Marine radioactivity in the Channel Islands

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A. Brown and L.S. Austin

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SUMMARY

The Directorate of Fisheries Research of the Ministry of Agriculture, Fisheries and Food carries out monitoring of the coastal area of the Channel Islands on behalf of the Channel Islands States. In April 1989, staff visited Jersey, Guernsey and Alderney to review the monitoring programme in detail and to carry out supplementary monitoring as appropriate. Our recommendations concerning the monitoring programme are as follows:

i) that the programme is generally adequate for judging the radiological significance of marine pathways on the islands;

ii) that a limited number of additional samples should be analysed so as to enhance our knowledge of radionuclide concentrations in cultivated ormers from Guernsey (annual sample), lobsters from Guernsey, Jersey and Alderney (annual sample), crabs from the edge of the Hurd Deep (annual sample), water from the desalination plant on Jersey (weekly sample bulked for a monthly analysis during operation) and seaweed from the outfall of the desalination plant (annual sample). The samples should be analysed by total beta counting and by gamma spectrometry with the exception of the drinking water which should be analysed for caesium-134 and -137. Because of the radiological importance of polonium-210, a naturally occurring radionuclide, an annual analysis of limpets and a biannual analysis of seaweed from Alderney is recommended. The additional monitoring could be offset by a reduction in the analysis of transuranics in seaweeds because the existing programme produces adequate data for these radionuclides from measurements in edible biota and sediments; and

iii) that the programme should continue to be reviewed on an annual basis and that annual summaries of the results should be provided. In addition, we recommend that a further visit should be made to the islands if discharges increase significantly from Etablissement de la Hague and, in any event, before the end of the century.

The results of gamma spectrometric analysis of the samples collected during the visit to the islands and from the routine monitoring programme show that the effects of discharges from the reprocessing plant at Etablissement de la Hague can be detected. However, we estimate that a critical group of seafood consumers would receive no more than 1% of the 1 mSv $year^{-1}$ ICRP recommended dose limit for members of the public due to man-made radionuclides. Measurements on beaches, nets and pots using beta and gamma detectors show no increase over levels expected from natural radiation. The whole body exposure from external irradiation due to man-made radionuclides for a hypothetical critical group is estimated to be no more than 0.3% of the 1 mSv $year^{-1}$ dose limit. Naturally-occurring radionuclides in the marine environment will result in critical group doses of approximately 0.7 mSv $year^{-1}$ from the consumption pathway and 0.1 mSv $year^{-1}$ from external irradiation.

A review of environmental concentrations of radionuclides, from wastes disposed into the sea from the nuclear industry on the people of the Channel Islands from the mid-nineteen sixties to date, shows that there have been no major trends in concentrations.

1. INTRODUCTION

The presence of radioactivity in the sea around the Channel Islands has been studied for over 20 years. French research has mapped the observed distributions of man-made radionuclides in sea water (Guegueniat *et al.*, 1988) and environmental models have been used to make predictions about marine dispersion from one of the major sources, the reprocessing plant located near Cap de la Hague, (Salomon *et al.*, 1988). Occasional monitoring has been carried out by universities (Cross and Day, 1981; Baumgartner *et al.*, 1987) but the routine programme has been operated by the UK, Ministry of Agriculture, Fisheries and Food (MAFF). This programme, which is part of surveillance throughout coastal waters of the British Isles, has involved the regular sampling and analysis of marine materials. The importance of providing information in the public domain has long been recognised and the first results for the Channel Islands were published in 1967 (Mitchell, 1967). Since that time, reports have generally been published annually, the most recent being for 1990 (MAFF, 1991). These have shown that whilst the effects of man-made sources of radionuclides can be detected in the Channel Islands, the levels have been low and of minor radiological significance.

Despite this finding, it is necessary to periodically review the adequacy of arrangements for monitoring because of possible changes in activities which may affect assessments of radiation exposure. This report presents the conclusions of such a review which was carried out in 1989. We present a discussion on the current sources of man-made radioactivity in the area and a summary of our understanding of the main pathways for exposure, which was gained from a visit to the Channel Islands during the course of the year. We include detailed assessments of the radiation exposure of individuals due to man-made and natural radionuclides from marine pathways and, on the basis of this information and our wider experience, make recommendations concerning the future of the programme.

2. SOURCES OF RADIONUCLIDES IN THE MARINE ENVIRONMENT OF THE CHANNEL ISLANDS

There are three main sources of man-made radionuclides into the sea near the Channel Islands. These arise from:

i) the French reprocessing plant at Etablissement de la Hague;

ii) the nuclear power station at Flamanville; and

iii) historical rights to waste disposal in the Hurd Deep to the north of Guernsey.

Discharges are also made from the Winfrith Technology Centre, and the nuclear reactors at Dungeness, Paluel and Gravelines but these are of minor significance to the Channel Islands. The locations of these sources in relation to the Channel Islands are shown in Figure 1. Other sources of man-made radionuclides in the general area of the English Channel have included fallout from the atmosphere due to the testing of nuclear weapons and the reactor accident at Chernobyl. However, none of these sources is likely to have a significant effect on exposures to members of the public in the Channel Islands. Natural radionuclides, produced by cosmic radiation and during the formation of the planet, will also be present in marine materials and will contribute significantly to radiation doses. These are discussed further in Sub-section 5.2. The remainder of Section 2 provides more information on the quantities and trends in waste disposal from the three main sources of man-made radionuclides in the area.

2.1 Etablissement de la Hague

The Compagnie Générale des Matiéres Nucléaires (COGEMA) operates the reprocessing plant at Etablissement de la Hague on the Cherbourg peninsula. Liquid effluents are discharged under authorisation by the French Government to the English Channel. The information on the radionuclide composition of the discharges is generally less detailed than those for other reprocessing plants but a recent review carried out on behalf of the Commission of the European Communities (CEC) (McColl *et al.*, 1990) has provided the most complete data set to date. The discharge data are shown as Annex I of this report.

Reprocessing started at Etablissement de la Hague in 1965 and the most recent information at the time of writing this report relates to 1986. Annual discharges of alpha emitters increased from 1965 onwards until they reached fairly constant levels in the early 1980s (Figure 2(a)). Annual discharges of beta emitters (excluding tritium) also increased until they reached fairly constant levels in the late 1970s (Figure 2(b)). The discharges are dominated by ruthenium-106 and this radionuclide is detected in the environmental samples collected by the French authorities and by MAFF's Directorate of Fisheries Research (DFR) on behalf of the Channel Islands States. Although reprocessing activities tend to lead to relatively high discharges within the nuclear fuel cycle, the total discharges from Etablissement de la Hague up to the end of 1986 were considerably lower than those from BNFL Sellafield, the main UK reprocessing plant. However, the relative importance of these sites is changing and if discharges from Etablissement de la Hague continue at their rates for 1986, the plant will now be discharging more radioactivity than the Sellafield plant.

The CEC project not only reviewed discharges from Etablissement de la Hague but also assessed the radiation exposure of critical groups in France (Camplin and Aarkrog, 1989). The assessment was based on environmental monitoring data published by the Commissariat a L'Energie Atomique (CEA) (Calmet *et al.*, 1985, 1986; Charmasson *et al.*, 1986, 1987). These reports and other recently published data (Chartier *et al.*, 1989) clearly show that the effects of discharges from Etablissement de la Hague are measurable in marine materials from the Cherbourg peninsula. The individual doses estimated for people eating high rates of seafood and spending a long time on the beach near Etablissement de la Hague were less than 0.04 and 0.3 mSv year^{-1} respectively during the period 1982-1986. The doses are within the dose limit for members of the public of 1 mSv year^{-1} and were likely to have been overestimated because of the assumptions employed in the calculations.

2.2 Flamanville

The Flamanville site consists of two pressurised water reactor power stations each of 1345 MW capacity. The plant began commercial operation during 1986 and would have begun to discharge radioactive waste at about this time. No discharge data were available to the authors at the time of writing this report but the discharge limits for the site are 80 TBq per year for tritium and 1.1 TBq per year for other radionuclides (Charmasson *et al.*, 1987). The discharges from this site are therefore small compared to those from Etablissement de la Hague. It is unlikely that the effects of discharges from Flamanville could be detected in marine materials around the Channel Islands.

2.3 Solid waste disposal in the Hurd Deep

The disposal of packaged radioactive waste at the eastern end of the Hurd Deep took place on fourteen occasions between 1950 and 1963. The disposals were authorised by the UK Govern-

ment and were carried out by the Navy on behalf of the Ministry of Supply and later by the United Kingdom Atomic Energy Authority. The quantities disposed of are shown in Table 1 (adapted from Camplin and Aarkrog, 1989). The waste resulted from various laboratory processes: much of it was laboratory rubbish such as gloves, glassware and paper.

Because of the small amounts of radioactivity involved, the packaging used and the depth of the site (about 200 metres), radionuclides released from the site will not have given rise to significant doses to man from the consumption of seafood caught in this area.

3. RADIOLOGICAL EXPOSURE PATHWAYS

3.1 General information

The main exposure pathways in the marine environment are through ingestion of radionuclides in seafood and external exposure over intertidal areas. Such exposures are dependent on the tides, the behaviour and concentration of radionuclides in the environment and the nature of the fisheries. A series of interviews were held with employees of the Channel Islands States and people who could describe the location and extent of these pathways. The information gained is summarised below.

3.2 The Channel Islands' fisheries

The Channel Islands' fisheries are primarily devoted to catching crustaceans, with fish and molluscs being of less importance. For example, seafood landings for Jersey in 1988, included 109 000 kg of lobster (*Homarus gammarus*); 485 000 kg of edible crab (*Cancer pagurus*) and 174 000 kg of spider crab (*Maia squinado*) compared with 23 000 kg of fish and 3 600 kg of molluscs (States of Jersey, 1989). The commercial fishing effort broadly divides into an offshore fleet, the Channel potting fleet and the inshore fishery (Culley, 1979). Guernsey has approximately 80 full-time commercial boats with about 180 crew and as many as 500 part-time fishermen, Jersey has approximately 50 full-time commercial fishermen and 200 part-time fishermen and Alderney has 6 resident full-time commercial fishermen and 20 part-timers. The way in which potting gear is operated has been described in detail (Dunn *et al.*, 1967; Bossy, 1986).

3.2.1 The offshore fleet

This fleet consists of vessels in excess of 25 metres that trawl for fish or scallops in the English Channel, including the area near the French coast known as the Schole Bank and Echrehos (Figure 1). Although vessels may be owned by Channel Islanders, the boats rarely visit the Islands, usually landing at ports on the south coast of England such as Brixham or on the French coast, for example, at Cherbourg.

3.2.2 The Channel potting fleet

Vessels from the Channel Islands regularly fish for lobsters and edible crabs in the area to the north of Alderney on the edge of the Hurd Deep (Figure 1). Over ten boats, each with a crew of four or five, will work typically 800-1000 pots per day, stopping overnight in Alderney and landing their catch for the week at Cherbourg. Due to the strong currents, pots cannot be worked during spring tides and the vessels are laid up at these times.

3.2.3 The local fleet and near/onshore fisheries

The local fleet is considered to be those vessels that fish on a daily basis throughout the year from a home port. They are primarily involved with catching lobsters, edible crabs or spider crabs. The latter species is mainly caught in the early spring and autumn to the south of Guernsey and Jersey as they migrate into and away from the shallow, sandy bays of the Islands. In the summer, they are fished from the bays. If the crustacean fishery is unprofitable, occasional use is made of trammel nets for bass (*Dicentrarchus labrax*) and flatfish and lines for bass and mackerel (*Scomber scombrus*). Some fishermen pot for prawns (*Palaemon* sp.) and whelks (*Buccinum undatum*) but none of these activities accounts for more than 10% in value of the annual catch of the average local professional (Bossy, 1986).

Winkles (*Littorina littorea*) are collected on Jersey and approximately 50 kg per year are sold in the local market. Limpets (*Patella vulgata*) are collected between April and October by Portuguese migrants who seek employment on Jersey as a casual labour force. The limpets are dried and pickled and either eaten by the migrants or sent for consumption in Portugal. No statistics exist on the extent of this practice. Oysters (*Crassostrea gigas*) are cultivated off the south east of La Rocque as are clams (*Chlamys sp.*). The latter species is also collected off Green Island. Ormers (*Haliotis tuberculata*) are rarely found in the wild but have been cultivated off Green Island.

On Guernsey, winkles are collected and oysters are cultivated at Rocquaine Bay and Grande Havre. About 50 000 ormers per year are reared at Rocquaine Bay. Scallops (*Pecten maximus*) are dredged by fishermen and collected by divers for local consumption.

Limpets, whelks, scallops and ormers are infrequently collected on Alderney for consumption there.

3.3 Consumption rates of seafood

The large fishing effort in the area suggests that seafood will be readily available to a large number of people throughout the year and that relatively high consumption rates can be expected. No attempt, however, was made to obtain specific consumption rates from potential critical group consumers during the period of field work. The consumption rates chosen for the assessment of exposure are discussed in Section 5.

3.4 Other ingestion pathways

There were three additional ingestion pathways which were noted during the visit but are considered to be of minor radiological significance. They are through:

- drinking desalinated water;
- inadvertent ingestion of sea water during swimming; and
- consumption of crops grown in soil treated with seaweed.

3.4.1 Drinking desalinated water

Drinking water is made from sea water by means of a desalination plant at Corbière in Jersey. The plant operates during the summer months to augment the natural supplies of drinking water and produces a concentrated, salty liquid waste which is pumped into the sea. The quantity of radionuclides in the water for human consumption will be very small and most will be discharged with the waste.

3.4.2 Inadvertent ingestion of sea water

Swimming and windsurfing are both popular activities on the Channel Islands. Sea water may be inadvertently ingested during these sports but the volumes will be small.

3.4.3 Consumption of crops grown in soil treated with seaweed

Seaweed has been regularly collected on the islands for many years and we were told, for example, that as much as 15 000 tonnes are washed up each year at St Aubins on Jersey. The seaweed is used as a mulch or fertiliser and a variety of crops, including potatoes and carrots, may be grown in soil that has been treated in this way. *Fucoids* and *Laminarians* are the predominant species collected near L'Etacq on Jersey. Here, they are left on nearby fields for a time between a few weeks and a few months and then ploughed in. On Guernsey, a few growers and farmers regularly collect *Fucoids* from the west coast beaches for use in greenhouses and on open land. The seaweed is collected in the autumn and ploughed into the land in the spring. Seaweed is collected at Clonque Bay, Braye Bay and the Corblets on Alderney for domestic use in gardens.

The approach used by DFR to assess these additional consumption pathways is discussed in Section 5.

3.5 External exposure

3.5.1 Occupancy over intertidal sediments

Most of the intertidal areas around the Channel Islands are either rocky or sandy. Mud which contains silt is potentially the most important sediment in radiological terms because of its ability to adsorb radioactivity. This was found at St Peter Port and St Sampson's harbours on Guernsey and St Helier harbour on Jersey, but on Alderney, mud was found only in Crabbe harbour and then it was mixed with sand. Activities that can lead to a large amount of time being spent near these sediments could be, for example, living on a houseboat, bait digging, spending time on board fishing boats while the tide is out, and boat maintenance on slipways. All of these activities could occur in the areas mentioned above but no evidence was found of large occupancies on houseboats. Bait digging was recorded in muddy sand at St Aubins Bay and the Royal Bay of Grouville on Jersey and on Guernsey at Belle Greve. Mechanical dredging of the harbours was noted but such operations are infrequent and usually occur less than once a year.

3.5.2 Swimming and other water sports

External exposure to the whole body and skin may occur during swimming and other water sports. However, doses will be lower than those from occupancy over areas of sediment for the same period of time because of the lower concentrations in the water and its shielding effect. There are several popular beaches on Jersey for swimming including St Aubins Bay, Catherines Bay, Rozel Bay, Bouley Bay, Grève de Lecq, St Ouens Bay and St Brelades Bay. On Guernsey, swimmers are found all round the island with the sandy west coast bays being the most popular. On Alderney, the bays of Braye, Crabby or Longis may be used daily by swimmers.

3.5.3 Handling of fishing gear

Fine particles of sediment can become entrained on fishing gear and are thus a potential source of whole body gamma radiation and skin exposure due to the beta particles. However, our

experience in other areas of the British Isles suggests that this pathway is of limited importance because whole body exposures are greater from other sources involving occupancy over large areas of sediment and skin exposures are subject to a higher dose limit than those for the whole body ones. Our monitoring was thus used to demonstrate that doses from nets and pots remain radiologically insignificant.

4. THE MAFF (DFR) MONITORING PROGRAMME

4.1 General information

Environmental monitoring programmes are designed to fulfil several objectives and criteria. These may be summarised as follows:

i) the assessment of the radiation dose equivalent received by members of the public, particularly those who by the nature of their habits may be considered to be the most exposed (i.e. the critical group);

ii) as a check that discharges comply with Authorised limits;

iii) as ensurance that doses received by individuals do not exceed the appropriate dose limits;

iv) the provision of independent surveillance for inadvertent or unrecorded discharges;

v) the determination of background levels prior to the operation of a site or before changes in discharge practice during the life of a station or during decommissioning. These data can also aid decision making during an emergency; and

vi) the provision of public information and reassurance.

The MAFF (DFR) programme has been designed with these objectives in mind though the responsibility for controlling discharges from French nuclear sites clearly lies with the French authorities.

Table 2 shows the routine MAFF (DFR) environmental sampling and analytical programme required for the Channel Islands during 1989. Essentially, the programmes for each island are the same as those which were instigated during the mid-nineteen sixties. Since that time, the changes that have been made have occurred primarily because of difficulties in obtaining samples at some locations (e.g. seaweeds). The indigenous ormer, which was once abundant, has become scarce and other molluscs have been substituted in the programme.

For Guernsey and Jersey, the programmes consist of a quarterly collection of seaweeds from at least two locations and an annual mud sample from each island. Crustaceans (crabs) and molluscs (limpets) are also collected annually. In addition, rays are caught near Guernsey and other molluscs (oysters) are caught near Jersey. Sea water is collected from both islands on a quarterly basis. The sampling locations are shown in Figures 3 and 4.

For Alderney, there is a similar programme of seaweed, sediment, mollusc and sea-water sampling as described above. The sampling locations are shown in Figure 5.

The main part of these programmes utilise indicator materials. Additionally, internal exposure can be assessed from the monitoring of fish, crabs, limpets and oysters. Total beta analysis will

detect radioactivity from man-made radionuclides, of which carbon-14, strontium-90, technetium-99 and promethium-147 are pure beta emitters, as well as indicating the level of natural radionuclides such as potassium-40 and the decay products of uranium and thorium. Gamma spectrometry is capable of detecting a large number of specific radionuclides, of which cobalt-60, ruthenium-106, antimony-125, caesium-134, caesium-137, europium-154, europium-155 are particularly relevant. Radiochemical separation is required for the analysis of carbon-14, strontium-90, technetium-99, promethium-147 and transuranic elements such as plutonium, curium and americium.

4.2 Interpretation of the 1989 monitoring data

The 1989 monitoring data obtained from the routine programme and during our review have been summarised. Table 3 shows the concentrations of individual radionuclides in environmental material analysed by gamma spectrometry and their total beta content. The results are expressed as becquerels per kilogram wet weight (Bq kg^{-1}) except for sediments where concentrations in dried material apply.

4.2.1 Biota

The concentrations of man-made radionuclides in biota were all very low in 1989. Cobalt-60, zinc-65, ruthenium-106, silver-110m, antimony-125 and caesium-137 were detected in molluscs and crustaceans.

Using limpets as an example of an edible species that is collected from each of the major islands, the data show that the highest concentrations occur on Alderney. Ruthenium-106 was detected at 19 Bq kg^{-1}, whereas on Guernsey or Jersey concentrations were lower at approximately 5 Bq kg^{-1}. Such results are indicative of the source being Etablissement de la Hague which discharges significant quantites of this radionuclide. A similar trend is seen for winkles collected from Alderney and Jersey. Cobalt-60 is also discharged from Etablissement de la Hague and was detected in all of the mollusc samples. The highest concentration was 7.1 Bq kg^{-1} in winkles from Alderney. No obvious correlation is seen for cobalt-60 concentrations in limpets collected at various distances from the Etablissement de la Hague outfall. Crabs were also analysed from each of the major islands. The highest concentrations occur in the Jersey sample, probably reflecting where the vessel had been fishing rather than indicating that stocks on Jersey have the highest concentrations. Rays landed on Guernsey only contained caesium-137 and this was at a very low concentration.

4.2.2 Seaweed

Fucoids, *Laminaria* and *Porphyra* were all sampled as indicators, as they have the ability to concentrate radionuclides such as ruthenium-106 and cobalt-60. Results for ruthenium-106 show a general trend of higher concentrations from the Alderney sample but this is not seen for cobalt-60. In *Porphyra*, concentrations of ruthenium-106 were higher in the first quarter than in the second quarter. Jersey and Alderney samples showed the highest results of 22 Bq kg^{-1} and 53 Bq kg^{-1} respectively during the last quarter. Elevated levels of cobalt-60 were noted in the autumn samples from Alderney and Guernsey. Both samples were subjected to further investigation by dividing them to ascertain whether the activity was biologically incorporated or unevenly distributed suggesting a discrete particle or particles. The results suggested that the cobalt-60 was biologically incorporated into the Alderney sample but not into the Guernsey sample. The latter was found to contain a single particle rich in cobalt-60 and measuring 0.25 mm. No other such particles have been identified in samples from the Channel Islands and our labora-

tory measurements, using a contamination monitor (Mini Instruments 900 fitted with a type 41 probe*), showed that there was no increase in dose rate on contact due to the activity in the particle. In addition, the particle could not be detected using auto-radiography.

Whilst the detection of this particle has little radiological significance, it is of interest in interpreting fluctuations in environmental concentrations. Therefore, in future, if samples of seaweed are found to have levels of cobalt-60 exceeding a few becquerels per kilogram, further investigation may be warranted.

4.2.3 Sediment

Manganese-54, cobalt-60, ruthenium-106, antimony-125, caesium-137, europium-154 and 155 and americium-241 were detected in marine sediments. Radionuclide concentrations were found to be lower in sand than in mud. This is aptly demonstrated in the gamma spectrometry results for mud from St Helier harbour and for sand from St Aubins Bay, two sites which are only 2 km apart. The ruthenium-106 concentrations in mud were 61 Bq kg^{-1}, and 3.3 Bq kg^{-1} in sand. Similarly, the cobalt-60 concentrations were 30 Bq kg^{-1} in mud and 0.56 Bq kg^{-1} in the sand. Caesium-137 concentrations were 7.0 Bq kg^{-1} in mud and 0.62 Bq kg^{-1} in sand. Mud sampled from Guernsey at Bordeaux harbour, St Peter Port and St Sampson's Bay had radionuclide concentrations lower than mud sampled from St Helier harbour or around Jersey. This is likely to be due to the quantity of small particles present with which some radionuclides have a high affinity. The most likely source of these radionuclides is the Etablissement de la Hague reprocessing plant.

4.2.4 Sea water

The seas around the Channel Islands are characterised by being relatively shallow and having strong tidal currents (Pingree and Mardell, 1987). Figure 6 shows the direction of the flow around the Cherbourg peninsular during part of the tidal cycle when the movement is towards the Channel Islands (adapted from Fowler, 1991). The extensive reefs and islands are likely to induce turbulence making the dispersion of radionuclides complex. Dispersion studies show that the overall movement is to the north east (Thomas, 1988; Le Fur, 1989). Caesium-137 is primarily transported northwards out of the English Channel into the Skagerrak to mix with caesium originating from Sellafield before either entering the Baltic or continuing northwards along the Norwegian coast (Kautsky, 1988). The radiocaesium concentrations in filtered sea water, shown in Table 4, demonstrate low concentrations ranging from 4.4 to 14 mBq l^{-1} for two locations on Jersey and one each on Guernsey and Alderney. Concentrations were very similar during the first half of 1989 but increased later in the year. Similar changes have been seen in previous years. There were no significant differences between the concentrations in samples from each island.

4.2.5 Results of radiochemical analyses

Results of radiochemical analyses of samples collected in 1989 are shown in Table 5. This includes data for transuranics, namely plutonium-238, plutonium-239+240, plutonium-241, americium-241, curium-244 and curium-242+243 in seafood, indicator materials and terrestrial crops grown in seaweed. Carbon-14 analyses were carried out on fish, crabs and winkles, where low concentrations were detected (19 Bq kg^{-1} (wet) in rays, 20 Bq kg^{-1} (wet) in crabs and 19 Bq kg^{-1} (wet) in winkles). Transuranics were also detected at low concentrations in all samples. Mud from St Helier harbour contained the highest concentrations (e.g. plutonium-239+240 at

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3.29 Bq kg^{-1} (dry)). Of the seafood, molluscs contained the highest concentrations (e.g. plutonium-239+240 at up to 0.02 Bq kg^{-1} (wet)) and fish, the lowest concentrations (e.g. plutonium-239+240 at 0.00024 Bq kg^{-1}). Alderney limpets had higher concentrations than samples from Guernsey or Jersey presumably reflecting the distance from Etablissement de la Hague.

4.3 Time trends

The annual monitoring reports produced by MAFF (DFR) summarise total beta concentrations and radionuclide concentrations in samples from the Channel Islands and elsewhere (see, for example, MAFF, 1991). *Porphyra* has been shown to be a sensitive indicator of Etablissement de la Hague discharges and Figure 7 shows a plot of mean total beta concentrations from Jersey, Guernsey and Alderney for the period 1966 to 1989. Concentrations have varied from 130 to 480 Bq kg^{-1} (wet) with the greatest variation being seen in the Alderney samples. No overall increase or decrease is apparent. Figure 8 shows a similar plot for ruthenium-106 in the same samples together with annual discharges from Etablissement de la Hague for comparison from 1971 to 1989. Whilst there are changes in discharges of up to a factor of two from year to year, no obvious correlation with *Porphyra* concentrations can be observed. Alderney samples have the highest concentrations and these are typically 40 Bq kg^{-1} or more than the Jersey or Guernsey samples. During the past 12 years, concentrations have varied from 5 Bq kg^{-1} (Guernsey) to over 200 Bq kg^{-1} (Alderney). Concentrations are generally similar or lower than those found in the late nineteen seventies.

4.4 Monitoring of beaches, harbours and fishing gear

Gamma dose rate measurements taken during 1989 are shown in Table 6. Four 300 second counts were made at one metre above a variety of intertidal sediments. Figure 9 shows this type of monitoring in progress. The highest doses recorded were 0.11 µGy h^{-1} on the mud in St Helier harbour and 0.11 µGy h^{-1} on the rocks at L'Etacq. The lowest reading was 0.062 µGy h^{-1} recorded at Longis Bay on Alderney. Natural radiation varies from 0.03-0.10 µGy h^{-1} over intertidal sediments (MAFF, 1992) and it is therefore difficult to distinguish our measured values from those expected due to natural radiation. For this reason we have relied upon a model to predict external dose rates in our assessment of critical group doses (Section 5).

Table 7 shows beta doses taken on contact with sediments and fishing gear and Figure 10 shows one example of this type of monitoring. In this case, a trawl net that had recently been used near Etablissement de la Hague, was being studied. Doses were very low and ranged from 0.11 to 0.33 µGy h^{-1} using a conversion factor of 0.11 µSv h^{-1} per c s^{-1}.

A close-contact beta/gamma probe (Huggins *et al.*, 1989) was used to look for particulate activity in intertidal areas. Figures 9 and 11 show some of this monitoring in operation. We surveyed all of the locations listed in Table 6 and no such activity was found.

5. INDIVIDUAL DOSES TO A HYPOTHETICAL CRITICAL GROUP

5.1 General Information

The radiation exposure of members of the public on the Channel Islands from marine pathways is from both man-made radionuclides and those that occur naturally. Individual doses to a

hypothetical critical group are presented in this section for both sources of exposure. The primary modes of exposure considered are consumption of fish and shellfish and external irradiation from intertidal sediments. Other pathways, such as handling of fishing gear and inhalation of resuspended activity, are generally less important and will not be considered further in this report. However, as noted in Section 3, swimming, consumption of desalinated water and the use of seaweed as a fertiliser and soil conditioner also take place on the Channel Islands. We have therefore carried out sensitivity analyses of these pathways in addition to those of consumption of seafood and external irradiation from sediments.

The system of dose limitation recommended by the International Commission on Radiological Protection (ICRP) has been adopted in the United Kingdom and the Channel Islands. With reference to individual dose limits, the principal limit is 1 milliSievert in a year and is relevant to all exposures excluding those from medical and natural sources. This applies to the quantity 'committed effective dose equivalent' which is described more fully by MAFF (1990). In this report, the dose quantity will simply be referred to as 'dose' for reasons of brevity.

Calculations of individual doses for comparison with the dose limit are made for the so-called 'critical group'. This is the group of people who, by virtue of their habits, are considered to receive the highest exposures. No detailed assessment of the habits of such people has been made in the Channel Islands, though the types of activity involved were studied during our visit and are reported in Section 3. In the absence of local numerical information, we have used generalised data which have been derived to encompass the normal range of critical group habits. These data are given in Table 8 and are taken from NRPB-GS10 (Robinson and Haywood, 1989). Separate calculations have been performed for infant, child and adult consumers because of the varying dosimetric consequences of intakes of radionuclides by different age groups. These calculations have shown that adult consumers receive the highest doses from man-made radionuclides when compared with those of infants and children. The results of dose calculations for such radionuclides in the remainder of this report refer to adults. Such differences are much smaller for the external exposure pathway and an occupancy of 1 000 hours per year over intertidal sediments has been taken to be representative of all age groups in this case.

The dosimetric data used to estimate the unit of activity of exposures due to consumption has been taken from three basic sources:

- ICRP 56 (ICRP, 1989);
- NRPB Documents (NRPB, 1990); and
- the NRPB 'RAPID' database (Greenhalgh *et al.*, 1986 as amended by changes in dosimetric factors outlined in Kendall *et al.*, 1987).

The most recent information is selected when there is more than one value available from these publications. Where a choice of gut uptake factors is available, the most restrictive dose per unit intake value has been adopted. The dose per unit intake data are provided in Table 8 for convenience.

5.2 Man-made radionuclides

5.2.1 Consumption of fish and shellfish

In addition to the information described earlier in this section, radionuclide concentrations are needed to estimate doses from the consumption pathway. Our environmental measurements

have shown that there is variability within a species group from sampling location to location. It would be unrealistic to adopt the highest concentrations observed within the islands and to combine these with the high consumption rates from the previous section. We have therefore chosen to use the average concentration of samples landed in the Channel Islands over the 5-year period, 1985-89. These data can be taken to be representative of recent environmental levels because there have been no major trends in concentrations during this period. The averaging process has the added advantage of smoothing out changes in concentrations which are due to the variability of fishing areas and the natural variability of environmental systems. The concentrations are presented in Table 9.

Carbon-14 will also have been present in organic materials in the sea and it has been assumed that the concentration of this radionuclide in all seafood is the same as that determined in the Alderney winkles in 1989. Because of the difficulties in analytical techniques, we have not measured the concentrations of other low-energy beta-emitting radionuclides, which are primarily strontium-90, technetium-99 and plutonium-241. The effects of these radionuclides are not likely to be dominant but, nevertheless, we have included an estimate of their contribution to the critical group dose by extrapolating from data on concentrations local to Etablissement de la Hague. For each species group, we have assumed that the concentration ratios of ^{90}Sr:^{137}Cs, ^{99}Tc:^{106}Ru and ^{241}Pu:$^{239/240}Pu$ at Etablissement de la Hague in 1986 (Camplin and Aarkrog, 1989) apply to the Channel Islands.

Finally, where a radionuclide was not detected using the analytical technique adopted, we have taken its concentration to be zero. Further information on the limits of detection of the method used for gamma-emitting radionuclides is provided by MAFF (1992).

The results of the dose calculations are summarised in Table 10. The highest predicted dose is 0.010 mSv year^{-1}. The radionuclide and pathway contributions to dose are shown in Figures 12 and 13. The most important radionuclides are caesium-137, carbon-14 and ruthenium-106 in fish and molluscs.

5.2.2 External irradiation

The environmental monitoring carried out during the visit suggested that gamma dose rates in intertidal areas were indistinguishable from natural radiation levels. In order to obtain an upper estimate of the likely level of dose due to man-made radionuclides, we have used a simple model of a uniformly contaminated beach. The dose rate from a radionuclide (D) is given by:

$$D(\text{mSv year}^{-1}) = K \times E \times O \times C \times W \times P \times F$$

where K is a constant (mGy hour^{-1} per MeV per disintegration per hour per year per Bq l^{-1} (wet));

E is the mean gamma energy per nuclear disintegration (MeV per disintegration);

F is the conversion factor from dose in air to dose in tissue (Sv Gy^{-1});

O is the time spent in intertidal areas (hours per year);

C is the concentration of the radionuclide in dry sediment (Bq kg^{-1});

W is the mass of sediment remaining after drying during analysis divided by the original mass of wet sediment (kg(dry) per kg(wet)); and

P is the density of wet sediment (kg l^{-1}).

The constant (K) takes the value 0.0001584 and has been derived from Hunt (1984). The dry/wet ratio (W), and sediment density (P) are taken to be 0.6 and 1.6 kg l^{-1} respectively from our measurements of typical marine sediments. The gamma energies of the radionuclides are given in Table 11 and are taken from Camplin and Aarkrog (1989). The air to tissue conversion factor is 0.87 Sv Gy^{-1} (Spiers *et al.*, 1981). Short-lived daughter products are included in the calculations. The approach to choosing suitable concentration data is similar to that adopted for the consumption pathway. We have used the average concentrations observed, over the five-year period 1985-89 (Table 9).

The radionuclide contributions to individual dose are shown in Figure 14. The highest contribution (see Figure 13) to the total dose of 0.0026 mSv $year^{-1}$ was from cobalt-60 which has both a high affinity for sediments and a high decay energy.

5.2.3 The use of seaweed as a fertiliser and soil conditioner

Although experience of this pathway in the vicinity of Sellafield has shown that it is unlikely to be important in terms of critical group exposures, we have carried out a brief analysis of it in this report in view of its potential importance on the Channel Islands. A theoretical treatment is detailed in Annex II and this assumes a nominal rate of application of seaweed of 1 kg (wet) m^{-2} $year^{-1}$. From discussions with local people, an upper estimate of this rate would be 50 kg (wet) m^{-2} $year^{-1}$. On this basis, the dose received by high-rate consumers of root crops, green vegetables or grain grown on land to which seaweed had been applied would then be no more than 0.0024 mSv $year^{-1}$.

The measurements (Tables 3 and 5) of radionuclide concentrations in carrots and potatoes which had been grown on fertilised land in the Channel Islands suggest doses of 0.00013 and 0.00011 mSv $year^{-1}$ taking a high-rate consumption of 20 kg $year^{-1}$ for carrots and 100 kg $year^{-1}$ for potatoes. These doses are very small.

5.2.4 Ingestion of sea water during swimming

The inadvertent ingestion of sea water during swimming and other water sports such as windsurfing is included here for completeness in view of the popularity of such activities on the islands. Measurements of radionuclides in sea water had previously been limited to analyses for radiocaesium and therefore it has been necessary to extend the dataset to include other radionuclides. The data for caesium-137 have been averaged over the four sampling stations on the islands for the period 1985-89 in a similar way to those for foodstuffs. They have then been extended to cover other radionuclides by applying the ratios of radionuclide concentrations in sea water in 1986 local to Etablissement de la Hague derived from Camplin and Aarkrog (1989). The full set is shown in Table 12.

The consumption rate of sea water is a highly uncertain quantity but we have assumed an intake of one hundred swallows of 100 ml each year (i.e. 10 litres per year). On this basis, the resulting dose would be no more than 0.000018 mSv $year^{-1}$, predominantly due to ruthenium-106.

5.2.5 Ingestion of desalinated water

The desalination plant at Corbières on Jersey operates on an occasional basis during the summer months. It is unlikely that an individual's drinking water supply would be limited to desalinated

water for more than 10% of the time. We have therefore chosen a consumption rate of 60 litres year^{-1}, being one tenth of the value given for a member of a critical group (Robinson and Haywood, 1989). Radionuclide concentrations in water will be reduced during the desalination process. The International Atomic Energy Agency has published values for the expected reduction in concentrations (IAEA, 1986) and these have been used in this assessment (see Table 13).

The predicted dose from consumption of desalinated water is 0.00000083 mSv year^{-1}. Ninety percent is due to tritium whose concentration is assumed not to change during desalination.

5.3 Naturally-occurring radionuclides

Naturally-occurring radionuclides can be found throughout the marine environment and are an important source of radiation, as is the case in the terrestrial environment. The nuclides involved include primordial nuclides such as potassium-40, those of the uranium-238 chain such as radium-226, lead-210 and polonium-210 and cosmogenic species, notably tritium and carbon-14. These radionuclides will contribute to the radiation of man's environment through both inhalation and external irradiation pathways, but in the marine sphere the dominant pathway will involve ingestion of seafoods. Any complete assessment of radiation exposure of the public should, therefore, include consideration of these pathways, although the dose limitation scheme of ICRP does not apply to exposures due to natural radionuclides which are not technologically enhanced.

5.3.1 Consumption of fish and shellfish

The concentrations of natural radionuclides will vary from place to place and from time to time and can be influenced by local sources such as phosphogypsum plants. However, the concentrations in Table 13 (Pentreath, 1988) can be taken as being representative of those that are likely to be found in fish and shellfish from the Channel Islands and these have been used in this report to assess critical group doses. The consumption rates used for the assessment of man - made radionuclides were taken to apply.

The doses from natural radionuclides (Table 14) in marine foods are of the order of 1 mSv year^{-1} for 10-year-old children and adults and are clearly much higher than those from the man-made radionuclides which are largely due to Etablissement de la Hague. The important foodstuff for adults is molluscs (Figure 14) and the dominant radionuclide is polonium-210 (Figure 15). The critical age group is 10-year-old children, though the doses to adults are similar.

5.3.2 External irradiation

Whilst the largest component to dose from natural radiation in marine pathways derives from foodstuff consumption, it is worthwhile briefly considering the likely magnitude of the dose to the critical group from external exposure to natural radiation in intertidal areas. A typical dose rate in such areas has been measured to be 0.10 μGy hour^{-1} (Table 6). This can be combined with the occupancy datum used in the assessment of dose from man-made radionuclides of 1 000 hours year^{-1} to provide an annual dose of 0.10 mSv. The maximum likely contribution to this from man-made radionuclides is likely to be 0.0026 mSv year^{-1} (see Sub-section 5.1.2) which is of very minor significance.

6. DISCUSSION AND CONCLUSIONS

6.1 Individual doses

Figure 16 shows the estimated contributions to the overall dose to the adult critical group from the major marine pathways. The data for 10-year-old children are similar to those for adults. By far the most important source of exposure is natural radionuclides in seafood. The contribution from man-made radionuclides such as those discharged from Etablissement de la Hague is very small, being less than 2% of the total. The dose due to man-made radionuclides is no more than 0.02 mSv $year^{-1}$ and this can be compared with the dose limit to members of the public of 1 mSv $year^{-1}$. The effects of marine discharges from Etablissement de la Hague are clearly very small indeed.

Further refinement of the predicted dose to a critical group of Channel Islanders would need specific habits survey information involving significant effort and cost. Such work is not considered to be necessary because of the low levels of predicted doses.

The more unusual pathways involving the use of seaweed as a fertiliser and soil conditioner, the inadvertent ingestion of sea water during swimming and the consumption of desalinated sea water have been considered as part of a sensitivity analysis. The doses from these pathways were less than those from consumption of shellfish and external irradiation.

6.2 Recommendations concerning the monitoring programme

6.2.1 General information

It was shown in Section 4 that the MAFF (DFR) aquatic monitoring carried out on behalf of the Channel Islands States already fulfils the objectives of a radiological protection programme. Analysis of a range of seafood and indicator materials shows the presence of ruthenium-106, americium-241, plutonium-238, plutonium-239+240, plutonium-241, cobalt-60 and caesium-137 which can be attributed to the discharges from Etablissement de la Hague. Radionuclide levels in marine species collected on Alderney tend to be higher than those on Jersey or Guernsey, presumably reflecting the comparative proximity of Alderney to Etablissement de la Hague. However, this is not always the case perhaps due to the complex tidal currents around the islands.

In the following sub-sections, recommendations are made concerning minor modifications to the MAFF (DFR) programme so as to add to the knowledge of concentrations in other edible species and reductions in the analyses of some of the indicator materials are suggested. The extension of monitoring by the Channel Islands States is also discussed.

6.2.2 The MAFF (DFR) programme

We propose the addition of five biota samples and the inclusion of a small programme of desalinated water monitoring with a reduction in the analysis of transuranics in seaweeds.

(a) Internal exposure: Molluscs have been shown to be one of the important phyla from the radiological point of view and limpets are already collected from each of the main islands. As ormers are now being cultivated, we suggest that an annual sample is collected from Guernsey to complement the oyster sample collected from Jersey. Thus, both grazing and filtering organisms would be monitored.

Crabs are collected from Guernsey and Jersey waters. However, no crab sample is routinely collected from Alderney waters or from the edge of the Hurd Deep. We recommend that an annual sample is collected from the area to the north-west of Alderney. Consideration should also be given to providing lobster samples which can have higher concentrations of radionuclides (e.g. technetium-99) than crabs collected from the same area (MAFF, 1992). Annual sampling would be sufficient from each of the major island waters.

Fish are sampled annually from Guernsey. The largest catches during 1988, in decreasing order of weight landed, were bass, conger eel, mackerel, skate/ray and plaice (States of Jersey, 1989). Mackerel and bass are migratory fish and so neither species is likely to reflect local contamination from the nuclear discharges. Bass are likely to have higher concentrations of radiocaesium compared to other species (MAFF, 1992) but are unlikely to be eaten regularly. Our judgement is that no change to the sampling programme is required.

Other species that are not sampled but are landed commercially include prawn, crawfish, cuttlefish, velvet crab, spider crab, scallop, squid and whelk. We feel that the proposed programme would adequately protect consumers, as it would be possible to infer concentrations of radionuclides from other samples that are already collected elsewhere. Therefore, routine sampling of these species is not required.

In Sub-section 3.4, the use of desalinated water for drinking was discussed. We consider the radiological significance of this pathway to be minor but for the purpose of reassurance we recommend that a few samples of drinking water should be obtained. As the desalination plant only operates for brief periods in the summer, weekly samples that are bulked for monthly analysis of radiocaesium and tritium would seem adequate. In addition, a sample of *Fucus vesiculosus* or *F. serratus* should be obtained close to the outfall of the plant and analysed by gamma spectrometry to establish that no local enhancement of man-made radionuclides is taking place.

(b) ***External exposure:*** Although we sampled muddy areas which are not routinely included in the monitoring programme, no change of sampling location is proposed as we feel that the existing sites provide adequate coverage. Beta and gamma monitoring could easily be undertaken by States staff and we see no need to send MAFF (DFR) staff to undertake routine monitoring.

(c) ***Indicator materials:*** *Fucus serratus* and *Porphyra* are sampled quarterly. Both are good indicators of ruthenium-106 and have the potential for either being used as a soil fertiliser or for direct consumption in the case of the latter. Sampling should thus continue, preferably collecting on staggered months rather than within a few days of one another so as to provide better comparative data of any changes in radionuclide concentrations.

Sea water is collected quarterly and is a good indicator of dispersion. We recommend that this should continue on each island but consider that sampling at Ecrehos need not be included.

(d) ***Analysis:*** Transuranic analysis is time consuming and expensive. A saving in effort could be achieved by limiting the analysis to seafood samples and sediments. However, plutonium-241 has been shown to be potentially important in seafood but is not analysed in the existing programme. We therefore recommend its inclusion on the annual bulk samples of molluscs, crustaceans and fish.

Carbon-14, technetium-99 and tritium are other radionuclides that are not currently monitored but should be considered for inclusion in the future as all are discharged from Etablissement de la Hague. We recommend that carbon-14 and technetium-99 are analysed on the annual bulk samples of fish, crab, lobster and oyster and that tritium is analysed in quarterly samples of sea water. The naturally-occurring radionuclide polonium-210 has been shown to be of potential radiological importance and we recommend an annual analysis of this radionuclide in limpets from Alderney. *Fucus vesiculosus* from Alderney should also be analysed biannually for polonium-210 to allow a comparison with other samples collected around the British Isles.

6.2.3 Monitoring by staff employed by the Channel Island States

Environmental gamma dose monitoring at one metre above intertidal areas, beta-gamma monitoring of fishing nets and close contact beta-gamma monitoring for particulates could easily be undertaken by States employees and would provide additional reassurance in both routine and emergency situations to the residents and visitors. We recommend that biannual gamma dose rate monitoring of beaches and harbours should be carried out at the locations shown in Tables 5 and 6.

If the Channel Island States wished to develop their capability in laboratory measurements by total beta counting and gamma spectrometry, we would be able to expand our knowledge of radionuclide concentrations in bass, conger eel, spider crab and whelks. The results could then be compared with those for other species from the MAFF (DFR) programme.

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Table 1. Annual quantities of waste disposed of in the Hurd Deep from 1950 to the present day

Year	Gross mass (t)	Activity (Ci (TBq))	
		Alpha	Beta/gamma
1950	350	2 (7.4 10^{-2})	20 (7.4 10^{-1})
1951	319	1 (3.7 10^{-1})	18 (6.7 10^{-1})
1952	534	2 (7.4 10^{-2})	29 (1.1)
	758	10 (3.7 10^{-1})	39 (1.4)
1954	1 145	23 (8.5 10^{-1})	55 (2.0)
1955	1 164	35 (1.3)	44 (1.6)
1956	1 038	44 (1.6)	33 (1.2)
1957	1 537	109 (4.0)	161 (6.0)
	1 011	58 (2.1)	57 (2.1)
1959	1 197	4 (1.5 10^{-1})	74 (2.7)
1960	2 551	74 (2.7)	218 (8.1)
1961	1 967	20 (7.4 10^{-1})	308 (11)
	1 444	5 (1.8 10^{-1})	76 (2.8)
1963	1 543	3 (1.1 10^{-1})	44 (1.6)

Notes: The number of digits quoted for mass and activity in curies reflect accounting procedures and do not give an indication of the accuracy of the data. The alpha activities include ^{226}Ra and the beta/gamma activities include ^{3}H.The data given in terabecquerels are rounded to two significant figures

Table 2. The MAFF (DFR) monitoring programme for the Channel Islands, 1989

Island	Location	Material	Sampling frequency	Analysis
Guernsey	Fermain Bay	*Fucus serratus*	Quarterly	Total beta, gamma spectrometry annual bulk for transuranics* and strontium-90
		Porphyra umbilicalis	Quarterly	Total beta and gamma spectrometry
	Bordeaux harbour	Sediment - mud	Annually	Total beta, gamma spectrometry and transuranics*
		Limpet	Annually	Total beta and transuranics*
		Sea water	Quarterly	Caesium-134 and -137
	Caught within 30 km of shore	Crab	Annually	Total beta, gamma spectrometry and transuranics*
	Schole Bank	Ray or skate	Annually	Total beta, gamma spectrometry and transuranics*
Jersey	La Rozel	*Fucus serratus*	Quarterly	Total beta, gamma spectrometry, annual bulk for transuranics* and strontium-90
		Limpet	Annually	Total beta, gamma spectrometry and transuranics*
	Greve de Lecq	*Porphyra umbilicalis*	Quarterly	Total beta and gamma spectrometry
	Echrehos	Crab	Annually	Total beta and transuranics*
		Sea water	Quarterly	Caesium-134 and -137
	La Rocque	Oyster	Annually	Total beta, gamma spectrometry and transuranics*
	Verclut	*Laminaria digitata*	Quarterly	Total beta and gamma spectrometry
	St Helier	Sediment - mud	Annually	Total beta, gamma spectrometry and transuranics*
Alderney	Quenard Point	*Fucus serratus*	Quarterly	Total beta and gamma spectrometry annual bulk for transuranics* and strontium-90
		Porphyra umbilicalis	Quarterly	Total beta and gamma spectrometry
		Sea water	Quarterly	Caesium-134 and -137
		Limpet	Annually	Total beta, gamma spectrometry and transuranics*
	Crabbe harbour	Sediment - sandy mud	Annually	Total beta and gamma spectrometry
	Caught on the edge of the Hurd Deep	Crab	Annually	Total beta and gamma spectrometry

**Transuranics - ^{238}Pu, $^{239}Pu+^{240}Pu$, ^{241}Am, ^{242}Cm, $^{243}Cm + ^{244}Cm$*
Pu - Plutonium, Am - Americium, Cm - Curium

Table 3. Total beta and gamma spectrometric data on environmental materials from the Channel Islands, 1989

Material	Sampling area	LSN	Date collected	Radioactivity concentration (Bq kg^{-1} wet)*												
				Total beta	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{154}Eu	^{155}Eu	^{241}Am
Seafood																
Ray	Guernsey	4338	17 Jul	120	ND	ND	ND	ND	ND	ND	ND	ND	0.69	ND	ND	ND
Crabs	Guernsey	4335	17 Jul	69	ND	ND	0.43	ND	ND	0.45	ND	ND	ND	ND	ND	ND
	Jersey	5563	10 Oct	120	ND	ND	1.7	ND	3.7	1.4	ND	ND	0.23	ND	ND	ND
	Alderney	7015	19 Oct	110	ND	ND	1.2	0.85	1.5	0.28	0.35	ND	0.18	ND	ND	ND
Oysters	Jersey	5564	4 Oct	72	ND	ND	1.1	1.6	4.8	2.5	ND	ND	ND	ND	ND	ND
Limpets	Guernsey	4337	14 Jul	96	ND	ND	1.1	ND	4.8	ND	ND	ND	0.44	ND	ND	ND
	E Alderney	4336	14 Jul	100	ND	ND	1.9	0.39	19	0.89	0.36	ND	ND	ND	ND	ND
	Jersey:															
	Verclut	2861	18 Apr	110	ND	ND	2.4	ND	3.8	0.48	ND	ND	ND	ND	ND	ND
	La Rozel	5565	18 Aug	81	ND	ND	0.9	ND	2.5	0.61	0.49	ND	ND	ND	ND	ND
Winkles	Alderney:															
	Quenard Point	2788	20 Apr	150	ND	ND	7.1	ND	45	1.9	ND	ND	0.91	ND	ND	ND
	Jersey:															
	La Rocque	2797	18 Apr	140	ND	ND	3.5	ND	28	ND	1.4	ND	ND	ND	ND	ND
Scallops	Guernsey:															
	St Peter Port	2784	19 Apr	86	0.27	ND	1.3	ND	10	0.8	ND	ND	0.26	ND	ND	ND
Cuttlefish	Jersey:															
	Verclut	3007	18 Apr	76	ND	ND	0.98	ND	ND	ND	1.2	ND	0.8	ND	ND	ND
Terrestrial crops																
Potato+	Jersey:															
	L'Etacq	2801	18 Apr	92	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Carrot+	Alderney:															
	St Annes	2792	20 Apr	120	ND	ND	ND	ND	ND	ND	ND	ND	0.08	ND	ND	ND
Seaweed																
Porphyra	Jersey:															
	Greve de Lecq	387	8 Feb	210	ND	ND	0.43	0.19	5.3	ND	ND	ND	0.09	ND	ND	ND
		2476	6 Apr	180	ND	ND	0.35	ND	2.9	ND	ND	ND	0.08	ND	ND	ND
		5569	18 Aug	140	ND	ND	1	ND	19	ND	ND	ND	0.1	ND	ND	ND
		7213	13 Nov	210	ND	ND	0.46	ND	22	ND	ND	ND	ND	ND	ND	ND
	Guernsey:															
	Fermain Bay	64	10 Jan	250	ND	ND	0.75	ND	12	ND	ND	ND	ND	ND	ND	ND
		1477	6 Apr	130	ND	ND	0.25	ND	3.2	ND	ND	ND	0.11	ND	ND	ND
		3648	7 Apr	82	ND	ND	0.59	ND	6	ND	ND	ND	ND	ND	ND	ND
		5643	3 Oct	230	ND	ND	0.48	ND	3.4	ND	ND	ND	0.13	ND	ND	ND
	Alderney:															
	Quenard Point	66	12 Jan	160	ND	ND	0.61	ND	18	ND	ND	ND	0.1	ND	ND	ND
		1559	7 Apr	110	ND	ND	0.46	ND	4.7	ND	ND	ND	ND	ND	ND	ND
		3650	6 Jul	82	ND	ND	0.84	ND	27	ND	0.13	0.04	0.27	ND	ND	ND
		5659	*12 Oct*	*200*	*ND*	*ND*	*3.6*	*ND*	*53*	*ND*	*ND*	*ND*	*0.72*	*ND*	*ND*	*ND*
Fucus spiralis	Guernsey:															
	Rocquaine Bay	2785	19 Apr	280	ND	ND	1.6	ND	ND	ND	ND	ND	0.12	ND	ND	ND
	Alderney:															
	Forte Clonque	2793	20 Apr	210	ND	ND	1.9	ND	1.4	ND	0.12	ND	0.1	ND	ND	ND
Fucus serratus	Jersey:															
	La Rozel	385	8 Feb	400	0.16	0.18	6.2	ND	5.6	0.35	0.28	ND	0.18	ND	ND	ND
		2474	6 Apr	350	ND	ND	6.7	ND	6.5	0.32	ND	ND	0.27	ND	ND	ND
		5567	18 Aug	350	ND	ND	5.5	ND	4.2	ND	0.31	ND	0.41	ND	0.18	ND
		7212	13 Nov	420	ND	ND	5.8	ND	5.7	ND	0.56	ND	0.4	ND	ND	ND
	Verclut	2798	18 Apr	490	0.11	ND	5.3	0.19	4.3	0.13	0.22	ND	0.27	ND	ND	ND
	Guernsey :															
	Fermain Bay	63	10 Jan	380	0.12	0.16	5.2	ND	5.5	ND	0.17	ND	0.19	ND	ND	ND
		1479	6 Apr	130	0.06	ND	2	ND	1.7	ND	ND	ND	0.07	ND	ND	ND
		3647	7 Apr	300	0.08	ND	2.2	ND	1.9	ND	ND	ND	0.21	ND	ND	ND
		5642	3 Oct	330	ND	ND	3.5	ND	2.7	ND	ND	ND	0.29	ND	ND	ND
	Alderney:															
	Quenard Point	65	12 Jan	310	0.26	ND	9.6	0.36	7.5	0.3	0.11	ND	0.19	ND	ND	ND
		1560	7 Apr	200	0.1	ND	4	0.18	2.5	0.16	0.08	ND	0.08	ND	ND	ND
		3649	6 Jul	250	0.15	ND	5.7	ND	6.5	ND	0.45	ND	0.22	ND	ND	ND
		5644	12 Oct	330	0.4	ND	12	ND	15	0.29	0.55	ND	0.49	0.34	0.14	ND

Table 3. Continued

Material	Sampling area	LSN	Date collected	Radioactivity concentration (Bq kg^{-1} wet)*												
				Total beta	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn	^{106}Ru	^{110m}Ag	^{125}Sb	^{134}Cs	^{137}Cs	^{154}Eu	^{155}Eu	^{241}Am
Fucus vesiculosus	Jersey:															
	Greve de Lecq	2796	18 Apr	240	ND	ND	1.8	ND	1.1	ND	ND	ND	0.18	ND	0.12	ND
	Alderney:															
	Quenard Point	2789	20 Apr	310	ND	ND	7.2	ND	2.5	0.3	ND	ND	0.18	ND	ND	ND
	Guernsey:															
	St Sampson's harbour	2782	19 Apr	240	ND	ND	1.8	ND	2.8	ND	0.4	ND	0.39	ND	ND	ND
	Picquerel Point	2787	19 Apr	410	ND	ND	2.3	ND	2	ND	0.21	ND	0.24	ND	ND	ND
Laminaria digitata	Jersey:															
	Verclut	386	8 Feb	450	ND	ND	0.62	ND	3.2	0.2	ND	ND	0.18	ND	ND	ND
		2475	6 Apr	570	ND	ND	0.33	ND	2.1	0.1	0.12	ND	0.28	ND	ND	ND
		5568	18 Aug	310	ND	ND	0.45	ND	4.4	ND	0.12	ND	0.3	ND	ND	ND
		7214	13 Nov	350	ND	ND	1.1	ND	7.2	ND	0.31	ND	0.35	ND	ND	ND
Sediment																
Mud	Jersey:															
	St Helier harbour	2795	18 Apr	770	2.5	ND	30	ND	61	ND	6.8	ND	13	3.7	3.6	4.6
		5566	17 Aug	620	1.6	ND	19	ND	41	ND	4.4	0.52	7.8	2.4	2.8	3.1
	St Aubins harbour	2799	18 Apr	610	2.7	ND	20	ND	54	ND	1.9	0.66	7	1.6	2.5	ND
Sand	Greve de Lecq	2794	18 Apr	670	ND	ND	0.36	ND	ND	ND	ND	ND	1.3	ND	ND	ND
	St Aubins Bay	2800	17 Apr	450	ND	ND	0.56	ND	3.3	ND	ND	ND	0.62	ND	ND	ND
Mud	Guernsey:															
	Bordeaux harbour	4339	14 Jul	510	ND	ND	1.6	ND	4.7	ND	1.1	ND	2.4	ND	ND	ND
	St Peter Port	2783	19 Apr	470	ND	ND	5.9	ND	16	ND	1.6	ND	3.6	ND	1.2	ND
	St Sampson's harbour	2781	19 Apr	450	0.84	ND	7.6	ND	19	ND	2.1	ND	6.2	ND	1	ND
Sand	Pembroke Bay	2780	19 Apr	420	ND	ND	ND	ND	ND	ND	ND	ND	0.82	ND	ND	ND
	Rocquaine Bay	2786	19 Apr	440	ND	ND	0.33	ND	ND	ND	ND	ND	1.8	ND	ND	ND
	Alderney:															
	Longis Bay	2790	20 Apr	270	ND	ND	ND	ND	5.2	ND	ND	ND	0.69	ND	0.96	ND
	Douglas harbour	2791	20 Apr	320	ND	ND	0.71	ND	5	ND	ND	ND	3.8	ND	0.67	0.7

LSN = Laboratory sample number
ND = Not detcted
* = *Except for sediment where dry concentrations apply*
\+ = *Grown on land fertilised with seaweed*

Table 4. Concentrations of radiocaesium in filtered sea water, 1989

Sampling area	LSN	Date collected	Concentration (mBq l^{-1})	
			^{134}Cs	^{137}Cs
Guernsey	187	16 Jan	ND	6
	2181	13 Apr	ND	5.3
	4438	11 Jul	ND	5.8
	5646	15 Oct	ND	9.1
Jersey, Ecrehos	388	30 Jan	ND	6
	1854	13 Apr	ND	4.7
	5570	14 Jul	ND	5.8
	7215	13 Nov	ND	10
Eastern Alderney	188	17 Jan	ND	4.7
	2180	14 Apr	ND	4.7
	4439	14 Jul	ND	14
	5645	15 Oct	4.7	14
Jersey, St Catherine's Bay	389	30 Jan	ND	4.4
	1853	13 Apr	ND	4.6
	5571	14 Jul	ND	4.1
	7216	13 Nov	ND	11

LSN = Laboratory sample number
ND = not detected

Table 5. Results from radiochemical analysis of samples taken from the Channel Islands in 1989

Material	Sampling area	LSN	Date collected	Radioactivity concentration (Bq kg^{-1} wet)*							
				^{14}C	^{90}Sr	^{238}Pu	^{239}Pu+ ^{240}Pu	^{241}Pu	^{241}Am	^{243}Cm+ ^{244}Cm	^{242}Cm
Seafood											
Ray	Guernsey	4338	17 Jul	19	NA	0.00017	0.00024	NA	0.00036	ND	ND
Crab	Guernsey	4335	17 Jul	NA	NA	0.00162	0.00326	NA	0.00471	0.00170	0.00007
	Jersey: Ecrehos	5563	10 Oct	NA	NA	0.00162	0.00312	NA	0.00647	0.00232	0.00007
	Alderney	7015	19 Oct	20	NA	NA	NA	NA	NA	NA	NA
Oysters	Jersey: La Rocque	5564	4 Oct	NA	NA	0.0927	0.01430	NA	0.01370	0.00485	0.00023
Limpets	Jersey: La Rozel	5565	18 Aug	NA	NA	0.00765	0.01190	NA	0.01680	0.00520	0.00056
	Guernsey	4337	14 Jul	NA	NA	0.01020	0.01610	NA	0.02640	0.00762	0.00136
	Alderney: East	4336	14 Jul	NA	NA	0.02310	0.02010	NA	0.06760	0.03170	0.00100
Winkles	Jersey: La Rocque	2792	18 Apr	19	NA	NA	NA	NA	NA	NA	NA
	Alderney: Quenard Point	2788	20 Apr	30	NA	0.09660	0.12800	NA	0.21000	0.08350	0.00212
Terrestrial crops											
Potato	Jersey: L'Etacq	2801	18 Apr	NA	NA	0.00018	0.00213	NA	0.00097	ND	ND
Carrot	Alderney: St Annes	2792	20 Apr	NA	NA	0.00115	0.00523	NA	0.00451	0.00035	0.00007
Seaweed											
Fucus serratus	Jersey: La Rozel	7832	1 Jul	NA	0.3630	0.06440	0.09590	NA	0.03710	0.01280	0.00046
	Guernsey: Fermain Bay	5657	1 Jul	NA	0.2010	0.02340	0.04040	NA	0.02280	0.00965	0.00134
	Alderney: Quenard Point	5658	1 Jul	NA	0.4120	0.05190	0.06010	NA	0.04660	0.02490	0.00242
Sediment											
Mud	Jersey: St Helier harbour	5566	17 Aug	NA	NA	1.430	3.29	NA	4.490	1.250	0.05830
Sand	Guernsey: Bordeaux harbour	4339	14 Jul	NA	NA	0.09960	0.37100	NA	0.30100	0.04970	ND

** = Except for sediment where dry concentrations apply*
LSN = Laboratory sample number
NA = Not analysed
ND = Not detected

Table 6. Gamma dose rates measured at 1 metre above intertidal areas on the Channel Islands in April 1989

Location	LSN	Station number	Longitude (N)	Latitude (W)	Instrument number*	Date monitored (April 1989)	Ground type	Dose rate in air μGy h^{-1}
Jersey, Greve de Lecq	3009	213	49.14 45'	2.11 0'	13	18	Fine sand	0.079
Jersey, St Helier	3018	214	49.10 42'	2.6 48'	11	18	Mud	0.110
Alderney, Quenard Point	3026	217	49.43 50'	2.9 31'	13	20	Rock	0.100
Jersey, La Rocque	3021	222	49.9 54'	2.1 54'	11	18	Fine sand	0.073
Jersey, Verclut	3022	230	49.13 0'	2.1 0'	11	18	Fine sand	0.078
Jersey, St Aubin's harbour	3014	232	49.11 17'	2.10 6'	13	18	Mud	0.101
Jersey, St Aubin's Bay	3019	233	49.11 44'	2.7 55'	13	17	Fine sand	0.078
Jersey, L'Etacq	3020	234	49.14 28'	2.14 48'	13	18	Rock	0.111
Alderney, Longis Bay	3025	235	49.43 9'	2.10 13'	11	20	Fine sand	0.062
Alderney, Douglas harbour	3024	236	49.43 26'	2.11 48'	11	20	Fine sand	0.063
Alderney, Crabby Bay	3023	238	49.43 21'	2.12 13'	13	20	Fine sand	0.063
Guernsey, St Sampson's harbour	3027	239	49.29 2'	2.30 59'	13	19	Mud/sand/stones	0.068

LSN = Laboratory sample number
** Mini Instruments type 6/80 with MC71 detector*

Table 7. Beta dose rates* measured on contact with sediments and fishing gear in April 1989

Location	LSN	Station number	Longitude (N)	Latitude (W)	Date monitored (April 1989)	Ground type	Dose rate in air $\mu Gy\ h^{-1}$
Jersey, Greve de Lecq	3010	213	49.14 45'	2.11 0'	18	Fine sand	0.33
Jersey, St Helier	3011	214	49.10 42'	2.6 48'	18	Mud	0.33
Alderney, Quenard Point	3035	217	49.43 50'	2.9 31'	20	Rock	0.22
Alderney, Braye harbour	3037	229	49.43 30'	2.12 6'	20	Net	0.22
Jersey, Verclut	3012	230	49.13 0'	2.1 0'	18	Fine sand	0.22
Guernsey, Pembroke Bay	3039	231	49.30 26'	2.31 51'	19	Fine sand	0.22
Jersey, St Aubin's harbour	3013	232	49.11 17'	2.10 6'	18	Mud	0.22
Alderney, Longis Bay	3040	235	49.43 9'	2.10 13'	20	Fine sand	0.11
Alderney, Douglas harbour	3041	236	49.43 26'	2.11 48'	20	Fine sand	0.22
Alderney, Crabby Bay	3042	238	49.43 26'	2.12 13'	20	Fine sand	0.11
Guernsey, St Sampson's harbour	3043	239	49.29 2'	2.30 59'	19	Mud/sand/stones	0.33
Guernsey, St Peter Port	3044	240	49.27 16'	2.32 3'	19	Lobster pot	0.22
Guernsey, Rocquaine Bay	3045	241	49.26 6'	2.39 29'	19	Fine sand	0.22

** Berthold type LB1210B Inst No. 24*
LSN Laboratory sample number

Table 8. Habits data used in the assessment of individual doses to the critical group

	Adults	10- year-old children	1-year-old children	Units
Fish consumption	110	70	13	$kg\ year^{-1}$
Crustacean consumption	7	5	0	$kg\ year^{-1}$
Mollusc consumption	18	12	0	$kg\ year^{-1}$
Intertidal occupancy	1000	1000	1000	$h\ year^{-1}$

Secondary pathways, involving the use of seaweeds as a fertiliser and soil conditioner, ingestion of sea water during swimming and consumption of desalinated sea water are considered in Sub-section 5.1

Table 9. Concentrations of man-made radionuclides used in the dose calculations (1)

Radionuclide	Activity concentration ($Bq\ kg^{-1}$ wet)						
	Fish	Crustaceans	Molluscs	Sediments (2)	Sea water	Carrots	Potatoes
Tritium	0	0	0	0	0.75	0	0
Carbon-14	30	30	30	0	0.00019	0	0
Manganese-54	0	0	0.006	0.25	0	0	0
Cobalt-90	0.05	1.9	1.7	4.4	0.00072	0	0
Zinc-65	0.02	0.58	0.69	0	0.000043	0	0
Strontium-90+	0.083	0.024	0.0088	2.8	0.014	0	0
Zirconium-95+	0	0	0	0	0.00001	0	0
Niobium-95	0	0	0	0	$4.2\ 10^{-11}$	0	0
Technetium-99	0.019	0	0.019	0.17	0.0035	0	0
Ruthenium-106+	0.05	4.1	11	20	0.014	0	0
Solver-110m+	0	0.88	0.65	0	$1.2\ 10^{-9}$	0	0
Antimony-125	0	0.097	0.11	2.4	0.045	0	0
Iodine-129	0	0	0	0	0.000038	0	0
Caesium-134	0.2	0	0	0.25	0.0012	0	0
Caesium-137+	2.4	0.2	0.15	4.8	0.0079	0.08	0
Cerium-144+	0	0	0	0	0.000013	0	0
Uranium-238+	0	0	0	0	0.000083	0	0
Plutonium-238	0.00033	0.0017	0.028	0	0	0.0012	0.00018
Plutonium-239/240	0.0013	0.0032	0.042	0.73	0.000012	0.0052	0.0021
Plutonium-241	0.08	0	0.08	44	0.00069	0	0
Americium-241	0.00057	0.0098	0.028	1	0	0.0045	0.00097
Curium-242	0	0.0013	0.016	0.015	0	0.00007	0
Curium-243	0.000005	0.006	0.027	0.26	0	0.00035	0

1. *The concentrations are derived by averaging all measurements for each material sampled from the Channel Islands over the five year period 1985-89. Also see text for sea water. Data given to two significant figures*
2. *Sediment concentrations are expressed in terms of dry weights*
\+ *The radiations of short-lived daughter products of this radionuclide are included in the assessment*

Table 10. The dose from ingestion of one becquerel of activity

Radionuclide	Dose per unit activity ingested (Sv Bq^{-1})		
	Adult	10-year-old children	1-year-old children
Tritium	$1.6\ 10^{-11}$	$1.9\ 10^{-11}$	$4.1\ 10^{-11}$
Carbon-14	$5.6\ 10^{-10}$	$7.7\ 10^{-10}$	$1.5\ 10^{-9}$
Manganese-54	$7.23\ 10^{-10}$	$1.28\ 10^{-9}$	$2.71\ 10^{-9}$
Cobalt-60	$7.04\ 10^{-9}$	$1.14\ 10^{-8}$	$2.52\ 10^{-8}$
Zinc-65	$3.90\ 10^{-9}$	$6.68\ 10^{-9}$	$1.42\ 10^{-8}$
Rubidium-87	$1.30\ 10^{-9}$	$3.00\ 10^{-9}$	$9.10\ 10^{-9}$
Strontium-90+	$3.77\ 10^{-8}$	$4.93\ 10^{-8}$	$1.1\ 10^{-7}$
Zirconium-95+	$1.8\ 10^{-9}$	$3.5\ 10^{-9}$	$1.0\ 10^{-9}$
Niobium-95	$6.8\ 10^{-10}$	$1.3\ 10^{-9}$	$3.7\ 10^{-9}$
Technetium-99	$3.46\ 10^{-10}$	$8.08\ 10^{-10}$	$2.41\ 10^{-9}$
Ruthenium-106+	$7.5\ 10^{-9}$	$1.6\ 10^{-8}$	$5.3\ 10^{-8}$
Silver-110m+	$2.89\ 10^{-9}$	$5.33\ 10^{-9}$	$1.20\ 10^{-8}$
Antimony-125	$7.02\ 10^{-10}$	$1.49\ 10^{-9}$	$3.78\ 10^{-9}$
Iodine-129	$6.4\ 10^{-8}$	$1.1\ 10^{-7}$	$1.3\ 10^{-7}$
Caesium-134	$1.9\ 10^{-8}$	$1.4\ 10^{-8}$	$1.5\ 10^{-8}$
Caesium-137+	$1.3\ 10^{-8}$	$9.83\ 10^{-9}$	$1.1\ 10^{-8}$
Cerium-144+	$5.8\ 10^{-9}$	$1.3\ 10^{-8}$	$4.3\ 10^{-8}$
Lead-210+	$2.03\ 10^{-6}$	$2.60\ 10^{-6}$	$3.81\ 10^{-6}$
Polonium-210	$4.35\ 10^{-7}$	$1.00\ 10^{-6}$	$2.99\ 10^{-6}$
Radium-226+	$2.96\ 10^{-7}$	$4.10\ 10^{-7}$	$1.03\ 10^{-6}$
Uranium-234	$7.03\ 10^{-8}$	$1.14\ 10^{-7}$	$2.88\ 10^{-7}$
Uranium-238+	$6.66\ 10^{-8}$	$1.10\ 10^{-7}$	$2.82\ 10^{-7}$
Plutonium-238	$4.3\ 10^{-7}$	$5.3\ 10^{-7}$	$9.5\ 10^{-7}$
Plutonium-239/240	$4.8\ 10^{-7}$	$5.9\ 10^{-7}$	$1.0\ 10^{-6}$
Plutonium-241	$9.3\ 10^{-9}$	$1.1\ 10^{-8}$	$1.5\ 10^{-8}$
Americium-241	$4.9\ 10^{-7}$	$6.0\ 10^{-7}$	$1.1\ 10^{-6}$
Curium-242	$1.8\ 10^{-8}$	$3.7\ 10^{-8}$	$1.1\ 10^{-7}$
Curium-243/244	$2.7\ 10^{-7}$	$3.4\ 10^{-7}$	$7.1\ 10^{-7}$

The dose quantity is the 'committed effective dose equivalent'

+ Radionuclides include radiations of their short-lived daughter products

Table 11. Half-lives and gamma energies used in the dose assessment

Radionuclide	Half-life (years)	Gamma energy (MeV per disintegration)
Manganese-54	0.856	0.836
Cobalt-60	5.27	2.5
Stontium-90+	29.1	3.16^{10-3}
Ruthenium-106+	1.01	0.205
Antimony-125	2.77	0.431
Caesium-134	2.06	1.55
Caesium-137+	30	0.565
Plutonium-238	87.7	1.81^{10-3}
Plutonium-239	$2.41\ 10^{4}$	8.06^{10-4}
Plutonium-241	14.4	2.55^{10-6}
Americium-241	432	3.25^{10-2}
Curium-242	0.446	1.83^{10-3}
Curium-243	28.5	1.35^{10-1}

+The radiations of short-lived daughter products of this radionuclide are included

Table 12. Concentration factors from sea water to desalinated water

Element	Concentration factor m^3 (sea water) m^{-3} (desalinated water)
H	1
C, I	$4\ 10^{-3}$
Co, Zn, Sr, Zr, Nb Tc, Ru, Ag, Sb, Cs, Ce, U, Pu	10^{-3}

Reference: IAEA, 1986

Table 13. Naturally-occurring radionuclides in marine foodstuffs - estimated values

Radionuclide	Concentrations (Bq kg^{-1} wet)		
	Fish	Crustaceans	Molluscs
^{14}C	15	15	15
^{87}Rb	1	1	1
^{210}Po	1.5	25	50
^{210}Pb	0.04	0.2	3
^{226}Ra	0.1	0.02	0.3
^{234}U	0.012	0.12	0.3
^{238}U	0.011	0.11	0.27

Table 14. Individual doses to the critical group from marine pathways

Pathway	Individual dose (mSv $year^{-1}$) Age group	Man-made radionuclides	Natural radionuclides
Consumption of seafood	Adults	0.01	0.67
	10 years	0.0085	0.94
	1 year	0.0012	0.06
External irradiation	All	0.0026	0.1

Note: Secondary pathways involving the use of seaweeds as a fertiliser and soil conditioner, ingestion of sea water during swimming and consumption of desalinated sea water are considered in Sub-section 5.1

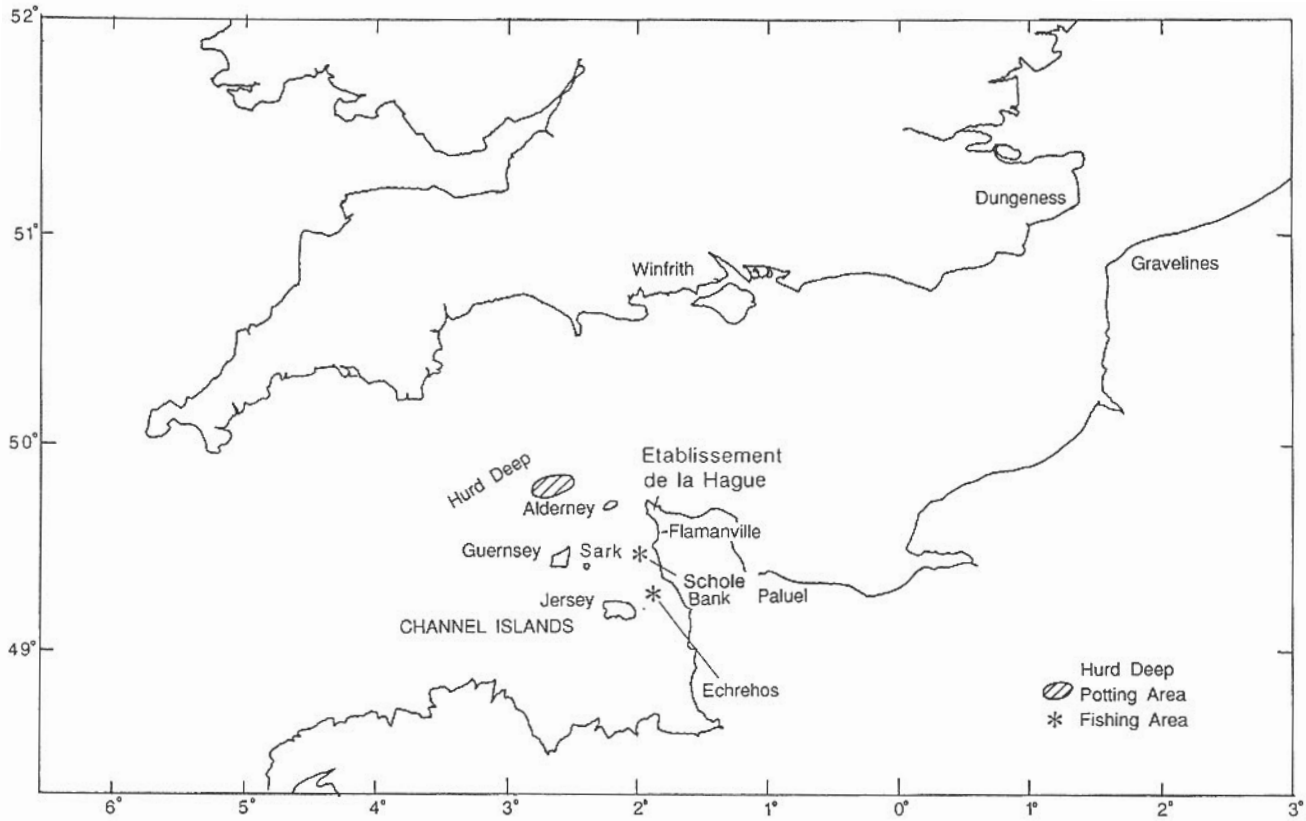

Figure 1. Sources of man-made radionuclides and selected fishing areas near the Channel Islands

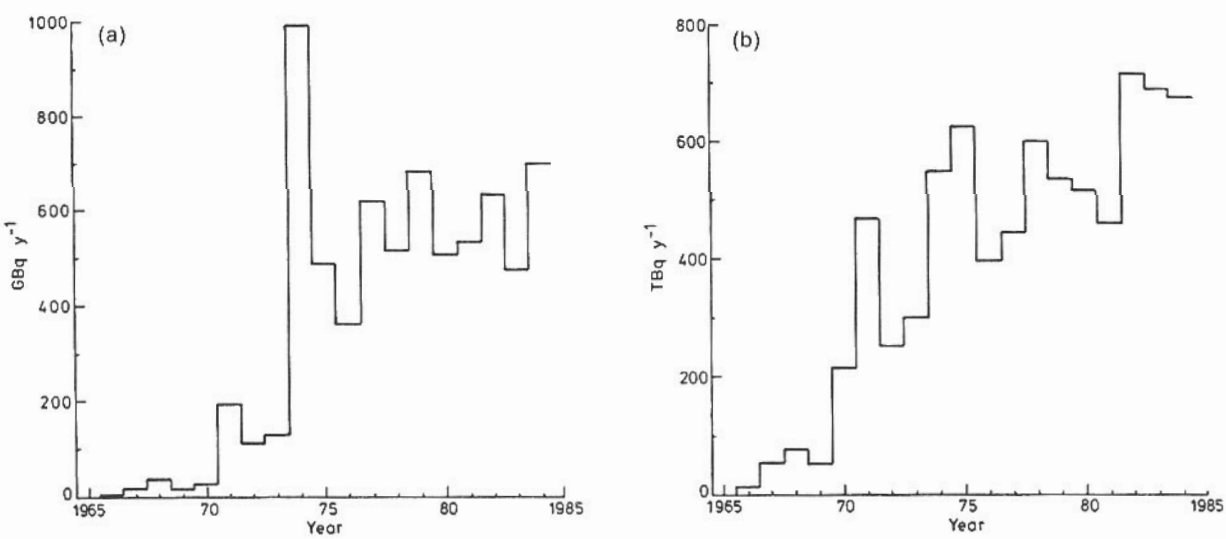

Figure 2. Liquid discharges of alpha and beta emitters from Etablissement de la Hague between 1965 and 1985 (from McColl et al., 1990): (a) alpha emitters; and (b) beta emitters

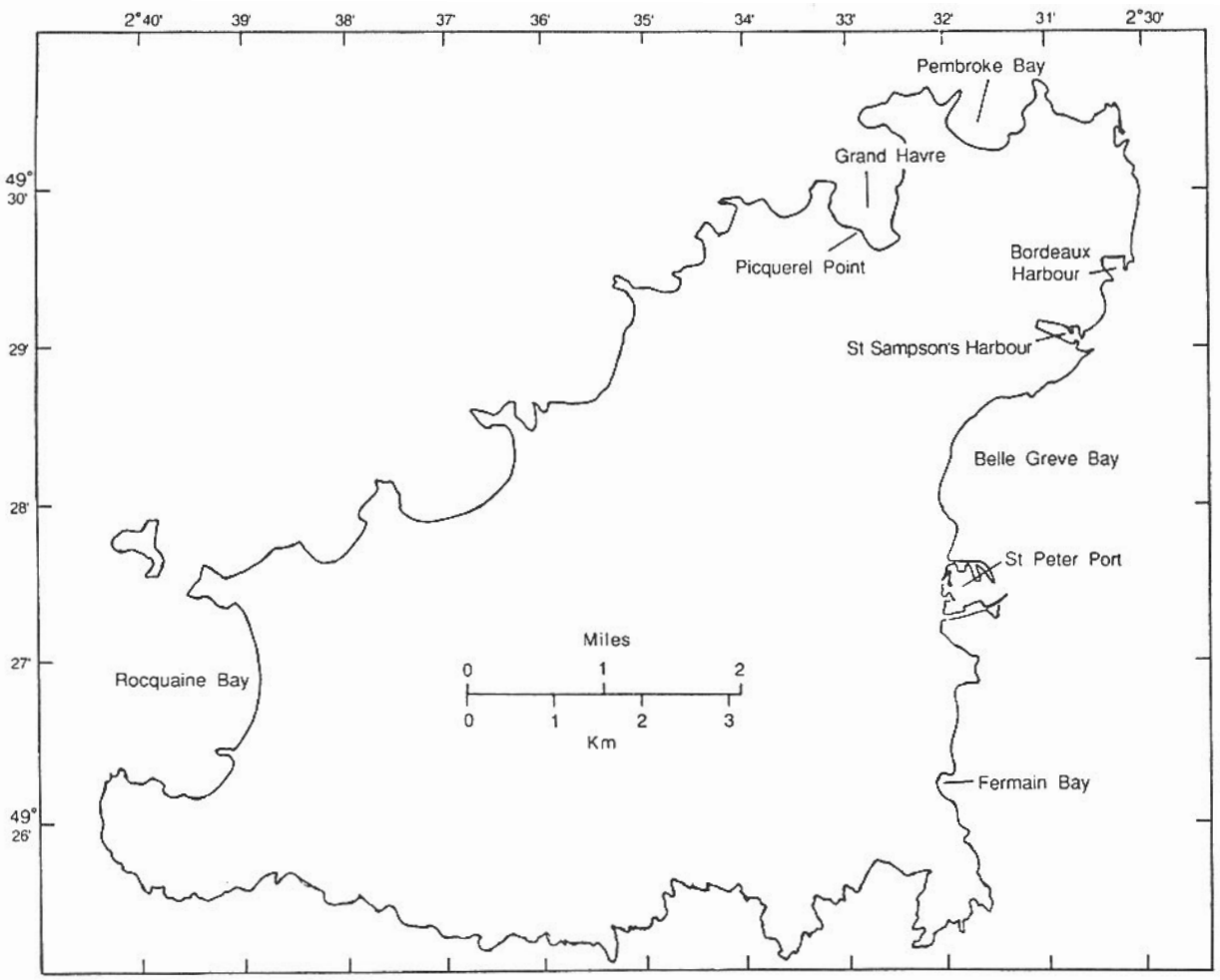

Figure 3. Sampling locations on Guernsey in 1989

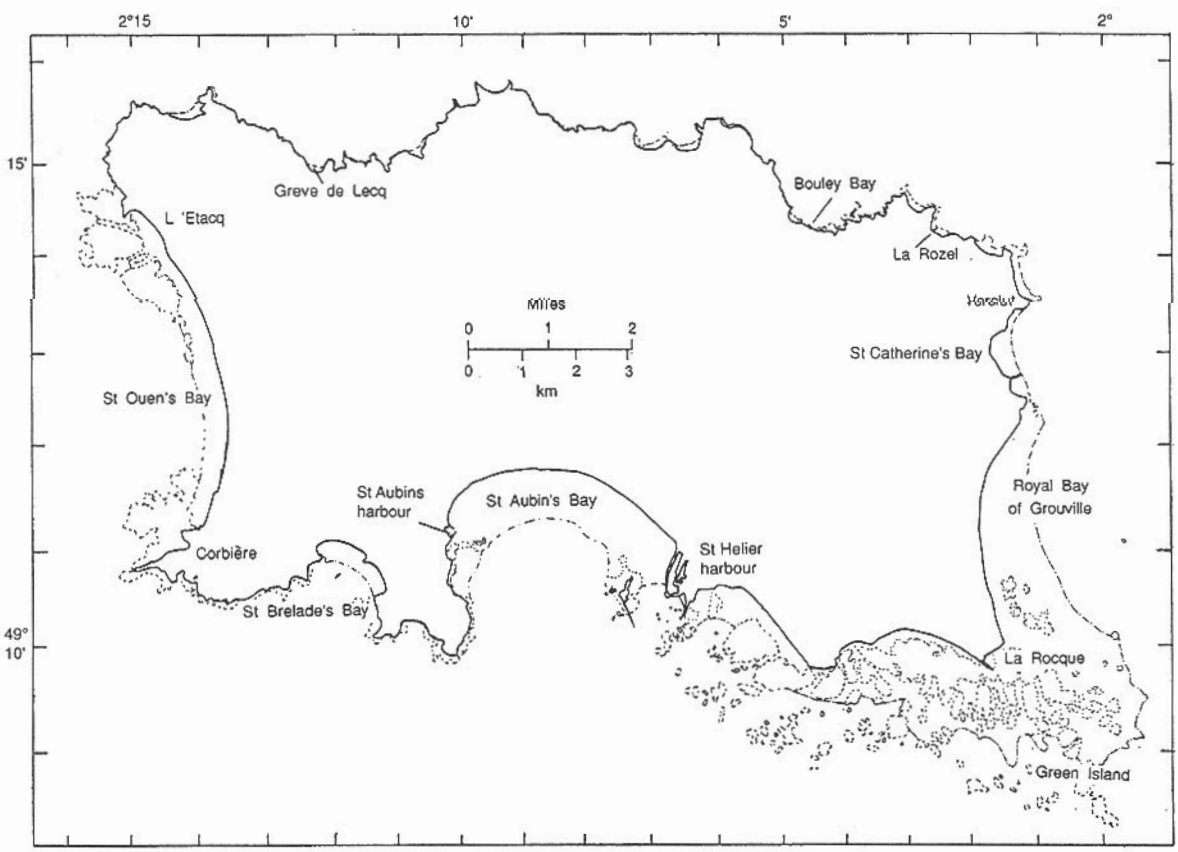

Figure 4. Sampling locations on Jersey in 1989

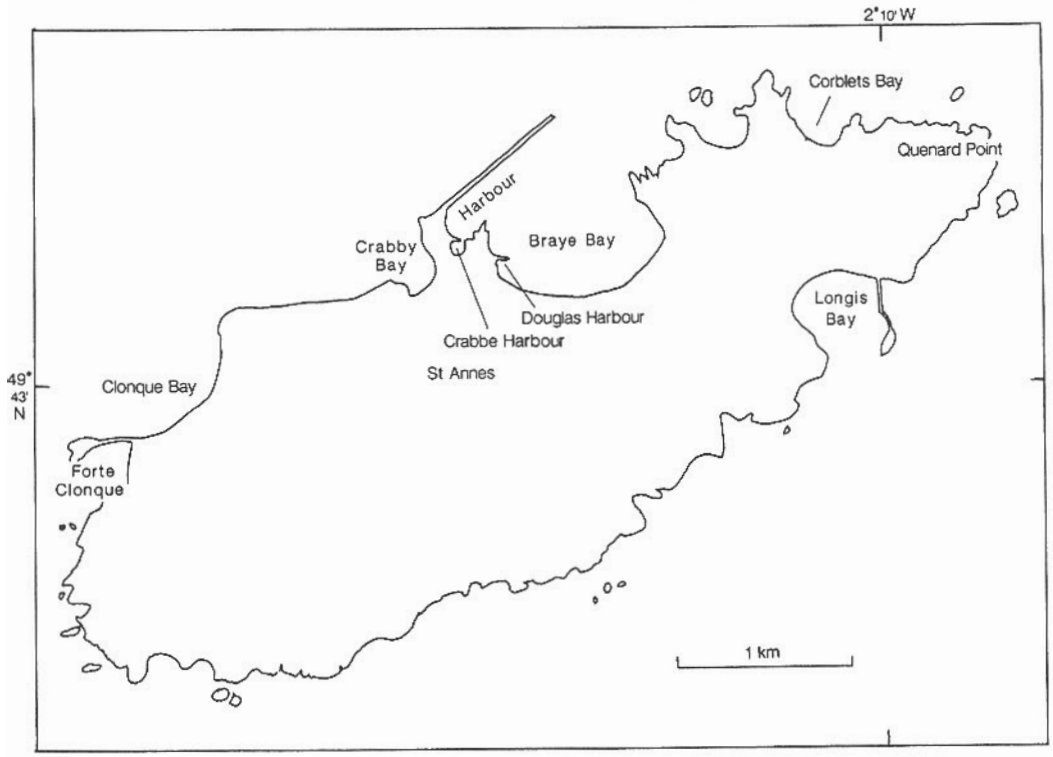

Figure 5. Sampling locations on Alderney in 1989

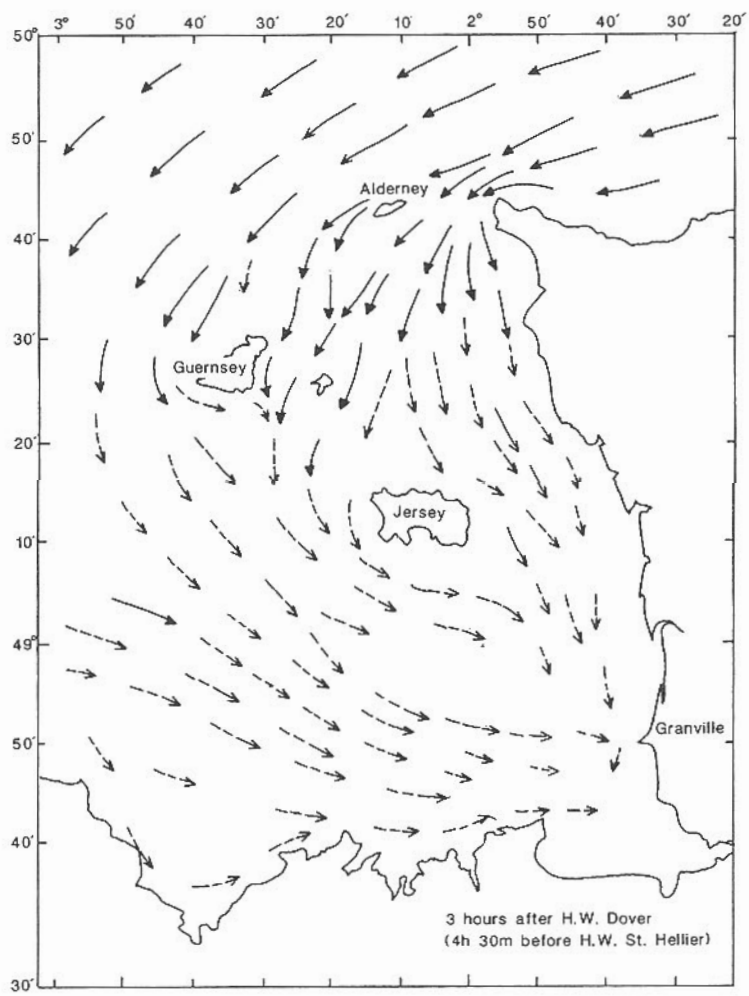

Figure 6. Tidal currents around the Channel Islands 4 h 30 min before high water at St Helier (adapted from Fowler, 1991)

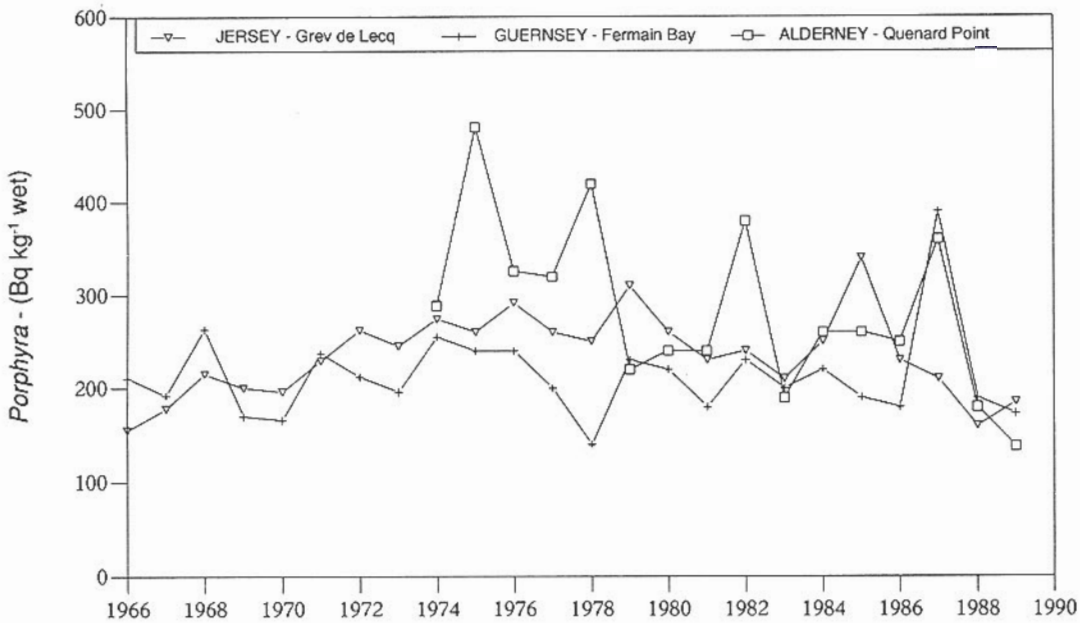

Figure 7. Annual total beta concentrations in Porphyra collected from Jersey, Guernsey and Alderney from 1966 to 1989

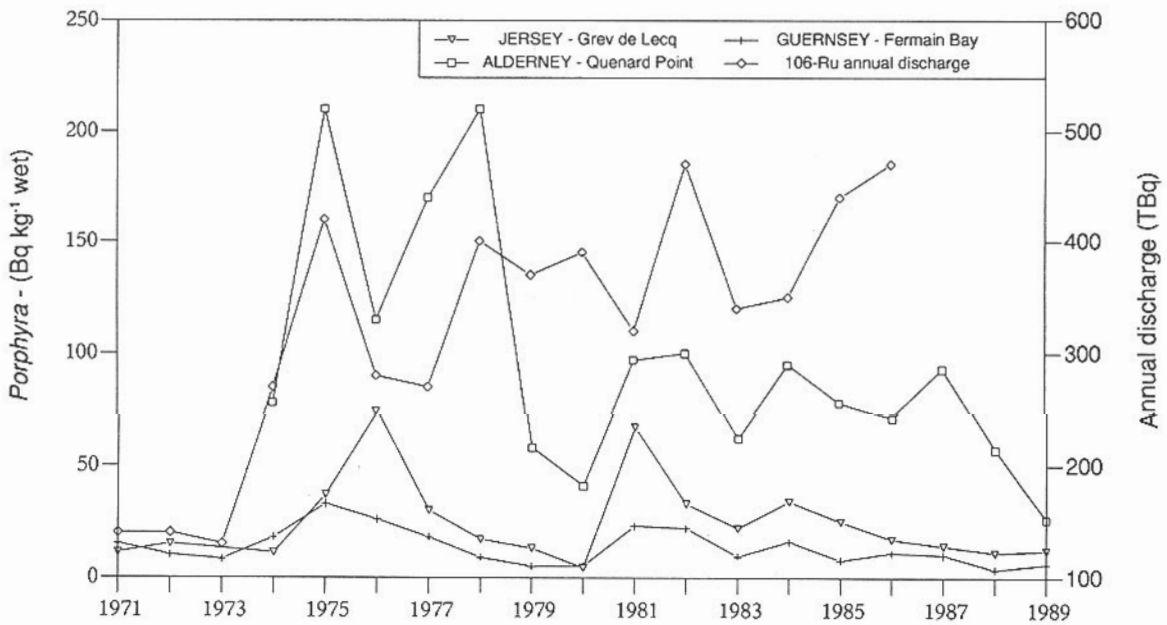

Figure 8. Annual ruthenium-106 concentrations in Porphyra collected from Jersey, Guernsey and Alderney from 1971 to 1989 compared with annual discharges from Etablissement de la Hague

Figure 9. Taking close-contact beta plus gamma dose measurements (on left) and gamma dose measurements in air (on right) at Rocquaine Bay beach Guernsey

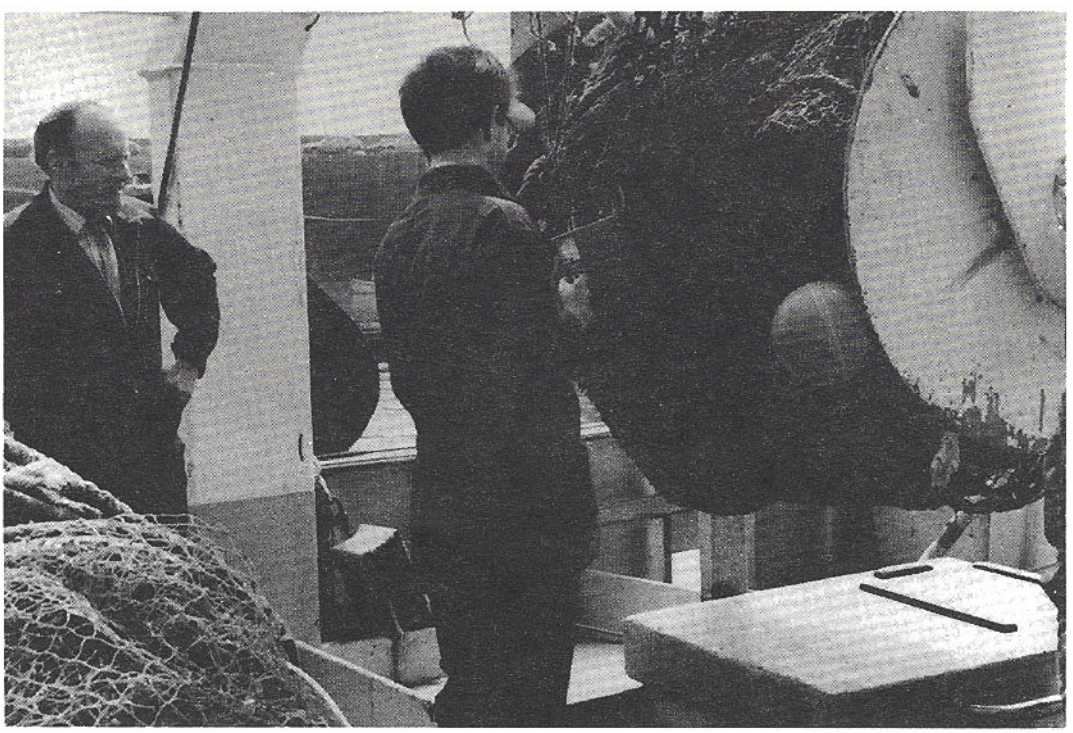

Figure 10. Beta plus gamma monitoring of a trawl net used recently near Etablissement de la Hague

Figure 11. Checking for particulate activity in St Aubin's harbour, Jersey using a close-contact beta plus gamma detector

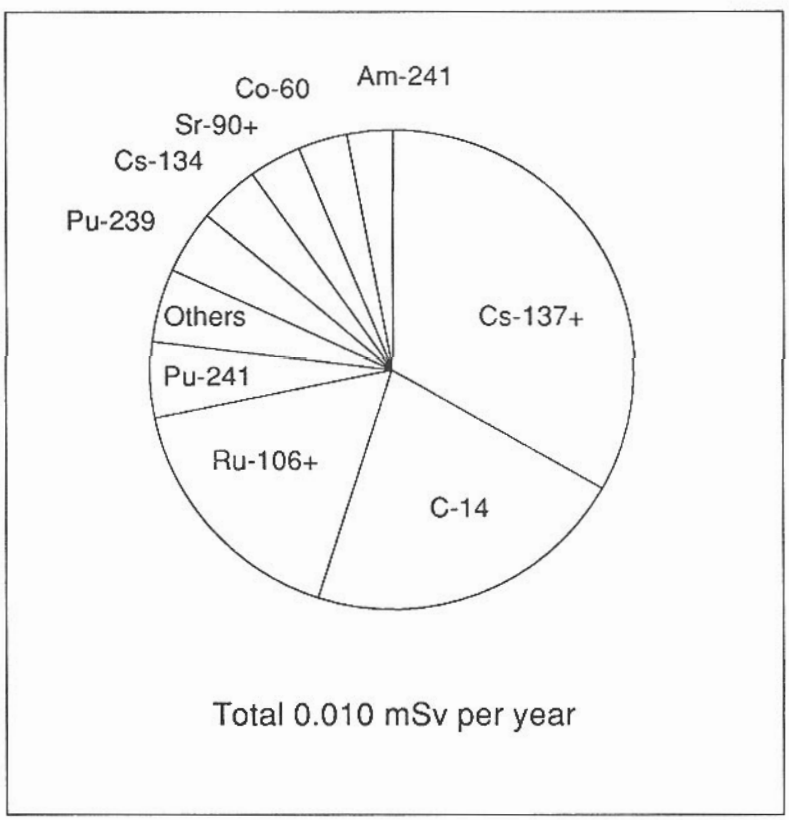

Figure 12. Contributions to individual dose due to artificial radionuclides from the consumption of seafood

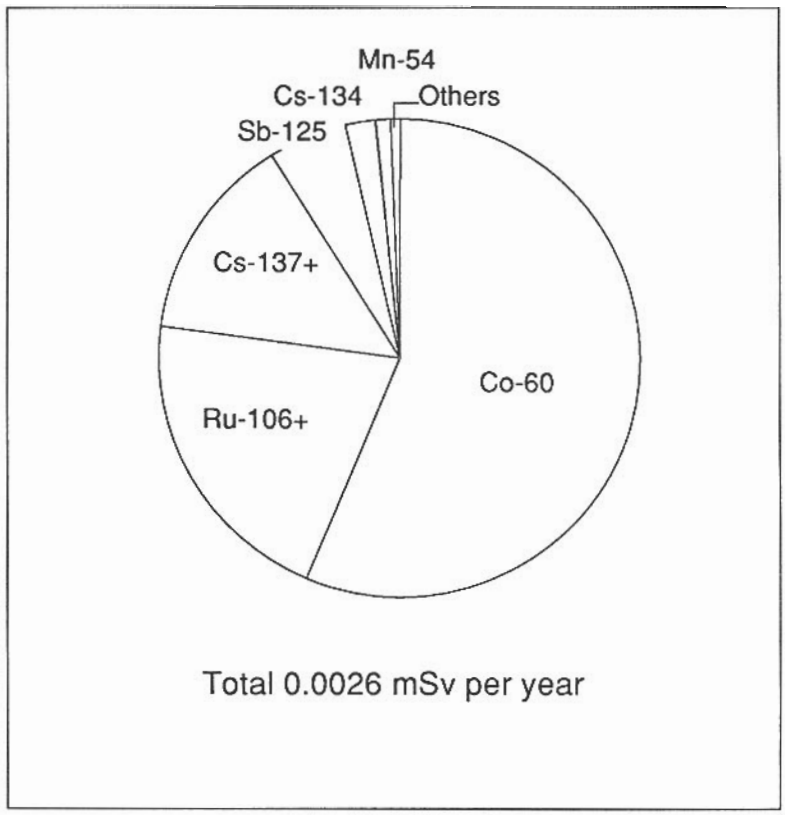

Figure 13. Contributions to individual dose due to artificial radionuclides from external irradiation

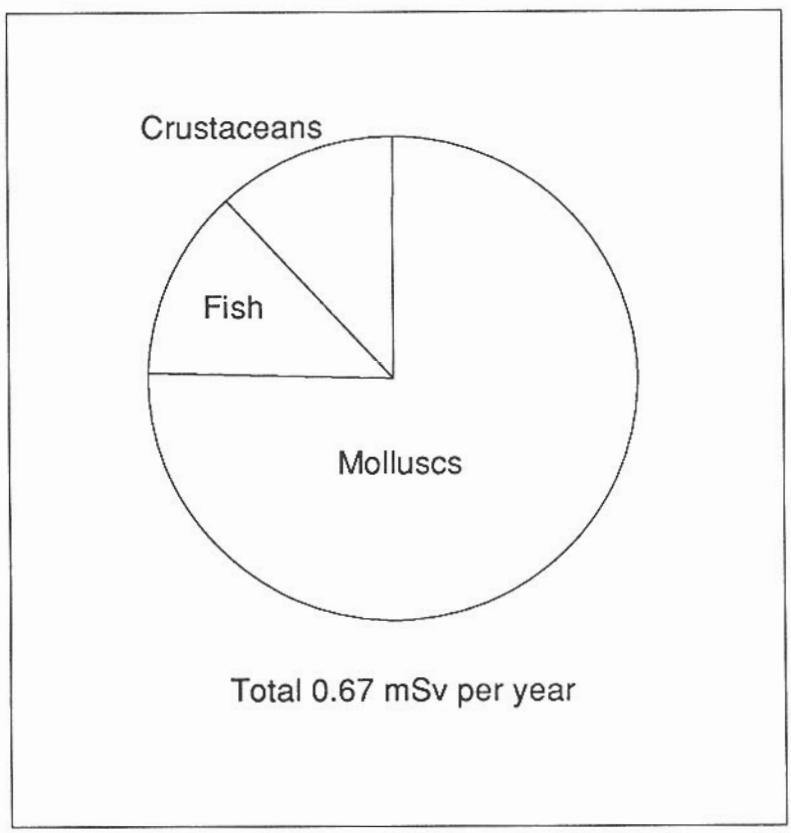

Figure 14. Contributions to individual dose due to natural radionuclides from the consumption of seafood

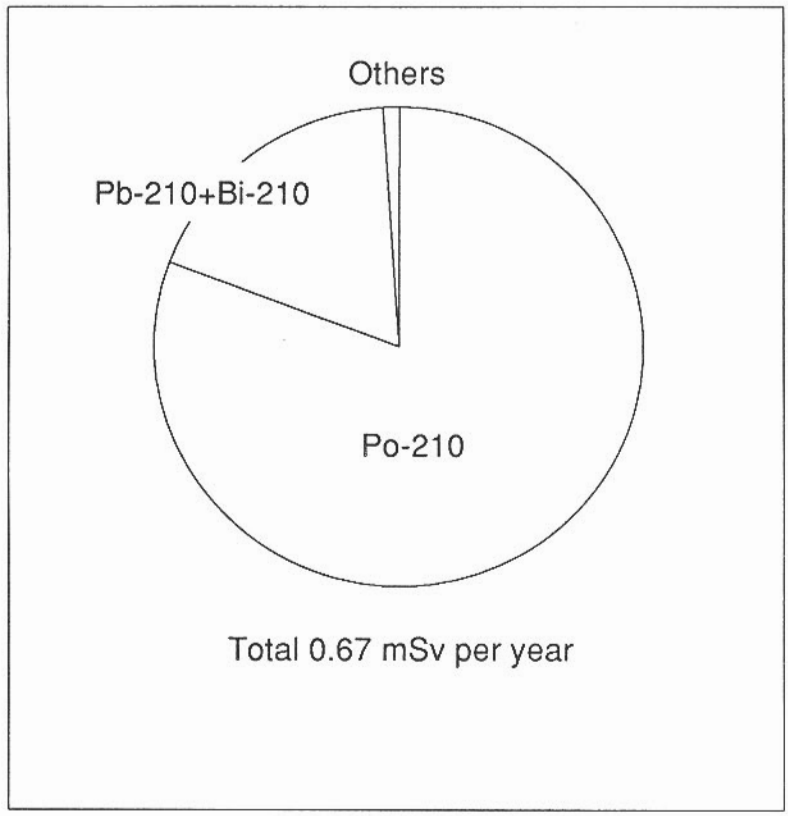

Figure 15. Contributions to individual doses from natural radionuclides

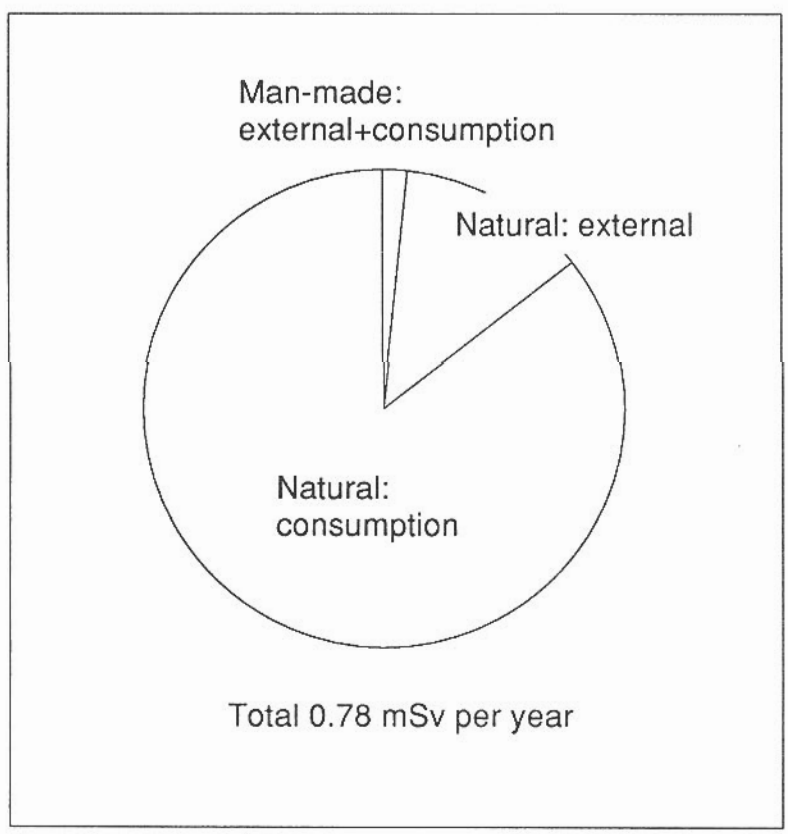

Figure 16. The maximum individual dose to Channel Islanders from marine pathways

ANNEX 1. LIQUID DISCHARGES FROM ETABLISSEMENT DE LA HAGUE (Bq) (from McColl *et al.*, 1990*)

Radionuclide	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
H-3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C-14	0.0	0.0	0.0	0.0	0.0	0.0	$7.0\ 10^{11}$	$7.0\ 10^{11}$	$7.0\ 10^{11}$	$7.0\ 10^{11}$
Co-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zn-65	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sr-89	0.0	0.0	0.0	0.0	0.0	0.0	$1.0\ 10^{12}$	$6.3\ 10^{11}$	$7.8\ 10^{11}$	$2.6\ 10^{11}$
Sr-90	0.0	0.0	0.0	0.0	0.0	0.0	$5.2\ 10^{11}$	$2.0\ 10^{11}$	$6.9\ 10^{11}$	$3.5\ 10^{11}$
Zr-95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	$1.0\ 10^{12}$	$2.5\ 10^{12}$	$2.2\ 10^{11}$
Nb-95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	$1.7\ 10^{12}$	$4.1\ 10^{12}$	$3.7\ 10^{11}$
Tc-99	0.0	0.0	0.0	0.0	0.0	0.0	$2.0\ 10^{10}$	$2.0\ 10^{10}$	$2.0\ 10^{10}$	$2.0\ 10^{10}$
Ru-103	0.0	0.0	0.0	0.0	0.0	0.0	$2.7\ 10^{12}$	$6.1\ 10^{12}$	$3.0\ 10^{12}$	$3.3\ 10^{11}$
Ru-106	0.0	0.0	0.0	0.0	0.0	0.0	$5.0\ 10^{11}$	$2.4\ 10^{13}$	$3.0\ 10^{13}$	$2.7\ 10^{13}$
Ag-110m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sb-125	0.0	0.0	0.0	0.0	0.0	0.0	$8.1\ 10^{10}$	$1.9\ 10^{11}$	0.0	$7.4\ 10^{11}$
I-129	0.0	0.0	0.0	0.0	0.0	0.0	$1.3\ 10^{11}$	$1.3\ 10^{11}$	$1.3\ 10^{11}$	$1.3\ 10^{11}$
Cs-134	0.0	0.0	0.0	0.0	0.0	0.0	$2.8\ 10^{11}$	$1.6\ 10^{12}$	$3.0\ 10^{12}$	$1.3\ 10^{12}$
Cs-137	0.0	0.0	0.0	0.0	0.0	0.0	$7.3\ 10^{12}$	$1.6\ 10^{13}$	$2.8\ 10^{13}$	$2.0\ 10^{13}$
Ce-144	0.0	0.0	0.0	0.0	0.0	0.0	0.0	$1.6\ 10^{11}$	$2.3\ 10^{12}$	$2.6\ 10^{11}$
Others	0.0	0.0	0.0	0.0	0.0	0.0	$5.2\ 10^{12}$	$3.2\ 10^{12}$	$3.1\ 10^{13}$	$3.0\ 10^{12}$
Pu-239	0.0	0.0	0.0	0.0	0.0	0.0	$1.1\ 10^{9}$	$1.2\ 10^{10}$	$3.1\ 10^{10}$	$1.3\ 10^{10}$
Pu-241	0.0	0.0	0.0	0.0	0.0	0.0	$6.7\ 10^{10}$	$7.1\ 10^{11}$	$1.9\ 10^{12}$	$8.0\ 10^{11}$
U-234	0.0	0.0	0.0	0.0	0.0	0.0	$2.1\ 10^{9}$	$3.5\ 10^{9}$	$3.1\ 10^{9}$	$1.8\ 10^{9}$
U-238	0.0	0.0	0.0	0.0	0.0	0.0	$2.1\ 10^{9}$	$3.5\ 10^{9}$	$3.1\ 10^{9}$	$1.8\ 10^{9}$
Total	0.0	0.0	0.0	0.0	0.0	0.0	$2.4\ 10^{13}$	$6.7\ 10^{13}$	$9.1\ 10^{13}$	$7.4\ 10^{13}$

Radionuclide	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
H-3	$6.1\ 10^{13}$	$7.8\ 10^{13}$	$8.4\ 10^{13}$	$1.1\ 10^{14}$	$2.8\ 10^{14}$	$4.1\ 10^{14}$	$2.6\ 10^{14}$	$3.3\ 10^{14}$	$7.3\ 10^{14}$	$5.8\ 10^{14}$
C-14	$7.0\ 10^{11}$	$7.0\ 10^{11}$	$7.0\ 10^{11}$	$7.0\ 10^{11}$	$7.0\ 10^{11}$	$7.0\ 10^{11}$	$7.0\ 10^{11}$	$7.0\ 10^{11}$	$7.0\ 10^{11}$	$7.0\ 10^{11}$
Co-60	0.0	0.0	0.0	$4.2\ 10^{11}$	$1.1\ 10^{10}$	$2.2\ 10^{11}$	$2.0\ 10^{11}$	$2.2\ 10^{11}$	$3.5\ 10^{11}$	$1.1\ 10^{12}$
Zn-65	0.0	0.0	0.0	0.0	$5.4\ 10^{10}$	$1.4\ 10^{9}$	$7.8\ 10^{9}$	$2.2\ 10^{11}$	$1.1\ 10^{10}$	0.0
Sr-89	$3.7\ 10^{11}$	$7.8\ 10^{11}$	$2.5\ 10^{12}$	$1.2\ 10^{12}$	$8.6\ 10^{12}$	$8.7\ 10^{12}$	$7.8\ 10^{11}$	$2.7\ 10^{12}$	$7.9\ 10^{11}$	$1.1\ 10^{12}$
Sr-90	$2.0\ 10^{12}$	$8.2\ 10^{12}$	$1.6\ 10^{13}$	$9.4\ 10^{12}$	$5.2\ 10^{13}$	$3.8\ 10^{13}$	$2.0\ 10^{13}$	$3.6\ 10^{13}$	$7.0\ 10^{13}$	$5.9\ 10^{13}$
Zr-95	$2.7\ 10^{12}$	$2.7\ 10^{12}$	$1.2\ 10^{13}$	$8.5\ 10^{11}$	$1.5\ 10^{13}$	$1.1\ 10^{13}$	$3.4\ 10^{12}$	$7.4\ 10^{11}$	$9.3\ 10^{10}$	$3.5\ 10^{11}$
Nb-95	$1.7\ 10^{12}$	$1.6\ 10^{12}$	$7.4\ 10^{12}$	$1.4\ 10^{12}$	$1.3\ 10^{13}$	$1.0\ 10^{13}$	$2.0\ 10^{12}$	$1.3\ 10^{12}$	$3.3\ 10^{11}$	$5.1\ 10^{11}$
Tc-99	$2.0\ 10^{11}$	$2.0\ 10^{11}$	$2.0\ 10^{11}$	$2.0\ 10^{11}$	$4.1\ 10^{11}$	$5.8\ 10^{11}$	$8.4\ 10^{11}$	$1.2\ 10^{12}$	$1.7\ 10^{12}$	$2.5\ 10^{12}$
Ru-103	$1.7\ 10^{12}$	$3.5\ 10^{12}$	$8.3\ 10^{12}$	$2.1\ 10^{12}$	$4.5\ 10^{12}$	$7.6\ 10^{12}$	$1.1\ 10^{12}$	$5.7\ 10^{11}$	$4.8\ 10^{10}$	$1.0\ 10^{11}$
Ru-106	$1.0\ 10^{14}$	$1.4\ 10^{14}$	$1.4\ 10^{14}$	$1.3\ 10^{14}$	$2.7\ 10^{14}$	$4.2\ 10^{14}$	$2.8\ 10^{14}$	$2.7\ 10^{14}$	$4.0\ 10^{14}$	$3.7\ 10^{14}$
Ag-110m	0.0	0.0	$1.1\ 10^{10}$	$4.8\ 10^{10}$	$1.8\ 10^{10}$	$1.8\ 10^{10}$	$2.6\ 10^{10}$	$2.2\ 10^{10}$	$1.7\ 10^{11}$	0.0
Sb-125	$9.3\ 10^{11}$	$2.5\ 10^{12}$	$1.8\ 10^{13}$	$6.6\ 10^{13}$	$6.9\ 10^{13}$	$7.2\ 10^{13}$	$3.6\ 10^{13}$	$5.5\ 10^{13}$	$6.2\ 10^{13}$	$5.4\ 10^{13}$
I-129	$1.3\ 10^{11}$	$1.3\ 10^{11}$	$1.3\ 10^{11}$	$1.3\ 10^{11}$	$1.3\ 10^{11}$	$1.3\ 10^{11}$	$1.3\ 10^{11}$	$1.3\ 10^{11}$	$1.3\ 10^{11}$	$1.3\ 10^{11}$
Cs-134	$1.4\ 10^{13}$	$4.8\ 10^{13}$	$6.1\ 10^{12}$	$8.4\ 10^{12}$	$9.0\ 10^{12}$	$4.3\ 10^{12}$	$6.6\ 10^{12}$	$9.6\ 10^{12}$	$7.8\ 10^{12}$	$3.6\ 10^{12}$
Cs-137	$8.9\ 10^{13}$	$2.4\ 10^{14}$	$3.3\ 10^{13}$	$6.9\ 10^{13}$	$5.6\ 10^{13}$	$3.4\ 10^{13}$	$3.5\ 10^{13}$	$5.1\ 10^{13}$	$3.9\ 10^{13}$	$2.2\ 10^{13}$
Co-144	$4.6\ 10^{11}$	$6.6\ 10^{12}$	$2.7\ 10^{12}$	$3.3\ 10^{12}$	$2.1\ 10^{13}$	$1.0\ 10^{13}$	$2.9\ 10^{12}$	$2.5\ 10^{12}$	$5.2\ 10^{12}$	$6.6\ 10^{12}$
Others	$1.6\ 10^{13}$	$4.5\ 10^{13}$	$2.3\ 10^{13}$	$4.8\ 10^{13}$	$7.2\ 10^{13}$	$9.9\ 10^{13}$	$2.7\ 10^{13}$	0.0	$7.8\ 10^{10}$	$6.3\ 10^{10}$
Pu-239	$2.4\ 10^{10}$	$1.5\ 10^{11}$	$6.6\ 10^{10}$	$8.1\ 10^{10}$	$5.5\ 10^{11}$	$2.6\ 10^{11}$	$1.6\ 10^{11}$	$2.4\ 10^{11}$	$2.2\ 10^{11}$	$2.4\ 10^{11}$
Pu-241	$1.4\ 10^{12}$	$8.7\ 10^{12}$	$4.0\ 10^{12}$	$4.9\ 10^{12}$	$3.3\ 10^{13}$	$1.5\ 10^{13}$	$9.4\ 10^{12}$	$1.4\ 10^{13}$	$1.3\ 10^{13}$	$1.4\ 10^{13}$
U-234	$2.4\ 10^{9}$	$2.5\ 10^{10}$	$2.4\ 10^{10}$	$2.6\ 10^{10}$	$2.2\ 10^{11}$	$1.2\ 10^{11}$	$1.0\ 10^{11}$	$1.9\ 10^{11}$	$1.5\ 10^{11}$	$2.3\ 10^{11}$
U-238	$2.4\ 10^{9}$	$2.5\ 10^{10}$	$2.4\ 10^{10}$	$2.6\ 10^{10}$	$2.2\ 10^{11}$	$1.2\ 10^{11}$	$1.0\ 10^{11}$	$1.9\ 10^{11}$	$1.5\ 10^{11}$	$2.3\ 10^{11}$
Total	$3.9\ 10^{14}$	$7.1\ 10^{14}$	$5.1\ 10^{14}$	$6.0\ 10^{14}$	$1.2\ 10^{15}$	$1.6\ 10^{15}$	$9.8\ 10^{14}$	$1.1\ 10^{15}$	$1.1\ 10^{15}$	$1.0\ 10^{15}$

Radionuclide	1980	1981	1982	1983	1984	1985	1986
H-3	$5.4\ 10^{14}$	$7.1\ 10^{14}$	$8.1\ 10^{14}$	$1.2\ 10^{15}$	$1.5\ 10^{15}$	$2.6\ 10^{15}$	$2.6\ 10^{15}$
C-14	$7.0\ 10^{11}$	$7.0\ 10^{11}$	$7.0\ 10^{11}$	$7.0\ 10^{11}$	$7.0\ 10^{11}$	$7.0\ 10^{11}$	$7.0\ 10^{11}$
Co-60	$2.3\ 10^{12}$	$4.0\ 10^{12}$	$3.1\ 10^{12}$	$1.3\ 10^{13}$	$2.5\ 10^{13}$	$1.5\ 10^{13}$	$1.5\ 10^{13}$
Zn-65	$1.1\ 10^{10}$	0.0	0.0	$7.2\ 10^{10}$	$2.7\ 10^{11}$	$2.2\ 10^{11}$	$2.2\ 10^{11}$
Sr-89	$2.8\ 10^{11}$	$3.1\ 10^{11}$	$4.7\ 10^{11}$	$8.2\ 10^{11}$	$1.1\ 10^{12}$	$2.9\ 10^{11}$	$2.9\ 10^{11}$
Sr-90	$2.9\ 10^{13}$	$2.7\ 10^{13}$	$8.7\ 10^{13}$	$1.4\ 10^{14}$	$1.1\ 10^{14}$	$4.7\ 10^{13}$	$4.7\ 10^{13}$
Zr-95	$6.7\ 10^{10}$	$9.3\ 10^{10}$	$5.0\ 10^{11}$	$1.1\ 10^{12}$	$8.6\ 10^{10}$	$8.9\ 10^{9}$	$8.9\ 10^{9}$
Nb-95	$5.4\ 10^{10}$	$2.8\ 10^{10}$	$4.7\ 10^{10}$	$1.3\ 10^{11}$	$2.6\ 10^{10}$	$2.0\ 10^{6}$	$2.0\ 10^{6}$
Tc-99	$3.6\ 10^{12}$	$5.1\ 10^{12}$	$7.4\ 10^{12}$	$1.2\ 10^{13}$	$1.2\ 10^{13}$	$1.2\ 10^{13}$	$1.2\ 10^{13}$
Ru-103	$6.3\ 10^{10}$	$5.9\ 10^{10}$	0.0	$5.0\ 10^{9}$	0.0	$1.0\ 10^{10}$	$1.0\ 10^{10}$
Ru-106	$3.9\ 10^{14}$	$3.2\ 10^{14}$	$4.7\ 10^{14}$	$3.4\ 10^{14}$	$3.5\ 10^{14}$	$4.4\ 10^{14}$	$4.7\ 10^{14}$
Ag-110m	$1.4\ 10^{9}$	$2.0\ 10^{9}$	0.0	0.0	0.0	$4.0\ 10^{6}$	$4.0\ 10^{6}$
Sb-125	$5.1\ 10^{13}$	$4.8\ 10^{13}$	$7.6\ 10^{13}$	$1.5\ 10^{14}$	$1.3\ 10^{14}$	$1.1\ 10^{14}$	$1.6\ 10^{14}$
I-129	$1.3\ 10^{11}$	$1.3\ 10^{11}$	$1.3\ 10^{11}$	$1.3\ 10^{11}$	$1.3\ 10^{11}$	$1.3\ 10^{11}$	$1.3\ 10^{11}$
Cs-134	$3.9\ 10^{12}$	$6.0\ 10^{12}$	$8.4\ 10^{12}$	$4.9\ 10^{12}$	$4.8\ 10^{12}$	$8.2\ 10^{12}$	$8.2\ 10^{12}$
Cs-137	$2.7\ 10^{13}$	$3.9\ 10^{13}$	$5.0\ 10^{13}$	$2.3\ 10^{13}$	$3.0\ 10^{13}$	$2.9\ 10^{13}$	$2.9\ 10^{13}$
Ce-144	$2.7\ 10^{12}$	$4.0\ 10^{12}$	$3.2\ 10^{12}$	$2.4\ 10^{12}$	$3.2\ 10^{12}$	$2.2\ 10^{12}$	$2.2\ 10^{12}$
Others	$9.8\ 10^{10}$	$5.2\ 10^{10}$	$1.0\ 10^{11}$	$3.7\ 10^{11}$	$3.8\ 10^{13}$	$1.1\ 10^{14}$	$1.1\ 10^{14}$
Pu-239	$1.9\ 10^{11}$	$1.7\ 10^{11}$	$1.9\ 10^{11}$	$8.4\ 10^{10}$	$1.4\ 10^{11}$	$1.4\ 10^{11}$	$1.4\ 10^{11}$
Pu-241	$1.1\ 10^{13}$	$9.9\ 10^{12}$	$1.1\ 10^{13}$	$5.0\ 10^{12}$	$8.2\ 10^{12}$	$8.4\ 10^{12}$	$8.4\ 10^{12}$
U-234	$1.6\ 10^{11}$	$1.9\ 10^{11}$	$2.2\ 10^{11}$	$2.0\ 10^{11}$	$2.9\ 10^{11}$	$2.9\ 10^{11}$	$2.9\ 10^{11}$
U-238	$1.6\ 10^{11}$	$1.9\ 10^{11}$	$2.2\ 10^{11}$	$2.0\ 10^{11}$	$2.9\ 10^{11}$	$2.9\ 10^{11}$	$2.9\ 10^{11}$
Total	$9.4\ 10^{14}$	$8.4\ 10^{14}$	$1.3\ 10^{15}$	$1.2\ 10^{15}$	$1.2\ 10^{15}$	$1.2\ 10^{15}$	0.0

*REFERENCE: McCOLL, M.P., VAN WEERS, A.W. and COOPER, J.R. 1990. *Civil nuclear discharges into north European Waters: Report of Working Group 1 of CEC Project MARINA. National Radiological Protection Board, Chilton, NRPB-M173, 143 pp.*

ANNEX 2. THE USE OF SEAWEED AS FERTILISER AND SOIL CONDITIONER ON THE CHANNEL ISLANDS: DOSES TO A HYPOTHETICAL CRITICAL GROUP

A possible route through which radioactivity may reach man from marine discharges is the use of seaweed as an agricultural fertiliser, followed by consumption of associated crops. For the Channel Islands, doses from six radionuclides were calculated, assuming that 1 kg of seaweed is deposited per square metre, and that this is mixed to 30 cm depth (Simmonds and Crick, 1982). An effective dry weight density for *in situ* soil of 1.3 t m^{-3} was used (IAEA, 1982). Thus, concentrations in seaweed (wet weight), derived from Hunt (1988) could be converted to concentrations in soil (dry weight). Committed dose equivalent rates (D) in μSv $year^{-1}$ were then calculated as:

$$
\begin{aligned}
&D\ (\mu Sv\ year^{-1}) \\
&= \text{dose per unit intake } (\mu Sv\ Bq^{-1}) \\
&\times \text{wet food consumption } (kg\ year^{-1}) \\
&\times \text{concentration factors } \frac{kg\ (dry\ soil)}{kg\ (wet\ food)} \\
&\times \text{soil activity } (Bq\ kg^{-1}\ (dry))
\end{aligned}
$$

The six nuclides considered were: ^{60}Co, ^{90}Sr, ^{106}Ru, ^{137}Cs, ^{239}Pu and ^{241}Am.

Calculations were carried out for rootcrops, grains and leafy vegetables. Radionuclide concentrations and dose per unit intakes are listed in Table A2.1. Critical group consumption rates are in Table A2.2 and concentration factors in Table A2.3. Results are summarised in Tables A2.4. It should be noted that these are the doses resulting from one year's fertilisation, using 1 kg seaweed m^{-2}.

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Table A2.1. Radionuclide concentrations and dosimetric data

Radionuclide	Conc. in seaweed[1] Bq kg^{-1}(wet)	Conc. in soil[2] Bq kg^{-1}(dry)	Committed dose equivalent[3] per unit activity ingested (mSv Bq^{-1}). Effective dose
^{60}Co	10	$7.7\ 10^{-3}$	$7.0\ 10^{-3}$
^{90}Sr	1	$7.7\ 10^{-4}$	$3.3\ 10^{-2}$
^{106}Ru	30	$2.4\ 10^{-2}$	$5.8\ 10^{-3}$
^{137}Cs	1	$7.7\ 10^{-4}$	$1.2\ 10^{-2}$
^{239}Pu	0.1	$7.7\ 10^{-5}$	$1.2\ 10^{-0}$
^{241}Am	0.1	$7.7\ 10^{-5}$	$1.2\ 10^{-0}$

(1) Rounded values typical of the highest concentrations reported by Hunt (1988)
(2) By mixing 1 kg to 30 cm depth (Simmonds and Crick, 1982) with an effective dry soil density of 1.3 t m^{-3} (IAEA, 1982)
(3) From Greenhalgh et al. (1987)

Table A2.2. Critical group consumption data

Foodstuff	Consumption[1] rate (kg $year^{-1}$)
Root crops	120
Green vegetables	80
Grain products	130

(1) From Harrison and Simmonds (1980)

Table A2.3. Concentrations factors (kg soil (dry weight)/kg foodstuff (wet weight))[1]

Element	Root crops	Green vegetables	Grain products
Co	$2\ 10^{-3}$	$1\ 10^{-3}$	$1\ 10^{-2}$
Sr	$6\ 10^{-2}$	$7\ 10^{-1}$	$2\ 10^{-2}$
Ru	$1\ 10^{-2}$	$4\ 10^{-3}$	$6\ 10^{-2}$
Cs	$5\ 10^{-3}$	$2\ 10^{-2}$	$6\ 10^{-3}$
Pu	$1\ 10^{-3}$	$1\ 10^{-4}$	$1\ 10^{-6}$
Am	$1\ 10^{-3}$	$1\ 10^{-3}$	$1\ 10^{-5}$

(1) From Simmonds and Crick (1982)

Table A2.4. Committed effective dose equivalent (μSv $year^{-1}$)

	Root crops	Green vegetables	Grain products
^{60}Co	$4.3\ 10^{-5}$	$1.4\ 10^{-5}$	$2.3\ 10^{-4}$
^{90}Sr	$6.0\ 10^{-4}$	$4.7\ 10^{-3}$	$2.2\ 10^{-4}$
^{106}Ru	$5.4\ 10^{-5}$	$1.4\ 10^{-5}$	$3.5\ 10^{-4}$
^{137}Cs	$1.8\ 10^{-5}$	$4.9\ 10^{-1}$	$2.4\ 10^{-5}$
^{239}Pu	$3.7\ 10^{-5}$	$2.5\ 10^{-6}$	$4.0\ 10^{-8}$
^{241}Am	$3.7\ 10^{-5}$	$2.4\ 10^{-5}$	$4.0\ 10^{-7}$
Totals	$7.9\ 10^{-4}$	$4.8\ 10^{-3}$	$8.2\ 10^{-4}$

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Marine radioactivity in the Channel Islands

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