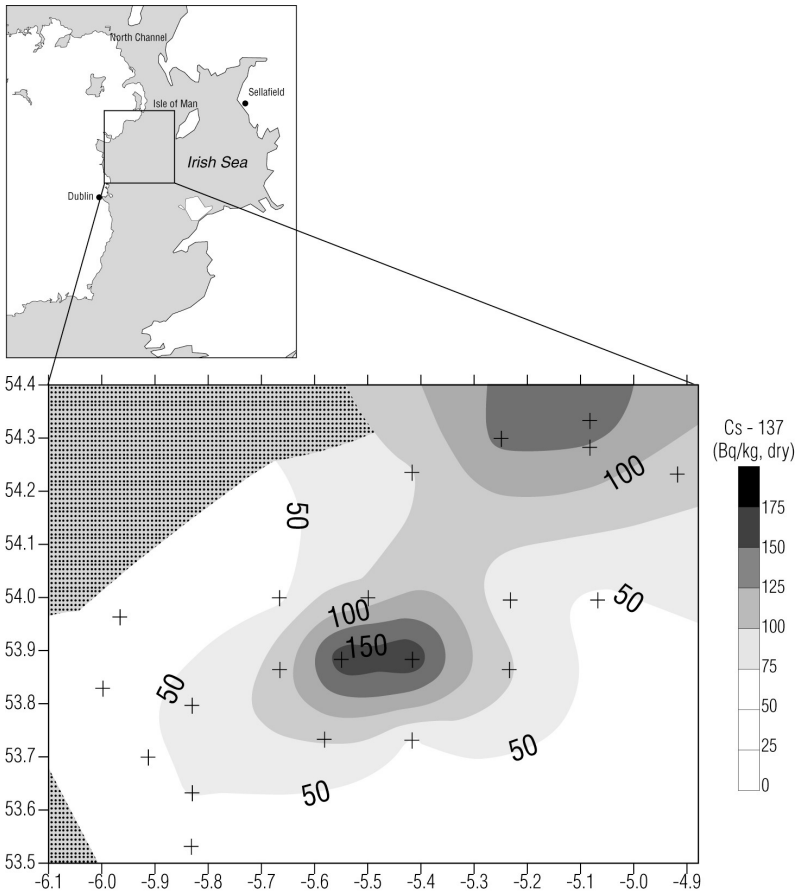


**Figure 16.** Caesium-137 Activity Concentration in the Top 2 cm of Sediments in the N.W. Irish Sea (Bq/kg, dry)

## 7. Conclusions

The consumption of fish and shellfish from the Irish Sea is the dominant pathway by which radioactive contamination of the marine environment results in radiation exposure of the Irish population. In 2000 and 2001 the committed radiation doses to a heavy consumer of seafood from the Irish Sea were 1.18 μSv and 1.20 μSv, respectively, due to the ingestion of caesium-137, technetium-99, plutonium-238,239,240 and americium-241. These doses compare with doses of 1.42 μSv and 1.33 μSv in 1998 and 1999, respectively. Caesium-137 remains the dominant radionuclide accounting for approximately 60 - 70% of these doses.

These doses can be compared with the annual dose of about 148 μSv received by the same consumer due to the presence of the naturally-occurring radionuclide polonium-210 in seafood, and with the average annual dose to a person in Ireland from all sources of radioactivity of about 3620 μSv.

The increased discharges of technetium-99 from Sellafield since 1994 have resulted in corresponding increases in the contribution of this radionuclide to the doses to seafood consumers during the period 1994 to 2001. However, because of the relatively low radiotoxicity of technetium-99 it currently contributes less than 30% of the dose arising from the ingestion of fish and shellfish.

Radiation doses to the Irish population resulting from the routine discharges from Sellafield are now very low and, on the basis of current scientific knowledge, do not pose a significant health risk to the public. It is emphasised that the levels of radioactive contamination which prevail at present, do not warrant any modification of the habits of people in Ireland, either in respect of consumption of seafood or any other use of the amenities of the marine environment.

Further reductions in these doses are being pursued through the implementation of the OSPAR Strategy with regard to Radioactive Substances. All signatories to the Strategy are committed to progressive and substantial reductions in radioactive discharges from their facilities. Compliance with the objectives of the OSPAR Strategy should ensure that the radiation doses attributable to the operations at Sellafield are even further reduced in future years. The Institute takes the view that the very highest possible standards of safety and waste management should apply in nuclear facilities including the implementation of best available techniques for the further reduction of discharges with a view to minimising their environmental impact.

## 8. Acknowledgements

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## 9. References


Baker, C.W., 1975. **The determination of radiocaesium in sea and fresh waters. Technical Report No. 16.** Lowestoft: Fisheries Radiological Laboratory, Ministry of Agriculture, Fisheries and Food.

Central Statistics Office, 1996. **Vital statistics fourth quarter and yearly summary 1995.** Dublin: Stationery Office.

Eisenbud, M. and Gessell, T., 1997. **Environmental radioactivity from natural, industrial and military sources**. Fourth edition. Academic Press, ISBN 0-12-235154-1.

EC, 1996. **Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public arising from ionising radiation**. Official Journal of the European Communities, L159.

Gray, J., Jones, S.R. and Smith, A.D., 1995. Discharges to the environment from the Sellafield site, 1951-1992. **Journal of Radiological Protection,** 15 (2), 99-131.

Harvey, B.R., Ibbett, K.D., Williams, J.K. and Lovett, M.B., 1991. **The determination of technetium-99 in environmental materials.** Aquatic Environment Protection: Analytical Methods Number 8. Directorate of Fisheries Research, Lowestoft.

Hunt, G.J., 1984. Simple models for prediction of external pathways. **Radiation Protection Dosimetry,** 8 (4), 215-224.

Hunt, G.J. and Kershaw, P.J., 1990. Remobilisation of artificial radionuclides from the sediment of the Irish Sea. **Journal of Radiological Protection,** 10 (2), 147-151.

International Atomic Energy Agency (IAEA), 1985. **Sediment $K_d$s and concentration factors for radionuclides in the marine environment.** Technical Report Series No. 247. Vienna: IAEA.

International Commission on Radiological Protection (ICRP), 1983. **Radionuclide transformations energy and intensity of emissions.** Annals of the ICRP, 11-13, Publication No. 38.

International Commission on Radiological Protection (ICRP), 1991. **1990 recommendations of the International Commission on Radiological Protection**. Annals of the ICRP, 21 (1-3), Publication No. 60.

International Commission on Radiological Protection (ICRP), 1996 (a). **Age-dependent doses to members of the public from intakes of radionuclides: Part 5, compilation of ingestion and inhalation coefficients.** Annals of the ICRP, 26 (1), Publication No. 72.

International Commission on Radiological Protection (ICRP), 1996 (b). **Conversion coefficients for use in radiological protection against external radiation.** Annals of the ICRP, 26 (3/4), Publication No. 74.

MAFF and SEPA, 1998. **Radioactivity in food and the environment, 1997**. Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research, Scottish Environment Protection Agency, RIFE-3, UK.

MAFF and SEPA, 2000. **Radioactivity in food and the environment, 1999**. Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research, Scottish Environment Protection Agency, RIFE-5, UK.

MAFF and SEPA, 2001. **Radioactivity in food and the environment, 2000**. Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research, Scottish Environment Protection Agency, RIFE-6, UK.

MAFF and SEPA, 2002. **Radioactivity in food and the environment, 2001**. Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research, Scottish Environment Protection Agency, RIFE-7, UK.

NAB, 2002. **D1 Directory of Accredited Laboratories**. Edition 7. Dublin: The Irish National Accreditation Board.

Pentreath, R.J., Camplin, W.C. and Allington, D.J., 1989. Individual and collective dose rates from naturally occurring radionuclides in seafood. In: **Proc. Fourth Int. Symp. of the Society of Radiological Protection, June 1989, Malvern, U.K.** 297 – 300. United Kingdom: Institute of Physics.

Pollard, D., Ryan, T.P. and Dowdall, A., 1998. The dose to Irish seafood consumers from Po-210. **Radiation Protection Dosimetry,** 75 (1-4), 139-142.

Ryan, T.P., McGarry, A.T., Lyons, S., Smith, V., Cunningham, J.D., Mitchell, P.I., León Vintró, L., Larmour, R.A. and Ledgerwood, F.K., 1996. Plutonium, americium and radiocaesium in sea water, sediment and biota in Lough Foyle. In **Irish Marine Science 1995,** Galway University Press Ltd., 585-600. Eds. Keegan, B.F. & O'Connor, R.

Ryan, T.P., Dowdall, A.M., Long, S., Smith, V., Pollard, D. and Cunningham, J.D., 1999. Plutonium and americium in fish, shellfish and seaweed in the Irish environment and their contribution to dose. **Journal of Environmental Radioactivity**, 44 (2-3), 349-369.

Ryan, T.P., Long, S., Dowdall, A., Hayden, E., Fegan, M., Sequeira, S., Pollard, D. and Cunningham, J.D., 2000. **Radioactivity monitoring of the Irish marine environment 1998 and 1999.** RPII 00/1. Dublin: Radiological Protection Institute of Ireland.

Walker, M.I. and Rose, K.S.B., 1990. The radioactivity of the sea. **Nuclear Energy**, 29 (4), 267-278.

## Reports in the RPII Marine Series

Cunningham, J.D. and O'Grady, J., 1986. **Radioactivity monitoring of the Irish marine environment during 1982-84.** Dublin: Nuclear Energy Board.

Cunningham, J.D., O'Grady, J. and Rush, T., 1988. **Radioactivity monitoring of the Irish marine environment, 1985-1986.** Dublin: Nuclear Energy Board.

O'Grady, J. and Currivan, L., 1990. **Radioactivity monitoring of the Irish marine environment 1987**. Dublin: Nuclear Energy Board.

O'Grady, J., Currivan, L., McEnri, C., O'Colmáin, M., Colgan, P.A. and Cunningham, J.D., 1991. **Radioactivity monitoring of the Irish marine environment, 1988-1990**. Dublin: Nuclear Energy Board.

Mitchell, P.I., Vives i Batlle, J., Ryan, T.P., McEnri, C., Long, S., O'Colmáin, M., Cunningham, J.D., Caulfield, J.J., Larmour, R.A. and Ledgerwood, F.K., 1992. **Artificial radioactivity in Carlingford Lough.** Dublin: Radiological Protection Institute of Ireland.

McGarry, A., Lyons, S., McEnri, C., Ryan, T., O'Colmáin, M. and Cunningham, J.D., 1994. **Radioactivity monitoring of the Irish marine environment 1991 and 1992.** Dublin: Radiological Protection Institute of Ireland.

Cunningham, J.D., Ryan, T.P., Lyons, S., Smith, V., McGarry, A., Mitchell, P.I., León Vintró, L., Larmour, R.A. and Ledgerwood, F.K., 1996. **Artificial radioactivity in Lough Foyle**. RPII-96/1, Dublin: Radiological Protection Institute of Ireland.

Pollard, D., Long, S., Hayden, E., Smith, V., Ryan, T.P., Dowdall, A., McGarry, A. and Cunningham, J.D., 1996. **Radioactivity monitoring of the Irish marine environment, 1993-1995.** RPII 96/5. Dublin: Radiological Protection Institute of Ireland.

Long, S., Pollard, D., Hayden, E., Smith, V., Fegan, M., Ryan, T.P., Dowdall, A. and Cunningham, J.D., 1998. **Radioactivity monitoring of the Irish marine environment 1996 and 1997.** RPII 98/2. Dublin: Radiological Protection Institute of Ireland.

Ryan, T.P., Long, S., Dowdall, A., Hayden, E., Fegan, M., Sequeira, S., Pollard, D. and Cunningham, J.D., 2000. **Radioactivity monitoring of the Irish marine environment 1998 and 1999.** RPII 00/1. Dublin: Radiological Protection Institute of Ireland.

## 10. Glossary of Terms

***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.

***Activity***

Activity describes the rate at which nuclear disintegration occurs. The unit of activity is the becquerel (Bq). One Bq is equivalent to one disintegration per second.

***Collective Effective Dose***

Total dose over a population group exposed to a given source. It is represented by the product of the average effective dose equivalent 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.

***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).

***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.

***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.

***Radiotoxicity***

A measure of the dose per becquerel resulting from the ingestion of a particular radionuclide.

## 11. Radiation Quantities and Units

**Activity and Dose Units**

| *Quantity* | *Unit and Symbol* |
|---|---|
| Activity | Becquerel (Bq) |
| Activity Concentration | Becquerel per unit mass or volume (Bq/kg or Bq/l) |
| Absorbed Dose | Gray (Gy) |
| Effective Dose | Sievert (Sv) |
| Committed Effective Dose | Sievert (Sv) |
| Equivalent Dose | Sievert (Sv) |
| Collective Effective Dose | Man sievert (manSv) |

**Commonly Used Activity and Dose Unit Multiples and Sub-multiples**

| Activity | | Dose | |
|---|---|---|---|
| 1 millibecquerel (1 mBq) | $=1 \times 10^{-3}$ Bq | 1 microsievert (1 μSv) | $=1 \times 10^{-6}$ Sv |
| 1 kilobecquerel (1 kBq) | $=1 \times 10^{3}$ Bq | 1 millisievert (1 mSv) | $=1 \times 10^{-3}$ Sv |
| 1 megabecquerel (1 MBq) | $=1 \times 10^{6}$ Bq | 1 nanogray (1 nGy) | $=1 \times 10^{-9}$ Gy |
| 1 terabecquerel (1 TBq) | $=1 \times 10^{12}$ Bq | 1 microgray (1 μGy) | $=1 \times 10^{-6}$Gy |

## Radionuclide Symbols, Principal Emissions and Half-lives[1]

| *Radionuclide* | *Symbol* | *Principal Emission[2]* | *Half-life* |
|---|---|---|---|
| Tritium | H-3 | β | 12.35 years |
| Carbon-14 | C-14 | β | 5730 years |
| Potassium-40 | K-40 | β | $1.28 \times 10^9$ years |
| Cobalt-60 | Co-60 | β | 5.27 years |
| Strontium-90 | Sr-90 | β | 29.12 years |
| Niobium-95 | Nb-95 | β | 35.15 days |
| Zirconium-95 | Zr-95 | β | 63.98 days |
| Technetium-99 | Tc-99 | β | 213 000 years |
| Ruthenium-106 | Ru-106 | β | 368.2 days |
| Iodine-131 | I-131 | β | 8.04 days |
| Caesium-134 | Cs-134 | β | 2.06 years |
| Caesium-137 | Cs-137 | β | 30 years |
| Cerium-144 | Ce-144 | β | 284.3 days |
| Polonium-210 | Po-210 | α | 138.38 days |
| Plutonium-238 | Pu-238 | α | 87.74 years |
| Plutonium-239 | Pu-239 | α | 24 065 years |
| Plutonium-240 | Pu-240 | α | 6537 years |
| Plutonium-241 | Pu-241 | β | 14.4 years |
| Americium-241 | Am-241 | α | 432.2 years |

Notes: (1) Source: ICRP, 1983
(2) α (alpha particle); β (beta particle); γ (gamma ray) – gamma rays very often accompany the principal emission of an alpha or beta particle

## 12. Tables

**Table 1**
**Discharges of Radionuclides from Sellafield to the Irish Sea[1], 1999, 2000 and 2001**

| *Radionuclide Category* | *Limit[2] TBq* | *Discharge TBq* | | |
|---|---|---|---|---|
| | | *1999[3]* | *2000[4]* | *2001[5]* |
| Total Alpha | 1.0 | 0.133 | 0.12 | 0.196 |
| Total Beta | 400 | 110 | 76.6 | 123 |
| Tritium | 31 000 (25 000) | 2520 | 2260 | 2560 |
| Carbon-14 | 20.8 | 5.76 | 4.61 | 9.47 |
| Cobalt-60 | 13 | 0.89 | 1.2 | 1.23 |
| Strontium-90 | 48 | 31.2 | 19.7 | 26.1 |
| Zirconium-95 + Niobium-95 | 9 | 0.182 | 0.18 | 0.272 |
| Technetium-99 | 200 (90) | 68.8 | 44.4 | 79.4 |
| Ruthenium-106 | 63 | 2.72 | 2.68 | 3.89 |
| Iodine-129 | 2.0 (1.6) | 0.485 | 0.47 | 0.629 |
| Caesium-134 | 6.6 | 0.34 | 0.23 | 0.483 |
| Caesium-137 | 75 | 9.12 | 6.91 | 9.57 |
| Cerium-144 | 8 | 0.60 | 0.55 | 0.789 |
| Americium-241 | 0.3 | 0.035 | 0.03 | 0.038 |
| Plutonium (alpha) | 0.7 | 0.115 | 0.12 | 0.155 |
| Plutonium-241 | 27 | 2.87 | 3.2 | 4.58 |
| Uranium (kg) | 2040 | 536 | 610 | 387 |

Notes:
(1) From sea pipeline
(2) Limits as set by UK authorities for 1999 with changes in 2000 in brackets
(3) MAFF and SEPA, 2000
(4) MAFF and SEPA, 2001
(5) MAFF and SEPA, 2002

**Table 2**
**Naturally Occurring Radionuclides in Seawater[1]**

| *Radionuclide* | *Activity Concentration, mBq/l* |
|---|---|
| Tritium | 0.6 |
| Carbon-14 | 4.3 |
| Potassium-40 | 12 000 |
| Lead-210 | 5.0 |
| Polonium-210 | 3.7 |
| Bismuth-214 | 0.7 |
| Radon-222 | 0.7 |
| Uranium-234 | 47.0 |
| Uranium-238 | 41.0 |
| Radium-226 | 3.6 |

Note: (1) Walker and Rose, 1990

**Table 3**
**Offshore Sampling Locations in the Irish Sea, 2000 and 2001**

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

**Table 4**
**Sampling Programme, 2000 and 2001**

| *Sampling Location* | *Sample Types* |
|---|---|
| Carlingford | Shellfish |
| Greenore | Seawater, Sediment, Seaweed |
| Dundalk Bay | Shellfish |
| Clogherhead | Fish, Shellfish |
| Balbriggan | Seawater, Sediment, Seaweed |
| Howth | Fish, Shellfish |
| Bull Island | Seawater, Sediment, Seaweed |
| Cahore | Seawater, Sediment, Seaweed |
| Dunmore East | Fish, Shellfish, Seawater, Sediment, Seaweed |
| Bantry | Shellfish |
| Castletownbere | Fish, Shellfish, Seawater, Sediment, Seaweed |
| Galway | Fish, Shellfish, Seawater, Sediment, Seaweed |
| Killybegs/ Mountcharles | Fish, Seawater, Sediment, Seaweed |
| Lough Foyle | Shellfish |
| Western Irish Sea | Seawater, Sediment |

**Table 5**
**Analytical Techniques used in the Determination of Radionuclides**

| ***Radionuclides measured*** | ***Sample types*** | ***Analytical techniques*** |
|---|---|---|
| K-40, I-131, Cs-137 and other gamma emitting radionuclides | Fish, shellfish, seaweed and sediment | High resolution gamma spectrometry using high purity germanium detectors |
| C-14 | Fish, shellfish | High temperature catalytic combustion to carbon dioxide followed by liquid scintillation counting |
| Cs-137 | Seawater | Radiochemical separation techniques in accordance with the method described by Baker [1975] followed by high resolution gamma spectrometry |
| Tc-99 | Fish, shellfish, seaweed and seawater | Radiochemical separation techniques in accordance with the method described by Harvey *et al.* [1991] followed by beta spectrometry using a gas flow proportional counter |
| Pu-238, Pu-239,240 | Fish and shellfish | Radiochemical separation techniques followed by alpha spectrometry using silicon surface barrier detectors |

**Table 6**
**Radioactivity in Coastline Seawater, 2000 and 2001**

| *Sampling Location* | *Month* | *Activity Concentration mBq/l* | | | |
|---|---|---|---|---|---|
| | | **2000** | | **2001** | |
| | | ***Tc-99*** | ***Cs-137*** | ***Tc-99*** | ***Cs-137*** |
| Greenore | Feb | - | 31 | - | 17 |
| | Jun | - | 29 | - | - |
| | Sep | - | - | - | 17 |
| | Aug | - | 31 | - | - |
| | Nov | - | 35 | - | - |
| | Dec | - | - | - | 15 |
| Balbriggan | Feb | 18 | - | 5 | 14 |
| | Mar | - | 25 | - | - |
| | Apr | 19 | - | 10 | - |
| | May | - | 27 | - | - |
| | Jun | 17 | - | 14 | - |
| | Jul | - | 27 | - | - |
| | Aug | 23 | - | - | - |
| | Sep | - | - | - | 16 |
| | Oct | 17 | - | - | 10 |
| | Nov | - | - | - | 12 |
| | Dec | 9 | - | - | - |
| Bull Island | Apr | - | 24 | - | - |
| | Sep | - | 27 | - | - |
| | Nov | - | - | - | 8 |
| Cahore | Apr | - | 18 | - | - |
| | Nov | 4 | - | - | 4 |
| Dunmore East | Sep | 1 | - | - | - |
| Castletownbere | Sep | 0.2 | 3 | - | - |
| Galway | Oct | - | nd | - | - |
| Killybegs | Oct | nd | 2 | - | - |

Note: nd = not detected

**Table 7**
**Radioactivity in Offshore Seawater, 2000 and 2001**

| *Sampling Location* | *Month* | *Activity Concentration mBq/l* | | | |
|---|---|---|---|---|---|
| | | **2000** | | **2001** | |
| | | ***Tc-99*** | ***Cs-137*** | ***Tc-99*** | ***Cs-137*** |
| Irish Sea - N1 | Aug | 22 | 35 | - | - |
| | Oct | - | - | - | 9 |
| Irish Sea - N2 | Aug | - | 35 | - | - |
| | Oct | - | - | - | 11 |
| Irish Sea - N3 | Aug | 22 | 27 | - | - |
| | Oct | - | - | - | 13 |
| Irish Sea - N4 | Aug | 24 | 27 | - | - |
| | Oct | - | - | 17 | 11 |
| Irish Sea - N5 | Aug | - | 28 | - | - |
| | Oct | - | - | 18 | 15 |
| Irish Sea - N6 | Aug | 30 | 30 | - | - |
| | Nov | - | - | 14 | 9 |
| Irish Sea - S1 | Aug | - | 29 | - | - |
| Irish Sea - S2 | Aug | - | 17 | - | - |
| Irish Sea - S3 | Aug | - | 23 | - | - |
| Irish Sea - S4 | Aug | - | 28 | - | - |
| Irish Sea - S5 | Aug | - | 26 | - | - |

**Table 8**
**Radioactivity in Coastline Marine Sediments, 2000 and 2001**

| *Sampling Location* | *Month* | *Cs-137 Activity Concentration Bq/kg, dry weight* | |
|---|---|---|---|
| | | **2000** | **2001** |
| Greenore | Feb | 8.7 | 8.2 |
| | Jun | 9.1 | 9.0 |
| | Aug | 9.7 | - |
| | Sep | - | 8.8 |
| | Nov | 9.7 | - |
| | Dec | - | 7.9 |
| Balbriggan | Mar | 11.7 | 11.7 |
| | May | 8.0 | 10.2 |
| | Jun | 10.4 | - |
| | Aug | 11.1 | - |
| | Sep | - | 5.7 |
| | Nov | 8.9 | 7.4 |
| | Dec | - | 11.5 |
| Bull Island | Apr | 5.0 | - |
| | May | - | 5.4 |
| | Sep | 4.2 | - |
| | Nov | - | 7.4 |
| | Dec | - | 11.5 |
| Cahore | Apr | 0.8 | - |
| | May | - | 0.5 |
| | Nov | 0.7 | 0.6 |
| Dunmore East | Sep | 0.7 | - |
| Castletownbere | Sep | 0.3 | - |
| Galway | Nov | 0.7 | - |
| Killybegs | Nov | 0.2 | - |

**Table 9**
**Radioactivity in Offshore Marine Sediments, 2000 and 2001**

| *Sampling Location* | *Month* | *Cs-137 Activity Concentration Bq/kg, dry weight* | |
|---|---|---|---|
| | | **2000** | **2001** |
| Irish Sea - N1 | Aug | 6.4 | - |
| Irish Sea - N2 | Aug | 13.2 | - |
| Irish Sea - N3 | Aug | 40.5 | - |
| Irish Sea - N4 | Aug | 52.8 | - |
| | Oct | - | 45.2 |
| Irish Sea - N5 | Aug | 96.7 | - |
| | Oct | - | 79.8 |
| Irish Sea - N6 | Aug | 49.0 | - |
| | Nov | - | 39.2 |
| Irish Sea - S1 | Aug | 2.1 | - |
| Irish Sea - S2 | Aug | - | - |
| Irish Sea - S3 | Aug | 0.8 | - |
| Irish Sea - S5 | Aug | 5.3 | - |

**Table 10**
**Radioactivity in *Fucus vesiculosus*, 2000**

| *Sampling Location* | *Month* | *Activity Concentration Bq/kg, dry weight* | | |
|---|---|---|---|---|
| | | *Tc-99* | *I-131*[(1)] | *Cs-137* |
| Greenore | Feb | 5613 | - | 4.0 |
| | Jun | 4097 | - | 6.7 |
| | Aug | 2224 | - | 7.1 |
| | Nov | 3686 | - | 5.2 |
| Balbriggan | Jan | - | - | 3.4 |
| | Feb | 3445 | - | 3.9 |
| | Mar | - | - | 4.3 |
| | Apr | 3641 | - | 5.1 |
| | May | - | - | 5.8 |
| | Jun | 2958 | - | 6.7 |
| | Jul | - | - | 6.5 |
| | Aug | 1782 | - | 7.3 |
| | Sep | - | - | 6.4 |
| | Oct | 2468 | - | 5.8 |
| | Nov | - | - | 5.8 |
| | Dec | 2113 | - | 4.8 |
| Bull Island | Feb | 2480 | 44.1 | 3.0 |
| | Apr | 3645 | 31.9 | 4.9 |
| | Sep | 1726 | 29.6 | 4.6 |
| | Dec | - | 82.9 | 3.5 |
| Cahore | Apr | 683 | - | 1.7 |
| | Nov | - | - | 0.7 |
| Dunmore East | Sep | 92 | - | nd |
| Castletownbere | Sep | 32 | - | nd |
| Galway | Oct | 11 | - | 0.3 |
| Killybegs | Oct | 10 | - | 0.6 |

Notes: (1) Analysis is performed on a wet sample, but results are quoted on a dry weight basis for ease of comparison
nd = not detected

**Table 11**
**Radioactivity in *Fucus vesiculosus*, 2001**

| *Sampling Location* | *Month* | *Activity Concentration Bq/kg, dry weight* | | |
|---|---|---|---|---|
| | | *Tc-99* | *I-131*[(1)] | *Cs-137* |
| Greenore | Feb | 3696 | - | 3.8 |
| | Jun | 2465 | - | 4.5 |
| | Sep | 2727 | - | 3.6 |
| | Dec | 2200 | - | - |
| Balbriggan | Jan | - | - | 4.2 |
| | Feb | 3945 | - | 3.8 |
| | Mar | - | - | - |
| | Apr | 2223 | - | 3.0 |
| | May | - | - | 3.2 |
| | Jun | 1750 | - | 2.9 |
| | Jul | - | - | 4.3 |
| | Aug | - | - | 3.5 |
| | Sep | 1827 | - | 2.9 |
| | Oct | 1449 | - | 3.5 |
| | Nov | - | - | 2.4 |
| | Dec | 2115 | - | 2.0 |
| Bull Island | May | 1201 | - | 2.4 |
| | Aug | - | 80.0 | - |
| | Nov | 419 | 9.1 | 2.3 |
| Cahore | May | 264 | - | nd |

Notes: (1) Analysis is performed on a wet sample, but results are quoted on a dry weight basis for ease of comparison
nd = not detected

**Table 12(a)**
**Radioactivity in Whiting, 2000 and 2001**

| *Sampling Location* | *Month* | *Activity Concentration Bq/kg, wet weight* | | | |
|---|---|---|---|---|---|
| | | **2000** | | **2001** | |
| | | ***Tc-99*** | ***Cs-137*** | ***Tc-99*** | ***Cs-137*** |
| Clogherhead | Feb | nd | 0.1 | 0.1 | 0.3 |
| | Jun | - | 0.3 | - | 0.3 |
| | Aug | 0.9 | 0.9 | - | - |
| | Sep | - | 0.3 | 2.2 | 2.9 |
| | Dec | - | - | - | 0.2 |
| Howth | Jan | - | 0.4 | - | 0.4 |
| | Feb | - | 0.7 | - | 0.4 |
| | Mar | - | 0.4 | - | 0.6 |
| | Apr | 0.1 | 0.3 | 0.4 | 0.8 |
| | May | - | 0.4 | - | 0.3 |
| | Jun | - | 0.8 | - | 0.4 |
| | Jul | - | 0.4 | - | 0.3 |
| | Aug | - | 0.3 | - | 0.4 |
| | Sep | - | 0.4 | - | 0.3 |
| | Oct | - | 0.1 | - | 0.3 |
| | Nov | nd | 0.4 | - | 0.3 |
| | Dec | - | 0.3 | nd | 0.3 |
| Dunmore East | Mar | - | 0.5 | - | - |
| | Jun | - | - | - | 0.4 |
| | Sep | - | 0.5 | - | - |
| Castletownbere | Apr | - | 0.3 | - | - |
| | May | - | - | - | 0.5 |
| | Sep | - | 0.5 | - | - |
| Galway | Mar | - | 0.3 | - | - |
| | May | - | - | - | 0.3 |
| Killybegs | Mar | - | 1.0 | - | 0.3 |

Note: nd=not detected

**Table 12(b)**
**Radioactivity in Whiting, 2000 and 2001**

| *Sampling Location* | *Year* | *Activity Concentration Bq/kg, wet weight* | | |
|---|---|---|---|---|
| | | *C-14* | *Pu-238* | *Pu-239,240* |
| Clogherhead | 2000 | 22.7 | nd | 0.0003 |
| Howth | 2000 | 19.2 | nd | nd |
| Clogherhead[(1)] | 2001 | 29.6 | nd | 0.00163 |
| Howth[(2)] | 2001 | 25.5 | nd | 0.00004 |

Notes: (1) Annual composite of 4 samples from Clogherhead
(2) Annual composite of 12 samples from Howth
nd = not detected

**Table 13(a)**
**Radioactivity in Cod, 2000 and 2001**

| *Sampling Location* | *Month* | *Activity Concentration Bq/kg, wet weight* | | | |
|---|---|---|---|---|---|
| | | **2000** | | **2001** | |
| | | ***Tc-99*** | ***Cs-137*** | ***Tc-99*** | ***Cs-137*** |
| Clogherhead | Feb | 0.1 | 1.0 | nd | 0.5 |
| | Jun | - | 3.4 | - | 5.3 |
| | Aug | nd | 1.7 | - | - |
| | Sep | - | - | nd | 1.0 |
| | Nov | - | 1.0 | - | - |
| | Dec | - | - | - | 2.8 |
| Howth | Jan | - | 2.4 | - | 3.4 |
| | Feb | - | 0.8 | - | 1.2 |
| | Mar | - | 0.3 | - | 1.9 |
| | Apr | 0.3 | 2.2 | 0.1 | 1.3 |
| | May | - | 5.7 | - | 0.4 |
| | Jun | - | 1.2 | - | 1.4 |
| | Jul | - | 0.4 | - | 1.4 |
| | Aug | - | 3.4 | - | 1.6 |
| | Sep | - | 2.3 | - | 1.9 |
| | Oct | - | 2.0 | - | 1.2 |
| | Nov | 0.1 | 0.6 | - | 0.4 |
| | Dec | - | 0.2 | nd | 0.4 |
| Dunmore East | Mar | - | 6.5 | - | - |
| | Jul | - | 0.4 | - | - |
| | Sep | - | 1.5 | - | - |
| | Sep | - | 0.4 | - | - |
| Castletownbere | Mar | - | 0.2 | - | - |
| | May | - | - | - | 0.2 |
| | Sep | - | 0.4 | - | - |
| Galway | May | - | - | - | 1.3 |
| | Dec | - | 0.3 | - | - |
| Killybegs | Mar | - | 0.4 | - | 0.4 |
| | Oct | - | 0.3 | - | - |

Note: nd = not detected

**Table 13(b)**
**Radioactivity in Cod, 2000 and 2001**

| *Sampling Location* | *Year* | *Activity Concentration Bq/kg, wet weight* | | |
|---|---|---|---|---|
| | | *C-14* | *Pu-238* | *Pu-239,240* |
| Clogherhead | 2000 | 25.5 | nd | 0.0002 |
| Howth | 2000 | 24.1 | nd | 0.00004 |
| Clogherhead[(1)] | 2001 | 28.2 | nd | nd |
| Howth[(2)] | 2001 | 31.8 | nd | 0.0001 |

Notes: (1) Annual composite of 4 samples from Clogherhead
(2) Annual composite of 12 samples from Howth
nd = not detected

**Table 14(a)**
**Radioactivity in Plaice, 2000 and 2001**

| *Sampling Location* | *Month* | *Activity Concentration Bq/kg, wet weight* | | | |
|---|---|---|---|---|---|
| | | **2000** | | **2001** | |
| | | ***Tc-99*** | ***Cs-137*** | ***Tc-99*** | ***Cs-137*** |
| Clogherhead | Feb | 0.3 | 0.4 | 0.5 | 0.7 |
| | Jun | - | 0.4 | - | 0.9 |
| | Aug | 1.0 | 0.6 | - | - |
| | Sep | - | - | 1.0 | 0.7 |
| | Nov | - | 0.7 | - | - |
| | Dec | - | - | - | nd |
| Howth | Jan | - | 0.3 | - | 0.2 |
| | Feb | - | 0.4 | - | 0.3 |
| | Mar | - | 0.3 | - | 0.3 |
| | Apr | 0.1 | nd | 0.1 | nd |
| | May | - | 0.3 | - | 0.3 |
| | Jun | - | 0.3 | - | 0.2 |
| | Jul | - | 0.7 | - | 0.2 |
| | Aug | - | 0.3 | - | 0.2 |
| | Sep | - | 0.4 | - | 0.2 |
| | Oct | - | 0.8 | - | 0.1 |
| | Nov | nd | 0.1 | - | 0.5 |
| | Dec | - | 1.3 | nd | 0.5 |
| Dunmore East | Mar | - | 0.2 | - | |
| | Jun | - | - | - | 0.4 |
| | Sep | - | 0.5 | - | - |
| Castletownbere | Mar | - | nd | - | - |
| | May | - | - | - | nd |
| | Sep | - | 0.2 | - | - |
| Galway | May | - | - | - | 0.1 |
| | Dec | - | 0.1 | - | - |
| Killybegs | Mar | - | nd | - | nd |

Note: nd = not detected

**Table 14(b)**
**Radioactivity in Plaice, 2000 and 2001**

| *Sampling Location* | *Year* | *Activity Concentration Bq/kg, wet weight* | | |
|---|---|---|---|---|
| | | ***C-14*** | ***Pu-238*** | ***Pu-239,240*** |
| Clogherhead[(1)] | 2000 | 32.4 | 0.0001 | 0.0005 |
| Howth[(2)] | 2000 | 24.6 | nd | 0.00002 |
| Clogherhead[(1)] | 2001 | 35.7 | nd | 0.00016 |
| Howth[(2)] | 2001 | 32.0 | nd | nd |

Notes: (1) Annual composite of 4 samples from Clogherhead
(2) Annual composite of 12 samples from Howth
nd = not detected

**Table 15**
**Radioactivity in Ray, 2000 and 2001**

| *Sampling Location* | *Month* | *Activity Concentration Bq/kg, wet weight* | | | |
|---|---|---|---|---|---|
| | | **2000** | | **2001** | |
| | | ***Tc-99*** | ***Cs-137*** | ***Tc-99*** | ***Cs-137*** |
| Clogherhead | Feb | - | - | - | 1.5 |
| | Jun | nd | 1.1 | 0.1 | 1.3 |
| | Aug | - | 1.1 | - | - |
| | Sep | - | - | - | 1.4 |
| | Nov | nd | 0.5 | - | - |
| | Dec | - | - | nd | 0.6 |
| Howth | Jan | - | 1.3 | - | 1.7 |
| | Feb | - | 1.1 | - | 1.5 |
| | Mar | - | 1.2 | - | nd |
| | Apr | - | 1.2 | - | 0.2 |
| | May | - | 0.3 | - | 0.7 |
| | Jun | - | 0.3 | - | 0.6 |
| | Jul | - | 0.7 | - | 1.0 |
| | Aug | - | 0.6 | - | 0.1 |
| | Sep | - | 1.5 | - | 0.5 |
| | Oct | - | 0.7 | - | 1.1 |
| | Nov | - | 1.7 | - | 0.5 |
| | Dec | - | 1.3 | - | 0.6 |
| Dunmore East | Mar | - | 0.2 | - | 0.4 |
| | Sep | - | 0.2 | - | - |
| Castletownbere | Mar | - | 0.2 | - | - |
| | May | - | - | - | nd |
| Galway | Mar | - | 0.2 | - | - |
| | May | - | - | - | 0.1 |
| | Dec | - | 0.1 | - | - |
| Killybegs | Mar | - | 0.2 | - | 0.1 |

Note: nd = not detected

**Table 16**
**Radioactivity in Herring, 2000 and 2001**

| *Sampling Location* | *Month* | *Activity Concentration Bq/kg, wet weight* | | | |
|---|---|---|---|---|---|
| | | **2000** | | **2001** | |
| | | ***Tc-99*** | ***Cs-137*** | ***Tc-99*** | ***Cs-137*** |
| Clogherhead | Feb | 0.1 | 0.2 | - | - |
| | Dec | - | - | 0.1 | 0.1 |
| Howth | Jan | - | 0.3 | - | - |
| | Feb | - | 0.2 | - | nd |
| | May | - | 0.5 | - | - |
| | Aug | - | - | - | 0.2 |
| | Sep | - | - | - | 0.2 |
| | Oct | - | 0.1 | - | - |
| | Nov | - | 0.2 | - | - |
| | Dec | - | 0.2 | - | 0.3 |
| Castletownbere | Feb | - | 0.4 | - | - |
| Killybegs | Mar | - | 0.3 | - | 0.1 |

Note: nd = not detected

**Table 17**
**Radioactivity in Mackerel, 2000 and 2001**

| *Sampling Location* | *Month* | *Activity Concentration Bq/kg, wet weight* | | | |
|---|---|---|---|---|---|
| | | **2000** | | **2001** | |
| | | ***Tc-99*** | ***Cs-137*** | ***Tc-99*** | ***Cs-137*** |
| Clogherhead | Feb | - | - | - | 0.2 |
| | Jun | - | 0.2 | - | - |
| | Aug | - | 0.2 | - | - |
| | Sep | - | - | - | 3.6 |
| | Nov | - | 0.9 | - | - |
| | Dec | - | - | - | 0.2 |
| Howth | Jan | - | 0.1 | - | 0.2 |
| | Feb | - | 0.1 | - | 0.2 |
| | Mar | - | 0.2 | - | 0.2 |
| | Apr | - | 0.2 | - | 0.1 |
| | May | - | 0.2 | - | - |
| | Jun | 0.5 | 0.2 | 0.1 | 0.1 |
| | Jul | - | - | - | 0.2 |
| | Aug | - | 0.3 | - | 0.2 |
| | Sep | - | 0.3 | - | 0.3 |
| | Oct | - | 0.2 | - | 0.3 |
| | Nov | - | 0.2 | - | 0.2 |
| | Dec | - | 0.5 | - | 0.1 |
| Dunmore East | Mar | - | 0.2 | - | - |
| | Sep | - | 0.5 | - | - |
| Castletownbere | Mar | - | nd | - | - |
| | May | - | - | - | nd |
| | Sep | - | 0.3 | - | - |
| Galway | Mar | - | 0.2 | - | - |
| | May | - | - | - | nd |
| | Dec | - | 0.2 | - | - |
| Killybegs | Mar | - | 0.2 | - | 0.2 |
| | Oct | - | 0.4 | - | - |

Note: nd = not detected

**Table 18**
**Radioactivity in Prawns, 2000**

| *Sampling Location* | *Month* | *Activity Concentration Bq/kg, wet weight* | | | | |
|---|---|---|---|---|---|---|
| | | *C-14* | *Tc-99* | *Cs-137* | *Pu-238* | *Pu-239,240* |
| Clogherhead | Feb | | 64 | 0.8 | | |
| | Jun | 21.9[(1)] | 87 | 1.0 | 0.003 [(1)] | 0.015[(1)] |
| | Aug | | 147 | 1.5 | | |
| Howth | Feb | | 58 | 0.8 | 0.003 | 0.018 |
| | Jun | - | - | 1.0 | 0.003 | 0.017 |
| | Jul | | 68 | 1.0 | 0.002 | 0.011 |
| | Nov | | - | 0.6 | 0.002 | 0.008 |
| Dunmore East | Mar | - | - | 0.1 | - | - |
| | Sep | - | - | nd | - | - |
| Castletownbere | Mar | - | - | nd | - | - |
| Galway | Mar | 14.5[(2)] | - | 0.1 | nd [(2)] | 0.003 [(2)] |
| | Dec | | - | nd | | |

Notes: (1) Results are based on the analysis of a composite of 3 samples
(2) Results are based on the analysis of a composite of 2 samples
nd = not detected

**Table 19**
**Radioactivity in Prawns, 2001**

| *Sampling Location* | *Month* | *Activity Concentration Bq/kg, wet weight* | | | | |
|---|---|---|---|---|---|---|
| | | *C-14* | *Tc-99* | *Cs-137* | *Pu-238* | *Pu-239,240* |
| Clogherhead | Feb | | 68 | 0.8 | | |
| | Jun | 34.9[(1)] | 2 | 0.1 | 0.014[(1)] | 0.067[(1)] |
| | Sep | | 23 | 0.4 | | |
| | Dec | | 20 | 1.6 | | |
| Howth | Feb | | 37 | 0.5 | 0.002 | 0.007 |
| | May | | - | 3.3 | 0.036 | 0.204 |
| | Jul | 27.9[(2)] | 22 | 0.4 | 0.003 | 0.016 |
| | Aug | | - | 0.6 | 0.003 | 0.016 |
| | Sep | | - | 0.2 | 0.002 | 0.010 |
| | Dec | | - | 0.1 | nd | 0.001 |
| Galway | May | - | - | nd | nd | 0.0035 |
| Castletownbere | May | - | - | nd | - | - |

Notes: (1) Results are based on the analysis of a composite of 4 samples
(2) Results are based on the analysis of a composite of 6 samples
nd = not detected

**Table 20**
**Radioactivity in Mussels, 2000**

| *Sampling Location* | *Month* | *Activity Concentration Bq/kg, wet weight* | | | | |
|---|---|---|---|---|---|---|
| | | *C-14* | *Tc-99* | *Cs-137* | *Pu-238* | *Pu-239,240* |
| Carlingford | Feb | 19.5 | 19 | 0.3 | 0.007 | 0.036 |
| | Jun | 18.4 | 35 | 0.9 | 0.036 | 0.217 |
| | Aug | 21.5 | 22 | 0.3 | 0.010 | 0.057 |
| | Nov | 20.7 | 19 | 0.4 | 0.012 | 0.071 |
| Casteltownbere | Mar | - | - | nd | - | - |
| Lough Foyle | Mar | - | - | 0.1 | - | - |

Note: nd = not detected

**Table 21**
**Radioactivity in Mussels, 2001**

| *Sampling Location* | *Month* | *Activity Concentration Bq/kg, wet weight* | | | | |
|---|---|---|---|---|---|---|
| | | *C-14* | *Tc-99* | *Cs-137* | *Pu-238* | *Pu-239,240* |
| Carlingford | Feb | 23.8 | 20 | 0.3 | 0.011 | 0.061 |
| | Jun | 26.0 | 51 | 0.4 | 0.030 | 0.174 |
| | Sep | 24.4 | 19 | 0.1 | nd | 0.033 |
| | Dec | 35.0 | 28 | 0.2 | 0.005 | 0.035 |

Note: nd = not detected

**Table 22**
**Radioactivity in Oysters, 2000**

| *Sampling Location* | *Month* | *Activity Concentration Bq/kg, wet weight* | | | | |
|---|---|---|---|---|---|---|
| | | *C-14* | *Tc-99* | *Cs-137* | *Pu-238* | *Pu-239,240* |
| Carlingford | Feb | 24.3 (1) | 6 | 0.3 | 0.011 (1) | 0.059 (1) |
| | Jun | | 4 | 0.2 | | |
| | Aug | | 4 | 0.3 | | |
| | Nov | | 3 | 0.2 | | |

Note: (1) Results are based on the analysis of a composite of 4 samples

**Table 23**
**Radioactivity in Oysters, 2001**

| *Sampling Location* | *Month* | *Activity Concentration Bq/kg, wet weight* | | | | |
|---|---|---|---|---|---|---|
| | | *C-14* | *Tc-99* | *Cs-137* | *Pu-238* | *Pu-239,240* |
| Carlingford | Feb | 22.6 | 6 | 0.1 | 0.008(1) | 0.045(1) |
| | Jun | | 6 | 0.2 | | |
| | Sep | | 4 | 0.2 | | |
| | Dec | | 2 | 0.1 | | |

Note: (1) Results are based on the analysis of a composite of 4 samples

**Table 24**
**Technetium-99 in Lobster(1), 2000 and 2001**

| *Sampling Location* | *Month* | *Tc-99 Activity Concentration Bq/kg, wet weight* | |
|---|---|---|---|
| | | **2000** | **2001** |
| Carlingford | Aug | 47 | - |
| Dundalk Bay | Jun | 41 | 63 |
| | Nov | - | 17 |
| Howth | Mar | - | 322 |
| | Apr | 45 | - |
| | Oct | 36 | 24 |

Note: (1) Tail meat only included in analysis

**Table 25**
**External Dose Rate Measurements, 2000 and 2001**

| *Sampling Location* | *Month* | *Site Description* | *Gamma Dose Rate μGy/h* | |
|---|---|---|---|---|
| | | | **2000** | **2001** |
| Greenore | Feb | Rocks/Sand | 0.082 | 0.083 |
| | Jun | Rocks/Sand | 0.081 | - |
| | Aug | Rocks/Sand | 0.077 | - |
| | Nov | Rocks/Sand | 0.074 | - |
| | Dec | Rocks/Sand | - | 0.046 |
| Blackrock (Co Louth) | Feb | Fine Sand | 0.065 | 0.060 |
| | Jun | Fine Sand | 0.054 | - |
| | Aug | Fine Sand | 0.058 | - |
| | Nov | Fine Sand | 0.072 | - |
| | Dec | Fine Sand | - | 0.058 |
| Carlingford | Dec | Rocks/Sand | - | 0.092 |
| Bull Island | Apr | Fine Sand | 0.053 | - |
| | May | Fine Sand | - | 0.053 |
| | Aug | Fine Sand | - | 0.054 |
| | Sep | Fine Sand | 0.061 | - |
| | Nov | Fine Sand | - | 0.050 |
| | Dec | Fine Sand | 0.053 | - |
| Balbriggan | Feb | Fine Sand | 0.058 | 0.053 |
| | May | Fine Sand | 0.054 | 0.058 |
| | Jun | Fine Sand | 0.060 | - |
| | Aug | Fine Sand | 0.060 | - |
| | Nov | Fine Sand | 0.058 | 0.071 |
| | Dec | Fine Sand | - | 0.063 |
| Cahore | Apr | Rocks/Sand | 0.071 | - |
| | May | Rocks/Sand | - | 0.070 |
| | Nov | Rocks/Sand | 0.074 | 0.074 |
| Dunmore East | Sep | Fine Sand | 0.080 | - |
| Cobh | Sep | Pebbles | 0.071 | - |
| Castletownbere | Sep | Pebbles | 0.078 | - |
| Galway (Salthill) | Nov | Fine Sand | 0.086 | - |
| Killybegs/ Mountcharles | Nov | Fine Sand | 0.079 | - |

**Table 26**
**Mean Activity Concentrations of Artificial Radionuclides in Fish and Shellfish Landed at North-East Ports, 2000**

| *Species Type* | *Activity Concentration Bq/kg, wet weight* | | | | |
|---|---|---|---|---|---|
| | ***Tc-99*** | ***Cs-137*** | ***Pu-238*** | ***Pu-239,240*** | ***Am-241(1)*** |
| Fish | 0.4 | 0.7 | 0.0001 | 0.0002 | 0.0002 |
| Crustaceans (Prawns) | 85 | 1.0 | 0.0026 | 0.014 | 0.022 |
| Molluscs (Mussels) | 24 | 0.4 | 0.016 | 0.095 | 0.043 |

Note: (1) Estimated using a mean americium/plutonium ratio in fish at Clogherhead [Ryan *et al*., 1999]

**Table 27**
**Mean Activity Concentrations of Artificial Radionuclides in Fish and Shellfish Landed at North-East Ports, 2001**

| *Species Type* | *Activity Concentration Bq/kg, wet weight* | | | | |
|---|---|---|---|---|---|
| | ***Tc-99*** | ***Cs-137*** | ***Pu-238*** | ***Pu-239,240*** | ***Am-241(1)*** |
| Fish | 0.5 | 0.8 | nd | 0.0005 | 0.0006 |
| Crustaceans (Prawns) | 29 | 0.8 | 0.010 | 0.045 | 0.007 |
| Molluscs (Mussels) | 30 | 0.3 | 0.015 | 0.076 | 0.034 |

Notes: (1) Estimated using mean americium/plutonium ratios in fish, prawns and mussels [Ryan *et al*., 1999]
nd = not detected

**Table 28**
**Dose Conversion Factors(1)**

| **Nuclide** | **Dose Conversion Factors Sv $Bq^{-1}$** |
|---|---|
| C-14 | $5.8 \times 10^{-10}$ |
| Cs-137 | $1.3 \times 10^{-8}$ |
| Tc-99 | $6.4 \times 10^{-10}$ |
| Pu-238 | $2.3 \times 10^{-7}$ |
| Pu-239 | $2.5 \times 10^{-7}$ |
| Pu-240 | $2.5 \times 10^{-7}$ |
| Am-241 | $2.0 \times 10^{-7}$ |

Note: (1) Source: ICRP, 1996 (a)

**Table 29**
**Committed Effective Doses, from Artificial Radionuclides, due to the Consumption of Fish and Shellfish Landed at North-East Ports, 2000 and 2001**

| *Radionuclide* | *µSv* | | *µSv* | |
|---|---|---|---|---|
| | *Heavy consumer* | *Typical consumer* | *Heavy consumer* | *Typical consumer* |
| | **2000** | | **2001** | |
| Tc-99 | 0.273 | 0.067 | 0.161 | 0.039 |
| Cs-137 | 0.731 | 0.149 | 0.811 | 0.165 |
| Pu-238,239,240 | 0.120 | 0.030 | 0.140 | 0.035 |
| Am-241 | 0.051 | 0.016 | 0.087 | 0.026 |
| Total | 1.175 | 0.262 | 1.200 | 0.265 |

**Table 30**
**Fish and Shellfish Landings at North-East Ports, 2000 and 2001[(1)]**

| **Landing Port** | **Year** | **Landed Weight (tonnes)** | |
|---|---|---|---|
| | | **Fish** | **Shellfish** |
| Clogherhead | 2000 | 175.8 | 577.6 |
| | 2001 | | |
| Skerries | 2000 | 56.6 | 563.9 |
| | 2001 | | |
| Howth | 2000 | 1545.5 | 2315.9 |
| | 2001 | | |

Note: (1) Source: Department of Communications, Marine and Natural Resources (Personal communication)

**Table 31**
**Collective Effective Doses to Irish Consumers, from Artificial Radionuclides, due to the Consumption of Fish and Shellfish Landed at North-East Irish Sea Ports, 2000 and 2001**

| *Radionuclide* | *manSv* | |
|---|---|---|
| | **2000** | **2001[(1)]** |
| Tc-99 | 0.0102 | |
| Cs-137 | 0.0041 | |
| Pu-238,239,240 | 0.0015 | |
| Am-241 | 0.001 | |
| Total | 0.0168 | |

Note: (1) Landing statistics for 2001 unavailable at time of printing