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Radiation protection 132

MARINA II

Update of the MARINA Project on the radiological exposure of the European Community from radioactivity in North European marine waters

Volume II

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Annex C: Analysis of Data on Seafood Catches and Trade

ANALYSES OF DATA ON SEAFOOD CATCHES AND TRADE

Report Of Working Group C

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Summary

The task of the Marina II - Working Group C was to make a survey of the quantities and utilisation of associated marine products, in order to provide a database for the calculations of the MARINA II - Working Group D of the exposure of the EU Member States via marine pathways from sources of radioactivity. Utilisation of marine produce from the Northeast Atlantic is considered to be proportional to catches and landings of each country from all areas, including imports. Areas considered are: all areas world-wide, freshwater areas and the Northeast Atlantic coinciding with the OSPAR area. Exports of marine produce are assumed to originate in the same ratio from catches and imports.

From the total annual catches and landings of EU Member States, and some other countries in the Northeast Atlantic area, the fractions of these catches and landings from the various MARINA II compartments of the Northeast Atlantic, and the flow of marine produce through imports and exports, the gross amounts of fish, crustaceans and molluscs which are available for human consumption in EU Member States from these compartments are calculated. All figures on catches and landings, imports and exports have been corrected for non-food uses.

Farmed marine fish may contribute significantly to the production of marine fish in some countries. However, as most animal feed products used in farming marine fish originate from the Pacific Ocean, e.g. Peru, farmed marine fish is not included into the production figures of marine fish from the Northeast Atlantic.

Gross amounts of marine produce are converted into net amounts by taking half of the gross weight for fish, one third for crustaceans, and one sixth for molluscs. These net amounts from the MARINA II compartments, available for human consumption, can directly be used as a basis for the calculation of the radiological exposure of the European Union from radioactivity in North European marine waters. Effects of critical group consumption on doses may be derived from average consumption rates of marine produce by multiplying with a factor 5.

In order to validate the figures produced by the analyses of data on seafood, a comparison has been made with overall figures on the amounts of fishery products available for human consumption given by FAO.

1 Introduction

Subtasks of the MARINA II Working Group C "Analysis of data on seafood catches and trade" are specified as:

1. Analysis and modification of ICES data on marine produce.
2. Collation of statistical data from EUROSTAT on trade.
3. Qualitative comments on uncertainties and proposals for future work.

In order to perform its subtasks Working Group C has made an inventory of where fisheries products, especially marine produce, originate from, where they go and what fraction is available for human consumption in the individual EU Member States. This implies that complete lists have been produced on national landings of fish, crustaceans and molluscs from the North European marine waters, together with imports and exports data of fisheries products from that area to EU Member States. For the different categories of marine produce corrections have been made for non-food uses in order to obtain the amounts directly available for human consumption. Finally, estimates have been made on average and critical group consumption rates of marine produce in the relevant countries.

As the geographic area for the assessment of the radiological impact on the population of EU Member States is restricted to the OSPAR are (Figure 1), the activities of Working Group C were concentrated on that area. However, as the MARINA II Project is directed to the radiological impact on all EU Member States, including those not bordering the Northeast Atlantic, the exports of marine produce from the Northeast Atlantic to these EU Member States have also to be taken into consideration.

The MARINA II Working Group C has not taken into consideration quantities and utilisation of fresh water fisheries products from Northwest Europe. Any contribution of radioactive releases into these freshwaters is taken into account of by their effects on marine produce from the Northeast Atlantic.

The MARINA II Working Group C has also not taken into consideration quantities and utilisation of farmed marine fish. Most animal feed products used in farming marine fish originate from the Pacific Ocean. Therefore, farmed marine fish is not considered to be a significant source of radiological imput from radioactivity in the Northeast Atlantic.

2 Methodology

The national landings of marine produce from the different compartments of the MARINA II Model were obtained from the ICES statistical areas used in the ICES CD-ROM "ICES Fisheries Statistics 1973-1999, Nominal Catch Statistics, STATLANT Programme, ICES, Copenhagen, Denmark, 2001." (1)

These ICES areas coincide, to a large extent, with the compartments of the Northeast Atlantic that are relevant to the MARINA radiological impact calculation (Figure 2). The data over the years 1994/1996/1998 on national landings were supplemented by data from the FAO on a CD-ROM "Fishery statistics", 1950-1999 data", EUROSTAT, European Commission, 2001 (2).

On the basis of the FAO data all catches of fish were corrected for non-food uses. It is assumed that these non-food uses, typically the fish meal industry pathway through animal feed products and animal husbandry, contributes only a small percentage of the total radiological input to the population of EU Member States from the Northeast Atlantic. One reason being that more than 90% of this marine produce will be lost in processing. Furthermore, most fish meal used in EU Member States for farming marine fish originates from areas outside the Northeast Atlantic, notably the Pacific Ocean at Peru.

Imports and exports data on fish, crustaceans and molluscs of EU Member States over the years 1994/1996/1998 have been derived from additional EUROSTAT data (3), total imports and exports data, corrected for non-food uses, from the FAO statistics.

Identifying quantities of marine produce from the different compartments of the MARINA II Model will tell little about their utilisation. Part may be consumed in the countries which produced it, part of it may be exported to other countries. This picture is complicated by the fact that large amounts of marine produce are imported, processed in some way and exported again. Some approximations have been made to circumvent these problems. The main one is that the consumption of marine produce of a EU Member State is considered to have the same relative composition as the total supply of marine produce from landings and imports of that EU Member State. That means that the fraction of marine produce from the Northeast Atlantic is the same in marine produce consumed and exported by an EU Member State. All marine produce imported by an EU Member State is considered to be consumed in the receiving EU Member State.

The total amounts of marine produce available for human consumption from the different compartments of the Northeast Atlantic, are obtained by adding the fractions of marine produce from the own catch of a EU Member State to the fractions represented by the imports of that EU Member State from all other EU Member States and Iceland, Norway and the Faroe Islands.

For the radiological impact calculations of the MARINA II Working Group D, the nominal (gross) landings have been converted into amounts actually available for human consumption (net), by taking half of the nominal weights for fish, one third for crustaceans and one sixth for molluscs.

Finally, estimated average (gross) consumption rates of marine produce have been derived from FAO statistics. Critical group consumption rates of less than 1% of the population may be obtained from those rates on multiplying by a factor 5.

3 Results

The following have been calculated and full details can be obtained from the Environment Directorate General of the European Commission on request.

- Total annual nominal catches and landings of fish, crustaceans and molluscs in all EU Member States and Iceland, Norway and Faroe Islands from all sources over 1994, 1996 and 1998.
- Catches and landings of fish in all countries corrected for non-food uses.
- Mean annual values over 1994, 1996 and 1998 by country and by sub-area of nominal landings and landings of fish from the Northeast Atlantic, corrected for non-food uses. Nominal landings of fish are exclusively farmed marine fish.
- Mean values over 1994/1996/1998 by country and by sub-area of nominal landings of crustaceans and molluscs from the Northeast Atlantic.
- Imports and exports data on fish, crustaceans and molluscs of EU Member States including imports and exports of Iceland, Norway and the Faröe Islands, taken from additional data from EUROSTAT obtained from the Agriculture Economics Research Institute (LEI), The Netherlands, in combination with FAO data on the relative composition of total imports and exports of fish, crustaceans and molluscs, corrected for non-food uses. Import and export data on fish are inclusive of farmed marine fish. In the case of Norway, where no imports/exports data were available from EUROSTAT, only the amounts of marine produce imported by EU Member States were subtracted from the amounts of fish, crustaceans and molluscs available for human consumption derived from catch data to obtain the amounts available for human consumption. That is, exports to other countries and all imports were not available and therefore not used.
- The amounts of consumption of their own catch of Northeast Atlantic fish by EU Member States, e.g. in EU Member States such as Finland, Italy and Greece, with no fish catch in the Northeast Atlantic, these values are zero. The only exposure of these countries to Northeast Atlantic fish is through imports from other countries with an own catch of Northeast Atlantic fish.
- The gross amounts of fish, crustaceans and molluscs as a mean over 1994/1996, 1998 available for human consumption in the EU Member States. These were calculated for the individual sub-areas of the Northeast Atlantic using data for the total annual catches and landings of the EU Member States, the shares of these catches and landings from the various sub-areas of the Northeast Atlantic, and the flow of marine products from the Northeast Atlantic through imports and exports. By multiplying the data on fish by 1/2, on crustaceans by 1/3 and on molluscs by 1/6 the net amount of fish, crustaceans and molluscs from the individual sub-areas of the Northeast Atlantic available for human consumption were also calculated.
- The data on fish, molluscs and crustaceans were split up over their respective MARINA II compartments as the ICES sub-areas of the Northeast Atlantic only partially coincided with the compartments relevant to Marina II.
- Total amounts of Atlantic salmon from marine farming in the relevant European countries. This was to ascertain the relative importance of marine farming compared to seafood catches

In order to give some indication about the trends in catches and landings of fish over an extended period of time, in Figure 3 the total catch of marine fish in the Northeast

Atlantic is given over the period 1950-1999. Trends in catches of crustaceans and molluscs over the period 1950-1999 are given in Figure 4 and 5 respectively. Trends in the production of marine farming of Atlantic salmon are given in Figure 6.

4 Discussion

On the basis of data from the FAO and additional data from the ICES and EUROSATAT MARINA II Working Group C succeeded in delivering a consistent data set on seafood catches and trade to be used in the assessment of the radiological impact to the population of EU Member States from the consumption of marine produce from the Northeast Atlantic by the MARINA II Working Group D.

As the sub-areas of the Northeast Atlantic derived from the ICES Statistical areas are in a number of cases not equivalent to the compartment structure for MARINA II a way had to be found to split up some of these ICES sub-areas into smaller compartments relevant to MARINA II. In this exercise most areas have been split up according to their relative surface areas.

When distributing fishing data into the much smaller compartments of the Irish Sea and the English Channel, the data have been split into local boxes; for fish in proportion to the volume of the water, for crustaceans in proportion to the surface are of the water, and for molluscs in proportion to the length of the coastline.

Catches and landings of fish from the North-East Atlantic have increased by some 50% between 1950 and 1975 and remained more or less constant since, or show a slight decrease over the period 1975 - 1999 (Figure 3).

The total catch of crustacea in the North-East Atlantic has doubled in the period 1950-1999, with the strongest increase since 1990 (Figure 4).

The total catch of molluscs in the North-East Atlantic more than tripled in the period 1950-1980, halved between 1980 and 1985, and remained constant thereafter (Figure 5).

The selection of 1994, 1996 and 1998 as basis for the analysis of data on fish, crustaceans and molluscs in this report may therefore be considered as reasonably representative.

Farmed marine fish may contribute significantly to the production of marine fish in some countries, e.g. up to 20% of the amounts of marine fish production corrected for non-food uses in Norway. Also the United Kingdom, Faröer Islands and Ireland produce relative large quantities of farmed marine fish, mainly Atlantic salmon. However, as most animal feed products used in farming marine fish originate from the Pacific Ocean, e.g. Peru, farmed fish is not included into the production figures of marine fish from the Northeast Atlantic. As can be seen from Figure 6, production of Atlantic salmon is still exponentially growing in the Northeast Atlantic. It is uncertain to what extent the water of the Northeast Atlantic in the marine farming areas itself may lead to the accumulation of radioactivity in farmed fish.

This suggests the need for future work into the radiological input of farmed marine fish to the population of EU Member States.

Catches and landings of marine produce plus imports gives the supply of fish, crustaceans and molluscs to an EU Member State. Taking into account the different fractions of marine produce from the Northeast Atlantic in the supply and the exports, gross amounts of marine produce available for human consumption for all EU Member States may be constructed. In this calculation it is assumed that marine produce which is imported by one of the EU Member States from the Northeast Atlantic, is not exported again by the receiving country. In the case of e.g. Belgium/Luxembourg, countries with much larger imports (199.000 ton/year) and exports (75.000 ton/year) than total fish catch (27.000 ton/year, of which 26.700 ton from the Northeast Atlantic), this means that of the total supply (catch plus imports) of 226.000 ton/year only 11.81% is from the Northeast Atlantic. As the export is considered to have the same composition as the total supply, the total fish catch from the Northeast Atlantic of 26.700 ton/year can be allocated to Belgium/Luxembourg for 17.800 ton and to exports for 8.900 ton. In the case of Ireland, where the total catch of fish is 10 times larger than the imports of fish, the total fish catch from the Northeast Atlantic of 288.000 ton/year is allocated for 61.000 ton to Ireland itself and 227.000 ton to exports. So under all circumstances no fish from the Northeast Atlantic is lost or created in the analyses.

Net available for human consumption for fish, crustaceans and molluscs is by no means identical to the amounts actually consumed by the population of the EU Member States. From the different food basket studies, the impression emerges that roughly half of the net amounts of marine produce available for human consumption is actually eaten by men. Therefore, taking the net available amounts of marine produce from the Northeast Atlantic as basis for the radiological impact calculations will certainly result in some overestimation.

In the MARINA II study this may, with the assumption that the consumption of the critical group consists completely of marine produce from the Northeast Atlantic, (or specific compartments thereof), take this overestimation even further.

5 References

1. ICES Fisheries Statistics 1973 - 1999, Nominal Catch Statistics, STATLANT Programme, ICES, Copenhagen, Denmark, 2001 (CD-ROM).

2. Fishery Statistics, 1950 - 1999 data, EUROSTAT, European Commission, 2001 (CD-ROM)

3. EU data (COMEXT), EUROSTAT, European Commission, 2001.

Figure 1 OSPAR area

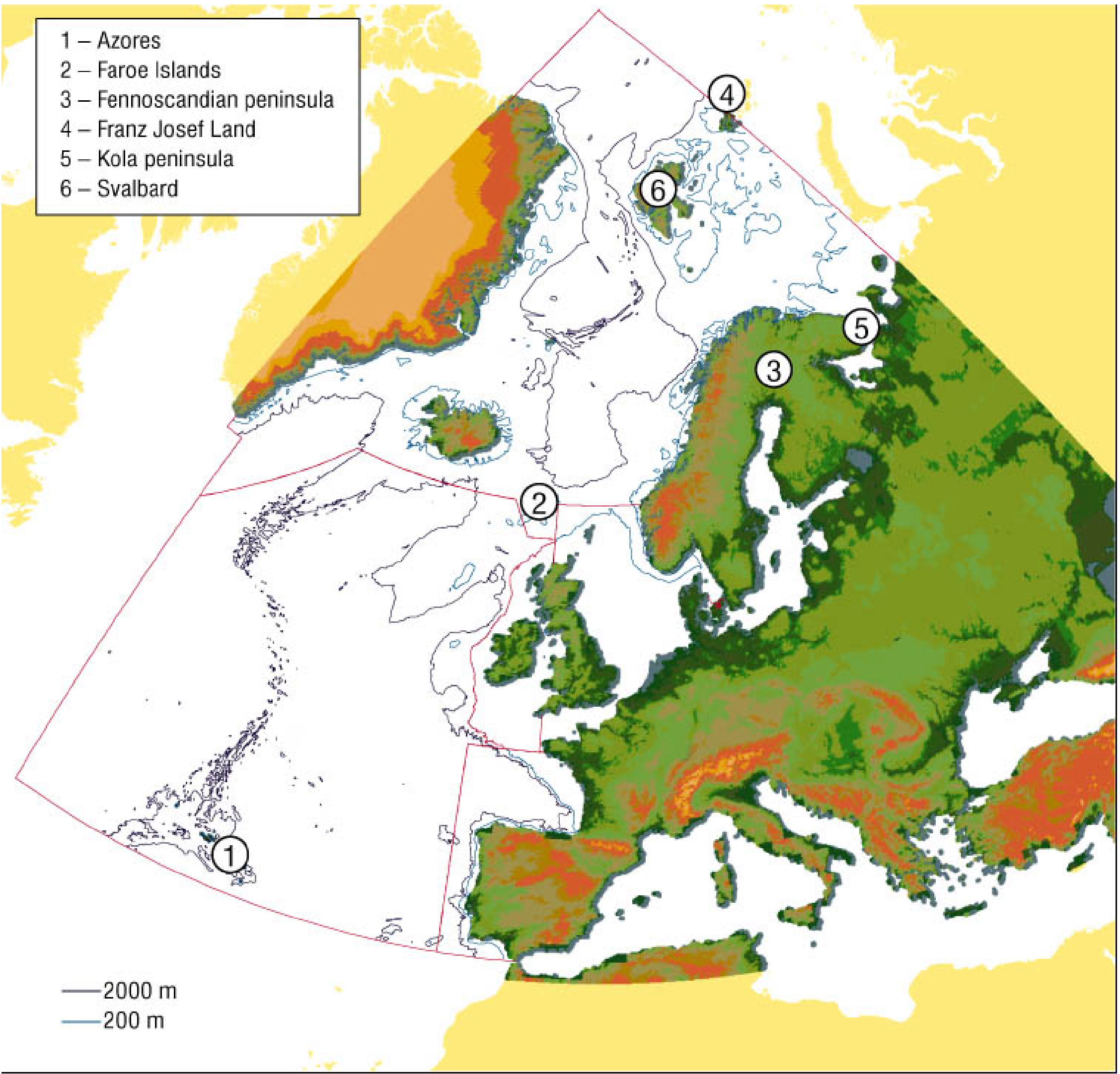


Figure 2 Compartments of OSPAR area

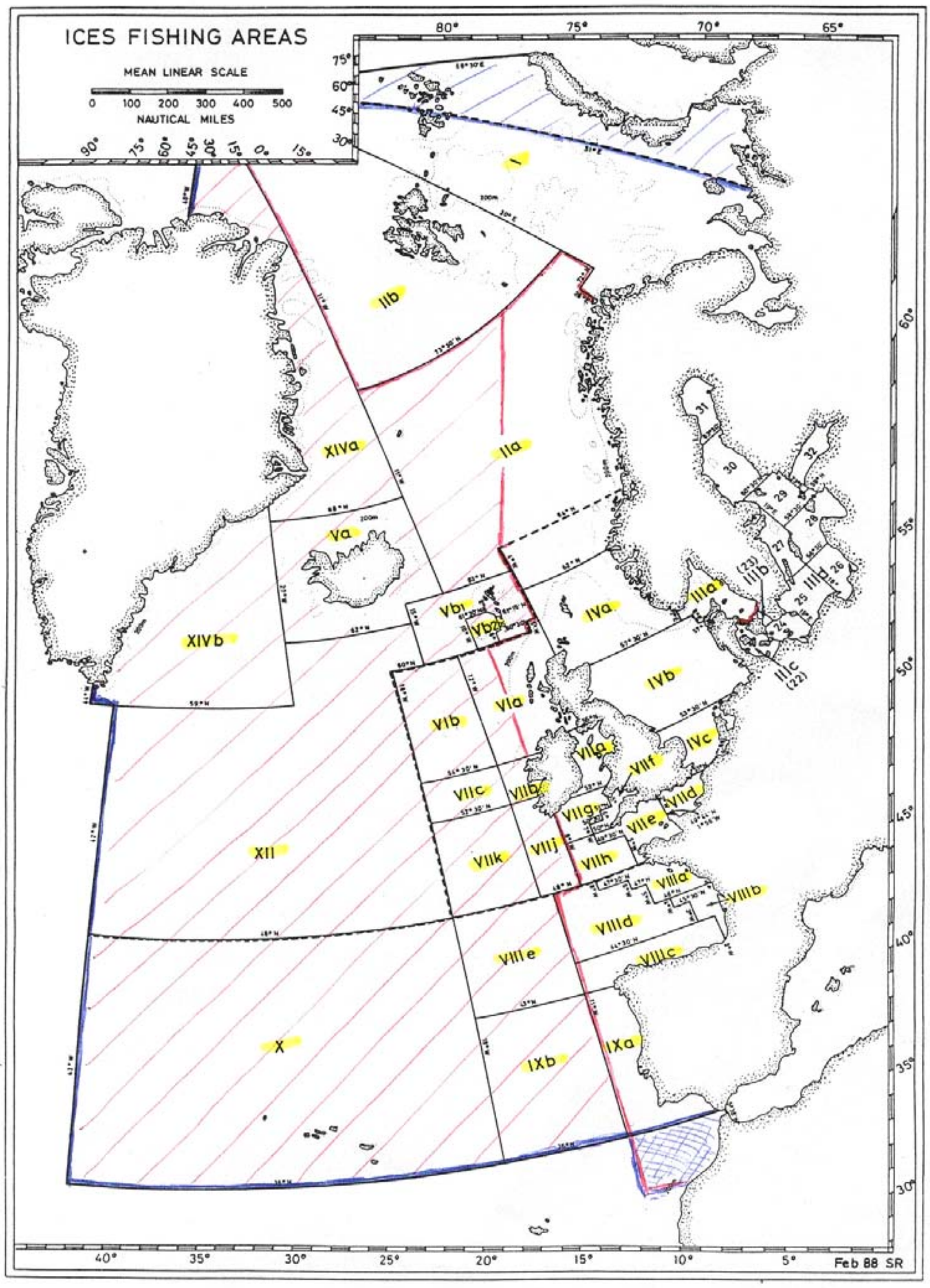


Figure 3 Total catch of marine fish in the Northeast Atlantic 1950-1999

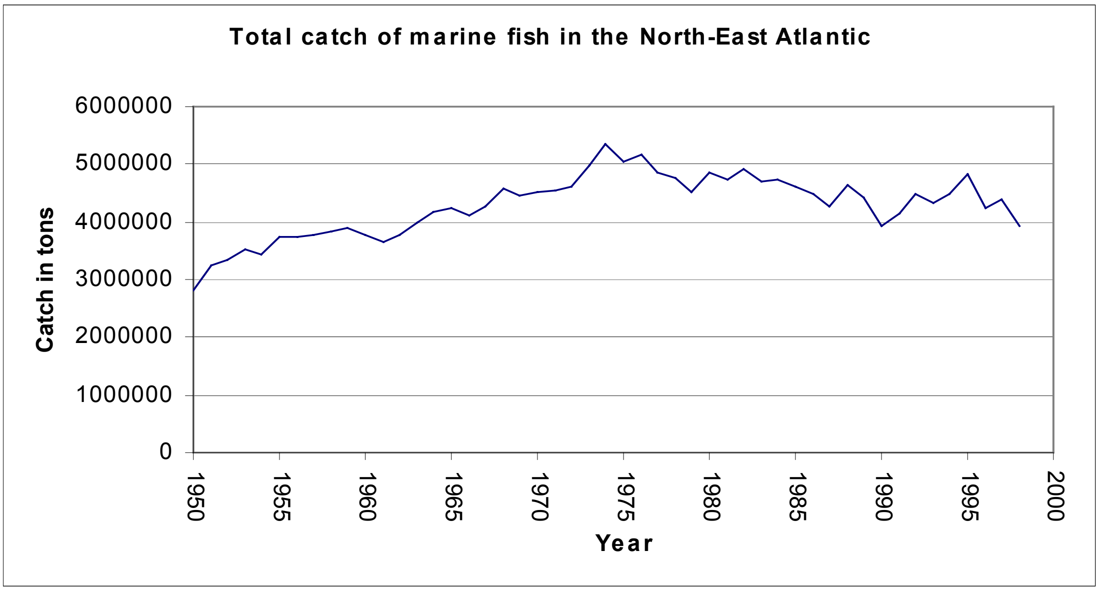


Figure 4 Total catch of crustaceans in the Northeast Atlantic 1950-1999

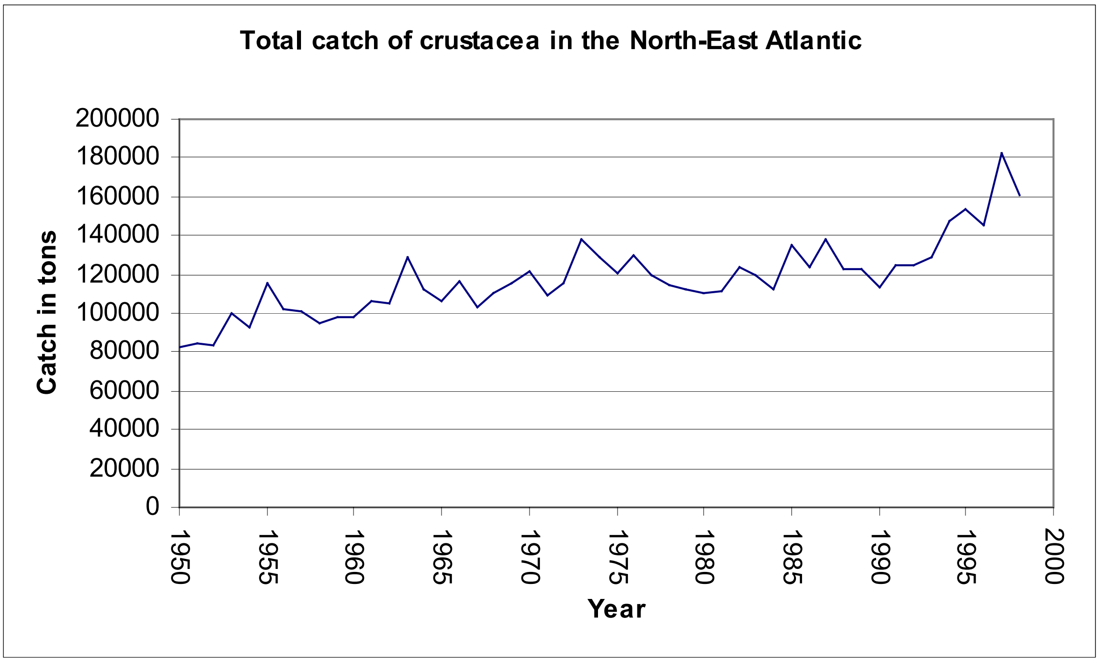


Figure 5 Total catch of molluscs in the Northeast Atlantic 1950-1999

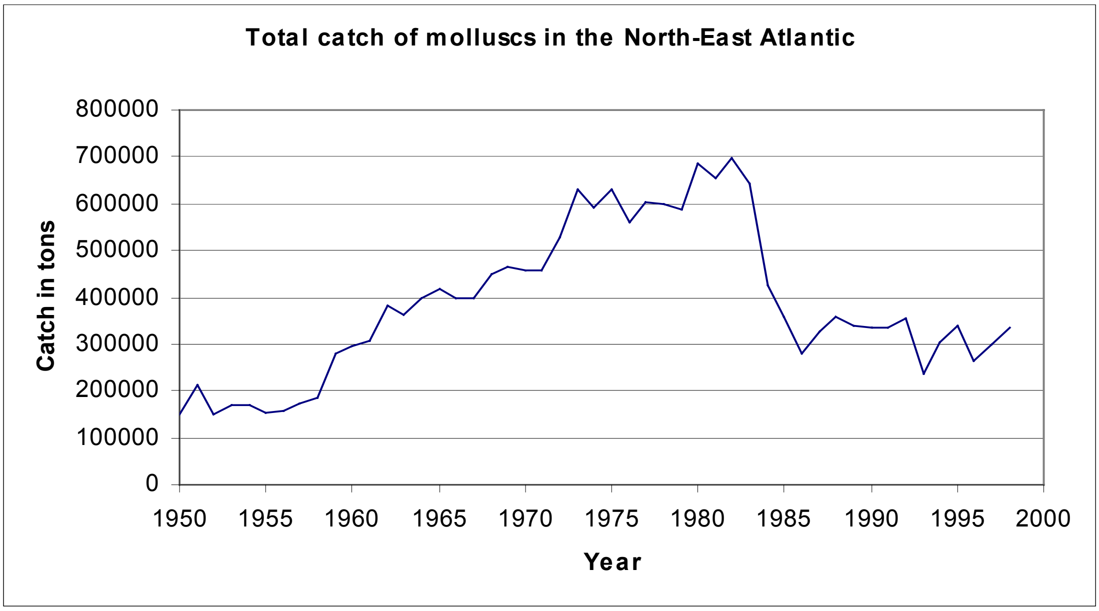
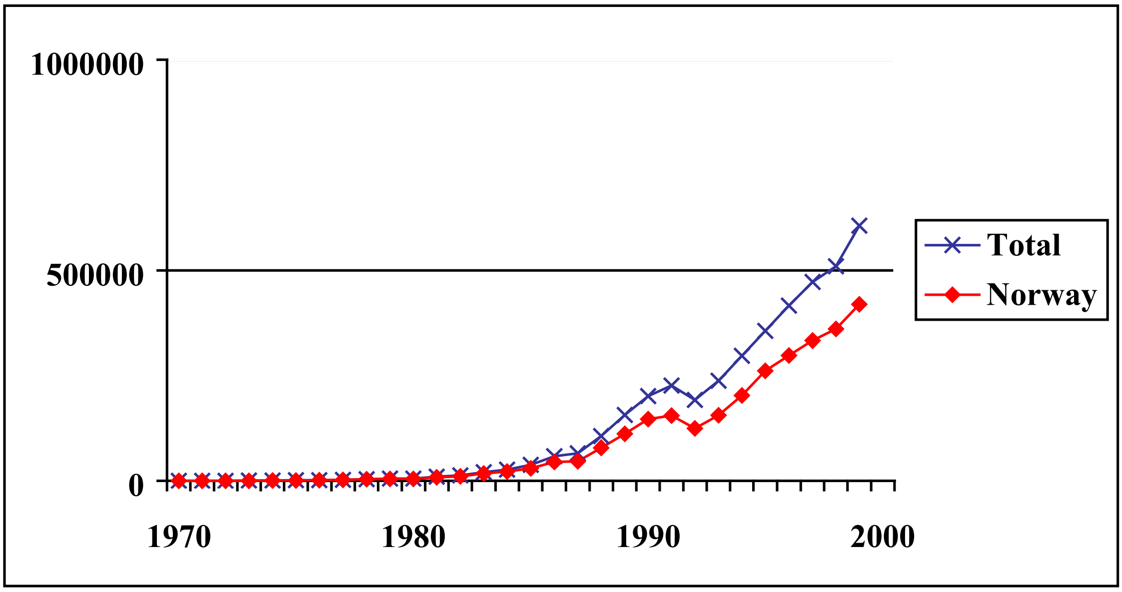


Figure 6 **Total marine farming of Atlantic salmon in the Northeast Atlantic 1970-1999**



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Annex D: Radiological Impact on EU Member States of Radioactivity in North European Waters

RADIOLOGICAL IMPACT ON EU MEMBER STATES OF RADIOACTIVITY IN NORTH EUROPEAN WATERS

Report of Working Group D

By

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Summary

The objective of this part of the MARINA II study was to assess the radiological impact to the population of the EU of radioactivity in North European waters. Collective doses were estimated for all sources of anthropogenic radionuclides in order to compare the radiological impact of these sources. Per caput dose is the collective dose divided by the exposed population and this was also estimated to give an indication of the average impact on individuals in each member state.

The sources considered were: routine liquid discharges from nuclear installations; discharges from the oil, gas, and phosphate industries that discharge Naturally Occurring Radioactive Materials (NORM); routine discharges from isotope production and use; discharges from the Baltic sea; routine discharges from military installations in the UK; the input from atmospheric testing of nuclear weapons; releases following the accident at the Chernobyl nuclear plant.

A compartmental model, MARINA II, was used to represent the dispersion of radionuclides in north European waters. This is an update of an earlier model and was verified by implementing the model at two different organisations and comparing the results. The activity concentrations estimated by the model were compared with measurement data to validate the model.

Collective dose rates and integrated collective doses were estimated for the EU as a whole and for individual member states together with per caput doses. The main results of the study are presented for the known sources and discharges up to 2000. Additional results are presented for comparative purposes assuming that discharges continue at 2000 rates up to 2020.

The peak collective dose rate of about 760 man Sv y^{-1} occurred in 1984 and by 2000 this had fallen to just under 220 man Sv y^{-1}. With no further input beyond 2000 the collective dose rate continues to fall and by 2500 is estimated to be about 0.95 man Sv y^{-1}. These values can be compared with a collective dose rate to the population of the European Union from naturally occurring radionuclides in the marine environment of 17 000 man Sv y^{-1} and a collective dose rate of 844 000 man Sv y^{-1} from all sources of natural background radiation.

Information on discharges from the NORM industries are only available from 1980 onwards and from 1981 on these discharges are the largest contributor to the collective dose rates. In 2000, NORM discharges are estimated to lead to over 90% of the collective dose rate.

The collective dose integrated to 2500 for known discharges to 2000 is estimated to be just under 20 000 man Sv. The NORM industries contribute about 67% of this integrated collective dose with discharges from the nuclear industry contributing about 26%. Fallout from the atmospheric testing of nuclear weapons contributes about 7% with all other sources making a negligible contribution.

If discharges are assumed to continue at 2000 levels until 2020 the collective dose rate in 2020 is estimated to be about 216 man Sv y^{-1} compared with about 85 man Sv y^{-1} for discharges to 2000 only. The integrated collective dose to 2500 increases from just under

20 000 man Sv to 25 500 man Sv if discharges at 2000 levels are assumed to continue until 2020.

The most important source of discharges for the NORM industries is from phosphate plants with discharges from the oil and gas industry becoming more important as discharges from these industries have increased and those from the phosphate industry have declined. The most important radionuclide for the NORM industries is polonium-210.

For the nuclear industries, the most important source of discharges is from fuel reprocessing sites, with the Sellafield nuclear site in the UK being the major contributor to the estimated doses. The collective dose rates from the nuclear industry alone reached a peak of about 280 man Sv y^{-1} in 1978 and since then have declined significantly to about 14 man Sv y^{-1} in 2000. In this case, the integrated collective dose is dominated by the early years of discharges and the effect of continuing discharges until 2020 is smaller than for discharges from the NORM industries.

A detailed comparison of the model results for activity concentrations with measured values gives confidence in the use of the models for the assessment of collective and per caput doses. However, the uncertainties associated with such an assessment should be recognised.

Uncertainties are greater for the assessment of doses from the NORM industries than for doses from the nuclear industries. Uncertainties are also greater for future doses than they are for current or past doses. For example, future changes in sea levels or water movements due to global warming and changes in the amount of seafood caught will all affect the dose estimation.

1 Introduction

The objective of MARINA II working group D was to carry out an assessment of the radiological impact to the population of the EU member states[*] of radioactivity in North European waters. This is part of the input to the Oslo and Paris (OSPAR) convention by the European Commission. There are two aspects to assessing the radiological impact of radiation discharges. Doses received by individuals and doses received by the population as a whole, referred to as collective dose. The doses received by the members of the public who are representative of those most exposed, the critical group, have been considered by Working Group B and are discussed in its report. The main aim of group D was to estimate collective doses[**] to the population of the European Union from all sources of anthropogenic radionuclides. However, per caput doses were also estimated to give an indication of the average impact on individuals in each member state, as the per caput dose is the collective dose divided by the exposed population. Collective doses are conventionally used as an input into the optimisation of protection (ICRP 1997). They can also be used to compare the radiological impact of particular practices and this is the main purpose of the estimation of collective doses in this study.

The study contained the following steps:

- The source term from working group A formed the basis of the assessment. This considers all significant sources of radionuclides in the OSPAR area.
- Discharges of radionuclides to rivers flowing into the OSPAR area were also considered with allowance made for the reduction in activity concentrations during the transport in the river.
- The effects of discharges from the start of operation of nuclear sites until 2000 were considered in the study. Radiation doses were estimated up to 2500 firstly resulting from discharges up to 2000 only and secondly assuming that discharges continued to 2020 at current (2000) rates.
- The compartmental model representing the dispersion of radionuclides in north European waters was further developed and implemented.
- The implementation of the revised model was verified by comparing the results of the model implemented independently at Centre d'études sur l'Evaluation de la Protection dans le domaine Nucléaire (CEPN) and the National Radiological Protection Board (NRPB).
- The activity concentrations estimated by the model were validated by comparing them with measurement data collated by Working Group B. The model also estimates activity concentrations in different media.
- Collective dose rates and integrated collective doses were estimated for the EU as a whole and for individual member states. Per caput doses were also estimated for each member state. An analysis of the results was carried out and a qualitative estimate of uncertainties made.

[*] The European Union is taken to comprise Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Portugal, Spain, Sweden, The United Kingdom. For the purposes of this assessment, Luxembourg has been grouped with Belgium.

[**] The word dose is used in this report to mean the effective dose and is the sum of the effective dose from intake of activity into the body in a year and the effective dose from external irradiation in that year. Collective dose is the total dose received by the exposed population.

The sources of radioactivity considered in the study were: routine liquid discharges from civil nuclear installations into northern European coastal waters (directly and via river systems); discharges from the oil, gas, and phosphate industries that discharge Naturally Occurring Radioactive Materials (NORM); routine discharges from isotope production and use; routine discharges from military sites in the UK; and discharges from the Baltic Sea. The input from atmospheric fallout from nuclear weapons testing and due to the Chernobyl reactor accident were also considered in the study. The data on the different sources were compiled by working group A and are described in its report.

This assessment builds on and replaces that published in the previous MARINA study (CEC, 1990). Mathematical models were used to predict the dispersion of radionuclides discharged into the marine environment and the resulting population exposure. These models are based on the MARIN1 system used previously (CEC, 1990) but have been developed to reflect knowledge gained since the original study was carried out. In particular, there is a more detailed description of marine dispersion in the Atlantic Ocean, the English Channel, the Irish Sea and the Barents Sea. The number of compartments representing the North European waters has been increased from 44 to 72. In addition, improvements have been made to the way the interaction of radionuclides between seawater and sediments is modelled. This is of increasing importance as discharges from nuclear sites have reduced significantly over the years and radionuclides that have previously been transferred to sediments are now a significant source of exposure. The revised model is called MARINA II. The modifications to the model and the differences in the predictions between MARIN1 and MARINA II are discussed in this report. Other aspects of the original MARINA study have also been updated, notably the information on catches and landings of marine foods in the region of interest. The differences between the results of the present study and those obtained previously are also discussed.

As part of the MARINA II study, working group D identified the appropriate methodology for use in the study and reviewed all of the necessary modelling parameters. The revised model was implemented by NRPB and CEPN and the results compared to verify the implementation. The model results have also been compared with activity concentrations measured in various marine media throughout the region of interest to validate the use of the model for assessing radiological impact. The main endpoint of the study is the collective dose rate as a function of time between the start of nuclear discharges and 2500, together with the integrated collective dose at the same times. The collective dose rate is also used to estimate per-caput doses per year for each of the EU Member States. There are uncertainties associated with any modelling system and these are discussed in a qualitative way in relation to MARINA II. The results of the study, particularly the validation, are used to identify deficiencies in the model and to make recommendations where future development would be useful.

2 Methodology

2.1 MARINA II

The model MARINA II was used to estimate the dispersion of radionuclides in northern European waters and hence activity concentrations in different aquatic media, such as fish and bed sediment. MARINA II is an updated version of the model, MARIN1 used in the previous MARINA study (CEC, 1990). It incorporates model developments carried out at NRPB, CEPN and the RISØ National Laboratory and also recent improvements in representing marine sedimentation processes (Lepicard and D'Ascenzo, 2000; Lepicard, 2001). Appendix A provides more detail on the MARINA II model.

The movement of water between various sea areas by processes of advection and diffusion is modelled by assuming instantaneous uniform mixing within each marine compartment with rates of annual transfer between adjacent compartments. The detailed structure of the model is shown in Figure 1 to Figure 4. Details of the compartment names are given in Table 1. The detail of the model compartments is greatest in Northern European waters; however the model includes transfer to and recycling from the rest of the World oceans. This is important for very long-lived radionuclides, such as carbon-14 and technetium-99, which remain in the water and potentially contribute to collective doses for long times.

The absorption of radionuclides by sediments can lead to a significant removal from water, due to both the partitioning between the liquid phase and suspended sediments, and the subsequent removal of the activity from the water column to bed sediments. This partitioning is described in the model using a distribution coefficient (K_d), defined as the ratio of the concentration of a radionuclide in dry sediment (in Bq t^{-1}) to its concentration in filtered water (Bq m^{-3}) at equilibrium. The movement of radionuclides within the seabed after being deposited from the overlying water and the return of radionuclides to the water phase is modelled using a multilayered bed structure as shown in Figure 5. This allows the various processes (molecular diffusion, porewater mixing, particle mixing and sediment turnover) to be taken into account. A distinction is made between deep and coastal waters in modelling the various processes due to factors such as the extent to which exchange with sediment occurs and the abundance of biota. Therefore, for coastal compartments, i.e. those with a depth less than or equal to 200m, different parameter values are used for diffusion, sediment re-working and porewater exchange as given in Appendix A. The sediment distribution coefficients used in this study are given in Table 2.

Dispersion of radionuclides in the immediate vicinity of a site is modelled in a similar manner to that undertaken in the original MARINA study (CEC, 1990). This approach consists of site-specific local marine compartments being derived from available data on sea depths in the proximity of the site; sedimentation rates; suspended sediment loads; the length of coastline in the local compartment and estimated exchange rates with the relevant regional marine compartment. In the absence of site specific data, generic local marine compartments were derived to represent estuarine, exposed and sheltered coastal environments. Details of the local compartment modelling parameters are given in Table 3 and Table 4.

The information available on discharges from the NORM industries is less detailed than that for the nuclear industries. Also for the oil and gas industries the discharges are diffuse with for example, several oil platforms operating in one area. It is, therefore, difficult to define the exact locations of the NORM discharges. For simplicity, discharges from the NORM industries were assumed to be directly into the relevant regional marine compartment and local compartments were not used.

Fallout from weapons testing and from the Chernobyl accident have been considered in this study. For these sources, estimates of the annual inputs to each regional marine compartment have been made using data provided by Working Group A. These inputs were then used within the MARINA II model to estimate the activity concentrations in each regional marine compartment.

The comparison of modelling output with environmental measurement data is of utmost importance to give confidence in the results of an environmental transport model. Validation for the MARINA II model has been carried out for several radionuclides of differing environmental behaviour in a range of environmental media over the available time series of data. The results of this validation are summarised in Section 4.1 and are presented in Appendix B. Data used for the validation of the model have been derived from separate sources to that used to develop the model wherever possible.

2.2 Rivers

A large number of the nuclear sites in the European Union are situated at inland locations with the liquid discharges of radionuclides being made to river systems. These river systems subsequently drain into northern European marine waters. Processes such as sedimentation, accumulation by biota and radioactive decay within the river result in a reduced inventory of activity draining from the river than that discharged upstream. These processes have been represented in modelling the total activity discharged to the marine environment from river discharges. Two major European rivers (Rhine and Loire) have been modelled to represent riverine discharges in the European Union. The Schaeffer (Schaeffer, 1976) modelling approach, as described in the EC methodology for routine radioactive discharges (Simmonds et al. 1995) and implemented in the compartmental biosphere transport model, BIOS (Martin et al. 1991), has been used. The two rivers were divided into several river sections for modelling purposes. The relevant inland sites were assumed to either discharge directly to the local marine compartment (in the case of estuarine sites) or to sections of the Rhine or Loire, which are assumed to represent the river into which the site actually discharges. The distance between discharge locations and the estuary were estimated. The river sections assumed for the modelling were the same as in a previous study (Smith et al. 2002). Modelling was carried out for all necessary radionuclides for a unit release of 1TBq for 1 year. The concentrations in the local marine compartment following discharge to the river were compared with those assuming the source is discharged directly into the local marine compartment. It should be noted that the local marine compartment is assumed to be the same for all rivers. The results were used to calculate a ratio between discharge to the river and discharge to a local marine compartment for each site. A similar approach was adopted for discharges to Lake Trawsfynydd in the UK, the activity concentrations in the local compartment were compared assuming discharge to Trawsfynydd lake and discharge to the local marine compartment. The calculated ratios were used to scale the river discharges (as provided by Working Group A) to estimate the input to the marine environment. The estimates of activity entering the marine environment from each discharging site are given in Appendix C.

2.3 Collective doses

Four exposure pathways are considered in the calculation of collective doses and collective dose rates in this study. These pathways are consumption of fish, crustaceans and molluscs; and external exposure from contaminated beach sediments. The MARINA II model estimates the activity concentrations and integrated activity concentrations in filtered seawater and bed sediment layers for each regional marine compartment and local compartment, if applicable. Activity concentrations in marine foodstuffs are then calculated using the filtered water activity concentration in the relevant marine compartment and an element-specific equilibrium concentration factor (as given in Table 2). Contaminated beach sediment activity concentrations are taken to be the same as the activity concentrations in the upper-most sediment layer in the relevant marine compartment.

Collective doses from consumption of seafood are calculated as the product of the activity concentration in the seafood, annual catch rate and dose coefficient for each radionuclide, summed over radionuclides and marine compartment. The catch rates used are the net amounts (in tonnes per year) of foodstuffs available for human consumption in each regional compartment (Working Group C report). The average catch data for the years 1994, 1996, and 1998 have been used for the calculations. These values include consideration of imports/exports, non-food use and the edible fractions of the foods. For local compartments, estimates of catches have been made by scaling by the ratio of the volume of the local compartment to the regional compartment for fish; the ratio of surface areas for crustaceans; and the ratio of coastline lengths for molluscs. For the purposes of the calculation, it has been assumed that the 1994-1998 rates apply throughout the period considered up until 2500. Although uncertain, this assumption is necessary to allow calculation of collective doses over long time periods.

Collective doses resulting from external exposure to contaminated beach sediments are estimated assuming the beach is a uniformly contaminated semi-infinite medium. The dose rates from such a medium can then be estimated (Hunt, 1984) and combined with an annual collective occupancy per unit length of coastline as identified in previous studies (Simmonds et al. 1995). The collective occupancy rates account for lower occupancies at higher latitudes. The assumption that the activity concentrations in beaches is the same as that in the top layer of bed sediment is likely to adequately represent observed activity concentration in silty intertidal sediments. However, activity concentrations in sandy beaches are likely to be overestimated by up to an order of magnitude (Simmonds et al. 1995) due to the coarser sediment grains. Therefore, the collective doses due to external exposure may be an overestimate. Each member state’s coastline may border one or more of the regional marine compartments in the MARINA II model. In such cases the relevant coastline lengths in each regional marine compartment have been used together with the collective occupancy rates described previously.

The collective doses and collective dose rates presented in this study have been calculated using the results of the MARINA II model with the described supporting data. Annual liquid discharges of radionuclides from each of the 88 sites or sources have been taken from the work of Working Group A. These data cover discharges from the start of operation of the sites until the end of 1999 or 2000. Two sets of calculations have been carried out. The first are collective doses and collective dose rates for discharges up to year 2000. In the case of data not being available for 2000, the discharges in 2000 were assumed to be the same as 1999. The second calculations are collective doses and collective dose rates assuming discharges continue until 2020 at 2000 discharge rates.

Collective doses and collective dose rates have been calculated for each year up to 2020 and then at appropriate intervals up to 2500. These results have been presented in graphical and tabular forms to allow identification of trends.

Additional calculations have been performed to estimate the individual doses received per head of population of each European Union member state. These individual doses are referred to as per caput doses.

3 Results

3.1 Overall Radiological impact

Results are presented for collective dose rates and collective doses integrated over time to the populations of EU member states from all anthropogenic sources of radioactivity in the north European waters. The main results are presented for the known sources and discharges up to 2000. Additional results are presented for comparative purposes assuming that discharges continue at 2000 rates up to 2020. Detailed results are provided for the major sources, i.e. discharges from the NORM industries and the civil nuclear power industry. In addition, results are presented showing which factors are the major contributors to the total impact of the discharges. These factors include the most important radionuclides; discharge sites and industries; and discharging and affected countries with detailed breakdown presented in Appendix D.

Figure 6 gives the collective dose rate from 1981 onwards for all sources based on known discharges up to 2000. There is no information available on discharges from the NORM industries before that time but information is available for the nuclear industry and this is presented separately. No account is taken of any discharges after 2000. The peak collective dose rate of about 760 man Sv y^{-1} occurred in 1984 and by 2000 this had fallen to just under 220 man Sv y^{-1}. With no further input beyond 2000 the collective dose rate continues to fall and by 2500 the collective dose rate was estimated to be about 0.95 man Sv y^{-1}; see Table 5. From 1981 onwards, discharges from the NORM industries are the largest contributor to the collective dose rates. The second largest contributor to the collective dose rates is discharges from the nuclear power industry. Figure 7 shows the contribution of the different sources to the total collective dose rate in 2000. Similar results are obtained for other times, although the contribution from the nuclear industry is bigger in the 1980s. The fallout from nuclear weapons testing makes a small contribution to the total collective dose rate at all times (3% in 2000) while the releases from the 1986 accident at the Chernobyl nuclear plant also contribute in 1986 and to a lesser extent in 1987 and 1988. The contributions from the other sources considered, isotope production, discharges from military sites in the UK and the flux of caesium-137 from the Baltic Sea, all make a negligible contribution to the total collective dose rate.

Collective doses integrated to various times have also been calculated and Table 6 gives the total collective dose integrated to 2000, 2020 and 2500 together with the integrated collective doses from the different sources. For 2020 and 2500, results are presented for the collective doses due to the known discharges up to 2000 only and for the collective doses assuming that discharges continue to 2020. In all cases the most important contribution to the total integrated collective dose is due to discharges from the NORM industries being 61% to 74% of the total integrated collective dose. The second most important source is discharges from the nuclear industry at 21% to 33% of the total. Other sources make a relatively small contribution with fallout from weapons testing contributing about 5%, the accident at Chernobyl about 0.3%, isotope production about 0.01%, discharges from UK military sites 0.000005% and the flux of caesium-137 from the Baltic about 0.05%.

From Table 6, it is seen that the majority of the integrated dose to 2500 is due to the known discharges up to 2000. If discharges continued to 2020 at 2000 rates this would increase the total integrated collective dose to 2500 by 29%. For the nuclear industries, continuing discharges to 2020 increases the integrated collective dose to 2500 by about 3%, while the NORM industries the increase is about 44%. Figure 8 shows the contribution of the major sources to the integrated collective dose to 2500 for known discharges up to 2000. Discharges from the NORM industries are the most important source (67%), followed by discharges from the nuclear industry (26%) and fallout from nuclear weapons testing (7%), other sources are negligible in comparison. Similar results are obtained if discharges are assumed to continue until 2020.

The collective dose rate as a function of time is shown in Figure 9 and Table 5 for known discharges to 2000 and assuming that discharges continue at 2000 levels until 2020. Between 2000 and 2020, the collective dose rate summed over all sources, assuming discharges continue, is a factor of 2 to 3 higher than the collective dose rate from the known discharges to 2000. Beyond 2020, the collective dose rates decline gradually in both cases and the difference between the estimated collective dose rates for the two cases is less than a factor of 2 in 2500.

3.2 The impact of discharges from the NORM industries

The collective dose rates due to discharges from different NORM industries are given in Figure 10 and Table 7 for 1980 onwards, for known discharges up to 2000. 1980 is the first year for which any information on discharges was available. The peak collective dose rate occurred in 1984 and was just over 600 man Sv y^{-1}. This collective dose was almost entirely due to discharges from the phosphate industry with the important sources being discharges into Cumbrian waters from the UK and into the North Sea from the Netherlands. The discharges from the phosphate industry, particularly in the UK, reduced in the 1990s and this is reflected in the collective dose rates. Figure 11 shows the relative contribution of the different sources to the collective dose rate from the NORM industries in 2000. The phosphate industry is still a major contributor to the collective dose rate with the Cumbrian Waters source contributing 19% of the total and the North Sea source contributing 40%. However, discharges from the oil and gas industry, which made a small contribution over much of the period from 1981 to 1999, have become relatively more important. In 2000, discharges from the oil and gas industry contribute about 39% to the total collective dose rate from the NORM industries with discharges into UK North Sea central (15%), Norway North Sea central (9%) and Norway North Sea N (5%) being the main sources. The collective dose rates beyond 2000 presented in Figure 10 are lower than those up to 2000 as there are no further discharges. The decline in collective dose rates with time after 2000 is relatively slow due to the ingrowth of polonium-210 from the earlier discharges of radium-226 and lead-210.

The estimated collective dose rates from the NORM industries are predominately from polonium-210 and are likely to be due to the ingestion of polonium-210 in seafood, although information on exposure pathways is not available. The polonium-210 arises from direct discharges of this radionuclide and also from ingrowth following discharges of radium-226 and lead-210. Figure 12 shows the contribution by different radionuclides to the collective dose rate for known discharges to 2000. The figure shows that doses from polonium-210 are the greatest contributor to the collective dose rates at all times. Figure 13 gives the contributions of the different radionuclides to the collective dose rate in 2000; the contribution of polonium-210 is 82% of the total with radium-228 giving 11%, radium-226 6% and lead-210 1%.

Collective dose rates have also been estimated assuming that discharges continue until 2020 at 2000 discharge rates. Figure 14 shows the estimated collective dose rates for the NORM industries. From 2000 to 2020, the collective dose rates increase even though the discharges are constant. This is due to the ingrowth of polonium-210 from radium-226 and lead-210. The different sources from the oil and gas industry are becoming more important relative to the dose from previous discharges from the phosphate industries.

3.3 The impact of discharges from the nuclear power industry

Figure 15 shows the estimated collective dose rates from 1952 onwards due to discharges from the nuclear power industry. The peak collective dose rate occurred in 1978 and was about 280 man Sv y^{-1} since then the collective dose rate has declined significantly reflecting reductions in discharges to sea from the major nuclear sites. In 2000, the collective dose rate from the nuclear sites is estimated to be about 14 man Sv y^{-1}. Without further discharges, the collective dose rates continue to decline to 0.11 man Sv y^{-1} in 2500. The major source is discharges from the Sellafield nuclear site in the UK which is the greatest contributor for all years except in 1987 and 1989 when discharges from the Cap de la Hague nuclear site in France led to a slightly higher collective dose rate than from Sellafield. These two sites both carry out nuclear fuel reprocessing and other operations and discharges from these sites make a far greater contribution to the collective dose rates than the discharges from all of the nuclear power stations added together. Figure 16 shows the contribution by nuclear operation to the estimated collective dose rate in 2000. The discharges from Sellafield lead to 72% of the total collective dose from nuclear sources, discharges from Cap de la Hague contribute 26% with only about 2% from nuclear power stations and other nuclear sites.

Discharges from nuclear sites contain many different radionuclides and the composition of the discharges from the major nuclear sites has changed with time. This is reflected in the pattern of the contribution of different radionuclides to the collective dose rates as a function of time as shown in Figure 17. Between 1950 and 1976, ruthenium-106 was the most important radionuclide but with an increasing contribution from caesium-137, which became the most important radionuclide. Also of importance are plutonium-239+240, plutonium-241 and caesium-134. Figure 18 shows the relative importance of different radionuclides to the collective dose rate in 2000 due to discharges from the nuclear industry. Here, carbon-14 makes the largest contribution (32%), followed by plutonium-239 (21%) and caesium-137 (18%). Other radionuclides, including technetium-99 at 3%, make a smaller contribution than these three radionuclides. Different contributions by radionuclide are found for the integrated collective dose from the nuclear industry as seen in Figure 19. As shown in Table 8, the integrated collective dose from nuclear discharges is mainly from discharges before 2000. The important radionuclides for the integrated collective dose are therefore, ruthenium-106 and caesium-137, reflecting their importance between 1950 and the early 1990s (see Figure 17).

Collective doses have also been estimated assuming that discharges continue at 2000 rates until 2020. Figure 20 shows the collective dose rates as a function of time for this case. The collective dose rates continue at about 2000 levels (14 man Sv y^{-1}) until after the discharges are assumed to stop in 2020. However, due to the contribution from pre 2000 discharges declining, the collective dose rate has fallen slightly to about 11 man Sv y^{-1} in 2020. By 2500, the collective dose rate from nuclear discharges has reduced to 0.11 man Sv y^{-1} and is only slightly higher than that due to the discharges up to 2000 only (see Table 5).

3.4 The impact of discharges on individual member states

Table 9 presents collective dose rates to the individual member states of the European Union for selected times resulting from the known discharges to 2000 and assuming discharges continue to 2020. Full results for all times are presented in Appendix D. The collective dose rate in 2007 for known discharges up to 2000 is apportioned as follows: United Kingdom 25%, Germany 17%, France 14%, Denmark 10%, Netherlands 9%, Spain 7%, Belgium 5%, Italy 4.5%, Ireland and Sweden both 2.7%, Portugal 2%, Austria, Finland and Greece all below 1%. The proportion of the collective dose rate received by member states varies relatively little over the times considered. The effect of discharges continuing to 2000 or to 2020 also results in little change to the proportion of the collective dose rate received by the member states. Appendix D also gives information on the collective dose rate for the discharges from each country. In 2000, about 41% of the collective dose rate is due to discharges from UK sources, including the phosphate and oil and gas industries, about 36% from sources in the Netherlands, about 13% from sources in Norwegian waters, 4% from sources in Denmark and about 3% from discharges from France.

Table 10 shows the doses received per head of population (per caput) in the individual member states of the European Union. These per caput doses are calculated by taking the estimated collective dose rate received by each country and dividing by the population. They are based on the net seafood catches, i.e. the seafood caught by the country minus the seafood exported. Where both of these numbers are large, for example for Denmark, the difference may not be a true representation of the actual intake in the country. In 1987, the highest per caput dose rate was about 11 microsieverts per year received by the population of Denmark. The lowest dose rate of 0.16 microsieverts per year was received by individuals in Greece. The highest per caput dose rate over all selected times is received by individuals in Denmark. In 2007, the effects of assuming discharges continue at 2000 levels to 2020 result in a per caput dose rate to Denmark of 4.25 microsieverts per year to compared 2.2 microsieverts per year for known discharges to 2000.

3.5 Discussion of results

The results presented here show that the largest contribution to the estimated collective doses is due to the ingestion of polonium-210 in seafood. However, there are a number of uncertainties associated with this estimate. Firstly, the discharges of natural radionuclides from the NORM industries are less well known than the discharges from the nuclear industry. In addition, the transfer of polonium-210 in the marine environment is subject to uncertainty due to the presence of naturally occurring polonium-210 and the comparatively few measurements available for this radionuclide. Finally, an experimental study (Hunt and Allington 1993) has shown that the dose coefficient for the ingestion of polonium-210 in crabmeat may be higher than the value used here as the gut uptake factor was found to be 0.8 rather than the default value of 0.5. A limited sensitivity analysis has been carried out to determine the effect of changing two parameter values on the results. In the original MARINA study, a value of 2000 Bq t^{-1} per Bq m^{-3} was used (IAEA, 1985) for the concentration factor for polonium-210 in fish. Based on more recent data this was increased to 20 000 Bq t^{-1} per Bq m^{-3} (Swift and Kershaw, 1999) in the current study. However, large variations are observed in the levels of polonium-210 measured in fish indicating that the concentration factor is also variable (Young et al. 2002). The collective doses for polonium-210 were re-estimated using a concentration factor of 2000 Bq t^{-1} per Bq m^{-3} and it was found that the collective dose rates were reduced by about a factor of 3. This meant that the peak collective dose rate in 1985 fell from about 600 man Sv y^{-1} to about 200 man Sv y^{-1}. A similar effect would be seen for the total collective dose rate from all radionuclides and sources given the importance of polonium-210. Conversely, changing the dose coefficient for the ingestion of polonium-210 from 1.20 10^{-6} Sv per Bq (ICRP, 1996) to 1.92 10^{-6} Sv per Bq (ICRP, 1994) based on the gut transfer factor of 0.8 for crabmeat increases the collective dose rate for polonium-210 by about a factor of 1.5. For example, the peak collective dose rate in 1985 increased from about 600 man Sv y^{-1} to about 930 man Sv y^{-1}. These limited results illustrate the uncertainty associated with the estimated doses due to polonium-210. However, even using a lower concentration factor for polonium-210 in fish NORM sources would still give the highest collective doses with the contribution from polonium-210 still being greater than that from other radionuclides.

In assessing the radiation doses from radionuclides in seafood, no account is taken of the radioactive decay that could occur between the harvesting of the seafood and its eventual consumption. A substantial proportion of fish and crustacea are frozen and can be stored for lengthy periods before consumption. This will not affect the concentrations and hence intakes of long lived radionuclides such as caesium-137 (half-life 30 y) or plutonium-239 (half-life 24 100 y) but it could reduce the activity concentrations of shorter lived radionuclides such as polonium-210 (half-life 138 d). However, the effects of not including radioactive decay between harvesting and consumption are probably small compared with the overall uncertainties associated with the results.

The relative importance of different radionuclides to the collective doses does not necessarily reflect the relative discharges of the radionuclides as presented in the Working Group A report. The radiation doses from the discharge of a particular radionuclide depends on a number of factors including their behaviour in the marine environment and their physical and chemical properties. From Table 2, it is seen that different elements have widely different parameter values. For example, the concentration factor between water and fish varies from 1 Bq t^{-1} per Bq m^{-3} for hydrogen to 20 000 Bq t^{-1} per Bq m^{-3} for carbon, phosphorous and polonium. Also of importance is the dose coefficient for ingestion, which can vary widely depending on the radionuclide (ICRP, 1996). Technetium-99 is a relatively weak beta emitter and for adults the dose coefficient for ingestion is 6.4 10^{-10} Sv Bq^{-1}. Caesium-137 is also a beta emitter but has a gamma emitting decay product and for adults the dose coefficient for ingestion is 1.3 10^{-8} Sv Bq^{-1}, a factor of 20 higher than for technetium-99. Polonium-210 and plutonium-239 are both alpha emitters and so have higher dose coefficients than caesium-137 but for intake by ingestion polonium-210 has a higher gut transfer factor of 0.5 than plutonium-239 for which a value of 0.0005 is used. This and other differences in their properties mean that the dose coefficient for ingestion of polonium-210 by adults is 1.2 10^{-6} Sv Bq^{-1} while that for plutonium-239 is 2.5 10^{-7} Sv Bq^{-1} (ICRP, 1996).

As discussed in Section 2.3, four exposure pathways were considered in estimating the radiation doses in this study. Information is not directly available on the relative importance of these exposure pathways but it is possible to obtain some idea from the information available on the relative importance of different radionuclides and knowledge of the important exposure pathways for those radionuclides. Polonium-210 is the most important contributor to the estimated doses and for this radionuclide, ingestion of seafood will be the most important route of exposure. For nuclear discharges, important radionuclides are ruthenium-106 and caesium-137 and for both of these the main route of exposure will again be the ingestion of seafood but there will also be a smaller contribution from external irradiation during time spent on the shoreline. Overall, ingestion of seafood is the most important source of the estimated collective and per caput doses and it is likely that all three groups of foods considered, fish, crustacea and molluscs, will all be important. External irradiation from radionuclides in sediment is likely to be a less important but a not negligible contributor to the overall dose.

Collective dose rates and integrated collective doses are presented in this report to compare the radiological impact of different anthropogenic sources of radioactivity in North European marine waters. Naturally occurring radionuclides in the marine environment also give rise to radiation doses. Appendix E gives an estimate of the collective dose rate from naturally occurring radionuclides in the marine environment. As discussed, the estimate is based mainly on measurements and these are sometimes variable. The collective dose rate due to naturally occurring radionuclides in the marine environment has been estimated to be 17 000 man Sv y^{-1} for the population of the European Union. It is also possible to estimate the collective dose rate to the population of the European Union from all sources of natural background radiation. Based on UK data (Hughes, 1999), the collective dose rate is 844 000 man Sv y^{-1}. Figure 21 compares the collective dose rates from anthropogenic sources estimated in this study with these estimated collective dose rates from natural radioactivity. The peak collective dose rate of about 760 man Sv y^{-1} is around a factor of 20 less than the annual collective dose from natural radioactivity in the marine environment.

It is of interest to compare the results of this study with those from other studies looking at the radiological impact of releases to the marine environment. A recent study for the European Commission (EC) by Smith et al 2002 assessed the radiological impact on the population of the European Union from European Union nuclear sites between 1987 and 1996. This study included liquid discharges to sea and the methodology was broadly the same as used here. However, the model for the dispersion in the marine environment was that from PC-CREAM and not the updated MARINA II model. The results of the two studies are not directly comparable as MARINA II is estimating collective dose rates and integrated collective doses from all discharges while the other EC study estimated integrated collective dose to 500 years from a single year’s discharge. However, the two studies did reach the same conclusions about the relative importance of different sources of radionuclides from the nuclear industry and the results are broadly compatible. The results from MARINA II can also be compared with those from the earlier MARINA study (CEC, 1990), although this did not consider discharges from the NORM industries. For discharges from the nuclear industry only, the first MARINA study estimated a peak collective dose rate from 1976 to 1978 of 310 man Sv y^{-1}. This study estimates a peak collective dose rate from nuclear sites of 280 man Sv y^{-1}, which is of the same order although the time distribution is slightly different. There have been a number of changes made in the models and data used between the two studies and it is difficult to determine the effects of each of the changes. Of particular importance are changes in the seafood catch data, changes in the dose coefficients for ingestion, changes in the model for dispersion of radionuclides in North European waters and changes in the concentration factors used to estimate the transfer of radionuclides to seafood. The first MARINA study also found ruthenium-106 and caesium-137 to be important contributors to the collective doses with Sellafield and Cap de la Hague being the major sources. The similarity of the two sets of results gives confidence in the results of this study.

4 Model Validation and Uncertainties

4.1 Model validation

Any modelling system can only be an approximation to the actual situation that is being modelled. It is therefore important to determine the validity of the model by comparing the predictions with measured activity concentrations in the environment being modelled. This process also helps to identify and to some extent, quantify the uncertainties associated with the application of the model. As part of the current study, an extensive validation of the model, MARINA II, has been carried out. This has made use of the large body of measurement data identified and collected by Working Group B. Two main types of validation were carried out. Firstly, for selected specific locations, radionuclides and media, measured activity concentrations were compared with those predicted by the model for the same situation. This was done for all times for which data were available. Secondly, for specific times, measured activity concentrations from a range of locations for a particular radionuclide and media were compared with the model predictions. The first type of comparison enables the way the model includes variations with time to be determined, while the second type enables the way the model deals with spatial variations to be assessed.

In carrying out the validation calculations with MARINA II, it is important to include all sources of activity. Although discharges from the Sellafield nuclear site may be the major source of activity in water, fish etc. close to the site, this is not the case further way. Account has to be taken of activity from fallout from nuclear weapons tests and from the accident at the Chernobyl nuclear plant as well as other relevant discharges from nuclear sites. Appendix B - Validation of MARINA II gives details of the full range of validation studies carried out with MARINA II; some key features are given here. In the validation, particular attention has been focused on a few key radionuclides. This partly reflects the amount of measurement data available and partly the properties of the radionuclide. The most important radionuclides for validation studies are technetium-99, caesium-137 and plutonium-239/240.

Caesium-137 has been widely studied for many years, it is also of radiological importance and its behaviour in the marine environment makes it useful for validation purposes. However, it is important to take account of fallout from weapons testing and Chernobyl when considering this radionuclide and this can limit the knowledge gained. Plutonium-239 is another important radionuclide and as it interacts with sediment to a relatively great extent it is important to include results for this radionuclide in validation studies. However, as for caesium-137, it is found in fallout from weapons testing which can have a significant influence on the validation results. When measurements are made of plutonium-239 they include plutonium-240. This is also the case for the modelled concentrations based on discharges. Therefore, where plutonium-239 is referred to in this report it should be taken to mean plutonium-239 plus plutonium-240. Also of interest for validation purposes is technetium-99, not for its radiological significance, which is relatively low, but because it is not found in significant quantities in fallout from weapons testing and is only discharged from a limited number of sites. Technetium-99 interacts with sediment to only a very limited extent and so a comparison of measured and estimated activity concentrations gives a good indication of how well water flows are modelled.

Figure 22 shows some of the results obtained for technetium-99 in seawater. The figure shows ratios of measured to estimated activity concentrations averaged between 1990 and 2000, for a number of different marine water compartments. The solid central diagonal line indicates perfect agreement between estimated and measured concentrations. Values above the central line indicate that the model results are higher than measurements while values below the line indicate that the model estimates are lower than the measured values. Also shown on the figure are dotted lines representing ratios of a factor of two and a factor of ten. For technetium-99 in filtered seawater, the estimated to measured ratios are all within an order of magnitude and most are within a factor of two. The model estimates are both higher and lower than the measured values. Further results for technetium-99 are given in Appendix B. The ratios of estimated and measured activity concentrations show a greater spread for seaweed than for seawater. This may be because the uptake of technetium-99 into seaweed depends on environmental factors such as water temperature and salinity (Aarkrog, 1985) or because the measurements are not representative of the situation being modelled. Results are also presented in Appendix B for the North Sea south west compartment. These show that most of the activity concentrations estimated by the model are within the range of measurements except where only limited measurements results were available at a time of increasing discharges from the Sellafield nuclear site. Discharges from Sellafield are generally the major source of technetium-99 in seawater in this and other compartments. However, in the mid to late 1980s discharges from Cap de la Hague made a greater contribution to the concentration of technetium-99 in seawater in the North Sea south west compartment. These results for technetium-99 give confidence in the way MARINA II models water movements.

There are good measurement data for caesium-137 over long time periods. A number of comparisons have, therefore, been made between estimated and measured activity concentrations of caesium-137 in various media and full details are given in Appendix B. Figure 23 compares estimated and measured activity concentrations in fish for a number of compartments; the results are averages for the period 1990 to 2000. Similar results are given in Appendix B for seawater. The ratios of estimated to measured activity concentrations for fish are all within a factor of four and show better agreement than the results for seawater, although many of the seawater results are within a factor of three. The good agreement for fish is encouraging as the intake of caesium-137 in fish is important in determining collective and per-caput doses resulting from nuclear discharges. Results for particular locations are given in Appendix B and show that the activity concentrations predicted by the model are within the range of measured data. Even at locations distant from the Sellafield nuclear site, the discharges from Sellafield are an important contributor to the concentration of caesium-137 in aquatic media. Between 1952 and 1967, fallout from weapons testing was important and the release from Chernobyl in 1986 was also relatively important for 1986 only.

Plutonium-239 is also of interest for model validation because it readily interacts with sediment and again there are many measurement data available over a relatively long time period. Figure 24 gives the ratios of estimated and measured concentrations of plutonium-239 in filtered seawater for a range of marine compartments. The ratios of estimated to measured concentrations are within a factor of two for most compartments with model estimates both higher and lower than measured values. Results are also presented for fish, molluscs and sediment, although fewer data are available than for filtered seawater. In most cases the model estimates are within an order of magnitude of the measured value although there are exceptions. For compartments away from the Sellafield nuclear site, e.g. the Norwegian Sea compartment, fallout from nuclear weapons testing is the most important contribution to the concentrations of plutonium-239 found in the marine environment. Plutonium is less mobile in seawater than caesium and technetium and therefore most of the activity discharged from nuclear sites remains in the area close to the discharge point.

4.2 Implications of the validation results and uncertainties

The process of model validation is to some extent subjective, especially for marine models covering large areas and time periods of 10s of years. The marine model represents complex processes in a relatively simple way and averages over space and time. The measurements against which the model results are judged also have limitations. Samples are taken at a specific location at a specific time. Implicit in using the data assembled for validation is that conditions at sea have not changed significantly between the ship taking the first and last samples and that the concentration measured at a specific point is representative of the concentration in the surrounding area. Short-term fluctuations in the amount of a radionuclide released into the sea together with the effects of changing tidal conditions may mean that a measurement from a particular location and time is not representative of the annual average it is assumed to represent. Measurements of activity concentrations in seawater are usually for unfiltered seawater and so include suspended sediment. The model estimates are made for seawater and suspended sediment separately and so should be compared with measurements for filtered seawater. It is not always clear whether this is the case and differences between filtered and unfiltered seawater can be large for radionuclides such as plutonium-239, which transfer to sediment. There are also intrinsic errors associated with any measurement depending on the sampling and analytical methods used. The question to be answered by the validation is, is the model adequate for its intended application? In this case we are interested in radiation doses received over periods of between a year and 500 years and which are delivered from seafood caught over wide areas. The validation results presented here show that the models give a good but not perfect representation of the main processes which disperse radionuclides released into the sea. They give confidence in the use of the model to estimate collective and per-caput doses for use in the MARINA II study.

The following points have emerged from the dose assessment and validation studies regarding the uncertainty associated with the MARINA II model.

- The uncertainties in key model parameters, such as K_d values, flows between different marine areas, transfers to marine foods etc. all contribute to the overall uncertainty in the results of the study. Any uncertainties in the source term will also be reflected in the uncertainty of the estimated doses and activity concentrations.

- Model estimates are both higher and lower than measured values. When estimating collective and per-caput doses, activity concentrations from many locations are used and the resulting doses summed. This means that the uncertainty in the estimated doses is lower than that in the activity concentrations at a specific location.

- The differences observed between measured and estimated activity concentrations reflect the variation observed in measurements taken at different times, at different locations within the same area and for different species.

- Uncertainties are greater for some radionuclides and media than for others depending on the extent to which they have been studied. For example, caesium-137 and plutonium-239 have been comparatively well studied and there is greater confidence in the results for these radionuclides than for less well-studied radionuclides, such as carbon-14, polonium-210 and cobalt-60. Fortunately for nuclear discharges, the radionuclides which have been relatively well studied are also those which have been of the most radiological significance in terms of their contribution to dose.

- There are also uncertainties in the seafood catch data and how much is actually consumed in each EU member state. The total EU collective dose is likely to be less uncertain than that for individual countries. This also affects the estimated per caput doses which are more uncertain than the total collective doses. The seafood catch data were derived from data for 1994, 1996 and 1998 and have been shown to be reasonably consistent with catch data for the earlier years considered in the study. However, their use beyond 2000 must be regarded as increasingly uncertain with amounts, types and sources of seafood catches all likely to change.

- The uncertainties in the estimated doses for the NORM discharges are greater than those for discharges from the nuclear industry. This reflects both greater uncertainties in the knowledge of the source term for NORM discharges and the limited data on levels and behaviour of the important radionuclides (such as polonium-210 and radium-226) in the marine environment. In addition the model has been developed primarily for considering discharges from the nuclear industry. The model is therefore more detailed in the regions where nuclear discharges occur, e.g. the Irish Sea and the English Channel, and is less detailed in other regions where NORM discharges may occur.

- The collective doses due to external irradiation from radionuclides in sediment are more uncertain than those resulting from the ingestion of seafood. The estimation relies on estimates of coastline lengths and knowledge of the collective occupancy of the coast, which are based on limited data on people's habits. However, this is likely to be a relatively unimportant pathway for estimating collective and per caput doses given the radionuclides found to be the greatest contributors to the dose.

- The model has only been validated for part of the period under consideration and estimated future doses will be more uncertain than current or past doses. The previous model, MARIN1, was considered valid in 1986 but was later found to underestimate activity concentrations when the remobilisation of radionuclides from sediments became increasingly important. Future changes in sea levels, water movements, the amount of seafood caught will all affect the dose estimation.

The results of this study are considered to be robust, at least at present and in the past. The validation studies show that for the major radionuclides the estimated activity concentrations are usually within a factor of 10 of the measured values and are often within a factor of 3. The estimated collective doses are thought to be within a factor of 5 of actual values although uncertainties are a lot greater than this beyond the immediate future. Changes in climate in the future could affect sea levels and water flows, which could have a significant effect on activity concentrations and hence doses. An increasingly important factor for some radionuclides is the remobilisation of radionuclides from sediments. It appears that this is currently represented adequately in the model but that may change. For the model to remain adequate in the future, further work may be required to reflect changes in the marine environment or in the location and nature of future discharges. The results presented above show the importance of programmes of work to measure activity concentrations in a range of aquatic media for important radionuclides. Such programmes must be maintained to provide confidence in future studies of the radiological impact of radioactivity in North European waters.

The assessment for discharges from the NORM industries is considered to be more uncertain than that for the nuclear industry discharges. The discharges of naturally occurring radionuclides in the produced water from the oil and gas industries are not currently regulated and hence discharges are not reported and have to be estimated. Reporting these and all other NORM discharges would improve the accuracy of the assessment. Better data on the amount of time people spend on the shoreline would be valuable to improve the accuracy of the study. Trends in seafood catch data and people's intakes should also be kept under review, as should the adequacy of the model predictions to ensure that they remain robust.

5 Conclusions

The following conclusions can be drawn from this study:

- Collective dose rates to the population of the European Union from anthropogenic sources of radioactivity in North European waters have reduced from a peak of about 760 man Sv y^{-1} in 1984 to just under 220 man Sv y^{-1} in 2000.

- These values can be compared with an annual collective dose to the population of the European Union from natural radionuclides in the marine environment of 17 000 man Sv and an annual collective dose of 844 000 man Sv from all sources of natural background radiation.

- The integrated collective dose to 2500 to the population of the European Union from the known discharges to 2000 is estimated to be 19 700 man Sv. This would increase to 25 500 man Sv if discharges continue to 2020 at 2000 rates.

- For discharges from the nuclear industry, most of the integrated collective dose is from discharges before 2000. If discharges continue to 2020 at 2000 rates this will only increase the integrated collective dose from about 5110 to about 5250 man Sv, within the uncertainty in the result.

- The biggest contributor to the collective doses is discharges from the NORM industries, particularly the phosphate industry. As discharges from the phosphate industry into North European waters have fallen, discharges of radionuclides with produced water from the oil and gas industry have become more important.

- Polonium-210 is the most important radionuclide in determining radiation doses. It is discharged directly from the NORM industries and is also a decay product of discharges of radium-226 and lead-210. The estimate of radiation dose for this radionuclide must be regarded as particularly uncertain.

- A detailed comparison of the model results of activity concentrations with measured values gives confidence in the use of the models for assessing collective doses. However, the uncertainties associated with such assessment should be recognised.

- Uncertainties are greater for future doses than they are for current or past doses. For example, future changes in sea levels, water movements and the amount of seafood caught will all effect the dose estimation.

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Table 1 MARINA II regional marine compartments

Compartment Number	Compartment Name
1	Other Oceans
2	Atlantic North N.E. (surface 0-1000m)
3	Atlantic North N.E. (middle 1000-2000m)
4	Atlantic North N.E. (bottom 2000-4000m)
5	Atlantic North N.W. (surface 0-1000m)
6	Atlantic North N.W. (middle 1000-2000m)
7	Atlantic North N.W. (bottom 2000-4000m)
8	Atlantic North S.E. (surface 0-1000m)
9	Atlantic North S.E. (middle 1000-2000m)
10	Atlantic North S.E. (bottom 2000-4000m)
11	Atlantic North S.W. (surface 0-1000m)
12	Atlantic North S.W. (middle 1000-2000m)
13	Atlantic North S.W. (bottom 2000-4000m)
14	Atlantic S. (surface 0-1000m)
15	Atlantic S. (bottom 1000-3000m)
16	Arctic Ocean
17	Arctic S. (surface 0-1000m)
18	Arctic S. (bottom 1000-3000m)
19	Spitzbergen
20	Kara Sea West (K1)
21	Kara Sea Novaya Zemlya Trough (K1a)
22	Kara Sea East (K2)
23	Barents Sea (B1)
24	Barents Sea (B2)
25	Barents Sea (B3)
26	Barents Sea (B4)
27	Norwegian Waters
28	Scottish Waters W.
29	Scottish Waters E.
30	Irish Sea N.W.
31	Irish Sea N.
32	Irish Sea N.E.
33	Irish Sea W.
34	Irish Sea S.E.
35	Cumbrian Waters
36	Irish Sea S.

Compartment Number	Compartment Name
37	Liverpool and Morecambe Bays
38	Celtic Sea
39	Bristol Channel
40	Bay of Biscay
41	French Continental Shelf
42	Cantabrian Sea
43	Portuguese Continental Shelf
44	Gulf of Cadiz
45	Mediterranean Sea
46	English Channel W.
47	Channel Islands
48	Cap de la Hague
49	Lyme Bay
50	Baie de la Seine
51	Sam's Beach
52	Central Channel S.E.
53	Central Channel N.E.
54	Isle of Wight
55	North Sea S.W.
56	North Sea S.E.
57	North Sea Central
58	North Sea E.
59	North Sea N.
60	Skagerrak
61	Kattegat (surface 0-20m)
62	Kattegat (bottom 20-120m)
63	Belt Sea (surface 0-14m)
64	Belt Sea (bottom 14-44m)
65	Bothnian Bay
66	Bothnian Sea
67	Baltic Sea W. (surface 0-49m)
68	Baltic Sea E. (surface 0-53m)
69	Baltic Sea W. (bottom 49-159m)
70	Baltic Sea E. (bottom 53-163m)
71	Gulf of Finland
72	Gulf of Riga

Table 2 Element-specific modelling parameters

Element	Concentration Factor (Bq t^{-1})/(Bq m^{-3})			Sediment partition coefficient (Bq t^{-1})/(Bq m^{-3})	
	Fish	Crustaceans	Molluscs	Regional	Coastal
H	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
C	2.00E+04	2.00E+04	2.00E+04	2.00E+03	2.00E+03
Na	1.00E-01	1.00E+01	3.00E+01	1.00E+00	1.00E-01
P	2.00E+04	1.00E+04	1.00E+04	1.00E+02	1.00E+01
S	2.00E+00	1.00E+00	4.00E+00	1.00E+00	5.00E+01
Ca	2.00E+00	5.00E+00	1.00E+00	1.00E+02	5.00E+02
Cr	2.00E+02	5.00E+02	8.00E+02	5.00E+04	5.00E+04
Mn	4.00E+02	5.00E+02	5.00E+04	2.00E+08	2.00E+05
Fe	5.00E+02	5.00E+03	3.00E+04	5.00E+07	5.00E+04
Co	1.00E+03	1.00E+04	5.00E+03	1.00E+07	2.00E+05
Ni	1.00E+03	1.00E+03	2.00E+03	1.00E+06	1.00E+05
Zn	1.00E+03	5.00E+04	3.00E+04	2.00E+05	2.00E+04
Y	2.00E+01	1.00E+03	1.00E+03	2.00E+06	1.00E+07
Sr	2.00E+00	2.00E+00	1.00E+00	2.00E+02	1.00E+03
Zr	2.00E+01	2.00E+02	5.00E+03	5.00E+05	1.00E+06
Tc	3.00E+01	1.00E+03	1.00E+03	1.00E+03	1.00E+02
Ru	2.00E+00	1.00E+02	2.00E+03	1.00E+03	3.00E+02
Ag	5.00E+02	5.00E+03	1.00E+04	1.00E+04	1.00E+03
Te	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Sb	4.00E+02	2.50E+01	2.00E+01	5.00E+02	1.00E+03
I	1.00E+01	1.00E+01	1.00E+01	2.00E+02	2.00E+01
Ba	1.00E+01	1.00E+00	2.00E+01	1.00E+04	5.00E+03
Cs	1.00E+02	3.00E+01	3.00E+01	2.00E+03	2.30E+02
Ce	5.00E+01	1.00E+03	2.00E+03	1.00E+08	2.00E+06
Pm	5.00E+02	1.00E+03	5.00E+03	1.00E+06	2.00E+06
Eu	3.00E+02	1.00E+03	7.00E+03	4.00E+06	5.00E+05
Ta	6.00E+01	3.00E+03	3.00E+03	5.00E+04	2.00E+05
Pb	2.00E+02	1.00E+03	1.00E+03	3.00E+07	5.00E+03
Po	2.00E+04	5.00E+04	1.00E+04	2.00E+07	1.00E+04
Ra	5.00E+02	1.00E+02	1.00E+03	3.00E+04	5.00E+03
Ac	5.00E+01	1.00E+03	1.00E+03	2.00E+06	2.00E+06
Th	6.00E+02	1.00E+03	1.00E+03	5.00E+06	2.00E+06
U	1.00E+00	1.00E+01	3.00E+01	5.00E+02	1.00E+03
Pu	1.00E+02	2.00E+02	3.00E+03	1.00E+05	1.00E+05
Am	1.00E+02	5.00E+02	2.00E+04	2.00E+06	2.00E+06
Cm	5.00E+01	5.00E+02	3.00E+04	2.00E+06	2.00E+06

Table 3 Site-specific local compartment parameters

Site	Adjacent regional compartment	Exchange rate	Volume	Depth	Sedimentation rate	SSL
		$km^3\ y^{-1}$	m^3	m	$t\ m^{-2}\ y^{-1}$	$t\ m^{-3}$
Aldermaston	55	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Almaraz 1+2	43	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Amersham	55	4.00E+00	2.00E+08	10	1.00E-04	2.00E-04
Barrow	37	4.00E+09	2.00E+08	10	5.00E-03	2.00E-04
Barsebäck 1+2	63	1.00E+11	5.00E+09	20	7.50E-04	1.00E-05
Belleville 1+2	41	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Berkeley A+B	39	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Beznau	56	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Biblis	56	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Blayais 1+2+3+4	41	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Borssele	56	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Bradwell A+B	55	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Brokdorf (KBR)	58	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Brunsbüttel (KKB)	58	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Capenhurst	37	8.00E+10	2.00E+09	20	5.00E-03	1.00E-04
Cardiff	39	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Cattenom 1+2+3+4	56	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Chapelcross A+B+C+D	32	1.00E+11	5.00E+09	20	5.00E-03	1.00E-05
Chinon	41	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Chooz	56	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Dampierre 1+2+3+4	41	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Devonport	46	4.00E+09	2.00E+08	10	2.00E-04	1.00E-04
Doel 1+2+3+4	56	4.00E+09	2.00E+08	10	1.10E-04	2.00E-04
Dodewaard	56	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Dounreay (site)	29	1.60E+11	3.20E+09	40	1.00E-04	1.00E-06
Dungeness AA+AB	54	8.00E+10	2.00E+09	20	1.00E-04	1.00E-05
Emsland (KKE)	58	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Faslane	28	1.00E+11	5.00E+09	20	1.00E-04	1.00E-05
Fessenheim 1+2	56	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Flamanville 1+2	47	1.00E+11	5.00E+09	20	1.00E-04	1.00E-05
Golfech 1+2	41	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Gösgen	56	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Grafenrheinfeld	56	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Gravelines 1+2+3+4+5+6	56	8.00E+10	2.00E+09	20	2.00E-04	1.00E-05
Grohnde (KWG)	58	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Hartlepool	57	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Harwell	55	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Heysham	37	8.00E+09	1.00E+08	10	4.90E-03	1.00E-05
Hinkley Point AA+AB	39	1.00E+11	5.00E+09	20	1.00E-04	2.00E-04
Hunterston	28	1.00E+11	5.00E+09	20	1.00E-04	1.00E-05
Jose Cabrera (Zorita)	43	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Kahl	56	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Karlsruhe	56	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Krümmel/Geesthacht	58	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
La Hague (site)	48	8.00E+10	2.00E+09	20	1.02E-04	1.00E-05
Leibstadt	56	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Muelheim-Kaerlich (KMK)	56	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Mühleberg	56	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Neckarwestheim	56	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Nogent 1+2	50	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Obrigheim (KWO)	56	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Oldbury AA+AB	39	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Paluel 1+2+3+4	51	4.00E+09	2.00E+08	10	5.00E-05	1.00E-05

Table 3 (cont'd)

Site	Adjacent regional compartment	Exchange rate	Volume	Depth	Sedimentation rate	SSL
		km^3 y^{-1}	m^3	m	t m^{-2} y^{-1}	t m^{-3}
Penly 1+2	51	8.00E+10	2.00E+09	20	1.00E-04	1.00E-05
Philippsburg	56	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Rheinsberg	58	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Ringhals	61	1.00E+11	5.00E+09	20	7.50E-04	1.00E-05
Risø	63	4.00E+09	2.00E+08	10	5.00E-04	2.00E-04
Rosyth	29	1.00E+11	5.00E+09	20	1.00E-04	1.00E-05
Sellafield	35	5.00E+11	2.00E+09	20	1.00E-02	5.00E-06
Sizewell	55	1.10E+10	3.00E+08	10	1.00E-04	8.00E-05
Springfields	37	4.00E+09	2.00E+08	10	5.00E-03	2.00E-04
St Laurent	41	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Stade (KKS)	58	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Tihange 1+2+3	56	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Torness 1+2	57	8.00E+10	2.00E+09	20	1.00E-04	1.00E-05
Trawsfynydd	36	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Trillo	43	4.00E+09	2.00E+08	10	2.00E-04	2.00E-04
Unterweser (KKU)	58	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Winfrith	49	4.00E+10	2.00E+09	20	1.02E-04	1.00E-05
Würgassen (KWW)	58	4.00E+09	2.00E+08	10	1.00E-04	2.00E-04
Wylfa A+B	33	4.00E+10	2.00E+09	20	5.00E-03	1.00E-05

Table 4 Generic local compartment parameters

Parameter	Value
Sediment reworking rate (m y^{-1})	5.00E-03
Pore water turnover rate (y^{-1})	1.00
Diffusion (m^2 y^{-1})	3.15 E-02
Density (t m^{-3})	2.6
Porosity	0.75

Table 5 Collective dose rates to the European Union population due to all sources/discharges (man Sv y^{-1})

Industry/Source	Year of collective dose rate				
	2000	2020		2500	
		Discharges up to 2000 only	Discharges continue to 2020	Discharges up to 2000 only	Discharges continue to 2020
Baltic Flux*	2.05E-01	1.72E-02	1.72E-02	1.04E-08	1.04E-08
Chernobyl*	4.67E-01	1.78E-01	1.78E-01	1.84E-07	1.84E-07
Fallout*	7.07E+00	4.99E+00	4.99E+00	3.72E-01	3.72E-01
Isotope production	9.97E-02	5.92E-03	1.08E-01	1.34E-04	3.28E-04
Total NORM	1.95E+02	7.53E+01	2.00E+02	4.72E-01	1.04E+00
Total Nuclear	1.40E+01	4.54E+00	1.08E+01	1.05E-01	1.08E-01
UK Military	1.75E-05	5.74E-07	1.18E-05	2.00E-23	9.02E-23
Grand Total	2.17E+02	8.50E+01	2.16E+02	9.50E-01	1.52E+00

*** Source term data only available up to 2000**

Table 6 Integrated collective doses to the European Union population due to all sources/discharges (man Sv)

Industry/Source	Year of collective dose truncation				
	2000	2020		2500	
		Discharges up to 2000 only	Discharges continue to 2020	Discharges up to 2000 only	Discharges continue to 2020
Baltic Flux*	8.59E+00	9.51E+00	9.51E+00	9.83E+00	9.83E+00
Chernobyl*	4.96E+01	5.54E+01	5.54E+01	6.04E+01	6.04E+01
Fallout*	6.75E+02	7.94E+02	7.94E+02	1.40E+03	1.40E+03
Isotope production	1.37E+00	1.59E+00	3.46E+00	1.95E+00	4.55E+00
Total NORM	8.27E+03	1.02E+04	1.20E+04	1.31E+04	1.88E+04
Total Nuclear	4.52E+03	4.64E+03	4.76E+03	5.11E+03	5.25E+03
UK Military	5.38E-04	6.19E-04	8.05E-04	6.23E-04	8.54E-04
Grand Total	1.35E+04	1.57E+04	1.76E+04	1.97E+04	2.55E+04

Table 7 Collective dose rates to the European Union population for selected years due to NORM discharges up to 2000 only (man Sv)

		Year of collective dose rate			
Industry	Site	1984	2000	2020	2500
Phosphates	Baie de la Seine	3.71E+01	3.45E+00	1.61E+00	3.34E-03
	Cumbrian Waters	2.48E+02	3.73E+01	1.72E+01	1.55E-02
	Gulf of Cadiz	3.45E-01	8.50E-01	2.98E-01	6.93E-03
	Irish Sea NW	1.25E+01	6.87E-01	3.30E-01	4.23E-04
	Kattegat	3.23E+01	2.36E-02	9.52E-03	3.41E-04
	North Sea SE	2.51E+02	7.69E+01	1.48E+01	4.35E-02
Oil &Gas	Denmark North Sea Central	7.37E-01	7.63E+00	3.89E+00	1.28E-02
	Netherlands North Sea SE	8.49E-01	1.85E+00	7.69E-01	3.32E-03
	Norway North Sea Central	2.88E+00	1.76E+01	1.03E+01	3.47E-02
	Norway North Sea North	1.57E+00	8.86E+00	3.22E+00	1.34E-01
	UK North Sea Central	1.38E+01	3.02E+01	1.90E+01	6.66E-02
	UK North Sea N	4.62E+00	8.00E+00	3.50E+00	1.50E-01
	UK North Sea SW	7.01E-01	1.84E+00	3.01E-01	4.09E-04
Total		6.06E+02	1.95E+02	7.53E+01	4.72E-01

Table 8 Integrated collective doses to the European Union population due to nuclear industry discharges (man Sv)

Site	Year of collective dose truncation					
	1990	2000	2020		2500	
			Discharges up to 2000 only	Discharges to 2020	Discharges up to 2000 only	Discharges to 2020
Nuclear Power Stations	1.85E+01	2.01E+01	2.10E+01	2.20E+01	2.43E+01	2.54E+01
Other Nuclear	3.81E+01	4.04E+01	4.27E+01	4.30E+01	5.52E+01	5.54E+01
La Hague	5.58E+02	6.00E+02	6.08E+02	6.73E+02	6.23E+02	7.00E+02
Sellafield	3.74E+03	3.86E+03	3.97E+03	4.02E+03	4.41E+03	4.47E+03
Total	4.35E+03	4.52E+03	4.64E+03	4.76E+03	5.11E+03	5.25E+03

Table 9 Collective dose rates by affected country due to all sources/discharges (man Sv y^{-1})

Country	Year of collective dose rate					
	1987	1997	2007		2500	
			Discharges up to 2000 only	Discharges continue to 2020	Discharges up to 2000 only	Discharges continue to 2020
Austria	2.31E+00	1.40E+00	4.84E-01	9.16E-01	2.97E-03	5.06E-03
Belgium	3.82E+01	2.18E+01	5.68E+00	1.15E+01	2.99E-02	5.01E-02
Denmark	5.60E+01	3.03E+01	1.17E+01	2.23E+01	9.36E-02	1.48E-01
Finland	9.47E-01	4.52E-01	1.87E-01	3.41E-01	2.05E-03	3.32E-03
France	1.07E+02	4.83E+01	1.58E+01	2.88E+01	1.42E-01	2.24E-01
Germany	8.26E+01	5.03E+01	1.86E+01	3.48E+01	1.35E-01	2.21E-01
Greece	1.71E+00	9.33E-01	3.52E-01	6.22E-01	4.25E-03	7.07E-03
Ireland	2.35E+01	5.58E+00	3.20E+00	3.77E+00	3.33E-02	5.32E-02
Italy	3.00E+01	1.56E+01	5.18E+00	9.49E+00	3.51E-02	5.69E-02
Netherlands	5.55E+01	3.39E+01	9.61E+00	1.90E+01	6.23E-02	1.05E-01
Portugal	9.49E+00	5.30E+00	2.19E+00	3.71E+00	4.28E-02	5.83E-02
Spain	4.52E+01	2.02E+01	7.75E+00	1.30E+01	1.00E-01	1.45E-01
Sweden	2.75E+01	8.18E+00	2.99E+00	6.39E+00	2.26E-02	3.52E-02
U.K.	1.61E+02	6.86E+01	2.86E+01	4.79E+01	2.57E-01	4.24E-01

Table 10 Per caput doses in European Union countries due to all sources/discharges (microSv y^{-1})

	Year of per caput dose rate					
	1987	1997	2007		2500	
Country			Discharges up to 2000 only	Discharges continue to 2020	Discharges up to 2000 only	Discharges continue to 2020
Austria	2.86E-01	1.73E-01	5.99E-02	1.13E-01	3.68E-04	6.27E-04
Belgium	3.63E+00	2.08E+00	5.41E-01	1.09E+00	2.85E-03	4.78E-03
Denmark	1.07E+01	5.78E+00	2.24E+00	4.25E+00	1.79E-02	2.83E-02
Finland	1.85E-01	8.81E-02	3.65E-02	6.65E-02	3.99E-04	6.48E-04
France	1.84E+00	8.29E-01	2.72E-01	4.95E-01	2.44E-03	3.85E-03
Germany	1.01E+00	6.14E-01	2.27E-01	4.26E-01	1.64E-03	2.69E-03
Greece	1.62E-01	8.89E-02	3.35E-02	5.92E-02	4.05E-04	6.73E-04
Ireland	6.49E+00	1.54E+00	8.83E-01	1.04E+00	9.17E-03	1.46E-02
Italy	5.23E-01	2.72E-01	9.03E-02	1.65E-01	6.12E-04	9.90E-04
Netherlands	3.58E+00	2.18E+00	6.20E-01	1.23E+00	4.02E-03	6.75E-03
Portugal	9.63E-01	5.37E-01	2.23E-01	3.76E-01	4.34E-03	5.91E-03
Spain	1.14E+00	5.09E-01	1.96E-01	3.29E-01	2.53E-03	3.65E-03
Sweden	3.12E+00	9.26E-01	3.38E-01	7.24E-01	2.55E-03	3.99E-03
U.K.	2.74E+00	1.17E+00	4.87E-01	8.17E-01	4.39E-03	7.22E-03

Figure 1 World regional marine compartments in MARINA II model

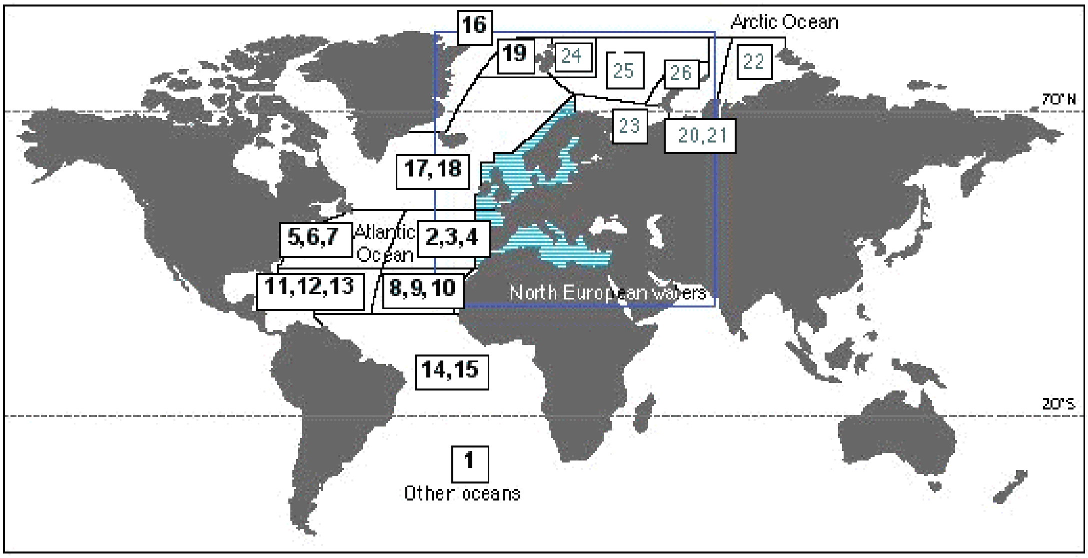


Figure 2 **North European regional marine compartments in MARINA II model**

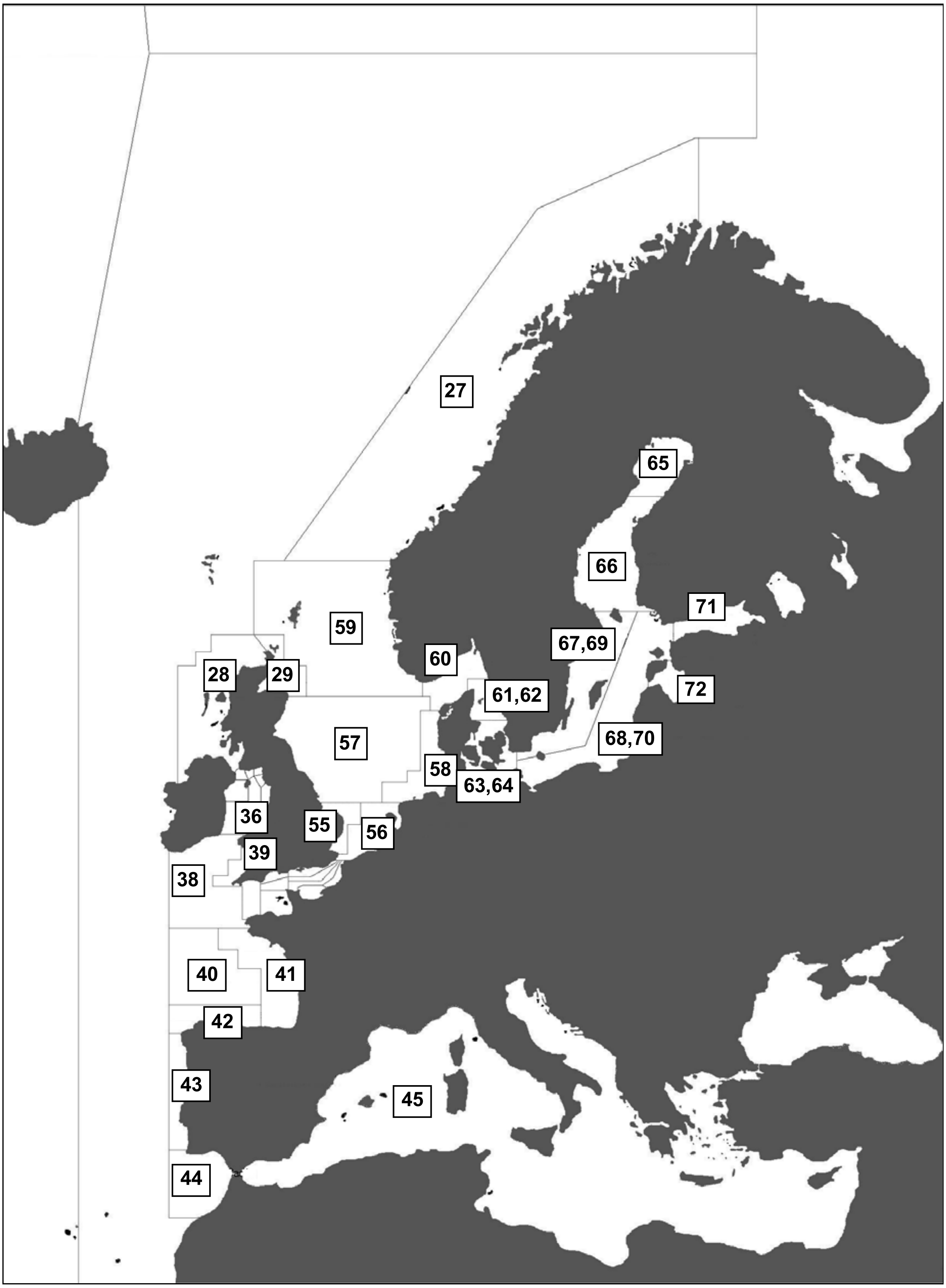


Figure 3 Irish Sea regional marine compartments in MARINA II model

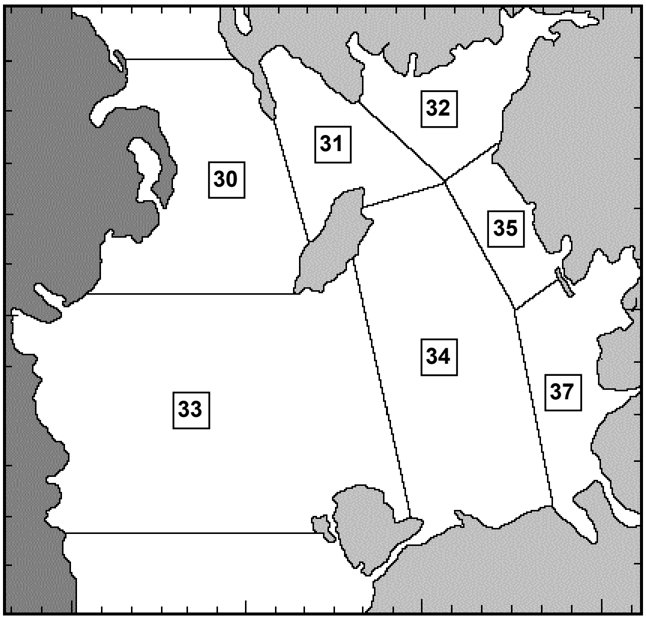


Figure 4 English Channel regional marine compartments in MARINA II model

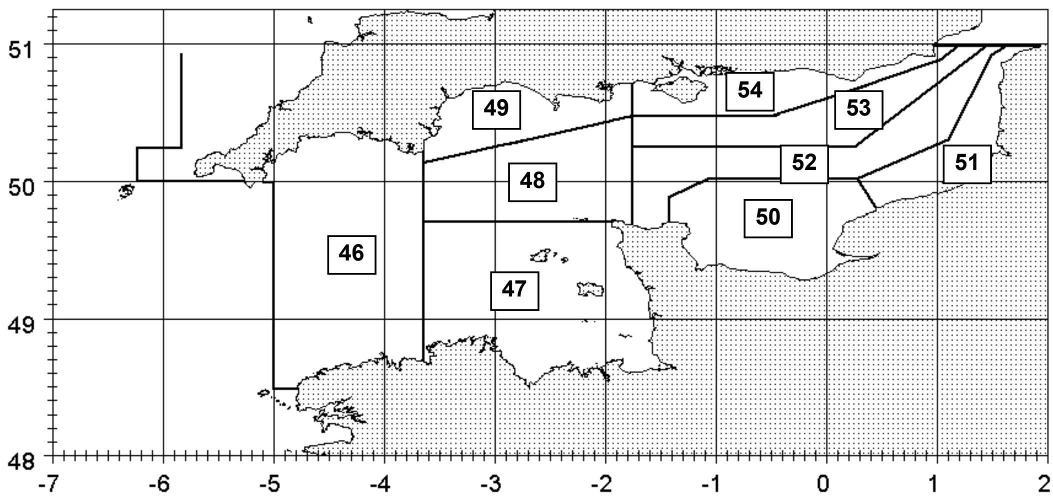


Figure 5 Generic water:sediment compartment structure in MARINA II model

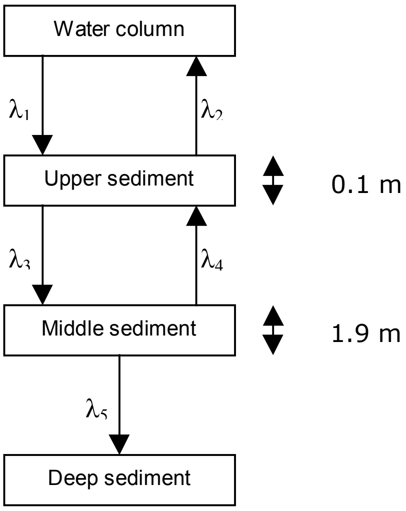


Figure 6 Collective dose rates by source to the European Union population due to discharges up to 2000 only

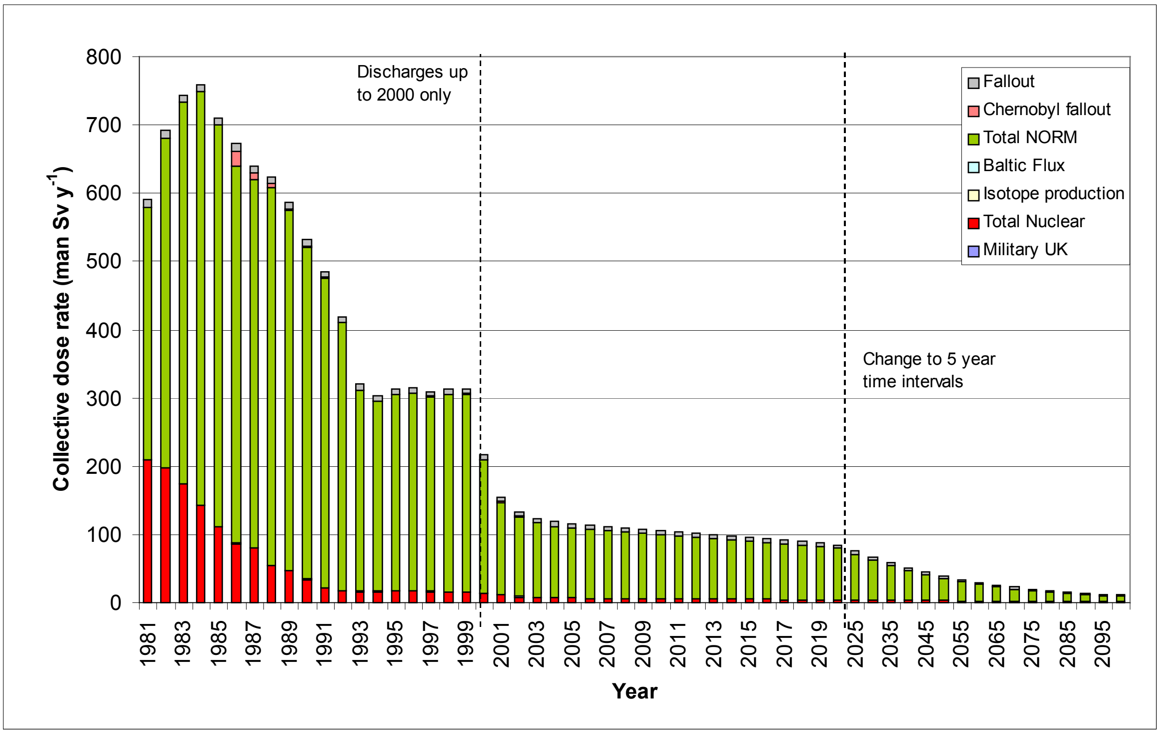


Figure 7 Breakdown of contribution by discharge/source of the collective dose rate received by the European Union population in 2000

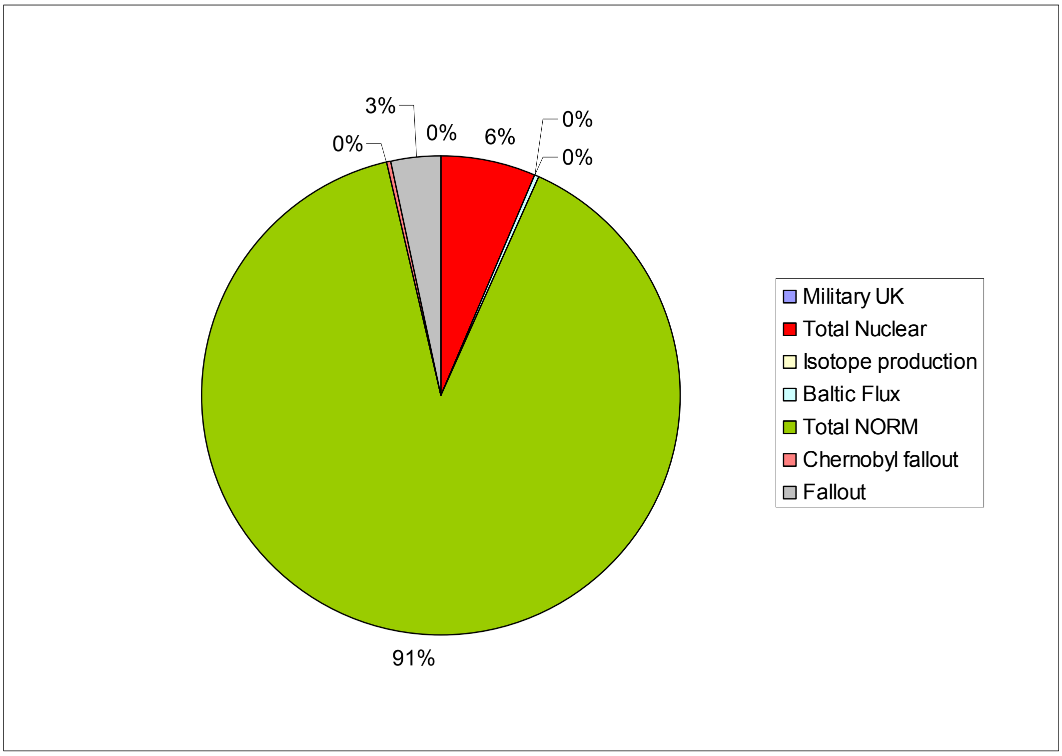


Figure 8 Breakdown of contribution by discharge/source of the collective dose truncated at 2500 received by the European Union population due to discharges up to 2000 only

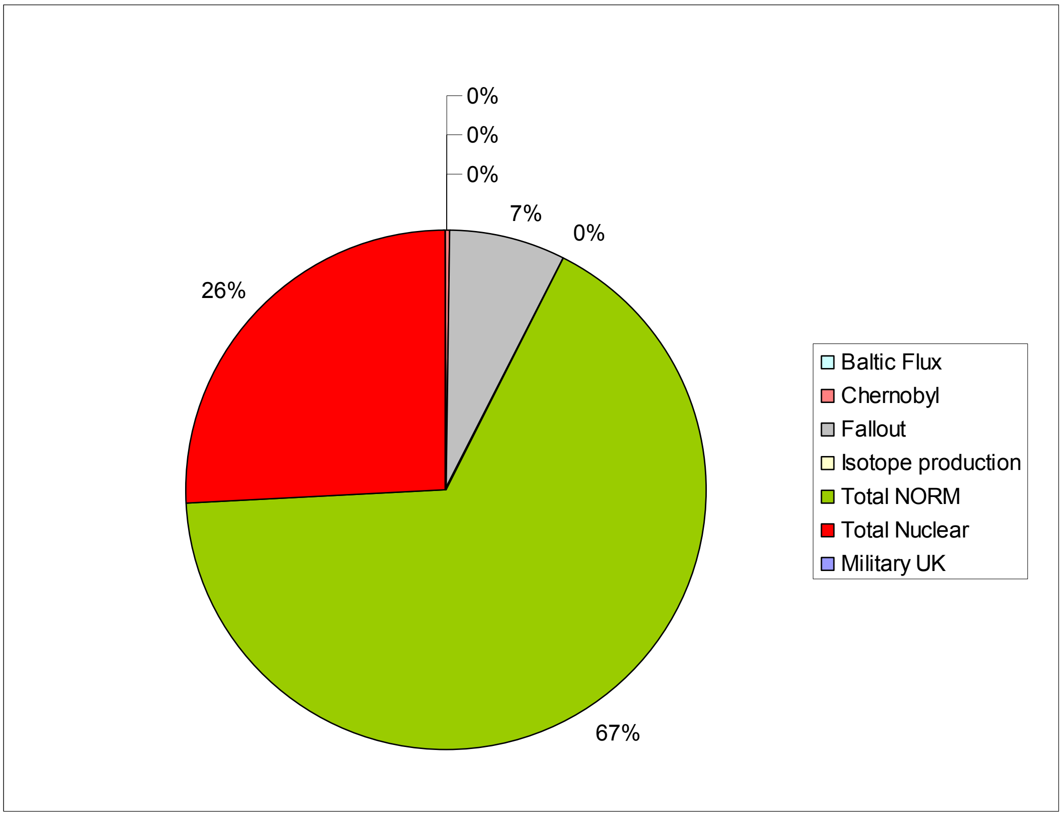


Figure 9 Collective dose rates by major source to the European Union population for discharges/sources up to 2000 only and continuing to 2020

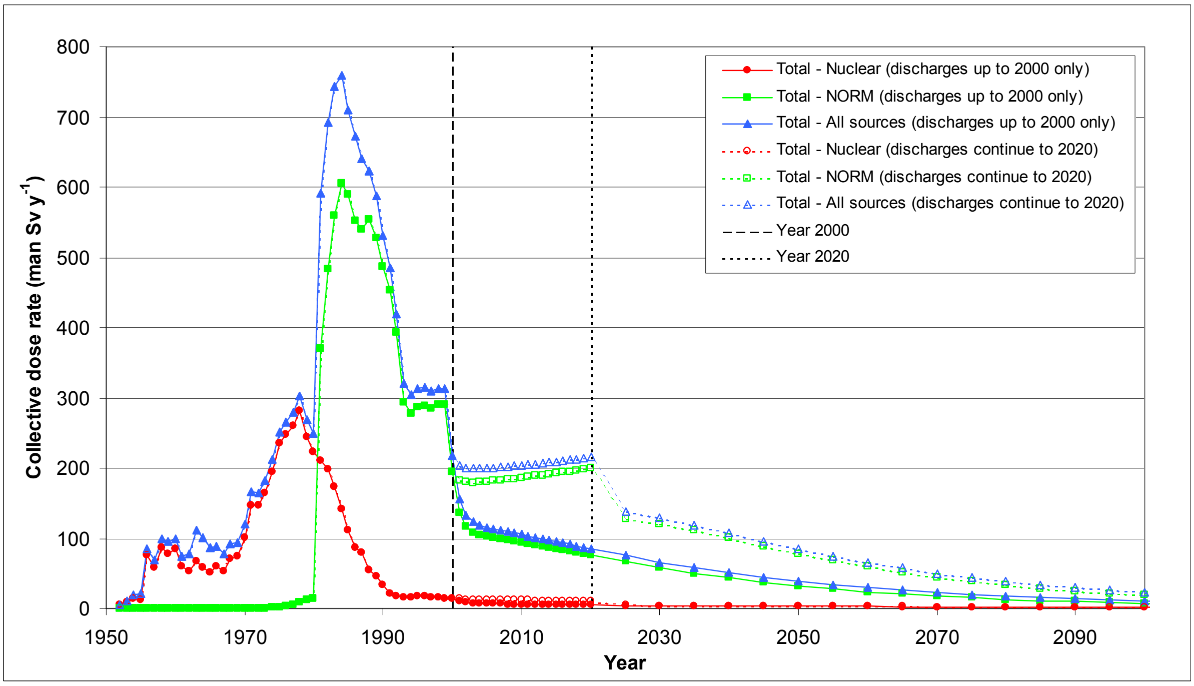


Figure 10 Collective dose rates to the European Union population due to NORM sites from discharges up to 2000 only

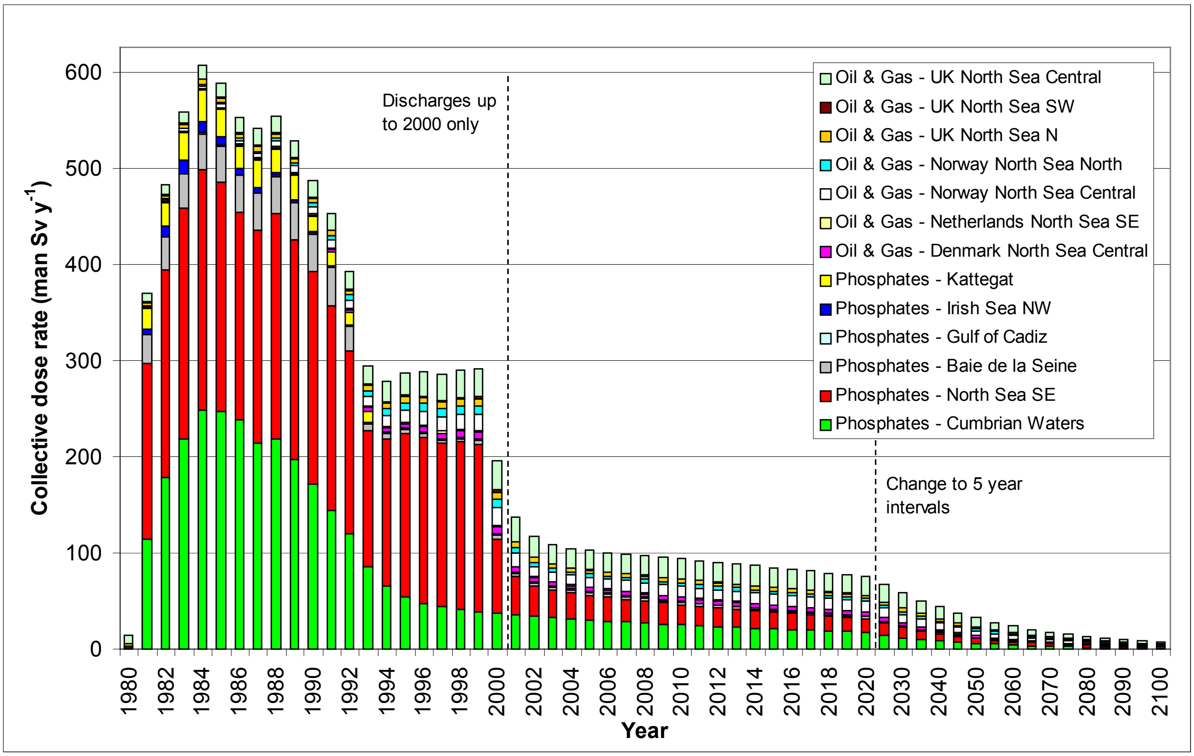


Figure 11 Breakdown of contribution of NORM sites to the collective dose rate received by the European Union population in 2000

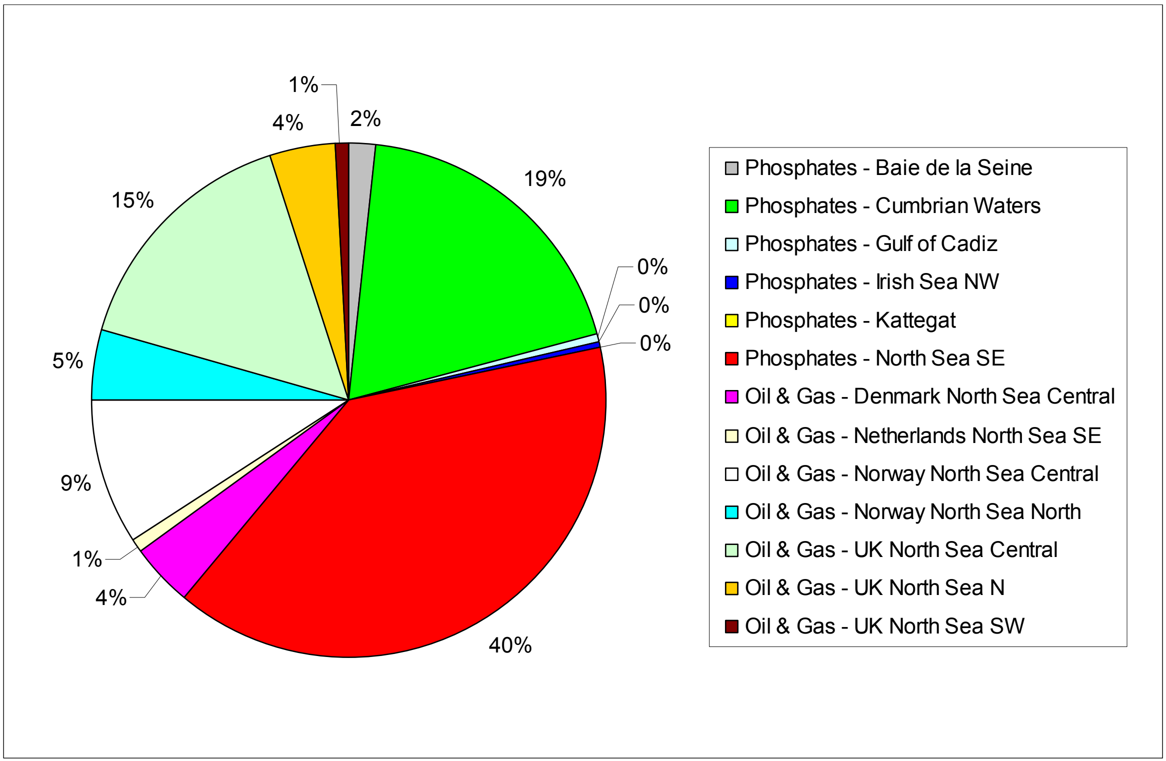


Figure 12 Collective dose rates to the European Union population by radionuclide for NORM sites due to discharges up to 2000 only

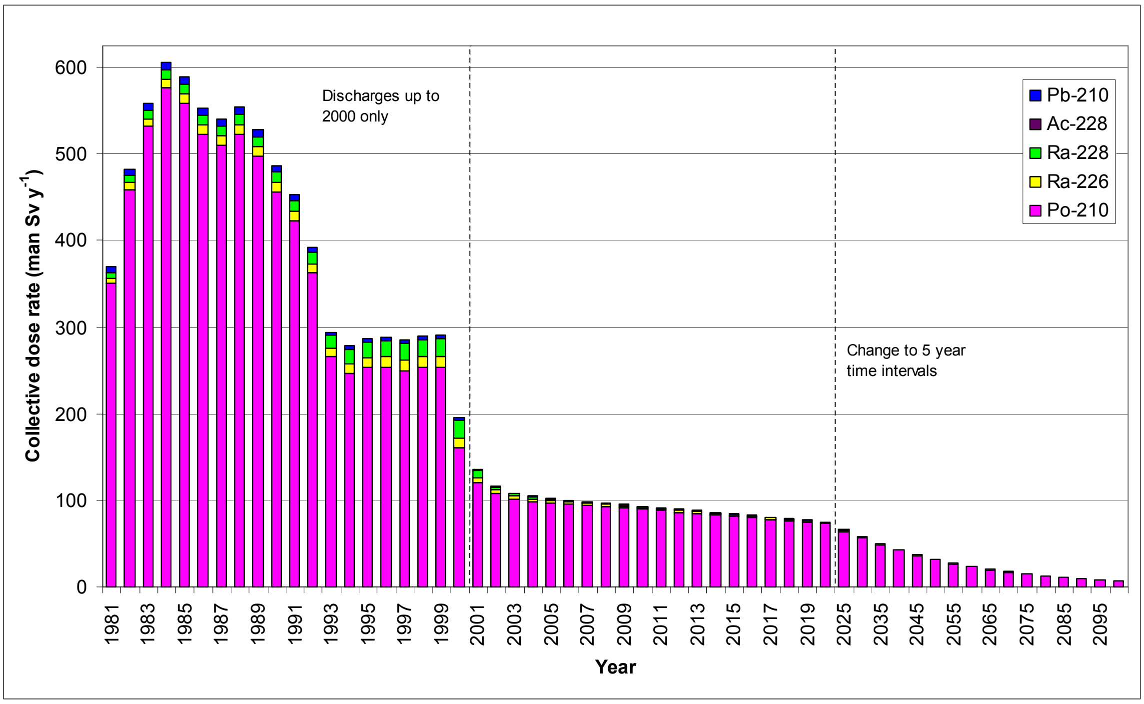


Figure 13 Breakdown of contribution by radionuclide discharged by the NORM industries to the collective dose rate received by the European Union population in 2000

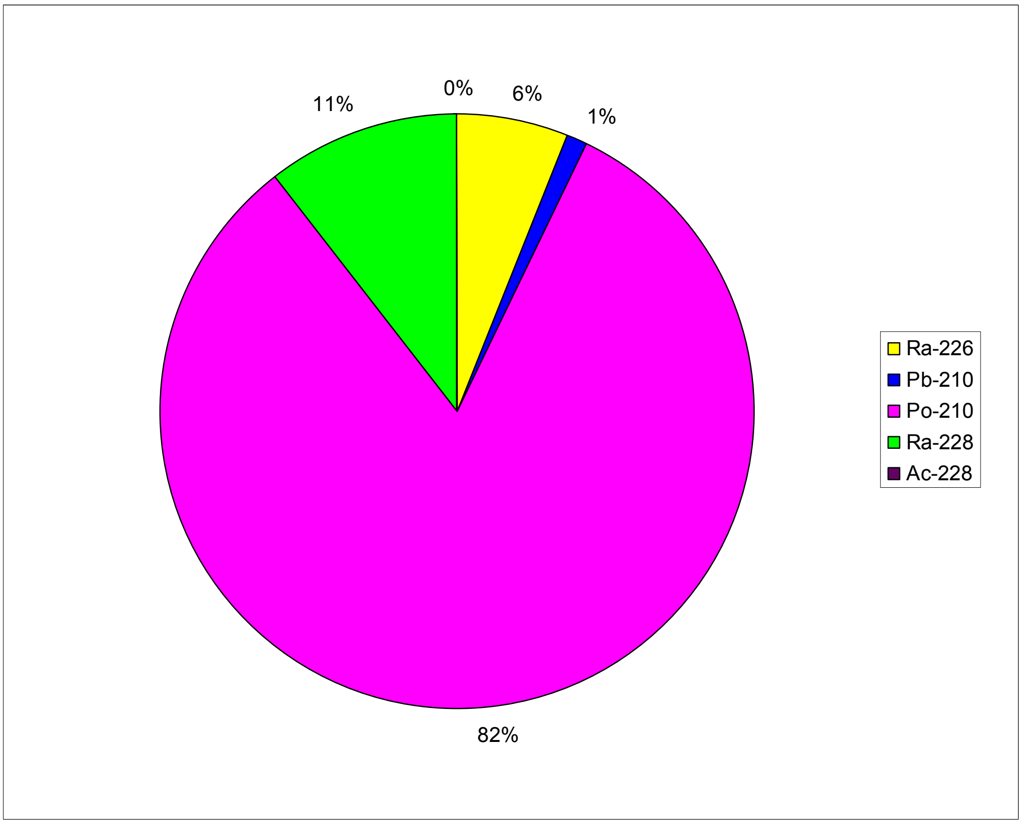


Figure 14 Collective dose rates to the European Union population due to NORM sites assuming discharges continue to 2020

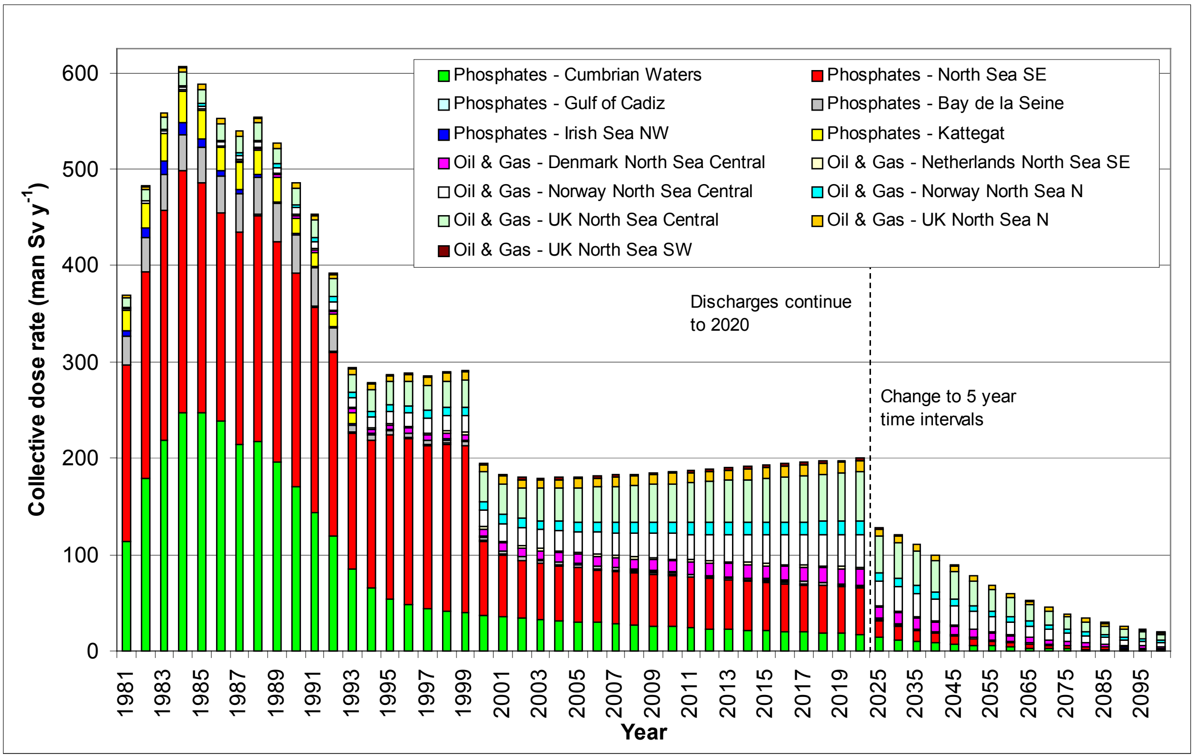


Figure 15 Collective dose rates to the European Union population due to nuclear industries from discharges up to 2000 only

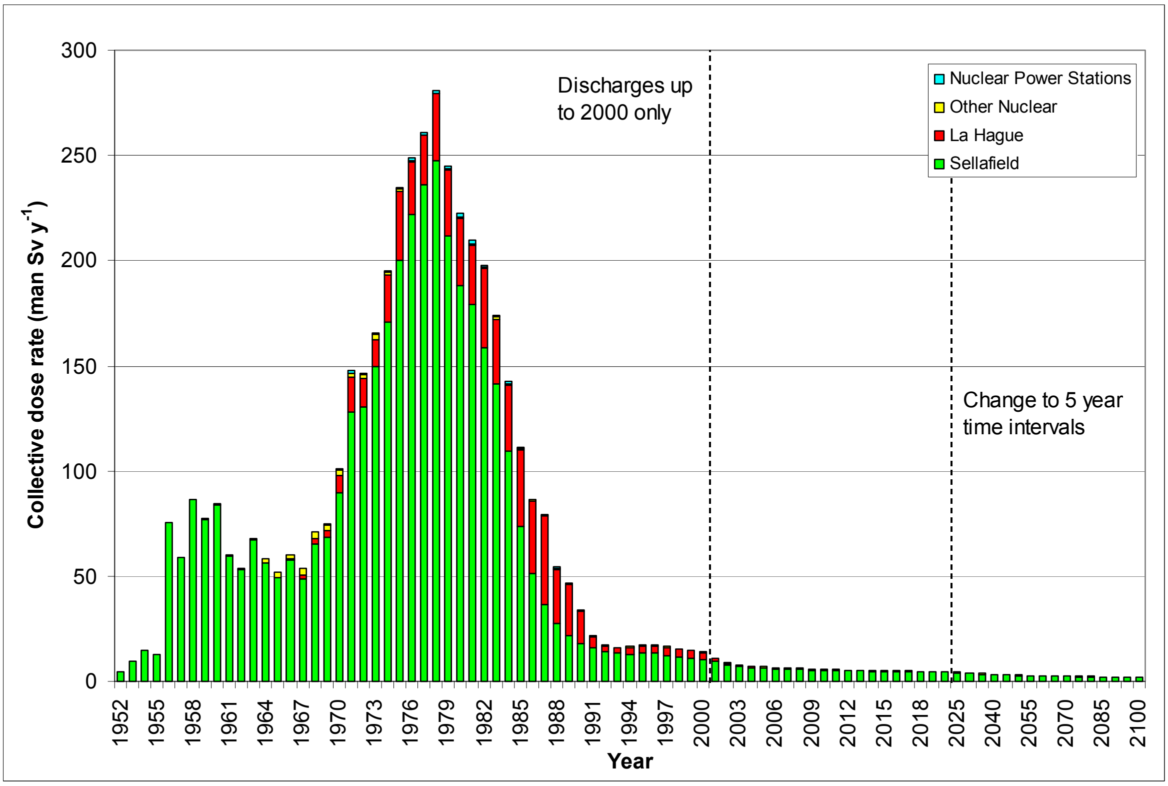


Figure 16 Breakdown of contribution by nuclear industries to the collective dose rate received by the European Union population in 2000

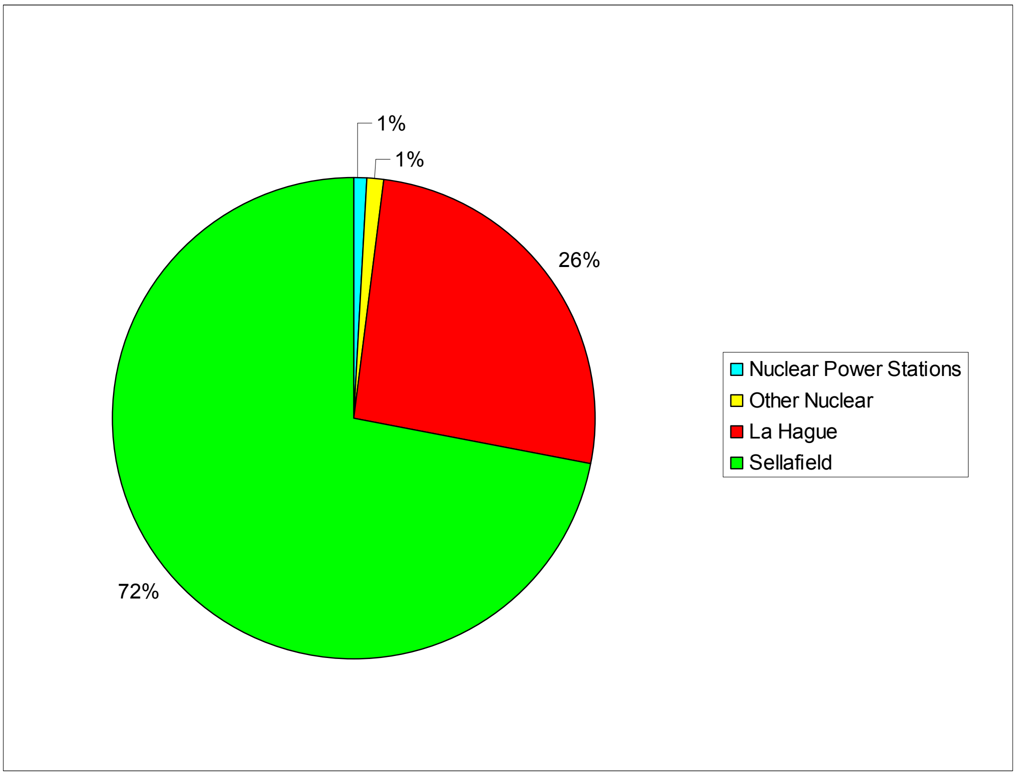


Figure 17 Collective dose rates to the European Union population by radionuclide for nuclear sites due to discharges up to 2000 only

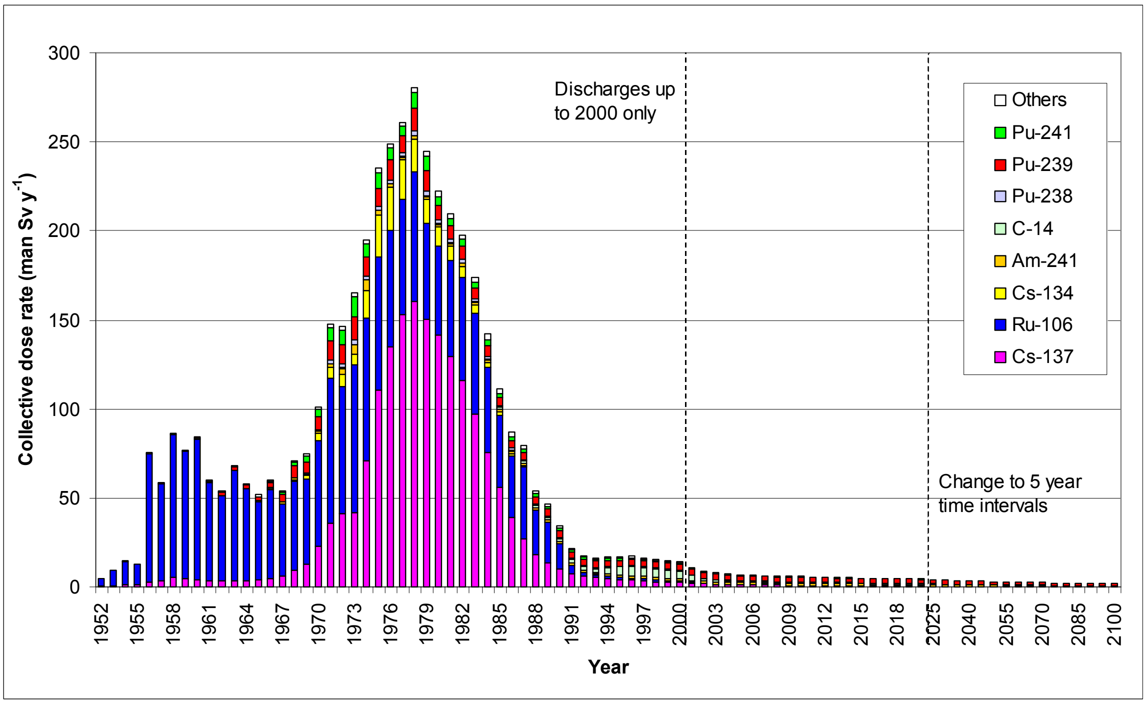


Figure 18 Breakdown of contribution by radionuclide discharged by the nuclear industries to the collective dose rate received by the European Union population in 2000

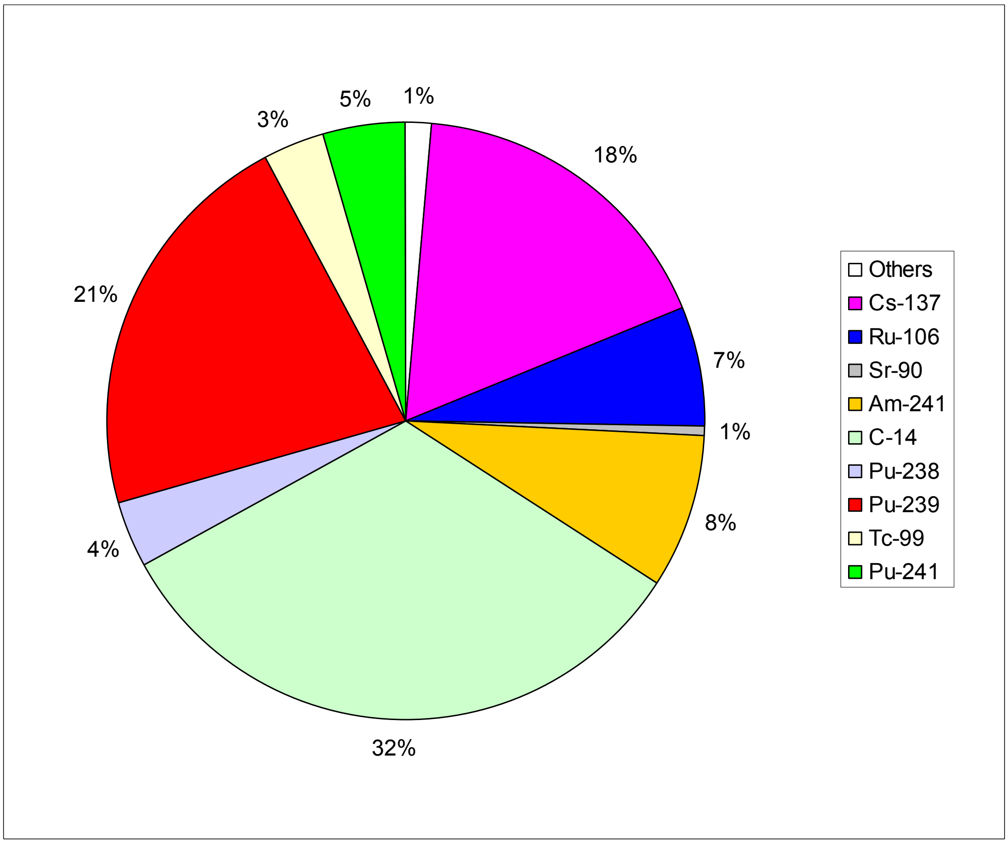


Figure 19 Breakdown of contribution by radionuclides discharged from the nuclear industry of the collective doses truncated at 2500 received by the European Union population due to discharges up to 2000 only

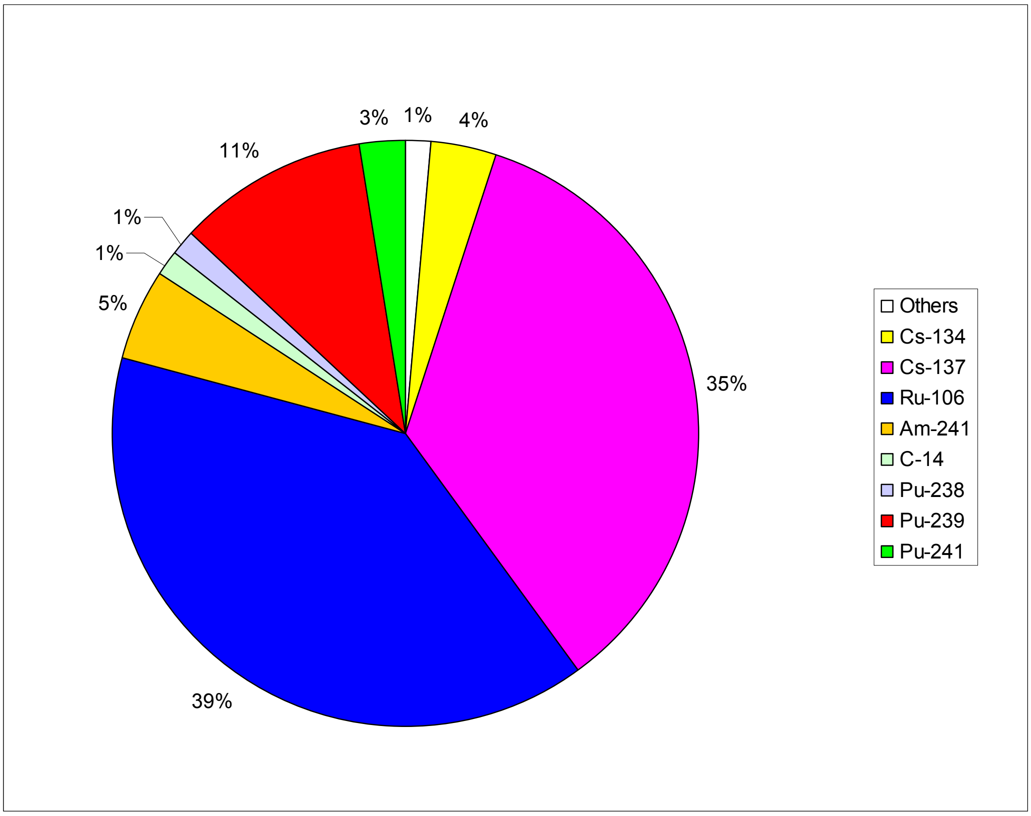


Figure 20 Collective dose rates to the European Union population due to nuclear industries assuming discharges continue to 2020

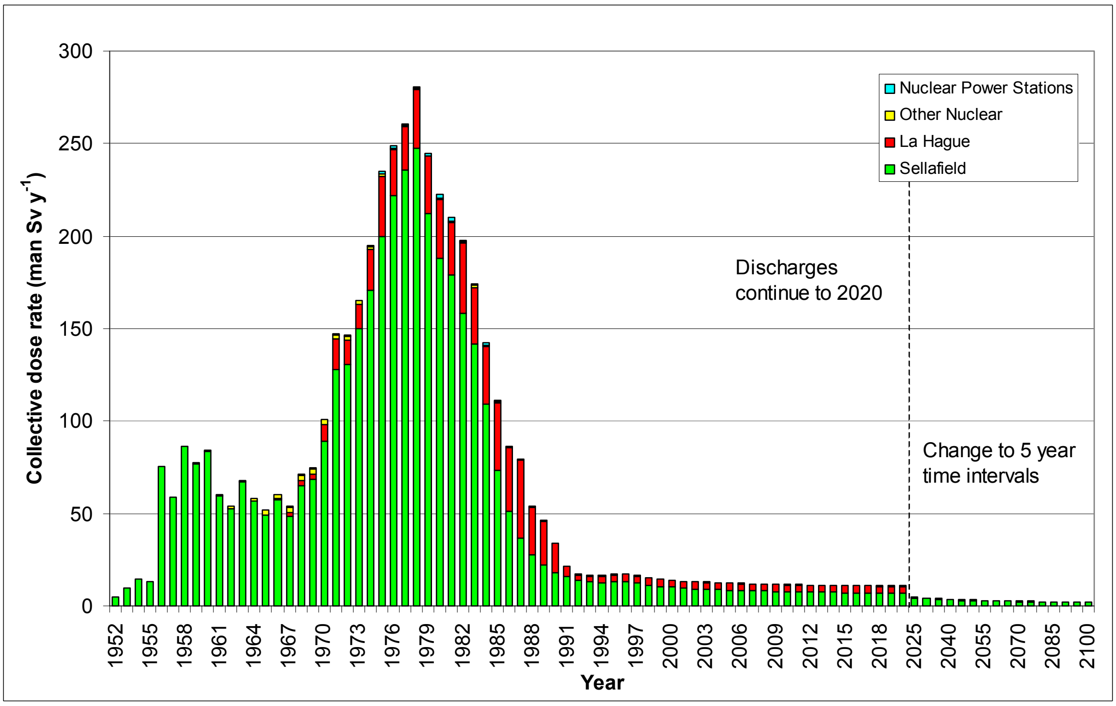


Figure 21 Collective dose rates to the European Union population from major sources compared with naturally occurring radioactivity

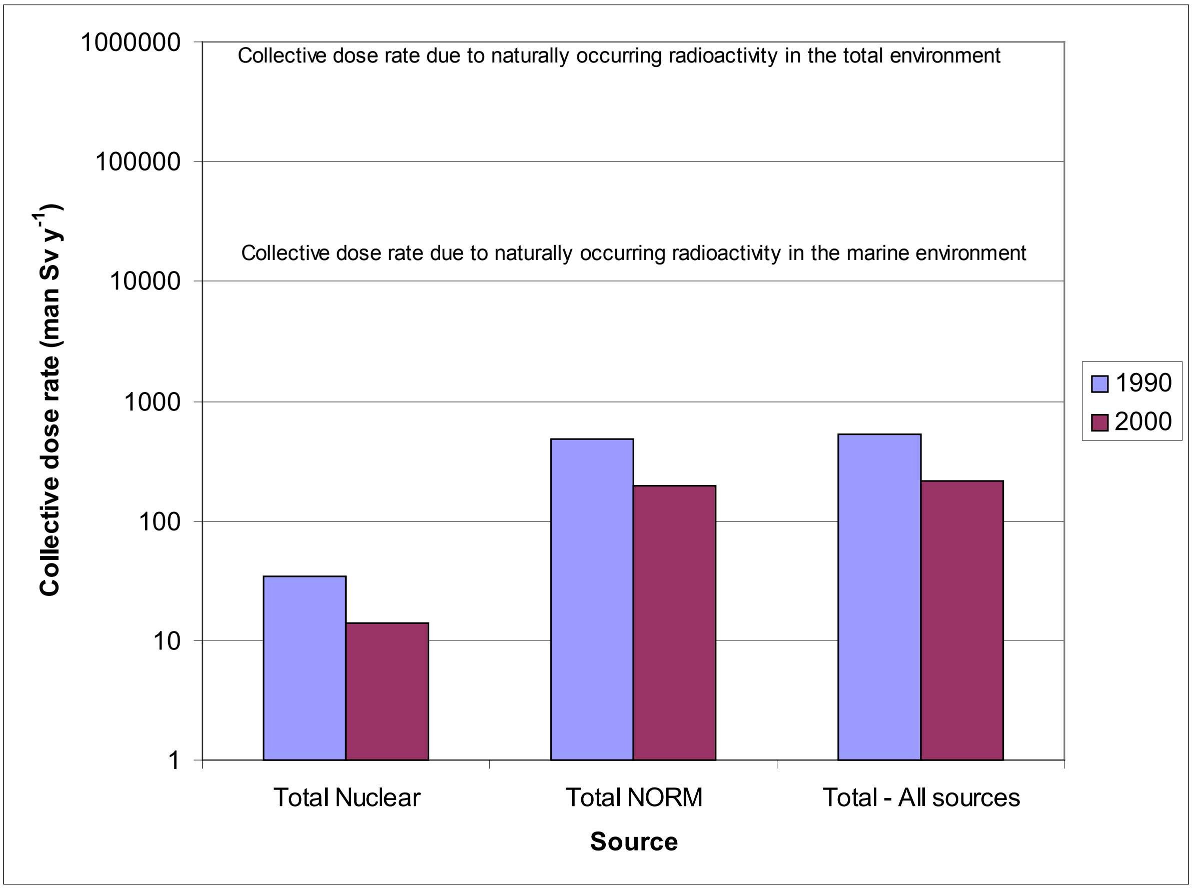


Figure 22 Estimated and measured activity concentrations of technetium-99 in filtered seawater for selected marine compartments, averaged between 1990 and 2000

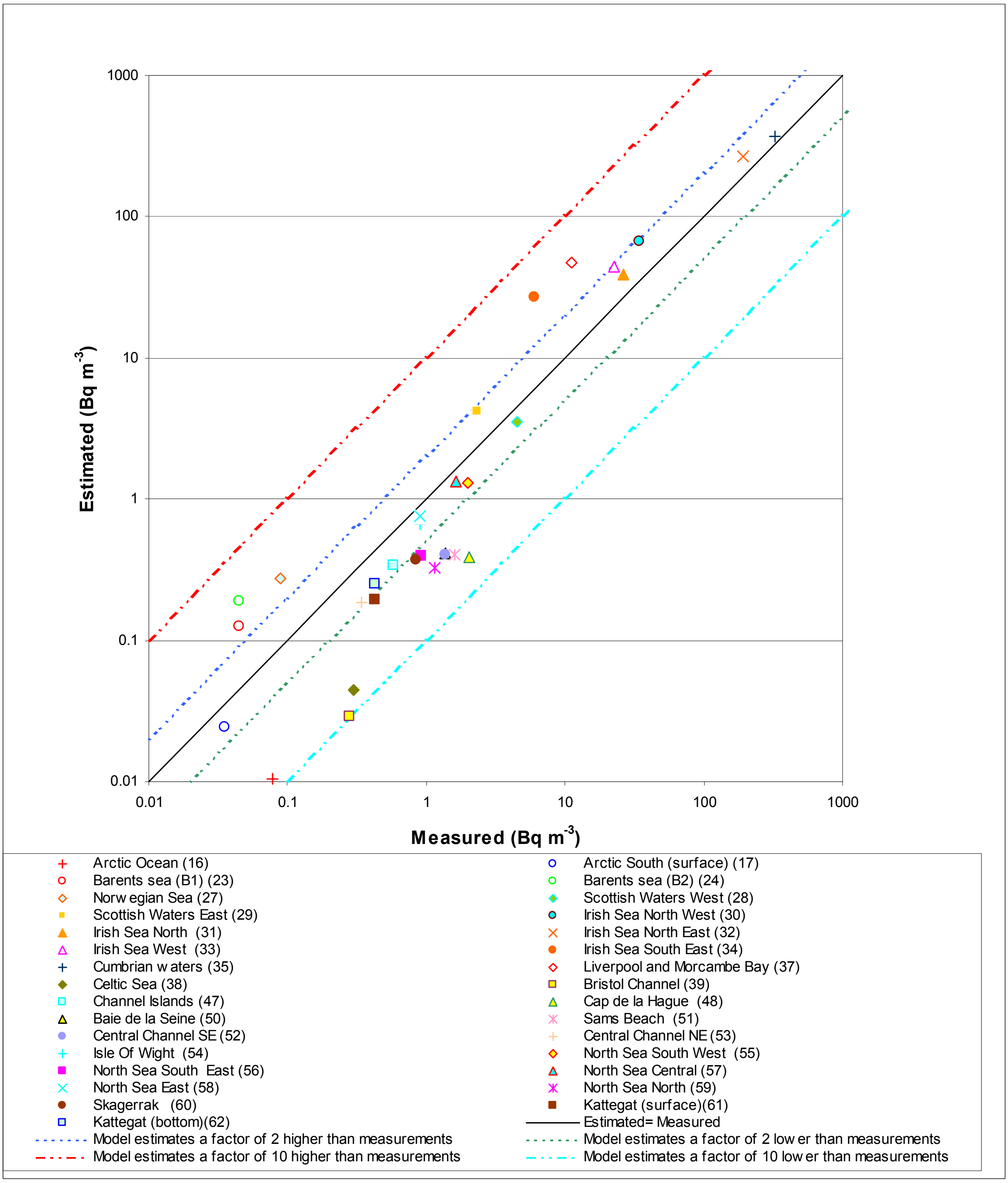


Figure 23 Estimated and measured activity concentrations of caesium-137 in fish (wet weight) for selected marine compartments, averaged between 1990 and 2000

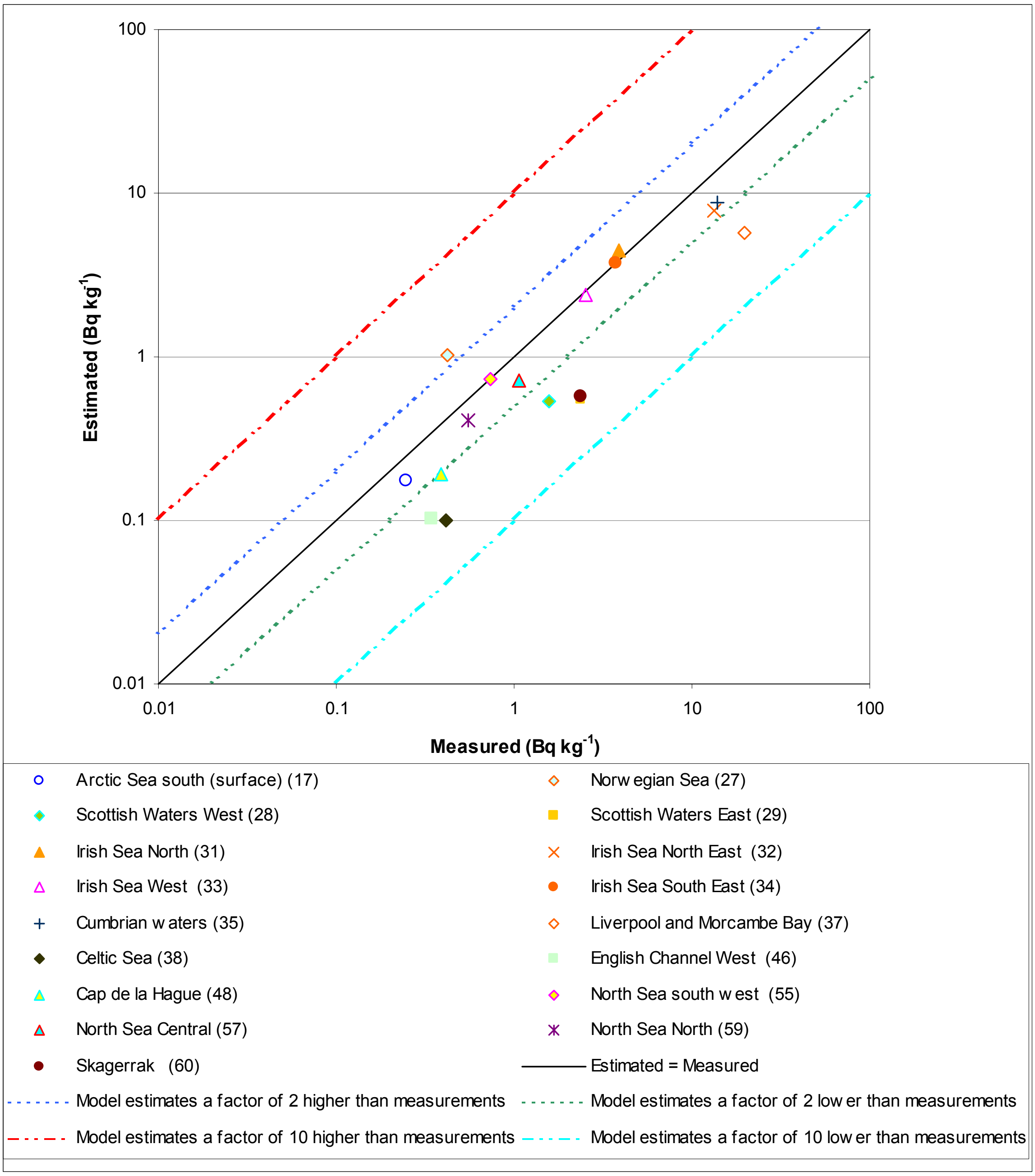
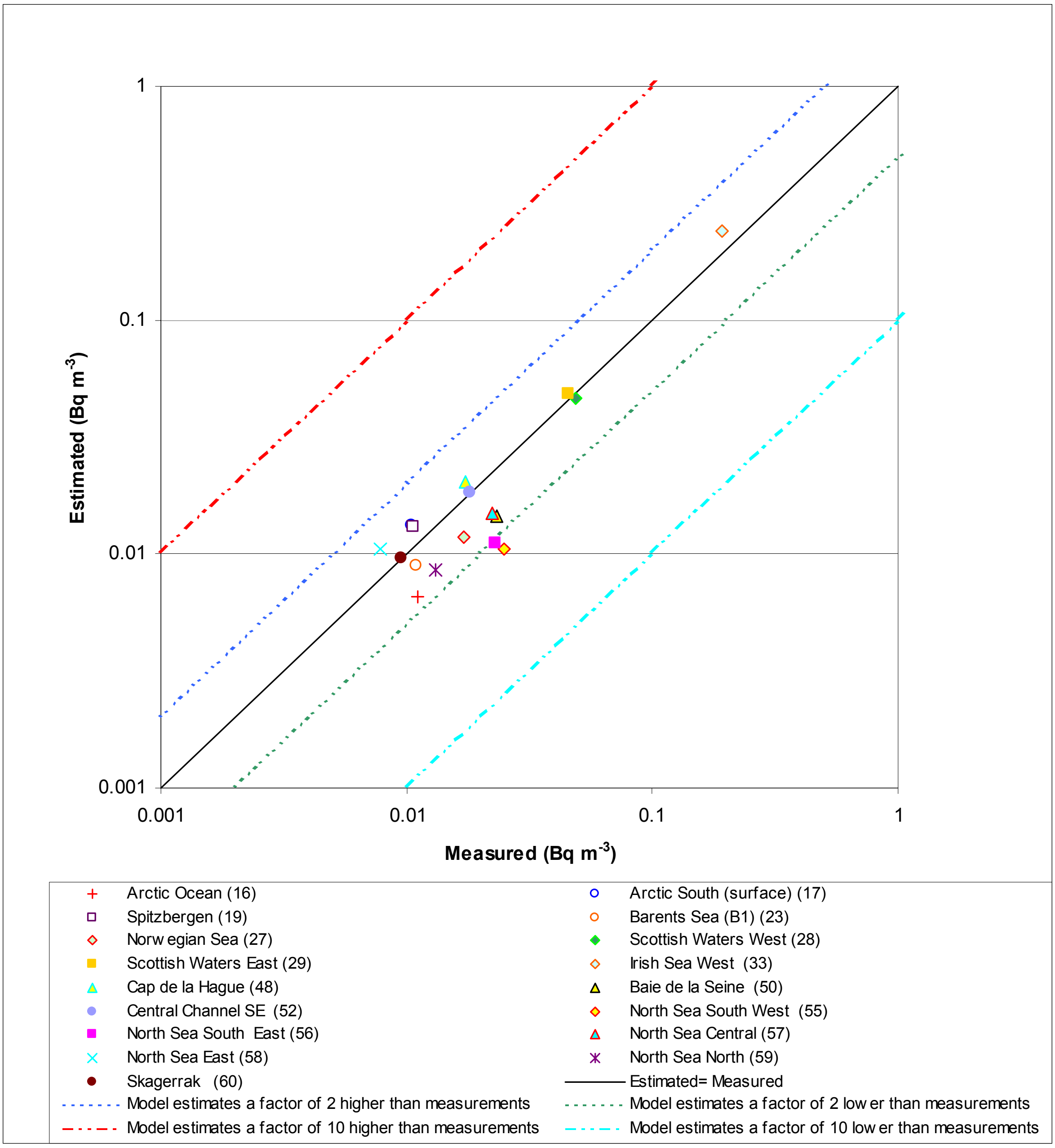


Figure 24 Estimated and measured activity concentrations of plutonium-239 in filtered seawater for selected marine compartments, averaged between 1990 and 2000



Appendix A - Technical description of MARINA II compartment marine dispersion model

1 Introduction

The task of Working Group D of the MARINA II project was to assess the radiation exposures to the member states of the European Union from radioactivity in north European waters. To fulfil this work, a model representing the dispersion of radionuclides in the marine environment was required. The previous MARINA project (CEC, 1990) developed a model (MARIN I) that has been used as the basis for the revised model given in this appendix. The original model consisted of 44 compartments representing northern European waters and relevant adjacent seas. The revised model expands upon the original model by increasing the resolution of the model in necessary locations such as previously poorly represented areas and in adjacent seas. The revised model consists of 72 compartments alongside a revised sedimentation model. This appendix provides a full technical description of the revised marine model as implemented within project MARINA II.

2 Revised Marine Model

2.1 Geographical compartmental structure

The revised model, called MARINA II, has an increased number of compartments over the previous MARINA model. The purpose of these increases is to address inadequacies in the previous model and to include recent modelling development (Lepicard and D'Ascenzo, 2000; Lepicard, 2001). The new model consists of 72 compartments as shown in Figures 1, 2, 3 and 4. Modifications have specifically been made to the Atlantic Ocean, English Channel and the Barents Sea. A list of compartment numbers is provided in Table 1.

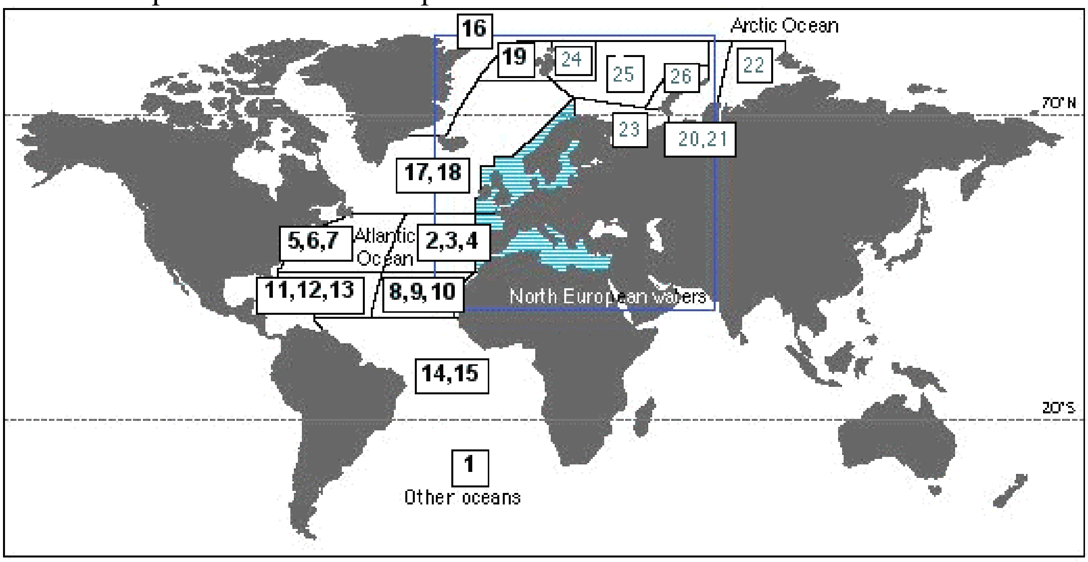


Figure 1 – World marine compartments in MARINA II model

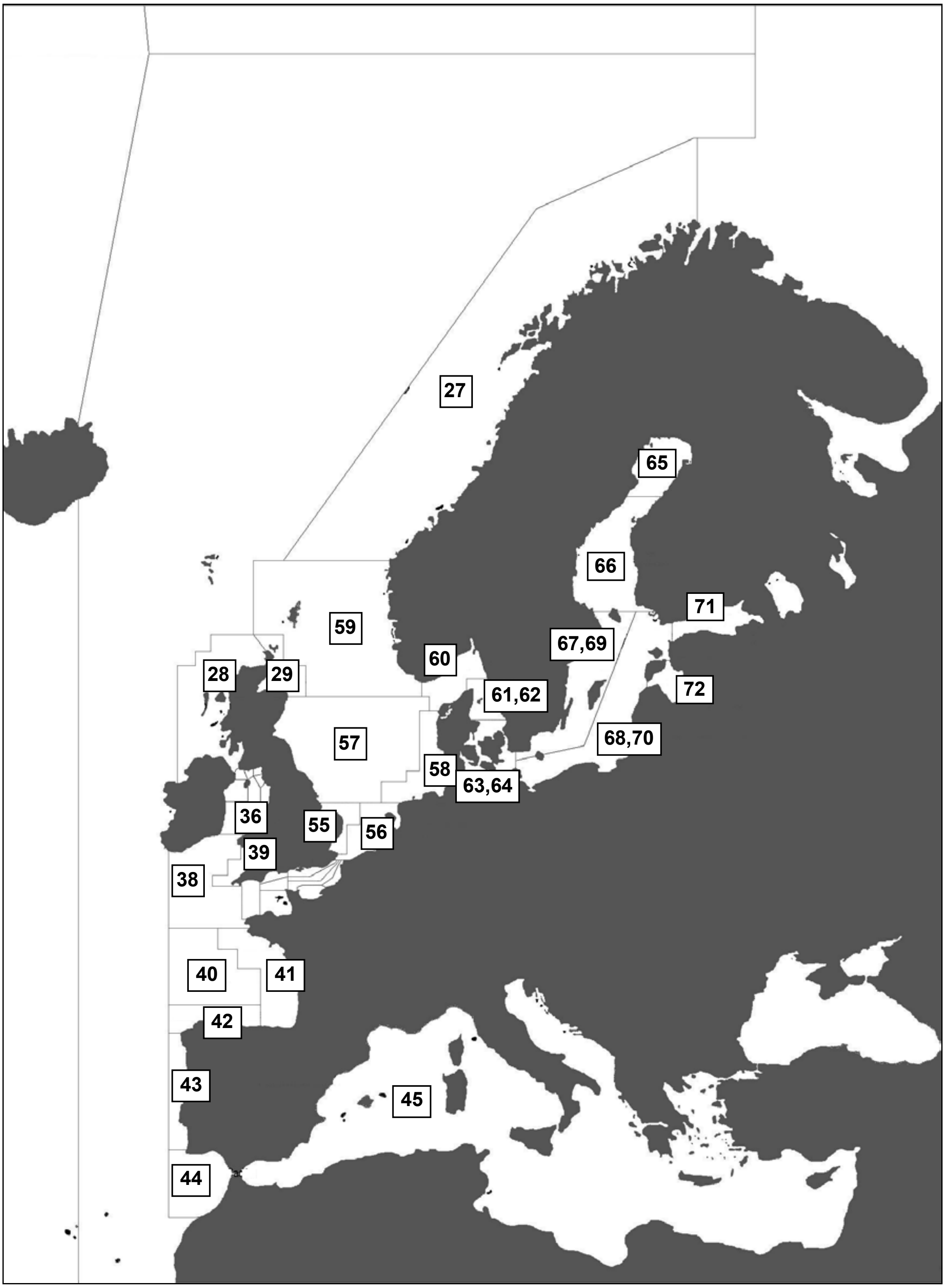


Figure 2 – North European regional compartments in MARINA II model

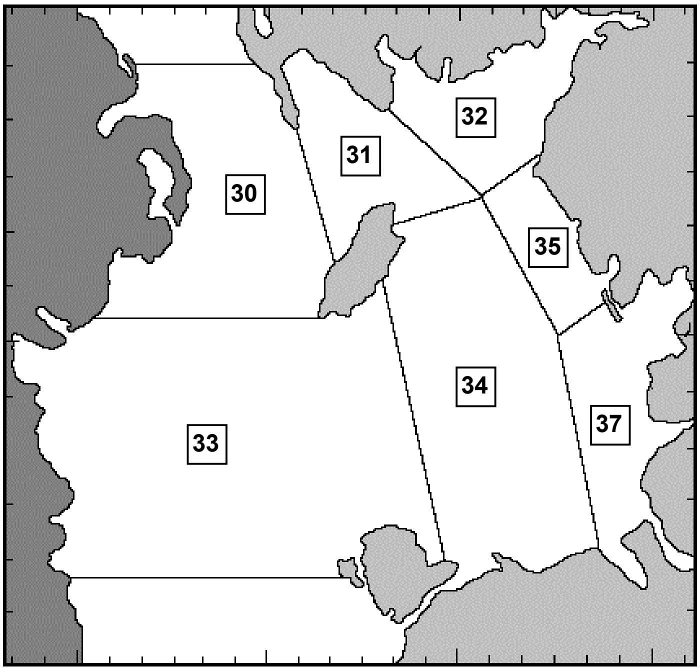


Figure 3 – Irish Sea regional compartments in MARINA II model

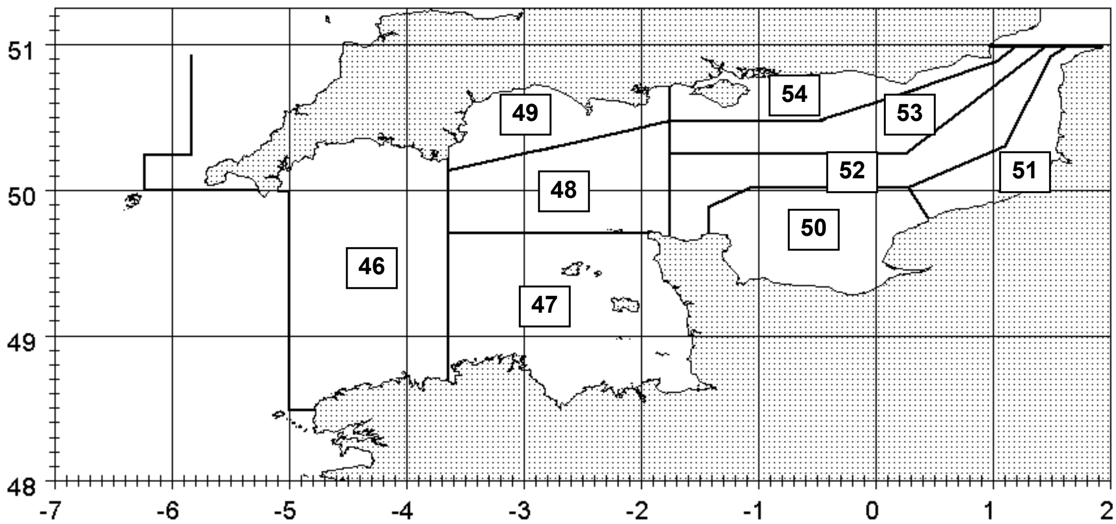


Figure 4 – English Channel regional compartments in MARINA II model

Table 1 Marina II model regional compartment names

Compartment Number	Compartment Name	Compartment Number	Compartment Name
1	Other Oceans	37	Liverpool and Morecambe Bays
2	Atlantic North N.E. (surface 0-1000m)	38	Celtic Sea
3	Atlantic North N.E. (middle 1000-2000m)	39	Bristol Channel
4	Atlantic North N.E. (bottom 2000-4000m)	40	Bay of Biscay
5	Atlantic North N.W. (surface 0-1000m)	41	French Continental Shelf
6	Atlantic North N.W. (middle 1000-2000m)	42	Cantabrian Sea
7	Atlantic North N.W. (bottom 2000-4000m)	43	Portuguese Continental Shelf
8	Atlantic North S.E. (surface 0-1000m)	44	Gulf of Cadiz
9	Atlantic North S.E. (middle 1000-2000m)	45	Mediterranean Sea
10	Atlantic North S.E. (bottom 2000-4000m)	46	English Channel W.
11	Atlantic North S.W. (surface 0-1000m)	47	Channel Islands
12	Atlantic North S.W. (middle 1000-2000m)	48	Cap de la Hague
13	Atlantic North S.W. (bottom 2000-4000m)	49	Lyme Bay
14	Atlantic S. (surface 0-1000m)	50	Baie de la Seine
15	Atlantic S. (bottom 1000-3000m)	51	Sam's Beach
16	Arctic Ocean	52	Central Channel S.E.
17	Arctic S. (surface 0-1000m)	53	Central Channel N.E.
18	Arctic S. (bottom 1000-3000m)	54	Isle of Wight
19	Spitzbergen	55	North Sea S.W.
20	Kara Sea West (K1)	56	North Sea S.E.
21	Kara Sea Novaya Zemlya Trough (K1a)	57	North Sea Central
22	Kara Sea East (K2)	58	North Sea E.
23	Barents Sea (B1)	59	North Sea N.
24	Barents Sea (B2)	60	Skagerrak
25	Barents Sea (B3)	61	Kattegat (surface 0-20m)
26	Barents Sea (B4)	62	Kattegat (bottom 20-120m)
27	Norwegian Waters	63	Belt Sea (surface 0-14m)
28	Scottish Waters W.	64	Belt Sea (bottom 14-44m)
29	Scottish Waters E.	65	Bothnian Bay
30	Irish Sea N.W.	66	Bothnian Sea
31	Irish Sea N.	67	Baltic Sea W. (surface 0-49m)
32	Irish Sea N.E.	68	Baltic Sea E. (surface 0-53m)
33	Irish Sea W.	69	Baltic Sea W. (bottom 49-159m)
34	Irish Sea S.E.	70	Baltic Sea E. (bottom 53-163m)
35	Cumbrian Waters	71	Gulf of Finland
36	Irish Sea S.	72	Gulf of Riga

2.2 Sedimentation compartment structure

Two types of marine environment are defined for the purpose of modelling: deep and coastal. These two environments are chosen to represent the differences apparent in rates of processes in the deep ocean compared to that in the coastal environment. These differences can be influenced by many factors, such as sediment exchangeability and abundance of biota. Therefore, for coastal compartments, i.e. depths less than 200m, different parameter values for diffusion, sediment reworking and porewater turnover are listed in Table 2.

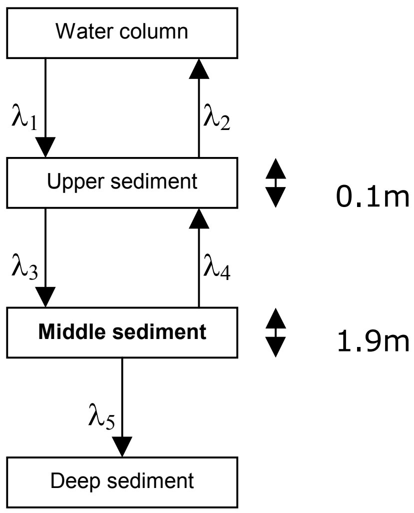


Figure 5 – Generic water:sediment compartment structure

For each water compartment directly in contact with the seabed (see section 2.5), the compartment structure shown in figure 5 is required to represent sedimentation.

The diffusion term is fully represented as: $\frac{D}{b.\min(b,c)}$, where b and c are the depths of sediment of the relevant two layers between which diffusion occurs. However, for all equations below, the diffusion term of the equation has been evaluated using the sediment layer depths shown in figure 5. Should these depths change, then the equations will require re-evaluation.

2.3 Sedimentation equations

The transfers between water and sediment compartments presented in Figure 5 are represented as follows:

λ_1 = Particle scavenging + Molecular diffusion + Porewater mixing + Particle mixing

$$\lambda_1 = \frac{S.k_d}{WD.(1+k_d.\alpha)} + \frac{D}{L_t.WD.(1+k_d.\alpha)} + \frac{R_T.\varepsilon.L_t}{WD.(1+k_d.\alpha)} + \frac{R_W.\rho.k_d.(1-\varepsilon)}{WD.(1+k_d.\alpha)}$$
(1)

Where:

k_d = sediment distribution coefficient $m^3\ t^{-1}$
S = sedimentation rate $t\ m^{-2}\ y^{-1}$ (Mitchell et al. 1999)
α = suspended sediment load $t\ m^{-3}$ (Mitchell et al. 1999)
D = diffusion (see Table 2)
WD = Water layer depth, m

L_t = upper sediment thickness (see Table 2)
ε = sediment porosity (see Table 2)
R_T = Pore-water turn over rate = 1 y^{-1} (Mitchell et al. 1999) for shallow seas (up to 200m depth), assume 0.1 per year for deep ocean
R_W = sediment reworking rate = 5 10^{-3} m y^{-1} (Mitchell et al. 1999) for shallow seas (up to 200m depth); 5 10^{-4} for deep seas
(Values of R_T and R_W for deep oceans taken from COLDOS (MacKenzie and Nicholson, 1987))
ρ = Density (see Table 2)

λ_2 = Molecular diffusion + porewater mixing + particle mixing

$$\lambda_2 = \frac{D.F_s}{L_t^{\,2}.\varepsilon} + R_T.F_S + \frac{R_W(1-F_S)}{L_t} \qquad (2)$$

Where:
D = diffusion
L_t = upper sediment depth
ε = sediment porosity
R_T = Pore-water turn over rate = (see above)
R_W = sediment reworking rate = (see above)

$$F_S = \frac{1}{1 + \frac{k_d.\rho.(1-\varepsilon)}{\varepsilon}} \qquad (3)$$

F_s is equivalent to 1/R (R = retardation coefficient) in (Simmonds et al. 1995)

λ_3 = sedimentation + diffusion

$$\lambda_3 = \frac{(1-F_s).S}{\rho.L_t.(1-\varepsilon)} + \frac{D.F_s}{L_t^{\,2}} \qquad (4)$$

λ_4 = diffusion

$$\lambda_4 = \frac{F_s.D}{L_m.L_t} \qquad (5)$$

where:

L_m = middle sediment depth (1.9m)

λ_5 = sedimentation

$$\lambda_5 = \frac{(1 - F_s).S}{L_m.(1 - \varepsilon).\rho} \quad (6)$$

2.4 Advective fluxes

For advective transfers, either vertically between water layers or horizontally between compartments, the following equation should be used:

$$k_{x,y} = \frac{\text{Water exchange rate from x to y}}{\text{Volume of x}}$$

The parameter, $k_{x,y}$ represents the transfer rate (y^{-1}) between compartment x and compartment y. This value is used to derive a first order differential equation representing inputs (e.g. discharges and incoming fluxes) and losses (e.g. decay, sedimentation and outgoing fluxes) from a model compartment.

2.5 Compartment and flux parameters

The parameters required for implementation of the model are contained in Tables 2 and 3. Table 2 describes the dimensions of the compartments and the key modelling parameters required for each compartment. A ‘1’ in the BC column of Table 2 indicates bottom layer compartments for which sediment compartments should be modelled. In general, radionuclide transport is modelled by an advective flux representing the action of currents. However, it should be noted that for deep compartments, especially in the Atlantic Ocean region, turbulent diffusion may have a significant contribution to radionuclide transport (in particular for vertical transport). Accordingly, turbulent diffusion has been modelled, where necessary, using a diffusion flux, complementary to the advective flux. Table 3 describes the fluxes between the compartments as advective and diffusive fluxes. These are summed to provide a total flux for implementation in the model.

Table 2: MARINA II model: Regional compartment characteristics

N°	Coa	Up	BC	Vol	Sed	Dp	SS	Dp Sed Up	Dp Sed Mid	PW Turnover	Sed Rework	Por	Dens	Diff
1	0	0	1	8.98E+17	3.00E-06	3.80E+03	1.00E-08	1.00E-01	1.90E+00	1.00E-01	5.00E-04	3.00E-01	2.60E+00	3.15E-03
2	0	0	0	1.02E+16	3.00E-06	1.00E+03	1.00E-08	1.00E-01	1.90E+00	1.00E-01	5.00E-04	3.00E-01	2.60E+00	3.15E-03
3	0	2	0	1.00E+16	3.00E-06	1.00E+03	1.00E-08	1.00E-01	1.90E+00	1.00E-01	5.00E-04	3.00E-01	2.60E+00	3.15E-03
4	0	3	1	2.10E+16	3.00E-06	2.00E+03	1.00E-08	1.00E-01	1.90E+00	1.00E-01	5.00E-04	3.00E-01	2.60E+00	3.15E-03
5	0	0	0	8.80E+15	3.00E-06	1.00E+03	1.00E-08	1.00E-01	1.90E+00	1.00E-01	5.00E-04	3.00E-01	2.60E+00	3.15E-03
6	0	5	0	1.14E+16	3.00E-06	1.00E+03	1.00E-08	1.00E-01	1.90E+00	1.00E-01	5.00E-04	3.00E-01	2.60E+00	3.15E-03
7	0	6	1	2.18E+16	3.00E-06	2.00E+03	1.00E-08	1.00E-01	1.90E+00	1.00E-01	5.00E-04	3.00E-01	2.60E+00	3.15E-03
8	0	0	0	5.80E+15	3.00E-06	1.00E+03	1.00E-08	1.00E-01	1.90E+00	1.00E-01	5.00E-04	3.00E-01	2.60E+00	3.15E-03
9	0	8	0	1.60E+16	3.00E-06	1.00E+03	1.00E-08	1.00E-01	1.90E+00	1.00E-01	5.00E-04	3.00E-01	2.60E+00	3.15E-03
10	0	9	1	3.51E+15	3.00E-06	2.00E+03	1.00E-08	1.00E-01	1.90E+00	1.00E-01	5.00E-04	3.00E-01	2.60E+00	3.15E-03
11	0	0	0	8.00E+15	3.00E-06	1.00E+03	1.00E-08	1.00E-01	1.90E+00	1.00E-01	5.00E-04	3.00E-01	2.60E+00	3.15E-03
12	0	11	0	2.20E+16	3.00E-06	1.00E+03	1.00E-08	1.00E-01	1.90E+00	1.00E-01	5.00E-04	3.00E-01	2.60E+00	3.15E-03
13	0	12	1	5.92E+15	3.00E-06	2.00E+03	1.00E-08	1.00E-01	1.90E+00	1.00E-01	5.00E-04	3.00E-01	2.60E+00	3.15E-03
14	0	0	0	7.45E+16	3.00E-06	1.00E+03	1.00E-08	1.00E-01	1.90E+00	1.00E-01	5.00E-04	3.00E-01	2.60E+00	3.15E-03
15	0	14	1	2.05E+17	3.00E-06	2.00E+03	1.00E-08	1.00E-01	1.90E+00	1.00E-01	5.00E-04	3.00E-01	2.60E+00	3.15E-03
16	0	0	1	1.69E+16	1.00E-05	1.20E+03	1.00E-07	1.00E-01	1.90E+00	1.00E-01	5.00E-04	7.50E-01	2.60E+00	3.15E-02
17	0	0	0	4.80E+15	3.00E-06	1.00E+03	1.00E-08	1.00E-01	1.90E+00	1.00E-01	5.00E-04	3.00E-01	2.60E+00	3.15E-03
18	0	17	1	2.28E+16	3.00E-06	2.00E+03	1.00E-08	1.00E-01	1.90E+00	1.00E-01	5.00E-04	3.00E-01	2.60E+00	3.15E-03
19	0	0	1	8.00E+13	1.00E-05	1.20E+03	1.00E-07	1.00E-01	1.90E+00	1.00E-01	5.00E-04	7.50E-01	2.60E+00	3.15E-02
20	1	0	1	1.20E+13	1.00E-05	1.90E+02	1.00E-07	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
21	1	0	1	1.60E+13	1.00E-05	2.00E+02	1.00E-07	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
22	1	0	1	7.00E+13	1.00E-05	5.00E+01	1.00E-07	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
23	1	0	1	1.02E+14	1.00E-05	1.70E+02	1.00E-07	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
24	1	0	1	2.00E+13	1.00E-05	1.00E+02	1.00E-07	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
25	0	0	1	1.61E+14	1.00E-05	3.80E+02	1.00E-07	1.00E-01	1.90E+00	1.00E-01	5.00E-04	7.50E-01	2.60E+00	3.15E-02

Table 2 (cont'd)

N°	Coa	Up	BC	Vol	Sed	Dp	SS	Dp Sed Up	Dp Sed Mid	PW Turnover	Sed Rework	Por	Dens	Diff
26	1	0	1	2.00E+13	1.00E-05	1.00E+02	1.00E-07	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
27	0	0	1	1.00E+15	1.00E-05	1.20E+03	1.00E-07	1.00E-01	1.90E+00	1.00E-01	5.00E-04	7.50E-01	2.60E+00	3.15E-02
28	1	0	1	1.00E+13	1.00E-04	1.10E+02	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
29	1	0	1	3.00E+12	1.00E-04	1.10E+02	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
30	1	0	1	4.08E+11	1.00E-04	9.30E+01	2.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
31	1	0	1	6.10E+10	1.00E-04	3.40E+01	2.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
32	1	0	1	5.20E+10	1.00E-04	2.40E+01	3.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
33	1	0	1	6.62E+11	1.00E-03	6.30E+01	3.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
34	1	0	1	1.62E+11	1.00E-04	3.10E+01	2.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
35	1	0	1	3.80E+10	6.00E-03	2.80E+01	1.00E-05	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
36	1	0	1	1.10E+12	1.00E-04	5.70E+01	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
37	1	0	1	3.20E+10	5.00E-03	1.30E+01	3.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
38	1	0	1	2.02E+13	1.00E-04	1.50E+02	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
39	1	0	1	1.00E+12	1.00E-04	5.00E+01	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
40	0	0	1	6.50E+14	1.00E-05	4.00E+03	1.00E-07	1.00E-01	1.90E+00	1.00E-01	5.00E-04	7.50E-01	2.60E+00	3.15E-02
41	0	0	1	3.50E+13	1.00E-04	3.50E+02	5.00E-07	1.00E-01	1.90E+00	1.00E-01	5.00E-04	7.50E-01	2.60E+00	3.15E-02
42	0	0	1	3.00E+13	2.00E-04	7.60E+02	1.00E-06	1.00E-01	1.90E+00	1.00E-01	5.00E-04	7.50E-01	2.60E+00	3.15E-02
43	0	0	1	1.50E+13	2.00E-04	4.90E+02	1.00E-06	1.00E-01	1.90E+00	1.00E-01	5.00E-04	7.50E-01	2.60E+00	3.15E-02
44	0	0	1	2.30E+14	5.00E-05	1.70E+03	2.00E-07	1.00E-01	1.90E+00	1.00E-01	5.00E-04	7.50E-01	2.60E+00	3.15E-02
45	0	0	1	3.91E+15	7.50E-05	1.40E+03	1.00E-06	1.00E-01	1.90E+00	1.00E-01	5.00E-04	7.50E-01	2.60E+00	3.15E-02
46	1	0	1	1.41E+12	1.00E-04	7.77E+01	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
47	1	0	1	6.99E+11	1.00E-04	4.72E+01	3.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
48	1	0	1	6.16E+11	1.00E-04	6.68E+01	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
49	1	0	1	2.01E+11	1.00E-04	3.95E+01	3.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
50	1	0	1	2.62E+11	1.00E-04	3.43E+01	3.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02

Table 2 (cont'd)

N°	Coa	Up	BC	Vol	Sed	Dp	SS	Dp Sed Up	Dp Sed Mid	PW Turnover	Sed Rework	Por	Dens	Diff
51	1	0	1	9.94E+10	1.00E-04	2.53E+01	3.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
52	1	0	1	4.08E+11	1.00E-04	4.90E+01	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
53	1	0	1	3.02E+11	1.00E-04	4.90E+01	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
54	1	0	1	1.53E+11	1.00E-04	2.95E+01	5.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
55	1	0	1	4.50E+11	1.00E-04	3.10E+01	6.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
56	1	0	1	9.50E+11	1.00E-04	3.70E+01	6.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
57	1	0	1	1.28E+13	1.00E-04	5.00E+01	6.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
58	1	0	1	1.20E+12	1.00E-04	2.20E+01	6.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
59	0	0	1	5.60E+13	1.00E-04	2.40E+02	6.00E-06	1.00E-01	1.90E+00	1.00E-01	5.00E-04	7.50E-01	2.60E+00	3.15E-02
60	0	0	1	6.78E+12	5.00E-03	2.10E+02	1.00E-06	1.00E-01	1.90E+00	1.00E-01	5.00E-04	7.50E-01	2.60E+00	3.15E-02
61	1	0	0	3.20E+11	7.50E-04	2.00E+01	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
62	1	61	1	2.00E+11	7.50E-04	1.00E+02	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
63	1	0	0	1.50E+11	7.50E-04	1.40E+01	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
64	1	63	1	1.40E+11	7.50E-04	3.00E+01	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
65	1	0	1	1.48E+12	5.00E-04	4.10E+01	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
66	1	0	1	4.89E+12	5.00E-04	6.20E+01	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
67	1	0	0	3.79E+12	5.00E-04	4.90E+01	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
68	1	0	0	6.97E+12	5.00E-04	5.30E+01	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
69	1	67	1	7.70E+11	5.00E-04	1.10E+02	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
70	1	68	1	1.53E+12	5.00E-04	1.10E+02	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
71	1	0	1	1.10E+12	5.00E-04	3.70E+01	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02
72	1	0	1	4.05E+11	5.00E-04	2.30E+01	1.00E-06	1.00E-01	1.90E+00	1.00E+00	5.00E-03	7.50E-01	2.60E+00	3.15E-02

Table 2 (cont'd)

Legend :

Coa	Coastal compartment (depth≤200m)	Dp	Depth in m	PW Turnover	Pore-water turnover rate in y^{-1}
Up	N° upper compartment	SS	Suspended sed. load in t m^{-3}	Sed Rework	Sediment reworking rate in m y^{-1}
BC	Bottom compartment	Dp Sed Up	Depth of upper sed. layer in m	Por	Porosity of bottom sediments
Vol	Volume in m^3	Dp Sed Mid	Depth of middle sed. layer in m	Dens	Density of bottom sediments in t m^{-3}
Sed	Sed rate in t m^{-2} y^{-1}			Diff	Diffusion coefficient in m^2 y^{-1}

Table 3: MARINA II model: Regional compartment characteristics

Orig .No.	Originating compartment	Dest. No.	Destination compartment	Advection ($m^3 y^{-1}$)	Diffusion ($m^3 y^{-1}$)	Total ($m^3 y^{-1}$)
1	Other oceans	14	Atlantic South (surface)	5.36E+14		5.36E+14
1	Other oceans	15	Atlantic South (deep)	1.58E+14		1.58E+14
2	Atlantic North N.E. (surface water)	3	Atlantic North N.E. (middle)		3.19E+13	3.19E+13
2	Atlantic North N.E. (surface water)	5	Atlantic North N.W. (surface)	1.74E+14	2.98E+13	2.03E+14
2	Atlantic North N.E. (surface water)	8	Atlantic North S.E. (surface)	3.39E+14	4.71E+13	3.86E+14
2	Atlantic North N.E. (surface water)	17	Arctic South (surface)	3.47E+14		3.47E+14
2	Atlantic North N.E. (surface water)	40	Bay of Biscay	6.70E+14		6.70E+14
2	Atlantic North N.E. (surface water)	42	Cantabrian Sea	1.11E+14		1.11E+14
2	Atlantic North N.E. (surface water)	43	Portuguese Continental Shelf	4.60E+14		4.60E+14
2	Atlantic North N.E. (surface water)	44	Gulf of Cadiz	5.10E+14		5.10E+14
3	Atlantic North N.E. (middle water)	2	Atlantic North N.E. (surface)	2.00E+14		2.00E+14
3	Atlantic North N.E. (middle water)	4	Atlantic North N.E. (deep)		3.22E+13	3.22E+13
3	Atlantic North N.E. (middle water)	6	Atlantic North N.W. (middle)	3.16E+13	2.98E+13	6.14E+13
3	Atlantic North N.E. (middle water)	9	Atlantic North S.E. (middle)	3.16E+13	4.71E+13	7.87E+13
4	Atlantic North N.E. (deep water)	9	Atlantic North S.E. (middle)		7.07E+13	7.07E+13
4	Atlantic North N.E. (deep water)	10	Atlantic North S.E. (deep)	1.58E+13	4.36E+13	5.93E+13
4	Atlantic North N.E. (deep water)	18	Arctic South (deep)	3.16E+13		3.16E+13
5	Atlantic North N.W. (deep water)	2	Atlantic North N.E. (surface)	3.79E+14		3.79E+14
5	Atlantic North N.W. (deep water)	6	Atlantic North N.W. (middle)	4.42E+13	2.78E+13	7.20E+13
5	Atlantic North N.W. (surface water)	11	Atlantic North S.W. (surface)	3.79E+14	5.93E+13	4.38E+14
5	Atlantic North N.W. (surface water)	17	Arctic South (surface)	3.31E+13		3.31E+13
6	Atlantic North N.W. (middle water)	5	Atlantic North N.W. (surface)	2.76E+13		2.76E+13
6	Atlantic North N.W. (middle water)	7	Atlantic North N.W. (deep)	4.26E+13	2.84E+13	7.10E+13
6	Atlantic North N.W. (middle water)	12	Atlantic North S.W. (middle)	5.05E+13	5.93E+13	1.10E+14
6	Atlantic North N.W. (middle water)	18	Arctic South (deep)	1.34E+13		1.34E+13
7	Atlantic North N.W. (deep water)	12	Atlantic North S.W. (middle)	2.84E+13	8.89E+13	1.17E+14
7	Atlantic North N.W. (deep water)	13	Atlantic North S.W. (deep)	3.00E+14	5.48E+13	3.55E+14
7	Atlantic North N.W. (deep water)	18	Arctic South (deep)	1.51E+13		1.51E+13
8	Atlantic North S.E. (surface water)	2	Atlantic North N.E. (surface)	4.81E+14		4.81E+14
8	Atlantic North S.E. (surface water)	9	Atlantic North S.E. (middle)		1.77E+13	1.77E+13
8	Atlantic North S.E. (surface water)	11	Atlantic North S.W. (surface)	1.74E+14	2.63E+13	2.00E+14
8	Atlantic North S.E. (surface water)	14	Atlantic South (surface)	1.26E+14	5.76E+13	1.84E+14
9	Atlantic North S.E. (middle water)	3	Atlantic North N.E. (middle)	4.73E+13		4.73E+13
9	Atlantic North S.E. (middle water)	10	Atlantic North S.E. (deep)		1.20E+13	1.20E+13
9	Atlantic North S.E. (middle water)	12	Atlantic North S.W. (middle)	3.16E+13	6.58E+13	9.74E+13
9	Atlantic North S.E. (middle water)	15	Atlantic South (deep)	1.58E+13	1.44E+14	1.60E+14
10	Atlantic North S.E. (deep water)	4	Atlantic North N.E. (deep)	3.16E+13		3.16E+13
10	Atlantic North S.E. (deep water)	15	Atlantic South (deep)	1.58E+13	5.33E+13	6.91E+13
11	Atlantic North S.W. (surface water)	5	Atlantic North N.W. (surface)	5.76E+14		5.76E+14
11	Atlantic North S.W. (surface water)	8	Atlantic North S.E. (surface)	3.79E+14		3.79E+14
11	Atlantic North S.W. (surface water)	12	Atlantic North S.W. (middle)	7.89E+12	2.52E+13	3.31E+13
11	Atlantic North S.W. (surface water)	14	Atlantic South (surface)		2.54E+13	2.54E+13
12	Atlantic North S.W. (middle water)	6	Atlantic North N.W. (middle)	7.89E+12		7.89E+12
12	Atlantic North S.W. (middle water)	13	Atlantic North S.W. (deep)		2.52E+13	2.52E+13
12	Atlantic North S.W. (middle water)	15	Atlantic South (deep)	1.10E+14	6.35E+13	1.74E+14
13	Atlantic North S.W. (deep water)	15	Atlantic South (deep)	3.00E+14	2.35E+13	3.23E+14

Table 3 (cont'd)

Orig. No.	Originating compartment	Dest. No.	Destination compartment	Advection (m^3 y^{-1})	Diffusion (m^3 y^{-1})	Total (m^3 y^{-1})
14	Atlantic South (surface water)	1	Other oceans	1.74E+14	9.02E+13	2.64E+14
14	Atlantic South (surface water)	8	Atlantic North S.E. (surface)	6.31E+13		6.31E+13
14	Atlantic South (surface water)	11	Atlantic North S.W. (surface)	4.10E+14		4.10E+14
14	Atlantic South (surface water)	15	Atlantic South (deep)	1.41E+14	1.89E+14	3.30E+14
15	Atlantic South (deep water)	1	Other oceans	5.21E+14	3.09E+14	8.30E+14
15	Atlantic South (deep water)	9	Atlantic North S.E. (middle)	6.31E+13		6.31E+13
15	Atlantic South (deep water)	10	Atlantic North S.E. (deep)	3.16E+13		3.16E+13
15	Atlantic South (deep water)	14	Atlantic South (surface)	1.26E+14		1.26E+14
16	Arctic Ocean	17	Arctic South (surface)	1.46E+14		1.46E+14
16	Arctic Ocean	25	Barents Sea (B3)	9.45E+12		9.45E+12
17	Arctic South (surface water)	2	Atlantic North N.E. (surface)		2.99E+13	2.99E+13
17	Arctic South (surface water)	5	Atlantic North N.W. (surface)	5.76E+13	2.87E+13	8.63E+13
17	Arctic South (surface water)	18	Arctic South (deep)	3.42E+14	1.64E+13	3.58E+14
17	Arctic South (surface water)	19	Spitzbergen	1.00E+14		1.00E+14
17	Arctic South (surface water)	23	Barents Sea (B1)	4.97E+13		4.97E+13
17	Arctic South (surface water)	24	Barents Sea (B2)	6.90E+12		6.90E+12
17	Arctic South (surface water)	28	Scottish Waters W.	1.04E+13		1.04E+13
17	Arctic South (surface water)	38	Celtic Sea	1.03E+13		1.03E+13
17	Arctic South (surface water)	59	North Sea N.	4.60E+13		4.60E+13
18	Arctic South (deep water)	3	Atlantic North N.E. (middle)	1.58E+13	2.99E+13	4.57E+13
18	Arctic South (deep water)	4	Atlantic North N.E. (deep)	1.58E+13	7.25E+13	8.83E+13
18	Arctic South (deep water)	6	Atlantic North N.W. (middle)	5.05E+13	2.87E+13	7.92E+13
18	Arctic South (deep water)	7	Atlantic North N.W. (deep)	3.01E+14	6.96E+13	3.70E+14
18	Arctic South (deep water)	17	Arctic South (surface)	1.97E+13		1.97E+13
19	Spitzbergen	16	Arctic Ocean	8.00E+13		8.00E+13
19	Spitzbergen	17	Arctic South (surface)	2.00E+13		2.00E+13
20	Kara Sea (K1)	16	Arctic Ocean	5.36E+12		5.36E+12
20	Kara Sea (K1)	22	Kara Sea (K2)	2.84E+13		2.84E+13
20	Kara Sea (K1)	26	Barents Sea (B4)	9.45E+11		9.45E+11
22	Kara Sea (K2)	16	Arctic Ocean	2.93E+13		2.93E+13
23	Barents Sea (B1)	20	Kara Sea (K1)	1.89E+13		1.89E+13
23	Barents Sea (B1)	26	Barents Sea (B4)	7.31E+13		7.31E+13
23	Barents Sea (B1)	27	Norwegian Waters	3.15E+13		3.15E+13
24	Barents Sea (B2)	17	Arctic South (surface)	1.89E+13		1.89E+13
25	Barents Sea (B3)	16	Arctic Ocean	6.30E+12		6.30E+12
25	Barents Sea (B3)	23	Barents Sea (B1)	9.45E+12		9.45E+12
26	Barents Sea (B4)	16	Arctic Ocean	3.62E+13		3.62E+13
26	Barents Sea (B4)	20	Kara Sea (K1)	1.58E+13		1.58E+13
26	Barents Sea (B4)	25	Barents Sea (B3)	6.30E+12		6.30E+12
27	Norwegian Waters	17	Arctic South (surface)	3.15E+13		3.15E+13
27	Norwegian Waters	23	Barents Sea (B1)	4.80E+13		4.80E+13
27	Norwegian Waters	24	Barents Sea (B2)	1.20E+13		1.20E+13
28	Scottish Waters W.	17	Arctic South (surface)	9.00E+11		9.00E+11
28	Scottish Waters W.	29	Scottish Waters E.	1.07E+13		1.07E+13
28	Scottish Waters W.	30	Irish Sea N.W.	2.00E+11		2.00E+11
29	Scottish Waters E.	28	Scottish Waters W.	5.00E+11		5.00E+11

Table 3 (cont'd)

Orig. No.	Originating compartment	Dest. No.	Destination compartment	Advection ($m^3 y^{-1}$)	Diffusion ($m^3 y^{-1}$)	Total ($m^3 y^{-1}$)
29	Scottish Waters E.	57	North Sea Central	8.00E+12		8.00E+12
29	Scottish Waters E.	59	North Sea N.	2.40E+12		2.40E+12
30	Irish Sea N.W.	28	Scottish Waters W.	9.20E+11		9.20E+11
30	Irish Sea N.W.	31	Irish Sea N.	3.33E+11		3.33E+11
30	Irish Sea N.W.	33	Irish Sea W.	5.00E+11		5.00E+11
31	Irish Sea N.	30	Irish Sea N.W.	8.33E+11		8.33E+11
31	Irish Sea N.	32	Irish Sea N.E.	1.83E+11		1.83E+11
31	Irish Sea N.	34	Irish Sea S.E.	1.73E+11		1.73E+11
32	Irish Sea N.E.	31	Irish Sea N.	2.88E+11		2.88E+11
32	Irish Sea N.E.	35	Cumbrian Waters	1.00E+11		1.00E+11
33	Irish Sea W.	30	Irish Sea N.W.	7.20E+11		7.20E+11
33	Irish Sea W.	34	Irish Sea S.E.	9.33E+11		9.33E+11
33	Irish Sea W.	36	Irish Sea S.	6.00E+11		6.00E+11
34	Irish Sea S.E.	31	Irish Sea N.	5.68E+11		5.68E+11
34	Irish Sea S.E.	33	Irish Sea W.	4.33E+11		4.33E+11
34	Irish Sea S.E.	35	Cumbrian Waters	2.30E+11		2.30E+11
34	Irish Sea S.E.	36	Irish Sea S.	7.50E+10		7.50E+10
34	Irish Sea S.E.	37	Liverpool and Morecambe Bays	1.29E+11		1.29E+11
35	Cumbrian Waters	32	Irish Sea N.E.	2.05E+11		2.05E+11
35	Cumbrian Waters	34	Irish Sea S.E.	1.45E+11		1.45E+11
35	Cumbrian Waters	37	Liverpool and Morecambe Bays	3.50E+10		3.50E+10
36	Irish Sea S.	33	Irish Sea W.	1.32E+12		1.32E+12
36	Irish Sea S.	34	Irish Sea S.E.	7.50E+10		7.50E+10
36	Irish Sea S.	38	Celtic Sea	6.00E+11		6.00E+11
37	Liverpool and Morecambe Bays	34	Irish Sea S.E.	1.09E+11		1.09E+11
37	Liverpool and Morecambe Bays	35	Cumbrian Waters	5.50E+10		5.50E+10
38	Celtic Sea	17	Arctic South (surface)	2.60E+12		2.60E+12
38	Celtic Sea	36	Irish Sea S.	1.32E+12		1.32E+12
38	Celtic Sea	39	Bristol Channel	2.00E+12		2.00E+12
38	Celtic Sea	40	Bay of Biscay	1.50E+14		1.50E+14
38	Celtic Sea	41	French Continental Shelf	1.40E+14		1.40E+14
38	Celtic Sea	46	English Channel W.	8.65E+12		8.65E+12
39	Bristol Channel	38	Celtic Sea	2.00E+12		2.00E+12
40	Bay of Biscay	2	Atlantic North N.E. (surface)	5.70E+14		5.70E+14
40	Bay of Biscay	3	Atlantic North N.E. (middle)	1.00E+14		1.00E+14
40	Bay of Biscay	38	Celtic Sea	1.50E+14		1.50E+14
40	Bay of Biscay	41	French Continental Shelf	5.80E+14		5.80E+14
40	Bay of Biscay	42	Cantabrian Sea	3.90E+14		3.90E+14
41	French Continental Shelf	38	Celtic Sea	1.40E+14		1.40E+14
41	French Continental Shelf	40	Bay of Biscay	5.80E+14		5.80E+14
41	French Continental Shelf	42	Cantabrian Sea	7.50E+13		7.50E+13
42	Cantabrian Sea	2	Atlantic North N.E. (surface)	1.10E+14		1.10E+14
42	Cantabrian Sea	40	Bay of Biscay	3.90E+14		3.90E+14
42	Cantabrian Sea	41	French Continental Shelf	7.50E+13		7.50E+13
42	Cantabrian Sea	43	Portuguese Continental Shelf	1.50E+13		1.50E+13

Table 3 (cont'd)

Orig. No.	Originating compartment	Dest. No.	Destination compartment	Advection ($m^3 y^{-1}$)	Diffusion ($m^3 y^{-1}$)	Total ($m^3 y^{-1}$)
43	Portuguese Continental Shelf	2	Atlantic North N.E. (surface)	4.60E+14		4.60E+14
43	Portuguese Continental Shelf	42	Cantabrian Sea	1.30E+13		1.30E+13
43	Portuguese Continental Shelf	44	Gulf of Cadiz	6.00E+13		6.00E+13
44	Gulf of Cadiz	2	Atlantic North N.E. (surface)	4.10E+14		4.10E+14
44	Gulf of Cadiz	3	Atlantic North N.E. (middle)	1.00E+14		1.00E+14
44	Gulf of Cadiz	43	Portuguese Continental Shelf	5.80E+13		5.80E+13
44	Gulf of Cadiz	45	Mediterranean Sea	5.29E+13		5.29E+13
45	Mediterranean Sea	44	Gulf of Cadiz	5.06E+13		5.06E+13
46	English Channel W.	38	Celtic Sea	3.69E+12		3.69E+12
46	English Channel W.	47	Channel Islands	2.95E+12		2.95E+12
46	English Channel W.	48	Cap de la Hague	3.30E+12		3.30E+12
46	English Channel W.	49	Lyme Bay	1.27E+12		1.27E+12
47	Channel Islands	46	English Channel W.	1.51E+12		1.51E+12
47	Channel Islands	48	Cap de la Hague	6.25E+12		6.25E+12
48	Cap de la Hague	46	English Channel W.	8.97E+11		8.97E+11
48	Cap de la Hague	47	Channel Islands	4.81E+12		4.81E+12
48	Cap de la Hague	49	Lyme Bay	2.73E+12		2.73E+12
48	Cap de la Hague	52	Central Channel S.E.	4.97E+12		4.97E+12
48	Cap de la Hague	53	Central Channel N.E.	1.07E+12		1.07E+12
49	Lyme Bay	46	English Channel W.	1.56E+11		1.56E+11
49	Lyme Bay	48	Cap de la Hague	3.41E+12		3.41E+12
49	Lyme Bay	54	Isle of Wight	6.29E+11		6.29E+11
50	Baie de la Seine	51	Sam's Beach	7.70E+11		7.70E+11
50	Baie de la Seine	52	Central Channel S.E.	2.61E+12		2.61E+12
51	Sam's Beach	50	Baie de la Seine	1.70E+11		1.70E+11
51	Sam's Beach	52	Central Channel S.E.	6.53E+12		6.53E+12
51	Sam's Beach	56	North Sea S.E.	6.07E+11		6.07E+11
52	Central Channel S.E.	48	Cap de la Hague	1.24E+12		1.24E+12
52	Central Channel S.E.	50	Baie de la Seine	3.21E+12		3.21E+12
52	Central Channel S.E.	51	Sam's Beach	6.38E+12		6.38E+12
52	Central Channel S.E.	53	Central Channel N.E.	9.45E+12		9.45E+12
52	Central Channel S.E.	56	North Sea S.E.	2.43E+12		2.43E+12
53	Central Channel N.E.	48	Cap de la Hague	2.86E+11		2.86E+11
53	Central Channel N.E.	52	Central Channel S.E.	8.43E+12		8.43E+12
53	Central Channel N.E.	54	Isle of Wight	6.89E+12		6.89E+12
53	Central Channel N.E.	56	North Sea S.E.	1.92E+12		1.92E+12
54	Isle of Wight	49	Lyme Bay	1.95E+11		1.95E+11
54	Isle of Wight	53	Central Channel N.E.	6.85E+12		6.85E+12
54	Isle of Wight	56	North Sea S.E.	5.47E+11		5.47E+11
55	North Sea S.W.	56	North Sea S.E.	6.09E+11		6.09E+11
55	North Sea S.W.	57	North Sea Central	3.81E+11		3.81E+11
56	North Sea S.E.	51	Sam's Beach	1.60E+11		1.60E+11
56	North Sea S.E.	52	Central Channel S.E.	1.63E+11		1.63E+11
56	North Sea S.E.	53	Central Channel N.E.	1.47E+11		1.47E+11
56	North Sea S.E.	54	Isle of Wight	7.60E+10		7.60E+10
56	North Sea S.E.	55	North Sea S.W.	2.94E+11		2.94E+11

Table 3 (cont'd)

Orig. No.	Originating compartment	Dest. No.	Destination compartment	Advection ($m^3 y^{-1}$)	Diffusion ($m^3 y^{-1}$)	Total ($m^3 y^{-1}$)
56	North Sea S.E.	57	North Sea Central	5.12E+11		5.12E+11
56	North Sea S.E.	58	North Sea E.	5.01E+12		5.01E+12
57	North Sea Central	29	Scottish Waters E.	1.00E+11		1.00E+11
57	North Sea Central	55	North Sea S.W.	6.96E+11		6.96E+11
57	North Sea Central	56	North Sea S.E.	5.40E+10		5.40E+10
57	North Sea Central	58	North Sea E.	2.66E+12		2.66E+12
57	North Sea Central	59	North Sea N.	8.96E+12		8.96E+12
57	North Sea Central	60	Skagerrak	2.68E+11		2.68E+11
58	North Sea E.	56	North Sea S.E.	1.50E+11		1.50E+11
58	North Sea E.	57	North Sea Central	1.63E+12		1.63E+12
58	North Sea E.	60	Skagerrak	5.90E+12		5.90E+12
59	North Sea N.	17	Arctic South (surface)	1.73E+12		1.73E+12
59	North Sea N.	27	Norwegian Waters	6.00E+13		6.00E+13
59	North Sea N.	29	Scottish Waters E.	1.00E+11		1.00E+11
59	North Sea N.	57	North Sea Central	2.05E+12		2.05E+12
59	North Sea N.	60	Skagerrak	2.58E+13		2.58E+13
60	Skagerrak	57	North Sea Central	1.68E+11		1.68E+11
60	Skagerrak	58	North Sea E.	1.00E+10		1.00E+10
60	Skagerrak	59	North Sea N.	3.23E+13		3.23E+13
60	Skagerrak	62	Kattegat (deep)	1.50E+12		1.50E+12
61	Kattegat (surface water)	60	Skagerrak	2.00E+12		2.00E+12
61	Kattegat (surface water)	62	Kattegat (deep)	1.00E+11		1.00E+11
62	Kattegat (deep water)	61	Kattegat (surface)	9.30E+11		9.30E+11
62	Kattegat (deep water)	64	Belt Sea (deep)	7.20E+11		7.20E+11
63	Belt Sea (surface water)	61	Kattegat (surface)	1.20E+12		1.20E+12
63	Belt Sea (surface water)	64	Belt Sea (deep)	7.00E+11		7.00E+11
64	Belt Sea (deep water)	63	Belt Sea (surface)	9.30E+11		9.30E+11
64	Belt Sea (deep water)	68	Baltic Sea E. (surface)	2.70E+11		2.70E+11
64	Belt Sea (deep water)	70	Baltic Sea E. (deep)	2.20E+11		2.20E+11
65	Bothnian Bay	66	Bothnian Sea	2.75E+11		2.75E+11
66	Bothnian Sea	65	Bothnian Bay	1.75E+11		1.75E+11
66	Bothnian Sea	67	Baltic Sea W. (surface)	7.15E+11		7.15E+11
67	Baltic Sea W. (surface water)	68	Baltic Sea E. (surface)	6.97E+12		6.97E+12
67	Baltic Sea W. (surface water)	69	Baltic Sea W. (deep)	1.07E+11		1.07E+11
68	Baltic Sea E. (surface water)	66	Bothnian Sea	5.25E+11		5.25E+11
68	Baltic Sea E. (surface water)	67	Baltic Sea W. (surface)	6.97E+12		6.97E+12
68	Baltic Sea E. (surface water)	70	Baltic Sea E. (deep)	2.08E+11		2.08E+11
68	Baltic Sea E. (surface water)	71	Gulf of Finland	5.95E+11		5.95E+11
68	Baltic Sea E. (surface water)	72	Gulf of Riga	3.12E+11		3.12E+11
69	Baltic Sea W. (deep water)	63	Belt Sea (surface)	2.20E+11		2.20E+11
69	Baltic Sea W. (deep water)	67	Baltic Sea W. (surface)	1.07E+11		1.07E+11
69	Baltic Sea W. (deep water)	70	Baltic Sea E. (deep)	2.20E+11		2.20E+11
70	Baltic Sea E. (deep water)	68	Baltic Sea E. (surface)	2.08E+11		2.08E+11
70	Baltic Sea E. (deep water)	69	Baltic Sea W. (deep)	4.40E+11		4.40E+11
71	Gulf of Finland	68	Baltic Sea E. (surface)	7.20E+11		7.20E+11
72	Gulf of Riga	68	Baltic Sea E. (surface)	3.44E+11		3.44E+11

3 Recommendations for amendments to sediment K_ds and biota concentration factors (CF)

A review of K_d and CF references has been carried out. The concentration factors for sediment and biota for a large selection of radionuclides, given in the papers, recommended changes from the current values. Review of those recommended changes has been carried out and the recommendations justified. This section provides recommended values. The units for concentration factors are Bq t^{-1} (wet mass) per Bq m^{-3}, for K_d, the units are Bq t^{-1} (dry sediment) per Bq m^{-3}.

Where a suggested change is based on the results from a laboratory study, it is considered inappropriate to make the change. This is mainly due to the difficulty in finding the correct equilibrium between the biota and the environment when carrying out and interpreting laboratory studies. This often leads to lower values than those derived from environmental measurements.

3.1 Coastal Sediment K_ds

3.1.1 Americium

Mitchell et al. 1999 suggest compartment-dependent K_d s for the Irish Sea for americium.

3.1.2 Cobalt

In Mahara and Kudo, 1981, the K_d for cobalt-60 varies considerably depending on whether the conditions are anaerobic or aerobic. The K_d is higher for deep water than for coastal water.

3.1.3 Caesium

A lower K_d value is recommended for coastal regions and the Irish Sea. The higher K_d for silt/clay is recommended to be used in areas where the bottom sediment is known to be dominated by silt/clay e.g. parts of the North sea. Otherwise a default value of 230 should be used, based on work carried out for the UK Environment Agency in Sellafield (Goshawk and Clarke, 2001) and (McDonald et al. 1992), which recommend coastal K_ds around the coast of the UK of about 200.

3.1.4 Iodine

The recommended value is appropriate for a high concentration of iodine in seawater, this may be lower if runoff of freshwater from the land is high and the K_d may be correspondingly higher ((Bishop et al. 1989) suggests 70).

3.1.5 Neptunium

The recommended K_d is based on the range in Bishop et al. 1989 and the mean IAEA values (IAEA, 1985).

3.1.6 Lead

These are taken from (McDonald et al. 1992) for coastal K_ds around the UK. The IAEA K_ds (IAEA, 1985) are deep water K_ds, based on older references and the IAEA assume that K_ds for coastal waters are the same as for deep waters.

3.1.7 Plutonium

Mitchell et al. 1999 have suggested compartment dependent K_ds for the Irish sea.

3.1.8 Zirconium

Pentreath, 1985 indicates that the K_d should be lower than the IAEA recommended value (IAEA 1985), but recent work on the Irish sea (Goshawk and Clarke, 2001), considers this should be similar to the IAEA mean.

3.1.9 Recommended values for coastal sediment K_ds (Bq kg^{-1} per Bq l^{-1})

Radionuclide	Generic		Irish sea only		IAEA (Mean)
	Recommended value	Reference	Value	Reference	
Am[1]	$2\ 10^{6}$	A; B	$1\ 10^{5}$	C; D	$2\ 10^{6}$
Co[2]	$2\ 10^{5}$		$2.5\ 10^{3}$	D	$2\ 10^{5}$
Cm	$2\ 10^{6}$				$2\ 10^{6}$
Cs[3]	230 (coastal sediment)	D; F	230	D; E; F	$3\ 10^{3}$
	$3\ 10^{3}$ (silt/clay)			D	
I [4]	$2\ 10^{1}$				20
Np[5]	$1\ 10^{3}$	G			$1\ 10^{3}$
Pb[6]	$5\ 10^{3}$	G			$2\ 10^{5}$
Po[6]	$1\ 10^{4}$	G			$2\ 10^{7}$
Pu[7]	$1\ 10^{5}$	G; H	$1\ 10^{5}$		$1\ 10^{5}$
U	$1\ 10^{3}$	F			$1\ 10^{3}$
Zn	$2\ 10^{4}$				$2\ 10^{4}$
Zr[8]	$1\ 10^{6}$				10^{6}
Ru	$3\ 10^{2}$		710	D	$3\ 10^{2}$

References
A: (Burton et al. 1986)
B: (Mitchell et al. 1999)
C: (Mcdonald et al. 2001)
D: (Goshawk and Clarke, 2001)
E: (Pentreath, 1985)
F: (McDonald et al. 1992)
G: (Bishop et al. 1989)
H: (Skipperud et al. 2000)

3.2 Deep Sediment K_ds

3.2.1 Technetium

Bishop et al. 1989 recommended a K_d value of $1\ 10^{3}$ for sediments rich in organic matter and under anoxic conditions.

3.2.2 Recommended values for deep ocean sediment (Bq kg^{-1} per Bq l^{-1})

Radionuclide	Recommended value	Reference	Old IAEA (Mean)
I	$2\ 10^{2}$		$2\ 10^{2}$
Np	$1\ 10^{3}$		$1\ 10^{3}$
Tc[1]	$1\ 10^{3}$	A	$1\ 10^{2}$

References
A: (Bishop et al. 1989)

3.3 Concentration Factors for Fish

The values recommended in IAEA 1985 have been used except where indicated.

3.3.1 Americium

The value suggested by Coughtrey et al. (1984) is higher than that given by IAEA and has ben used in this study. The concentration factors given by Swift and Kershaw, 1999 are based on fish that is less likely to be eaten in Europe, i.e sharks and rays.

3.3.2 Cobalt

The concentration factors given in (Harrison, 1985) are based on a laboratory study and are much smaller than field measurements, so the IAEA value has been retained.

3.3.3 Iron

The concentration factor for fish varies considerably depending on the location of the measurement. Pentreath, 1977 has suggested CFs for North Sea and North Atlantic Ocean, which have been used in this study.

3.3.4 Polonium

Swift and Kershaw, (1999) and Pentreath, (1977) have suggested that high concentrations of polonium are found in larger fish.

3.3.5 Plutonium

Swift and Kershaw, (1999) and Gomez et al. (1985) have suggested higher values for concentration factors in fish for plutonium than those recommended by the IAEA.

3.3.6 Antimony

The concentration factor for antimony varies considerably and Pentreath, (1977) has suggested a lower value of about 10 in UK waters in the south. A recent study in France (Nord-Cotentin, 2000) recommends 20. Since there is a discrepancy between the IAEA and other references it was decided to leave the value the same as the IAEA value of 400 (IAEA, 1985).

3.3.7 Technetium

A number of authors (Bishop et al. 1989), (Beasley and Lorz, 1986), and (Thomson et al. 1972), have suggested a low CF of about 10 but the Nord-Cotentin study (Nord-Cotentin 2000) suggested a value of 80. Since there is a discrepancy between the different references it was decided to retain the IAEA 1985 value of 30.

3.3.8 Recommended values for fish concentration factors Bq t^{-1} per Bq m^{-3} (wet weight)

Nuclide	Recommended value	Reference	IAEA (Mean)
Am	$1\ 10^2$	A	$5\ 10^1$
Co	$1\ 10^3$		$1\ 10^3$
Cr	$2\ 10^2$		$2\ 10^2$
Cs	$1\ 10^2$		$1\ 10^2$
Fe	$5\ 10^2$	B	$3\ 10^3$
I	$1\ 10^1$		$1\ 10^1$
Po	$2\ 10^4$	C; D	$2\ 10^3$
Pu	$1\ 10^2$	C; D	$4\ 10^1$
Ru	2		2
Sb	$4\ 10^2$		$4\ 10^2$
Sr	2		2
Tc	$3\ 10^1$		$3\ 10^1$
Zn	$1\ 10^3$		$1\ 10^3$

References
A: (Coughtrey et al. 1984)
B: (Pentreath, 1977)
C: (Swift and Kershaw, 1999)
D: (Gomez et al. 1985)

3.4 Concentration Factors for Lobsters and crustacea

3.4.1 Plutonium

Swift and Kershaw, (1999) have suggested a value of $1.9\ 10^2$. This was based on two laboratory studies and an environmental study. The range of all three studies was 75-250, therefore the value of 300 taken from (IAEA, 1985) appears to be too large. Baxter et al. (1995) have presented a value of $2.0\ 10^4$ for prawns taken from the Irish Sea, and a value of around 80 for crabs from the Northeast Pacific. Gomez et al. (1985) have suggest a value of 5 based on a laboratory study, while an in-situ study has suggested a value between 130 and 330 based on the whole of the crustacean.

The three references indicate that a value of 200 would not be an unreasonable one to adopt, especially considering the values given by Swift and Kershaw, (1999).

3.4.2 Technetium

Bishop et al. (1989) have presented values for technetium in lobsters and other crustacea separately. The values presented range between $1\ 10^3 – 1.4\ 10^3$ for lobsters and 4 – 30 for other crustaceans. These values are based on laboratory studies, predominantly through spiking of water. A paper by Busby et al. (1997) was mainly concerned with the distribution of technetium in the organs of crustacea. No whole body values were presented, however, it is mentioned that the work supports the IAEA value of 1000 (IAEA, 1985). Swift and Kershaw, (1999) have suggested a value of 980 as a mean, with a range from 15-7700. This is based on a review of 4 articles in the literature (3 laboratory-based, 1 environmental). Brown et al. (1998) cite the value of 720 (abdomen muscle) directly from (Busby et al. 1997). Aprosi and Masson, (1984) have presented a series of values for different crustacea. In general, the CFs are suggested to be low (3-20), with the exception of lobsters (100-1000).

All the references for technetium in crustacea suggest that the IAEA 1985 value of 1000 remains suitable.

3.4.3 Cobalt

Harrison, (1985) has presented a range from 4-520, however these are all laboratory-derived values based on exposure up to a maximum of 35 days. Therefore, they may not fully represent equilibrium conditions. The IAEA 1985 value has, therefore been retained.

4.4 Antimony

Swift and Kershaw, (1999) have presented a value of 25 based on the review of one literature article. This article is based on environmental measurements taken in the region of Cap de la Hague. It is proposed that this value is used.

3.4.5 Recommended values for crustacean concentration factors Bq t^{-1} per Bq m^{-3} (wet weight)

Radionuclide	Recommended value	Reference	IAEA (mean)
Pu	$2\ 10^2$	A	$3\ 10^2$
Tc	$1\ 10^3$	A	$1\ 10^3$
Co	$1\ 10^4$		$5\ 10^3$
Sb	$2.5\ 10^1$	A	$4\ 10^2$

References
A: (Swift and Kershaw, 1999)

3.5 Concentration Factors for Molluscs

3.5.1 Manganese

The value recommended by Swift and Kershaw, (1999) has been used here, although this is lower than the value currently recommended by IAEA (5,000 (IAEA, 1985)).

3.5.2 Iron

A number of laboratory-based studies have been reviewed by Swift and Kershaw, (1999). The Nord-Cotentin study (Nord-Cotentin 2000) recommends a decrease from 30,000 to 20,000 whilst pointing out that there appears to be considerable variation between and within species. For the purposes of this study, the value of 30 000 (IAEA, 1985) was retained.

3.5.3 Cobalt

A change is not recommended as the review by Swift and Kershaw, (1999) is based on laboratory studies.

3.5.4 Zirconium/Niobium

Again only laboratory studies are included in the review by Swift and Kershaw, (1999) and therefore a change is not recommended.

3.5.5 Antimony

For antimony Swift and Kershaw recommend a value of 20 based on both a laboratory study and environmental measurements (Swift and Kershaw, 1999). This value represents a decrease from the previous value of 200 (IAEA, 1985).

3.5.6 Cerium

The review given by (Swift and Kershaw, 1999) suggests a value for cerium of 20 based on a laboratory study. This is much lower than the current IAEA value of 5000 (IAEA, 1985). However, a French study (Nord-Cotentin, 2000) recommends a decrease from 5,000 to 2,000.

3.5.7 Californium

This radionuclide is assumed to behave similarly to americium, based on Nord-Cotentin data (Nord-Cotentin, 2000).

3.5.8 Iodine

A value of 100 is suggested in a review by Pentreath, (1985), which looked at acute and chronic contamination situations. This may not be relevant to the continuous release situation and therefore it is recommended that the value remains the same as the current IAEA value (IAEA, 1985)

3.5.9 Recommended values for mollusc concentration factors Bq t^{-1} per Bq m^{-3} (wet weight)

Nuclide	Recommended value	Reference	IAEA (mean)
Mn	$6\ 10^{2}$	A	$5\ 10^{3}$
Fe	$3\ 10^{4}$		$3\ 10^{4}$
Co	$5\ 10^{3}$		$5\ 10^{3}$
Zr/Nb	$5\ 10^{3}$		$5\ 10^{3}$
Sb	$2\ 10^{1}$	A	$2\ 10^{2}$
Ce	$2\ 10^{3}$	B	$5\ 10^{3}$
Cf	$1\ 10^{3}$	B	$2\ 10^{4}$
I	$1\ 10^{1}$		$1\ 10^{1}$

References
A: Swift and Kershaw (1999)
B: Nord-Cotentin (2000)

3.6 Summary of parameter review

The sediment partition coefficients and concentration factors required for the MARINA II study have been reviewed and recommendations made for changes from the current IAEA recommended values. A summary table of all parameters used in the study is provided (Table 4).

Table 4: Element-specific modelling parameters

	Concentration Factor (Bq t^{-1}) per (Bq m^{-3})			Sediment partition coefficient (Bq t^{-1}) per (Bq m^{-3})	
Element	Fish	Crustaceans	Molluscs	Regional	Coastal
H	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
C	2.00E+04	2.00E+04	2.00E+04	2.00E+03	2.00E+03
Na	1.00E-01	1.00E+01	3.00E+01	1.00E+00	1.00E-01
P	2.00E+04	1.00E+04	1.00E+04	1.00E+02	1.00E+01
S	2.00E+00	1.00E+00	4.00E+00	1.00E+00	5.00E+01
Ca	2.00E+00	5.00E+00	1.00E+00	1.00E+02	5.00E+02
Cr	2.00E+02	5.00E+02	8.00E+02	5.00E+04	5.00E+04
Mn	4.00E+02	5.00E+02	6.00E+02	2.00E+08	2.00E+05
Fe	5.00E+02	5.00E+03	3.00E+04	5.00E+07	5.00E+04
Co	1.00E+03	1.00E+04	5.00E+03	1.00E+07	2.00E+05
Ni	1.00E+03	1.00E+03	2.00E+03	1.00E+06	1.00E+05
Zn	1.00E+03	5.00E+04	3.00E+04	2.00E+05	2.00E+04
Y	2.00E+01	1.00E+03	1.00E+03	2.00E+06	1.00E+07
Sr	2.00E+00	2.00E+00	1.00E+00	2.00E+02	1.00E+03
Zr	2.00E+01	2.00E+02	5.00E+03	5.00E+05	1.00E+06
Tc	3.00E+01	1.00E+03	1.00E+03	1.00E+03	1.00E+02
Ru	2.00E+00	1.00E+02	2.00E+03	1.00E+03	3.00E+02
Ag	5.00E+02	5.00E+03	1.00E+04	1.00E+04	1.00E+03
Te	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Sb	4.00E+02	2.50E+01	2.00E+01	5.00E+02	1.00E+03
I	1.00E+01	1.00E+01	1.00E+01	2.00E+02	2.00E+01
Ba	1.00E+01	1.00E+00	2.00E+01	1.00E+04	5.00E+03
Cs	1.00E+02	3.00E+01	3.00E+01	2.00E+03	2.30E+02
Ce	5.00E+01	1.00E+03	2.00E+03	1.00E+08	2.00E+06
Pm	5.00E+02	1.00E+03	5.00E+03	1.00E+06	2.00E+06
Eu	3.00E+02	1.00E+03	7.00E+03	4.00E+06	5.00E+05
Ta	6.00E+01	3.00E+03	3.00E+03	5.00E+04	2.00E+05
Pb	2.00E+02	1.00E+03	1.00E+03	3.00E+07	5.00E+03
Po	2.00E+04	5.00E+04	1.00E+04	2.00E+07	1.00E+04
Ra	5.00E+02	1.00E+02	1.00E+03	3.00E+04	5.00E+03
Ac	5.00E+01	1.00E+03	1.00E+03	2.00E+06	2.00E+06
Th	6.00E+02	1.00E+03	1.00E+03	5.00E+06	2.00E+06
U	1.00E+00	1.00E+01	3.00E+01	5.00E+02	1.00E+03
Pu	1.00E+02	2.00E+02	3.00E+03	1.00E+05	1.00E+05
Am	1.00E+02	5.00E+02	2.00E+04	2.00E+06	2.00E+06
Cm	5.00E+01	5.00E+02	3.00E+04	2.00E+06	2.00E+06

4 Areas reviewed in finalising the model description

4.1 Fluxes

The flows in the Irish Sea have been considered in a number of papers including those of Mitchell et al. (1999) and Young et al (2001).

The review by Young showed that wind-forcing generally reduced the net flow through the Irish Sea from the Celtic Sea to the Scottish waters West. This was based on calculating fluxes through the North Channel and Irish Sea based on wind driven effects for a typical wind rose for the Irish Sea. The flow for the western Irish Sea was assumed to be reduced, but the flow through the Eastern Irish Sea was assumed to be the same as the previous model (Simmonds et al. 1995). The net flow through the channel is now assumed to be 7.2 10^{11} m^3 y^{-1} northwards, instead of 2.4 10^{12} m^3 y^{-1}, for the previous model. The main justification for this is that southerly winds generally result in a faster northerly flow through the North Channel, but winds which act across the channel (i.e westerly) or from the north result in a net flow south. The net average flow using the windrose for the Irish Sea is essentially northwards but smaller than assumed in the previous model. The review (Young and others 2001) also shows that there is evidence for wind-driven movement from the eastern Irish Sea to the west without flushing through the North Channel

The effect of the Irish Sea gyre, which causes an anti-clockwise flow in the western Irish Sea during the summer months, would also have an effect of recirculating activity within the Irish Sea west compartment, before it is flushed through the North Channel.

The flows between the Sellafield local compartment and the Cumbrian waters compartment were also examined and the flow between these two compartments was increased to $5\ 10^{11}$ $m^3\ y^{-1}$ from $8\ 10^{10}\ m^3\ y^{-1}$.

4.2 Sedimentation

The equations representing sedimentation described in section 2 differ from those presented previously (Simmonds et al. 1995). The equations presented above are intended to better represent the processes during sedimentation and subsequent remobilisation of radionuclides. Bioturbation is now considered in two aspects. The first is during pore water exchange in which biota create holes in the sediment for respiration purposes. These holes allow water to exchange between the sediment and the water column. The second aspect is in sediment re-working which represents the physical movement of sediment allowing direct contact with seawater at the sediment:water interface. This movement of sediment is carried out by wave action and by burrowing of biota.

Sedimentation rates and suspended sediment loads were updated following a review of the Irish Sea model (Mitchell et al. 1999). The review suggested there was less sedimentation in the Western Irish Sea than previously assumed. The sedimentation rates were reduced in compartments 30,31,32,33,34 and increased slightly in the Cumbrian waters compartment (35).

Values for suspended sediment load were reduced in compartments 30, 31, 34 and 35. The values for sedimentation and suspended sediment load in the local Sellafield compartment were assumed to be the same as that in compartment 35.

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Appendix B - Validation of MARINA II

1 Introduction

In order to validate the use of MARINA II in this study, the model results have been compared with measured activity concentrations for a selection of radionuclides and environmental media where data were available. This appendix contains detailed results of this comparison.

2 Methodology

Section 2 of the main report describes the methodology used to obtain estimated activity concentrations using MARINA II. Results were obtained for a selection of radionuclides, locations and environmental media. The estimated concentrations are summed for all sources and information is provided on the contribution of the different sources. The radionuclides chosen for the validation exercise were those which were important for validation purposes and for which most data were available, namely caesium-137, technetium-99, plutonium-239/240 and americium-241. Measurements of plutonium-239 include any contribution of plutonium-240. This is also the case for modelled concentrations based on discharges. Therefore, where plutonium-239 is referred to in this appendix it should be taken to be the sum of plutonium-239 and plutonium-240. More limited data were also available for a selection of other radionuclides and these were also included in the comparison; the radionuclides were tritium, carbon-14, cobalt-60, ruthenium-106 and polonium-210. The measurement data were obtained from the MARINA II working group B compilation available on CD-ROM. Most of the data were obtained from the MARINA-2B summary data sets. However, for some radionuclides such as tritium, carbon-14, cobalt-60 and ruthenium-106, the data were supplemented, or entirely taken from the IAEA-Glomard and Nord-Contentin data sets. Measured activity concentrations in seawater are often reported for unfiltered water and so include suspended sediment. The model results are for filtered seawater, excluding any contribution from suspended sediment. Where possible and appropriate measurements in filtered seawater have been used in the comparison.

The estimated and measured activity concentrations for various environmental media are presented in this Appendix in graphical form. Two types of graphs are used. The first type compares estimated and measured values averaged over a time period for a number of marine compartments. This shows how well the model estimates concentrations spatially over a wide area with a range of different characteristics. The second type of graph compares estimated and measured concentrations for a single marine compartment over the time period over which the discharges occur to examine the way the model includes variation with time. For this second comparison the compartment chosen reflects the data available and the likely importance of different sources such as the sources of NORM radionuclides, the major nuclear sites, fallout from weapons testing and Chernobyl. For nuclear discharges, estimated and measured data for caesium-137, technetium-99 and plutonium-239 were compared for the Irish Sea West and cumbrian waters (technicium –99 only), compartments over the time period of the discharge from Sellafield. This was to determine how well the model performed at times when the activity in the water was likely to be due directly to discharges from the site and at later times when remobilisation of activity from sediments could contribute.

3 Results

3.1 Caesium-137

Figure 1 compares estimated and measured activity concentrations in seawater for a selection of compartments; the results are averages for the period between 1990 and 2000. The figure shows ratios of observed to estimated activity concentrations of caesium-137 in water. The solid central diagonal line indicates perfect agreement between estimated and measured concentrations. Values above the central line indicate that the model results are higher than measurements while values below the line indicate that the model estimates are lower than the measured values. Also shown on the figure are dotted lines representing ratios of a factor of two and a factor of ten. In most cases the ratios of estimated to measured results are within a factor of three and in all but one case are within a factor of 10. The exception is for the Scottish Waters West compartment, which the model appears to underestimate by about a factor of 20. This is a large compartment close to a source of caesium-137 and the measurements may not be representative of the compartment as a whole. For the compartments close to the major sources of discharge (Sellafield and Cap de La Hague), the estimated to measured ratios are generally within a factor of three. In some cases compartments further from the source show greater differences between estimated and measured data. This may be due to a number of factors including an insufficient spread of measurement data over the complete area of the compartment and a greater influence of other sources such as fallout from nuclear weapons testing and Chernobyl. There is also likely to be greater uncertainty in the model parameters and processes for different marine compartments away from areas where the model was originally developed i.e. the Irish Sea and coastal waters. The model estimates concentrations lower than those measured for the Kattegat compartment and this could indicate that the flux of caesium-137 from the Baltic Sea is underestimated. However, the model estimate shows good agreement with the measurements for the Arctic seas where a high proportion of the activity is from fallout from weapons testing and Chernobyl.

Figure 2 shows similar results comparing estimated and measured activity concentrations of caesium-137 in fish. The ratios of estimated to measured values for fish are all within a factor of four and show better agreement than for seawater. The result for Scottish waters west does not show the same large difference between estimated and measured values as seen for water. These results could indicate that measurements in fish are generally more reliable and account for variation of activities over space and time better than the water data. The estimated concentrations in fish are also more important for determining collective and per-caput doses, the aim of the study.

Results for a particular location are given in Figure 3, which compares estimated and measured concentrations in seawater for the Irish Sea West compartment as a function of time. The main contribution to the estimated activity concentration is from discharges from the Sellafield site and these discharges are also shown on the figure. It can be seen that the concentrations follow the pattern of the discharges. The ranges of measured activity concentrations in the region are also shown in Figure 3. The estimated activity concentrations in filtered seawater are within the range of measured data throughout the period considered. Results for a compartment further away from nuclear discharge sources are given in Figures 4 and 5, which show estimated and measured activity concentrations in seawater for the North

Sea South West compartment. Figure 4 again shows that the estimated values are within the range of the measurements. Figure 5 gives the contributions from fallout from weapons testing and Chernobyl and from discharges from nuclear sites. Between 1952 and 1967 the major contribution to the activity is fallout from weapons testing, after which the activity is predominately due to discharges from Sellafield. The peak release from Chernobyl in 1986 is relatively important at that time. This graph shows that there is little contribution from all the inland nuclear sites discharging caesium-137 into the Rhine and hence into the North Sea.

The estimated and measured concentrations of caesium-137 in sediment averaged between 1990 and 2000 for a selection of compartments are compared in Figure 6. The estimated to measured ratios are all within a factor of 10 and most are within a factor of five for all sites except the Arctic South sediment compartment. Here the model underestimates the measured value by about a factor of 60. This is likely to be because the nature and properties of the sediment where the measurement was taken is inconsistent with the generic assumptions used in the model. Other model inconsistencies are unlikely since the estimated seawater concentrations in this compartment compare well with the measured values. Figure 7 gives a comparison of estimated and measured concentrations in sediment for Cumbrian Waters over the entire period of discharges from the Sellafield nuclear site. This shows that the estimated concentration of caesium-137 in the top sediment layer is within the measured range where data are available.

3.2 Technetium-99

Filtered seawater measurements for technetium-99 were available for a large number of marine compartments and Figure 8 compares the estimated and measured activity concentrations in filtered seawater averaged between 1990 and 2000 for these compartments. The estimated to measured ratios are all within an order of magnitude and most are within a factor of two. The model estimates are both higher and lower than the measured values. Figure 9 gives similar results for technetium-99 in seaweed (Fucus). The ratios of estimated to measured concentrations in seaweed are generally within an order of magnitude, except for the Irish Sea South, where the model results are about a factor of 100 greater than the measured values. The estimated and measured results show a greater spread for seaweed, for some compartments, than for filtered seawater. This may be because the measurements are for different species of seaweed or because the uptake of radionuclides in marine species depends on environmental factors such as water temperature and salinity (Aarkrog 1985). The measurements may have also been confined to the coastal fringe of the marine compartments, which may not represent the average activity concentration for a compartment as estimated by the model.

Figures 10 and 11 give the estimated and measured concentrations of technetium-99 in filtered seawater for the North Sea South West compartment. Figure 10 shows that the estimated values are within the range of the measurements up to 1994, but are lower than the 2 measurements available between 1994 to 2000. Figure 11 also shows the contributions of the discharges of technetium-99 from Sellafield and Cap de la Hague. The major contribution is due to discharges from Sellafield, except for the mid to late 1980’s when the discharge from Cap de La Hague is more important. For technetium-99 there is no significant contribution from weapons testing fallout (Aarkrog et al 1988) and little from the other two sites which discharge technetium: Capenhurst and Springfields. The measured and estimated activity concentrations of technetium-99 in crustacea from Cumbrian Waters are given in

Figure 12. Measurements were available between 1988 and 2000 and for most times the estimated concentrations are within the measured range except where there were only limited measurement data available. In 1995 and 1996, when concentrations of technetium-99 were relatively high, the highest measurement (measured maximum) was an order of magnitude greater than the average of all measurements, showing that there is a large variability in measurements of technetium-99 in crustacea. As the interaction of technetium-99 with sediment is very small there were no measurements available for sediment.

3.3 Plutonium-239

Measurements of plutonium-239/240 in filtered seawater are available for a number of compartments. Figure 13 compares estimated and measured activity concentrations in filtered seawater averaged between 1990 and 2000 for these compartments. The ratios of estimated to measured concentrations ratios are within a factor of two for most compartments with model estimates both higher and lower than measured values. The model estimates for concentrations of plutonium-239 in filtered seawater are the closest to measured values found in this validation exercise. Figure 14 gives results for activity concentrations in fish. The ratios of estimated to measured concentrations are all within a factor of 10, except for the Irish Sea North East compartment where the model result is about a factor of 40 greater than the measured value. Estimated and measured concentrations of plutonium-239 in molluscs are compared in Figure 15. Fewer data are available than for plutonium-239 in seawater and the ratios were generally within an order of magnitude, except for the Irish Sea North compartment where the model estimate is a factor of 40 greater than the measured data.

Figure 16 compares estimated and measured concentrations of plutonium-239 in filtered seawater for the Irish Sea West compartment as a function of time. The Sellafield discharges are also shown and it is seen that when the discharges fell after 1980 this was not reflected in the concentrations in water. This is due to the remobilisation of plutonium-239 from sediments where activity had accumulated from previous discharges. Where data are available, the estimated concentrations in seawater are within the measured range. Figures 17 and 18 show the estimated and measured activity concentrations in filtered seawater for the Norwegian Sea compartment. This again shows that the estimated values are generally within the range of the measured values where available. Figure 18 also shows the contributions to the estimated concentrations from fallout from weapons testing and from discharges from nuclear sites. Unlike caesium and technetium, the most important contribution for all times is due to fallout from nuclear weapons testing in the 1960's. The remaining activity is due to discharges of plutonium-239 from nuclear sites, particularly Sellafield, Cap de La Hague and Dounreay. Plutonium is less mobile in seawater than caesium and technetium and therefore most of the activity discharged from the nuclear sites remains in the area close to the discharge point.

When plutonium is discharged into marine waters a significant fraction will become attached to suspended sediment and then be deposited on the seabed. It is therefore of interest to consider the concentrations of plutonium-239 in bed sediment. Figure 19 compares estimated and measured activity concentrations of plutonium-239 in sediment averaged between 1990 and 2000 for a selection of compartments. The ratios of estimated to measured concentrations are within a factor of three, except for the Isle of Wight sediment compartment, where the model estimate is about a factor of 20 more than the measured value. Figure 20 shows a comparison between estimated and measured concentrations of plutonium-239 in sediment for the Irish Sea North East compartment as a function of time. Where measurements are available the estimated activity concentration in top sediment is generally within the measured range.

3.4 Americium-241

Only limited measurement data are available for this radionuclide for marine biota and sediment in a few marine compartments. No data were available for filtered seawater. The comparison of model estimates and measured data is also complicated by the need to include the ingrowth of americium-241 from discharges of its parent, plutonium-241. Figure 21 shows the contribution to the estimated concentration of americium-241 in filtered seawater due to fallout from weapons testing and due to discharges from the major nuclear sites for the North Sea South West compartment. The most important contribution over time is from fallout from the nuclear weapons testing carried out in the 1960's. There are smaller contributions from discharges of americium-241 from Sellafield, Cap de La Hague and Dounreay. For fallout the americium-241 is due to ingrowth from plutonium-241 releases from the weapons testing. The americium-241 from the nuclear sites is a combination of direct discharges of americium-241 and due to ingrowth from discharges of plutonium-241.

Estimated and measured activity concentrations of americium-241 in fish averaged between 1990 and 2000 are compared in Figure 22 for a selection of compartments. The ratios of estimated to measured concentrations are generally within an order of magnitude for the compartments close to Sellafield discharge point. For sites further from the discharge point and also for the Liverpool and Morecambe Bay compartment, the model estimates are up to two orders of magnitude less than the measured values. As shown in Figure 23 similar results are obtained for concentrations of americium-241 in molluscs, although some of the model results for molluscs are in better agreement with measured values than was found for fish. Figure 24 gives estimated and measured activity concentrations in molluscs as a function of time for the Irish Sea North East compartment. Where measurement data are available the estimated values are within the range of the measurements. The observed differences in the estimated and measured values in filtered water and biota, may reflect uncertainty in the way americium disperses in the marine environment and interacts with sediments. This uncertainty may be greater away from the major nuclear discharge points, e.g. in the North Sea, where the main contribution to concentrations is from the decay of plutonium-241 in fallout from nuclear weapons testing. Also the number of measurements for fish and molluscs in these compartments are more limited than in areas close to nuclear sites. Figure 25 gives estimated and measured activity concentrations in the top bed sediment as a function of time for the Cumbrian Waters compartment. There is good agreement between the estimated and measured values.

3.5 Other radionuclides

Where measurement data are available for other radionuclides these have also been compared with the results estimated by MARINA II. The radionuclides considered are tritium, carbon-14, polonium-210, cobalt-60 and ruthenium-106. As the measurements are limited for these radionuclides the comparison is also limited.

Tritium Measured activity concentrations of tritium are only available for seawater. Figure 26 compares the estimated and measured activity concentrations in seawater averaged between 1990 and 2000 for a selection of compartments. The ratios of estimated to measured activity concentrations are all within a factor of 5. As found for other radionuclides the best agreement between estimated and measured results is for compartments close to major sources of discharge. The model estimates also show good agreement with measurements for the Arctic and the Barents Sea compartments where a high proportion of the activity is from fallout from weapons testing. There are also background levels of tritium in seawater from cosmogenic sources in seawater at levels of about 200 – 900 Bq m^{-3} (Kaufman and Libby 1954). If this source had been included in the model estimates there would have been closer agreement with the measured values for compartments further from Sellafield. Figures 27 and 28 give estimated and measured concentrations of tritium in filtered seawater for the North Sea east compartment as a function of time. The measured concentrations are generally about a factor of two greater than the estimated values. Figure 28 shows the contribution to the concentration from fallout from weapons testing and from discharges from nuclear sites. Between 1952 and 1984 the major contribution is due to fallout from weapons testing, after which the most important source for North Sea East is the discharge from Cap de La Hague with a small contribution from all the other nuclear sites.

Carbon-14 Measurement data are very limited for carbon-14 and background levels due to cosmogenic sources are relatively important. Figure 29 compares estimated and measured activity concentrations in filtered seawater averaged between 1980 and 1990 for a limited selection of compartments. The ratios of estimated to measured concentrations are within an order of magnitude for all compartments except the Barents sea (B4), where the model estimate is about a factor of 15 less than the measured value. The background levels of carbon-14 from cosmogenic sources in seawater are about 6 Bq m^{-3} (Charles, 1990). If this additional component were included, then in most cases the model estimates would match the measured data more closely. In Figure 30 estimated and measured activity concentrations of carbon-14 in molluscs are compared for the English Channel compartments for 1997. The ratios of estimated to measured concentrations are all within a factor of four. Figure 31 shows the contribution to the activity concentrations due to fallout from weapons testing and from discharges from nuclear sites as a function of time. Between 1952 and 1988 the major contribution to the activity is due to fallout from weapons testing, after which the discharge from Cap de La Hague becomes more important; there is a negligible contribution from all the other nuclear sites.

Polonium-210 There are very limited measurement data for polonium-210 and the situation is complicated by the relatively high levels of naturally occurring polonium-210 which mask any additional concentrations due to NORM discharges. A limited comparison with model estimates has been carried out for filtered seawater. Figure 32 compares estimated and measured activity concentrations in filtered seawater in 1989 for a selection of compartments. The model results are all over an order of magnitude lower the measured concentrations in seawater except for Cumbrian Waters, where the measured data are still higher. This is due to the high natural levels of polonium-210 in seawater. The natural level of polonium-210 has been found to vary around the UK coast depending on the levels of polonium found in the rocks fringing the coast. The average background level is assumed to be about 2 Bq m^{-3} (Charles, 1990), with a range around the UK from south to north of between 1 Bq m^{-3} and 4 Bq m^{-3}, (McDonald, 1991). Figure 33 shows the same data as Figure 32 with the average level of natural background indicated. The measured data are generally within the range of background levels, although concentrations for the Irish Sea and Scottish Waters compartments are slightly elevated. This probably reflects the known discharge of polonium-210 from a phosphate plant at Whitehaven in Cumbria. It is not possible to validate the MARINA II model for polonium-210 as the estimated concentrations are below background levels. Figure 34 shows the contribution from the major NORM sources to the estimated concentrations of polonium-210 in the North Sea Central compartment. The most important source of polonium-210 is discharges from the phosphate industry with a relatively small contribution from the decay of radium-226 and lead-210 discharged from the oil and gas industry. The levels of polonium-210 in this compartment are well below background concentrations.

Cobalt-60 The only measurement data available for cobalt-60 are for molluscs from the English Channel and Southern North Sea compartments. In both cases the model estimate is lower than the measured concentration by a factor of two for Cap de la Hague, but by a factor of 50 for the North Sea compartment. Figure 35 shows estimated and measured activity concentrations in molluscs for the Cap de La Hague compartment as a function of time. The estimated values are generally within a factor of three of the measurements. Figures 36 and 37 show the contributions to the estimated concentrations of cobalt-60 in filtered seawater due to discharges from the major nuclear sites for the Cap de La Hague and North Sea South West compartments, respectively. For the Cap de La Hague compartment the major contribution is due to discharges from the Winfrith nuclear site in the UK before the early 1980's and due to discharges from Cap de La Hague for later times. For North Sea South West there are contributions from a number of nuclear sites such as Bradwell nuclear power station in the UK.

Ruthenium-106 Measurement data were only available for molluscs from the English Channel. Figure 38 shows estimated and measured activity concentrations in molluscs for the Cap de La Hague compartment as a function of time. The activity concentrations estimated by MARINA II are about a factor of two greater than the measured values. Figure 39 gives the contributions due to discharges from the major nuclear sites to the concentration of ruthenium-106 in filtered seawater for the Cap de La Hague compartment. The discharge from Cap de La Hague is the most important source of ruthenium-106 in this region from 1966 onwards. Before this time the concentration is negligible in comparison and was due to discharges from Sellafield.

4 Discussion

The results presented here give confidence in the use of the MARINA II model for estimating collective and per-caput doses for use in this study. The model estimates are both higher and lower than measured values. When estimating collective doses activity concentrations from many locations are used and the resulting dose summed. This means that the uncertainty in the estimated collective and per-caput doses is less than the uncertainty in activity concentrations at a particular location.

The model has been extensively tested for caesium-137, plutonium-239 and technetium-99 for which relatively large amounts of data are available. These three radionuclides behave differently in the marine environment with technetium staying in the water phase, plutonium having a strong affinity for sediments and caesium having behaviour between these two extremes. The good agreement found between estimated and measured activity concentrations for these three radionuclides gives a measure of confidence in applying the model to other radionuclides. The limited comparison carried out for other radionuclides also supports this view. However, the model results are obviously more uncertain for other radionuclides. This is particularly the case for the radiologically significant radionuclides polonium-210 and carbon-14 where only limited data are available and the situation is complicated by the presence of naturally occurring activity of these radionuclides.

5 References

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Figure 1: Estimated and measured activity concentrations of caesium-137 in filtered seawater for selected marine compartments, averaged between 1990 and 2000

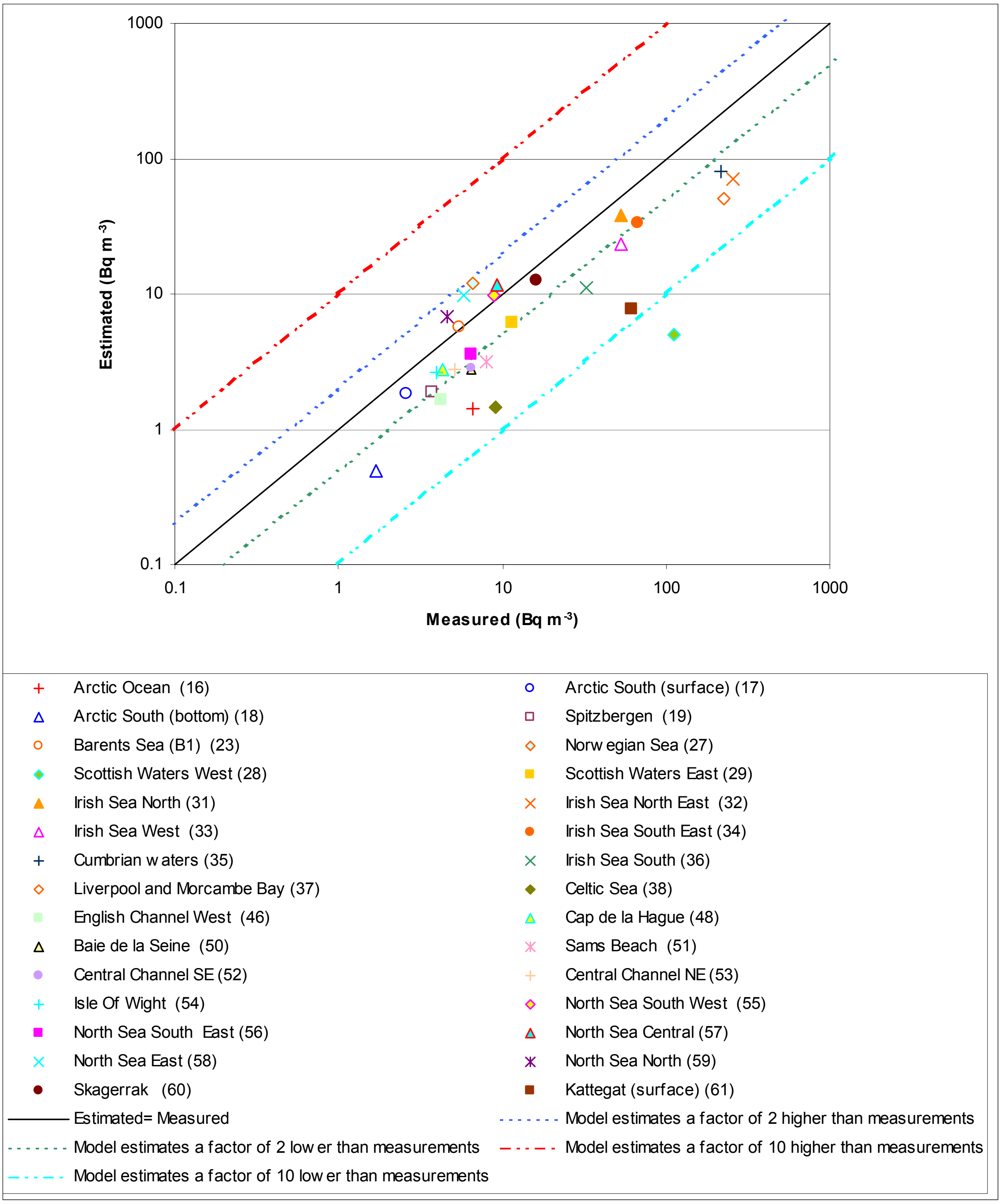


Figure 2: Estimated and measured activity concentrations of caesium-137 in fish (wet weight) for selected marine compartments, averaged between 1990 and 2000

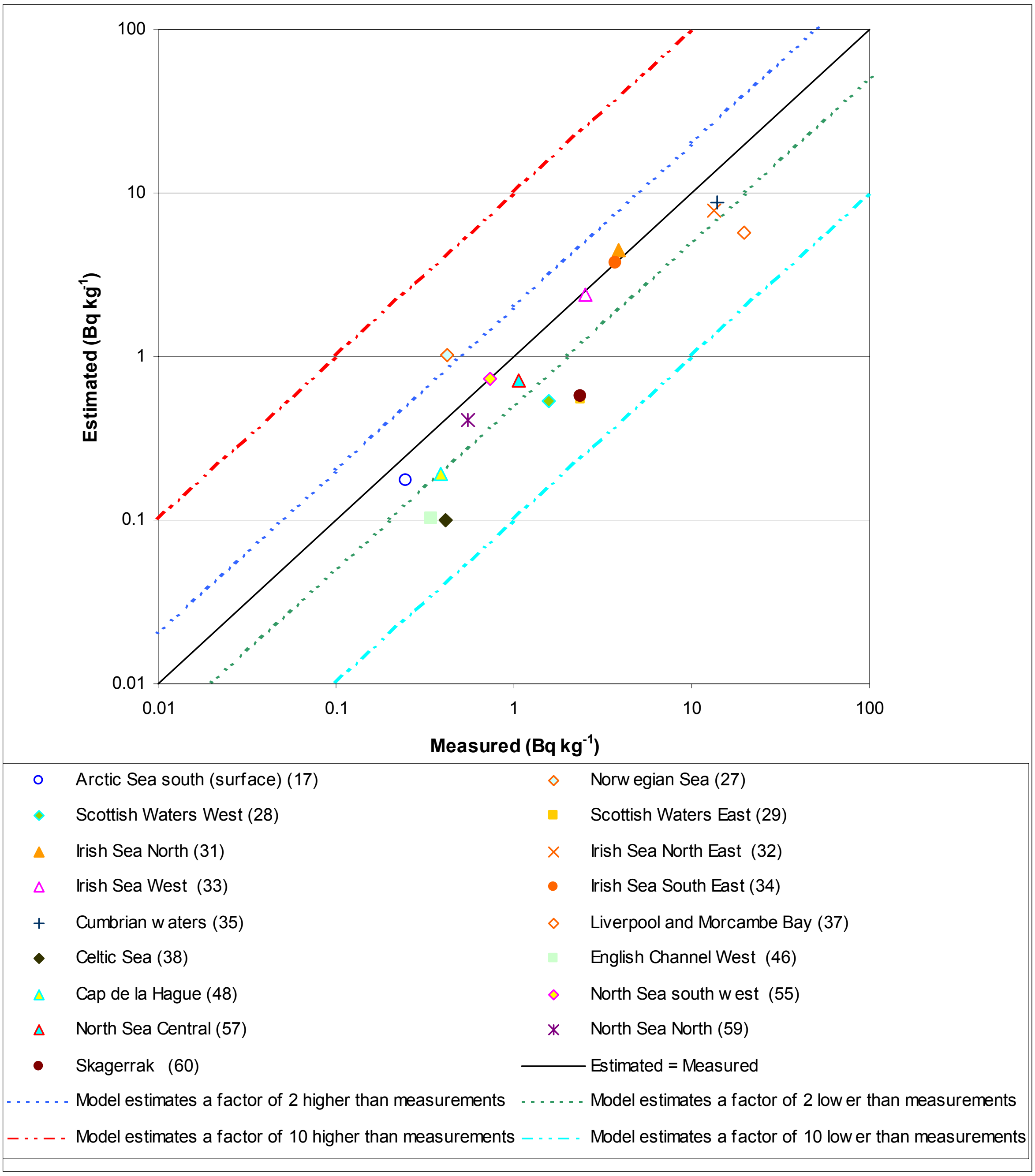


Figure 3: Estimated and measured activity concentrations of caesium-137 in filtered seawater for Irish sea west compartment

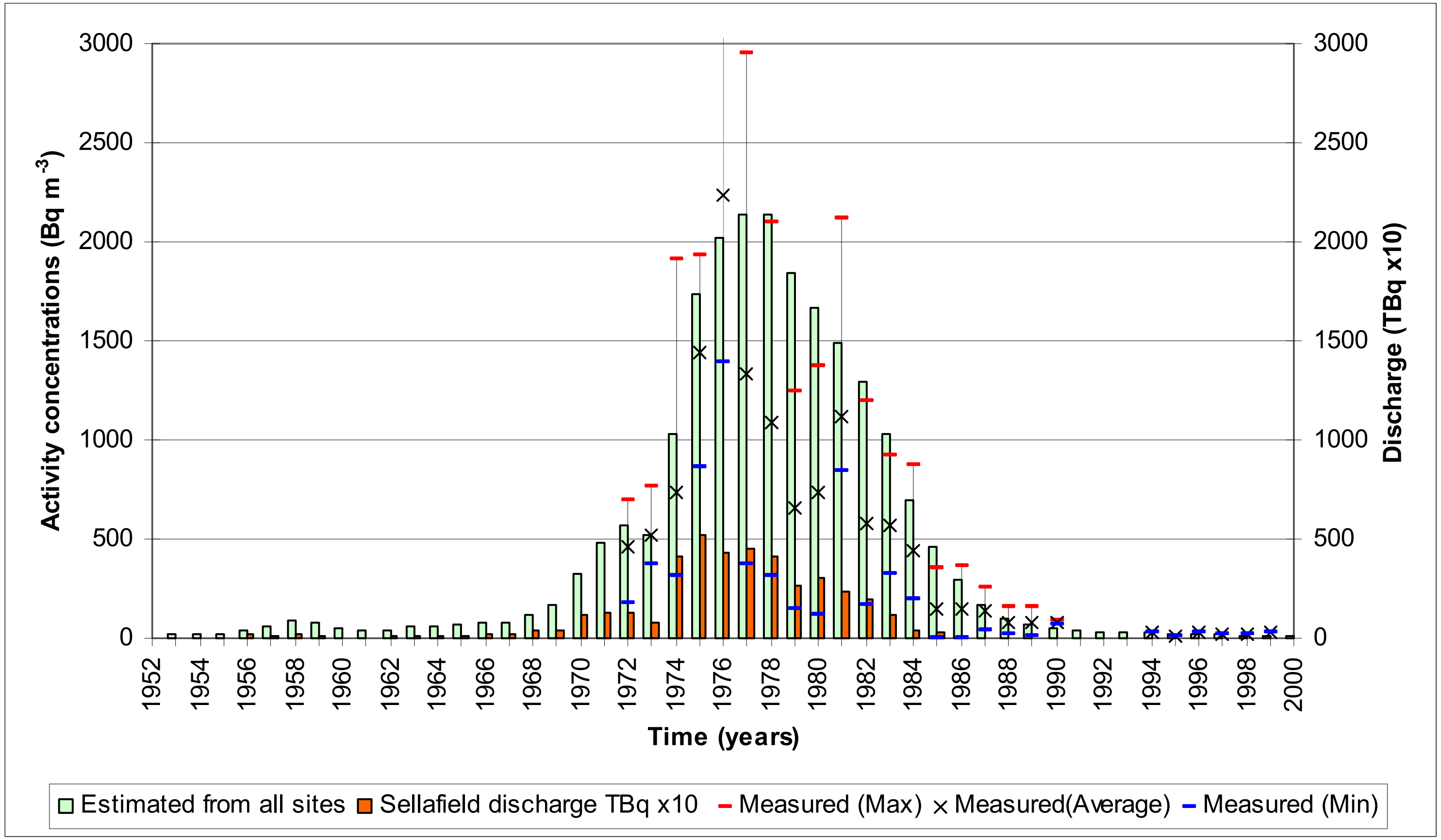


Figure 4: Estimated and measured activity concentrations of caesium-137 in filtered seawater for North sea south west compartment (55)

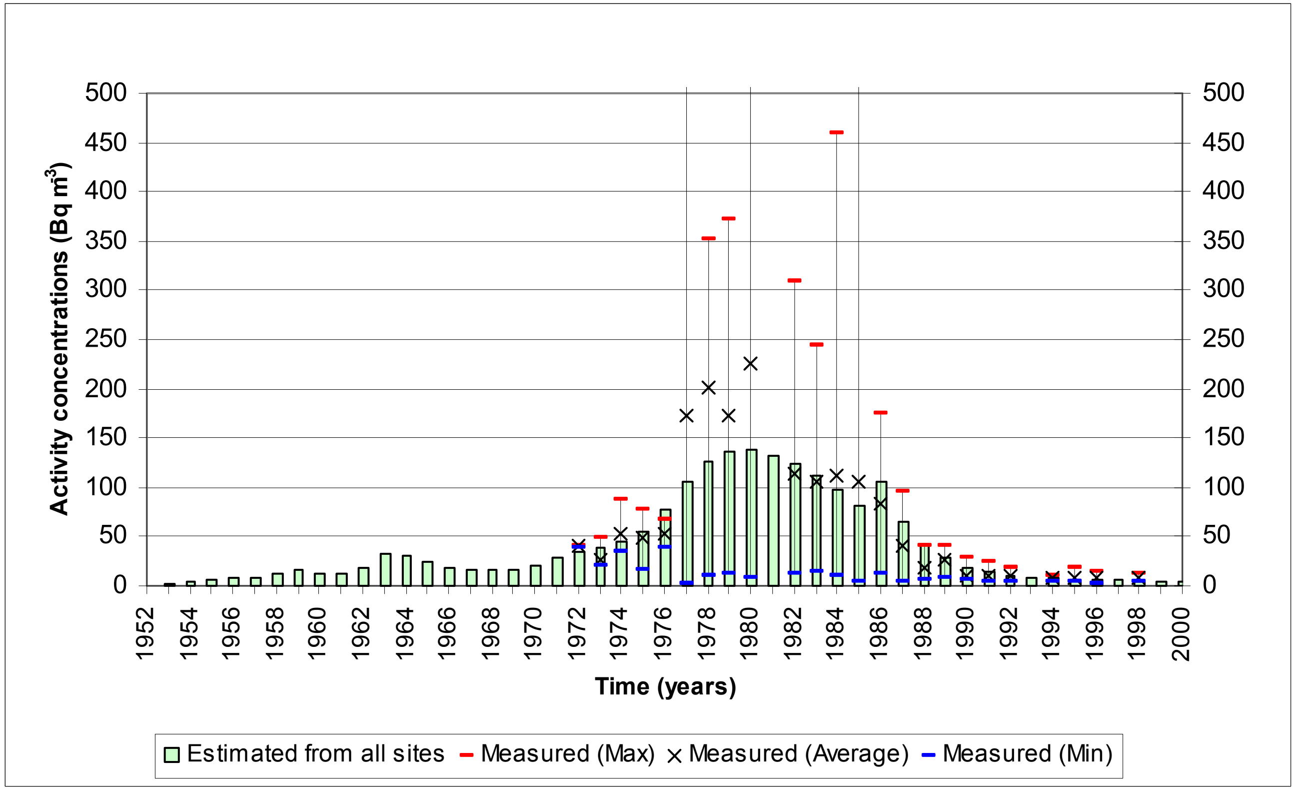


Figure 5: Estimated and measured activity concentrations of caesium-137 in filtered seawater for North sea south west compartment (55), showing contributions from different sources.

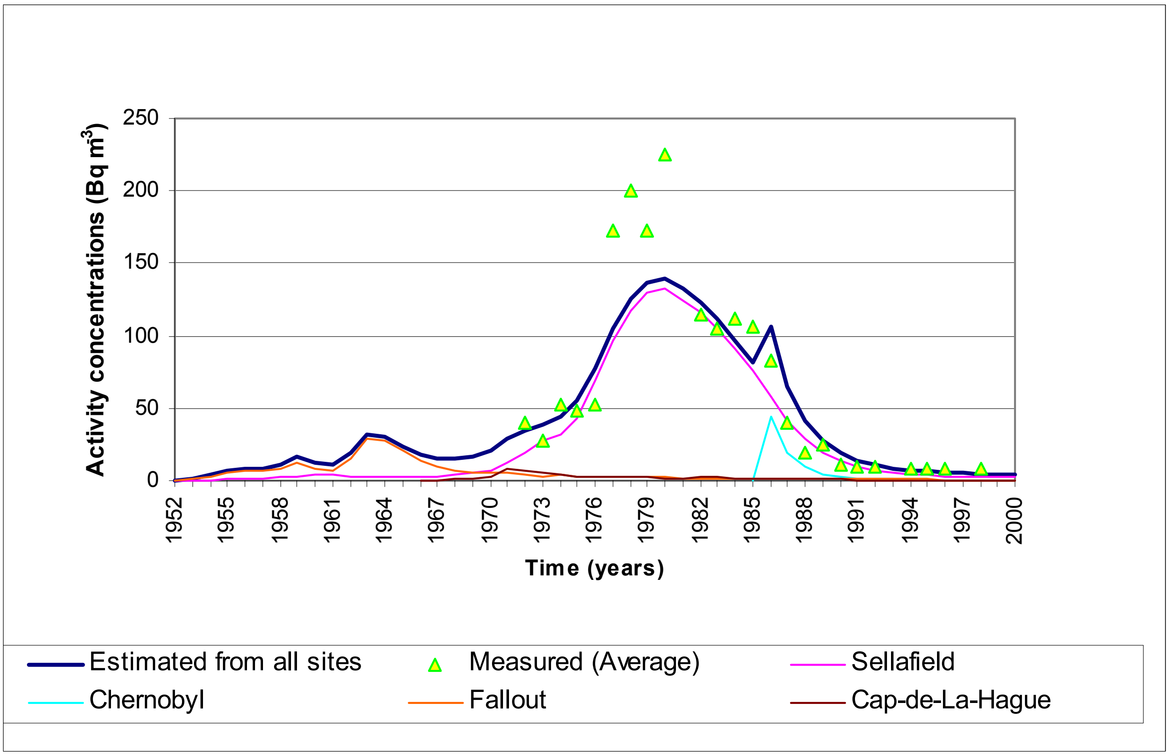


Figure 6: Estimated and measured activity concentrations of caesium-137 in top sediment (dry weight) for selected marine compartments, averaged between 1990 and 2000

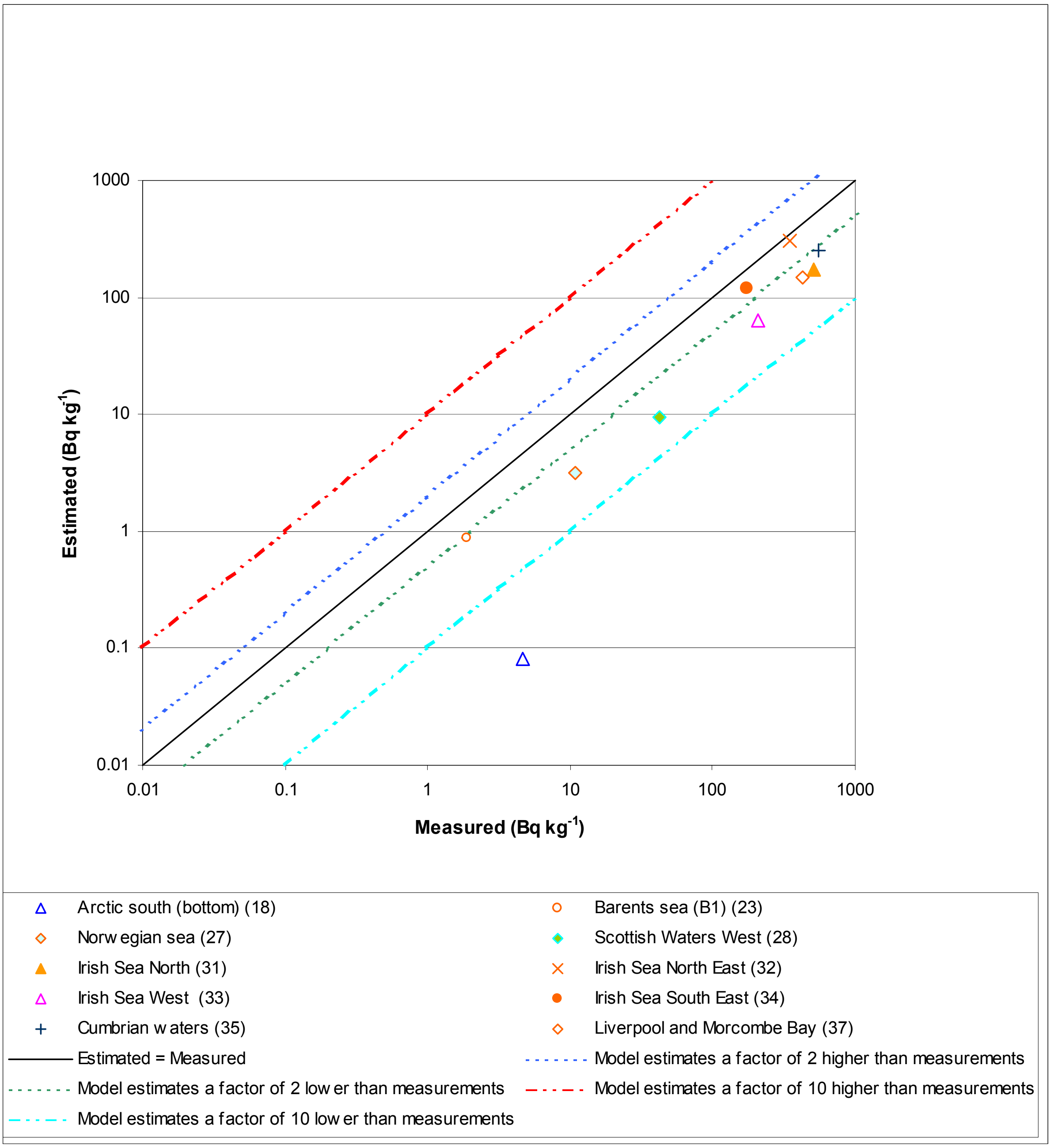


Figure 7: Estimated and measured activity concentrations of caesium-137 in top sediment (dry weight) for Cumbrian waters compartment (35)

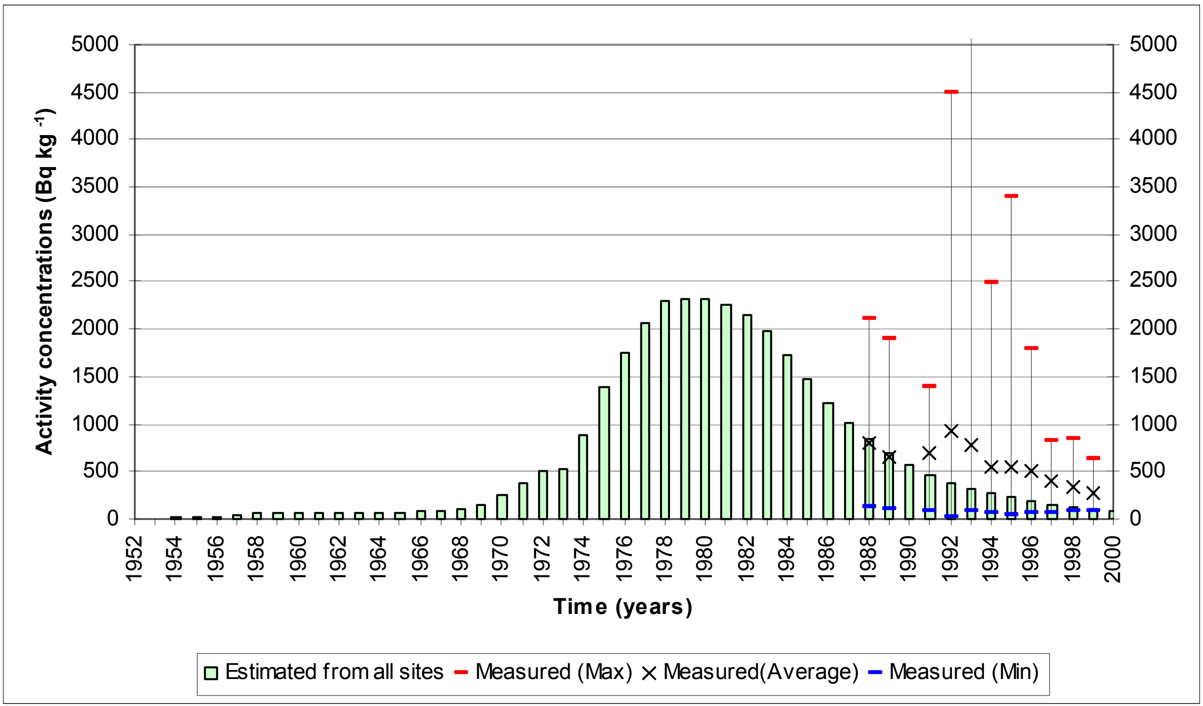


Figure 8: Estimated and measured activity concentrations of technetium-99 in filtered seawater for selected marine compartments, averaged between 1990 and 2000

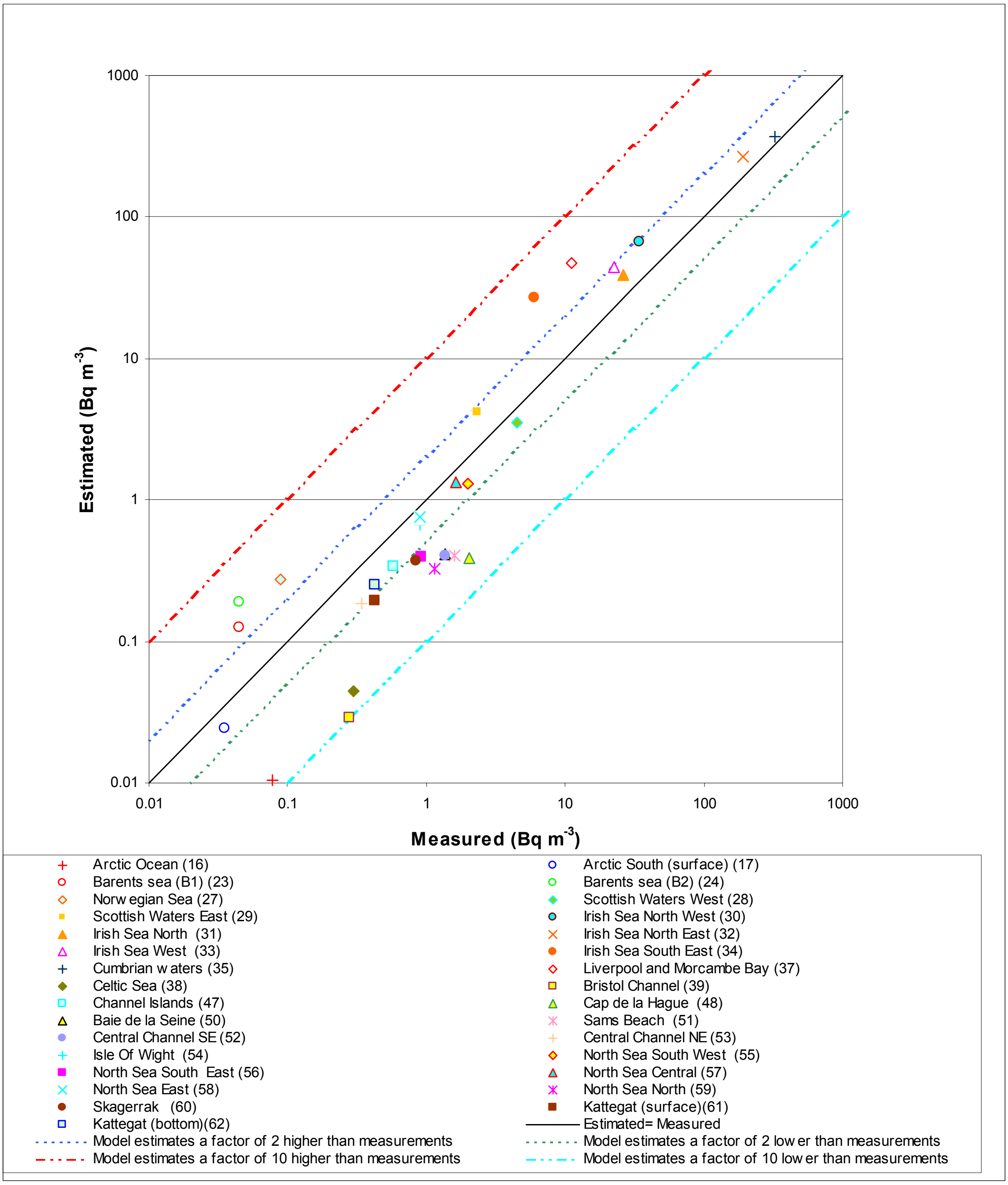


Figure 9: Estimated and measured activity concentrations of technetium-99 in seaweed (wet weight) for selected marine compartments, averaged between 1990 and 2000

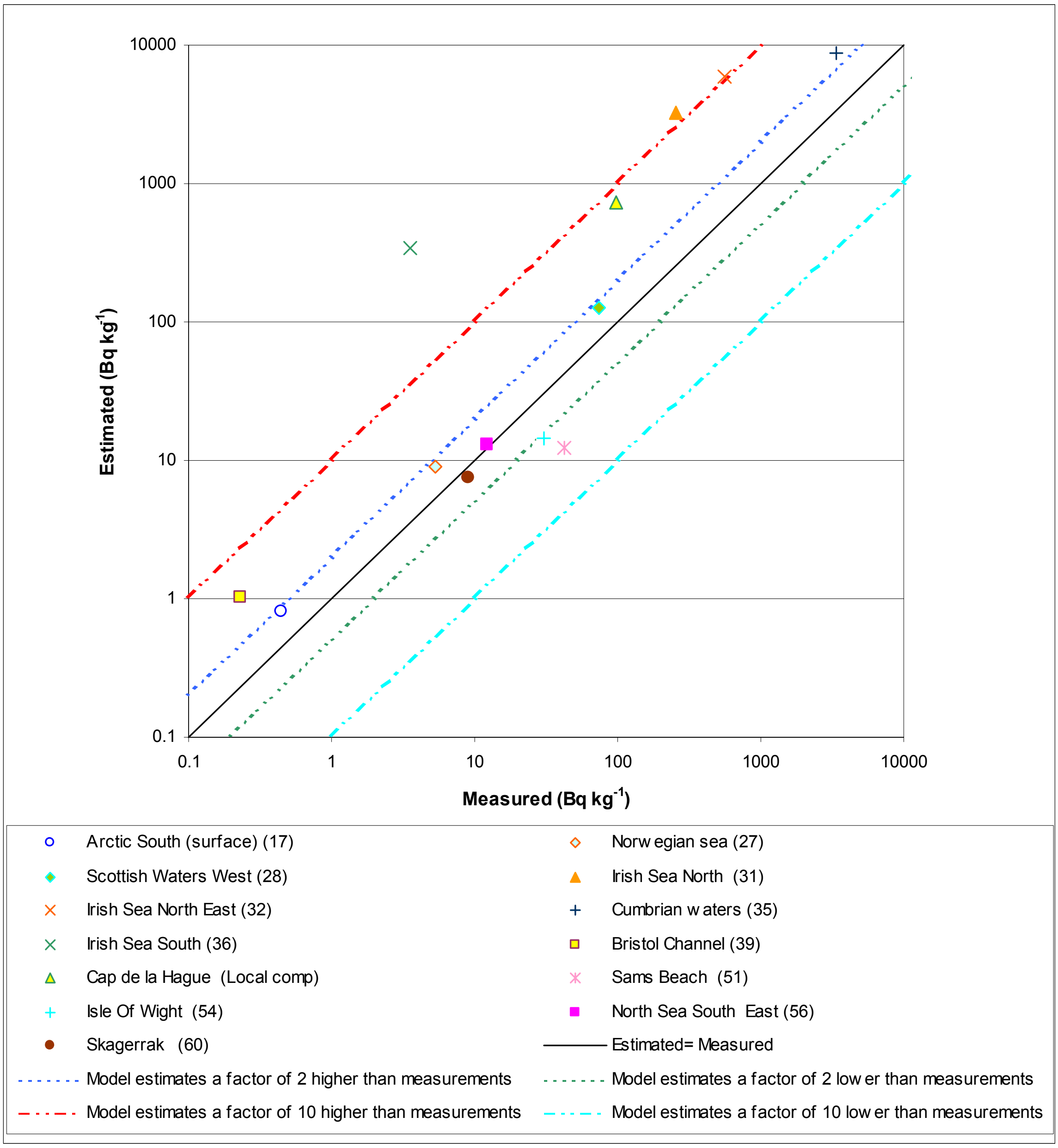


Figure 10: Estimated and measured activity concentrations of technetium-99 in filtered seawater for North sea south west compartment (55)

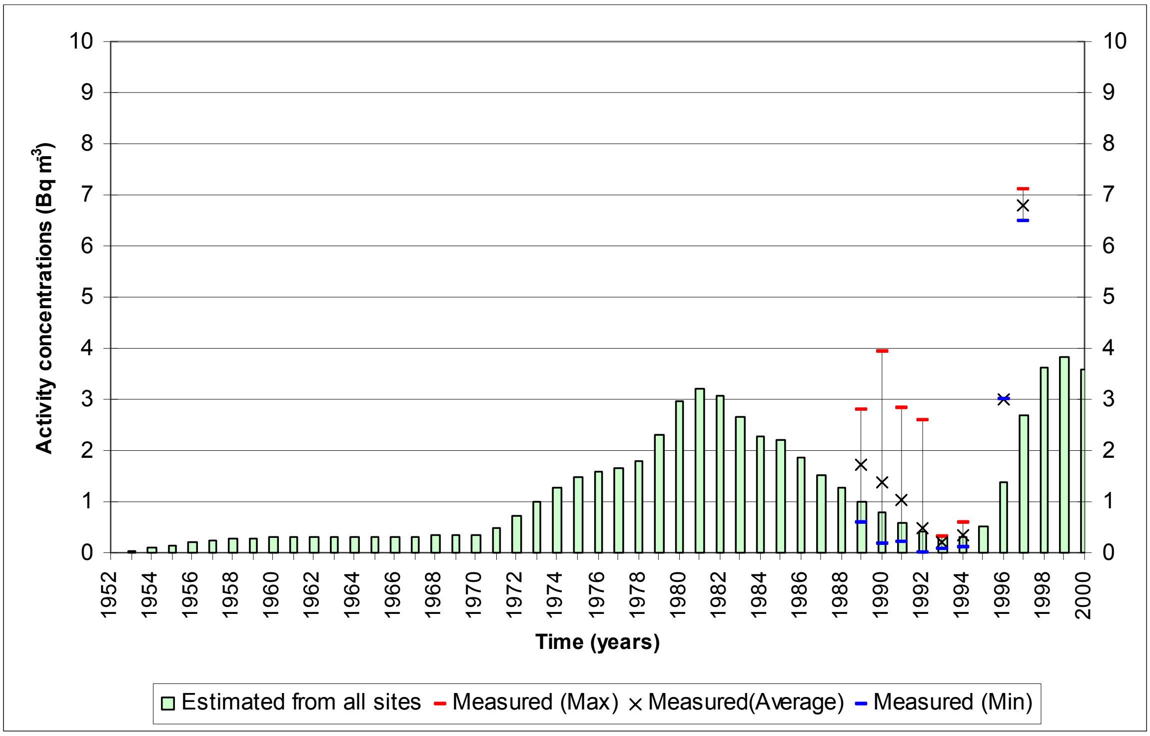


Figure 11: Estimated and measured activity concentrations of technetium-99 in filtered seawater for North sea south west compartment (55), showing contributions from different sources

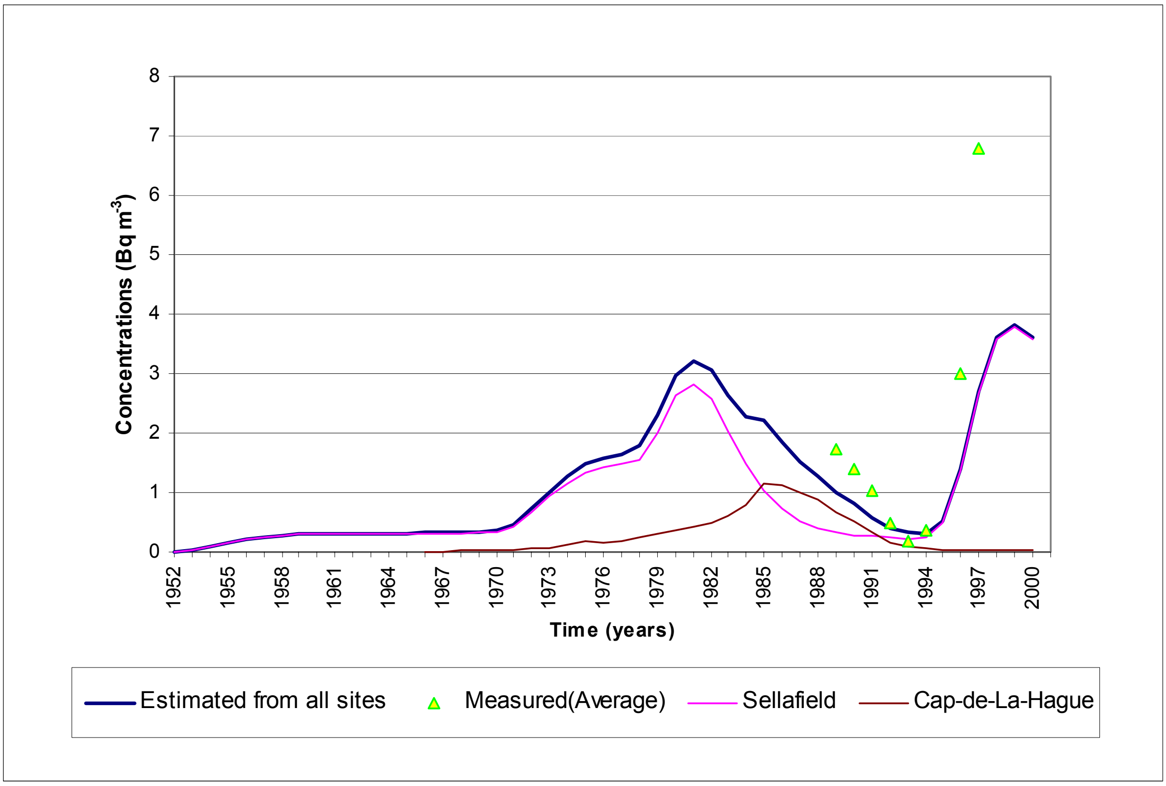


Figure 12: Estimated and measured activity concentrations of technetium-99 in crustacea (wet weight) for Cumbrian waters compartment (55)

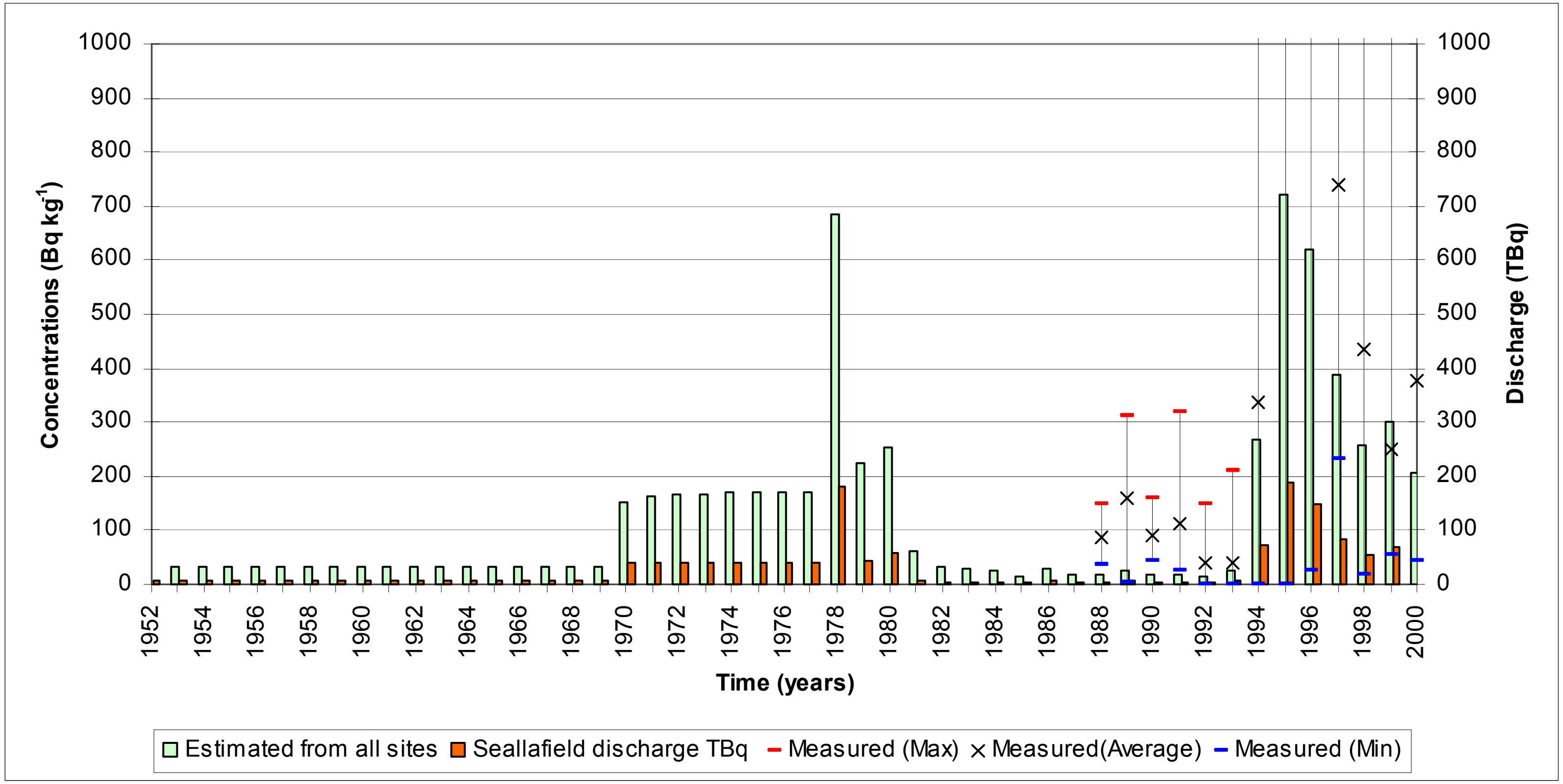


Figure 13: Estimated and measured activity concentrations of plutonium-239 in filtered seawater for selected marine compartments, averaged between 1990 and 2000

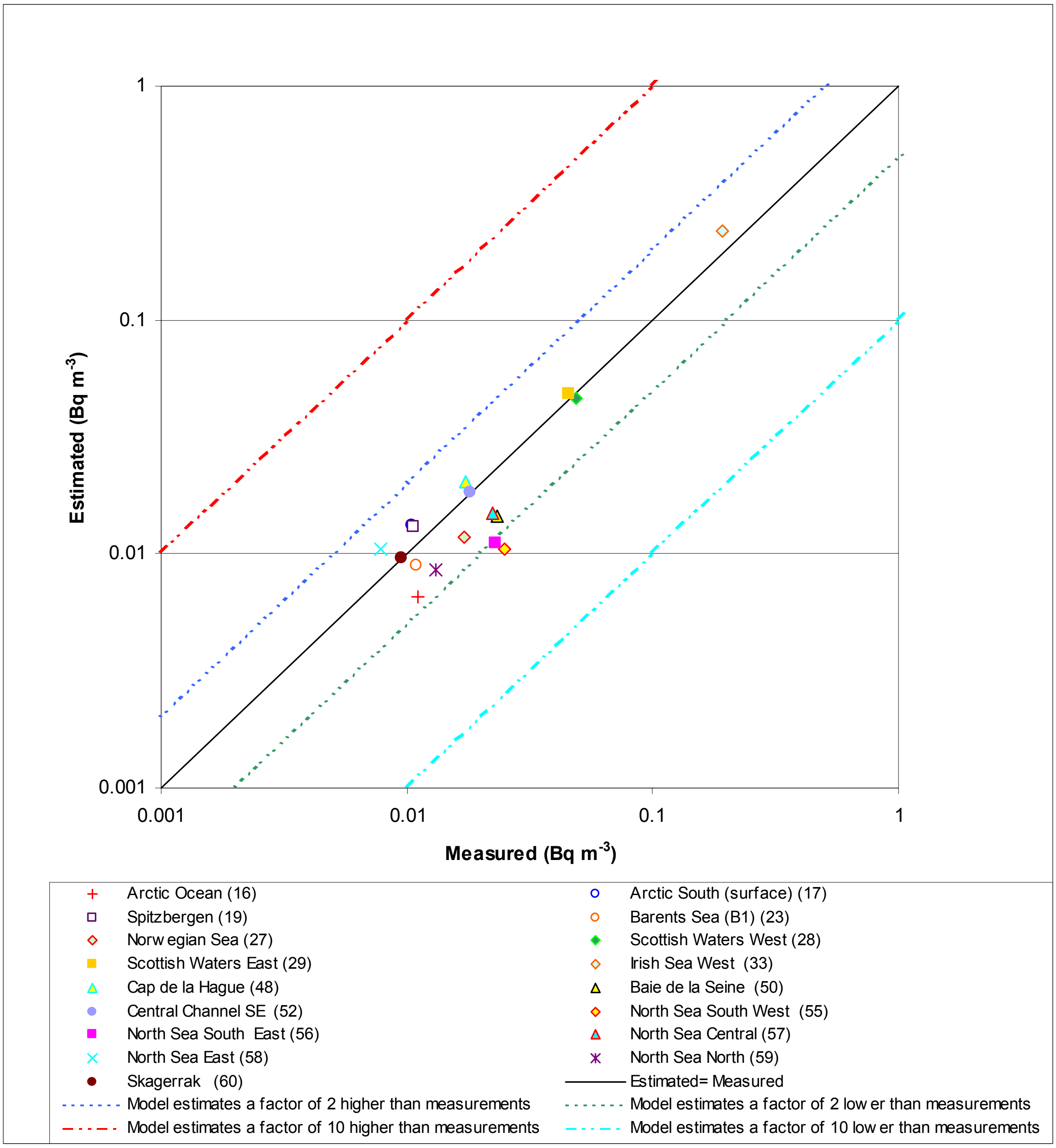


Figure 14: Estimated and measured activity concentrations of plutonium-239 in fish (wet weight) for selected marine compartments, averaged between 1990 and 2000.

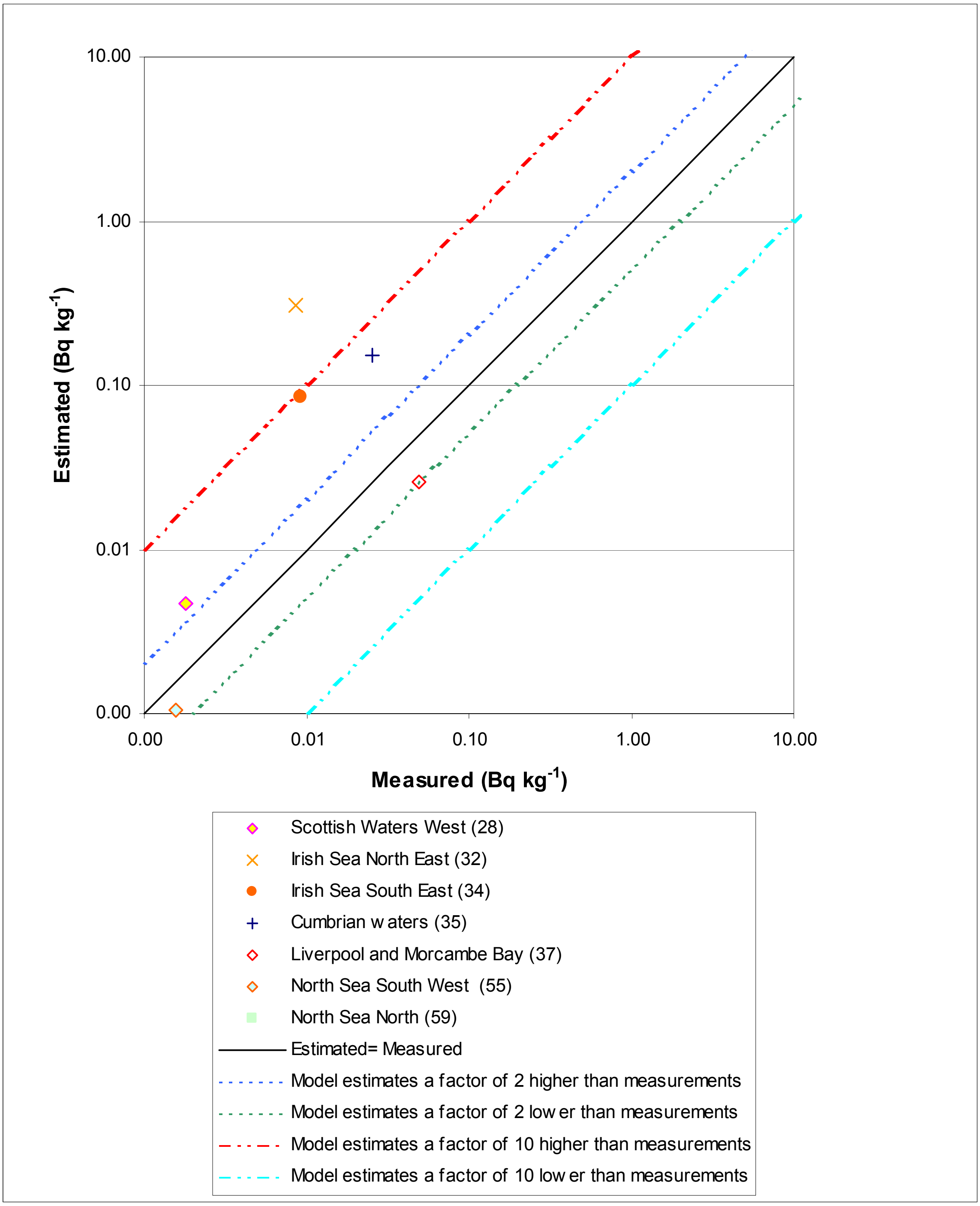


Figure 15: Estimated and measured activity concentrations of plutonium-239 in molluscs (wet weight) for selected marine compartments, averaged between 1990 and 2000

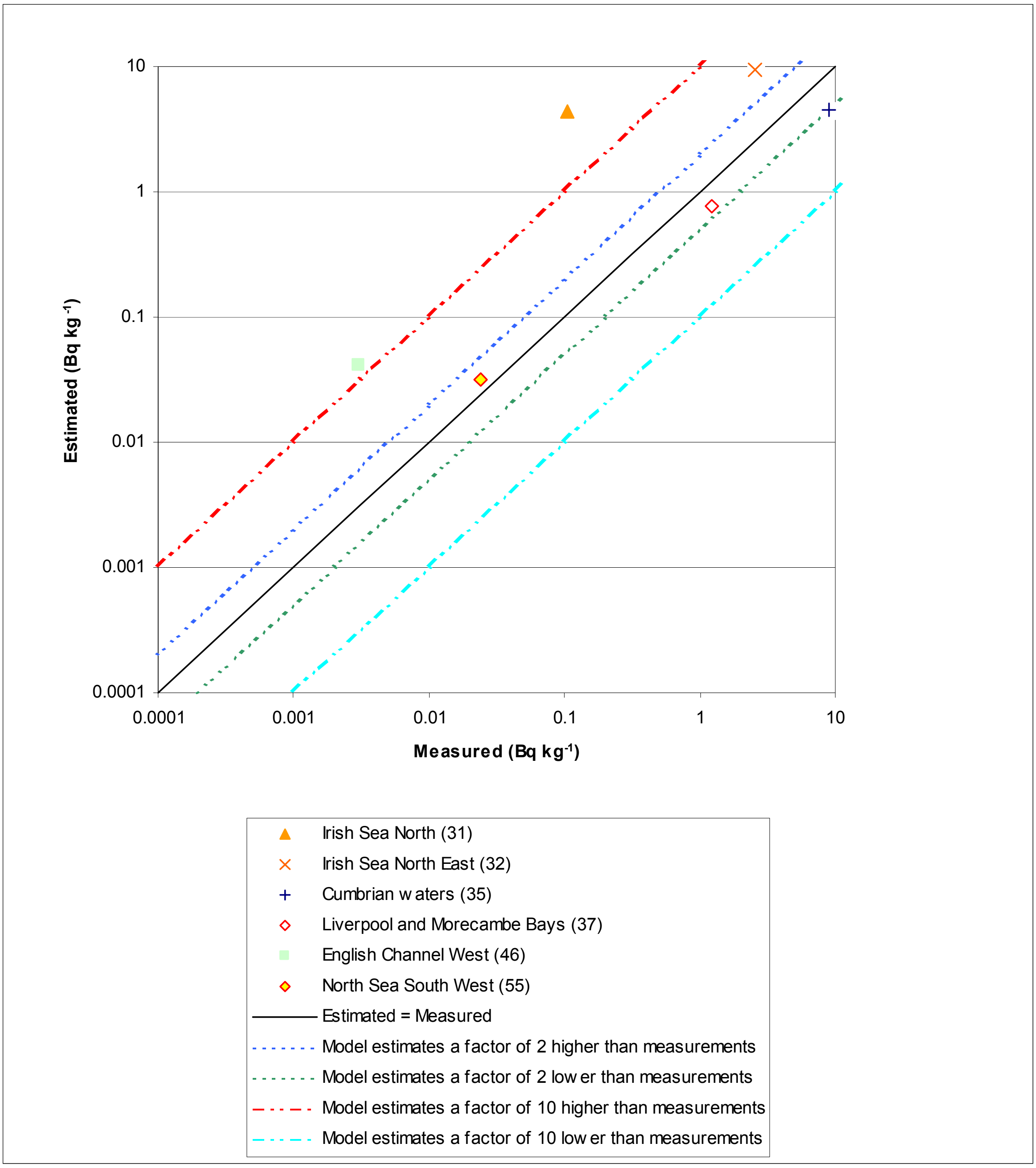


Figure 16: Estimated and measured activity concentrations of plutonium-239 in filtered seawater for Irish sea west compartment

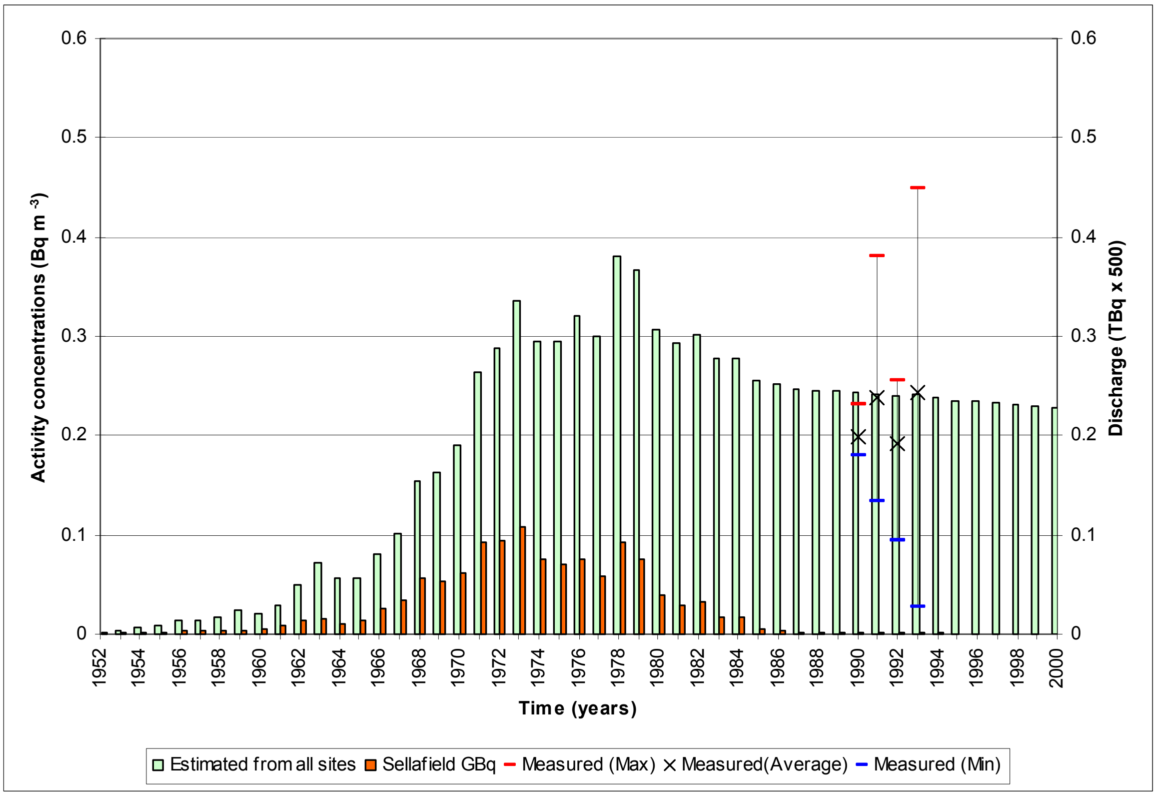


Figure 17: Estimated and measured activity concentrations of plutonium-239 in filtered seawater for Norwegian sea compartment (27)

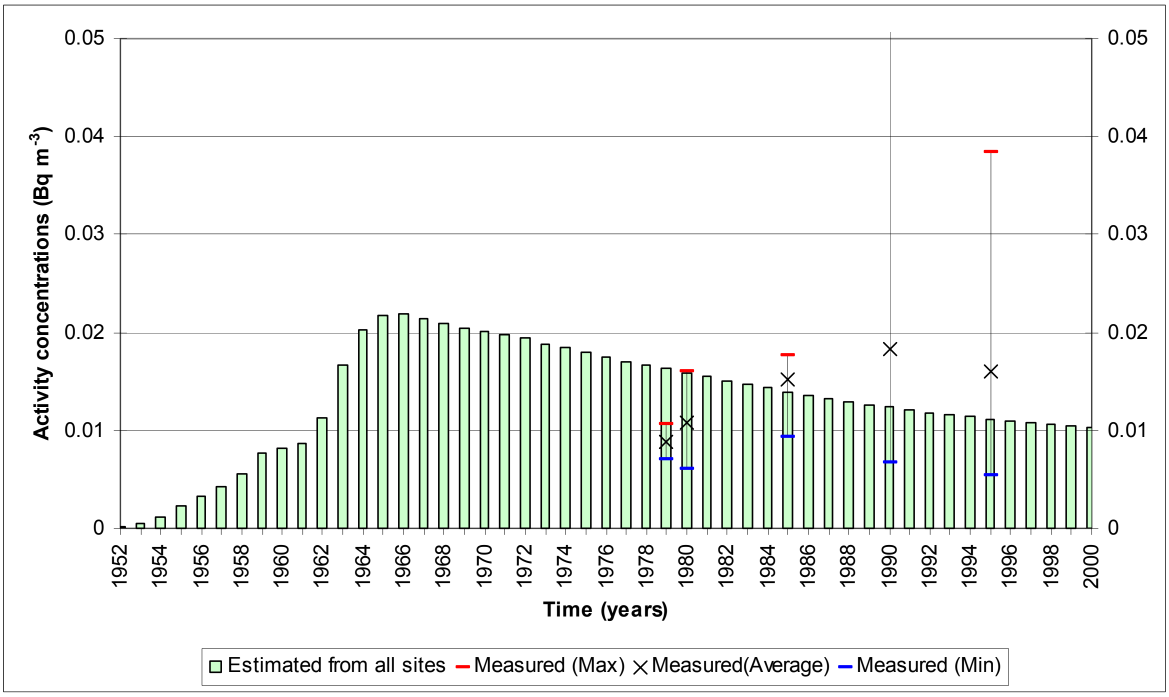


Figure 18: Estimated and measured activity concentrations of plutonium-239 in filtered seawater for Norwegian sea compartment (27), showing contributions from different sources.

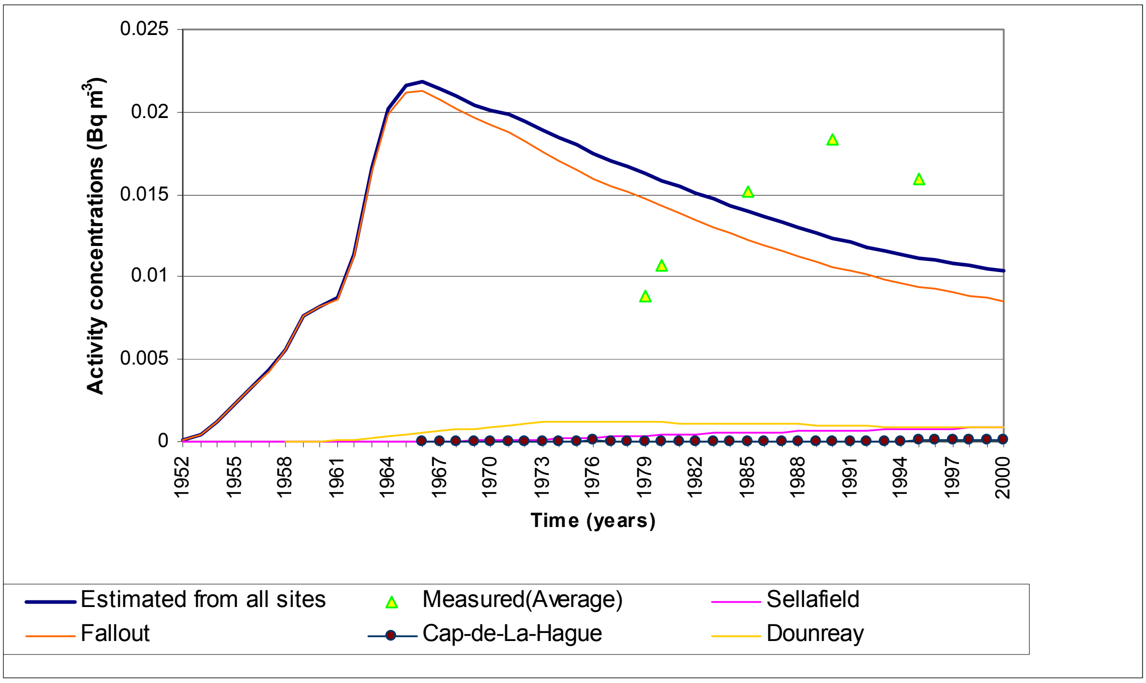


Figure 19: Estimated and measured activity concentrations of plutonium-239 in top sediment (dry weight) for selected marine compartments, averaged between 1990 and 2000

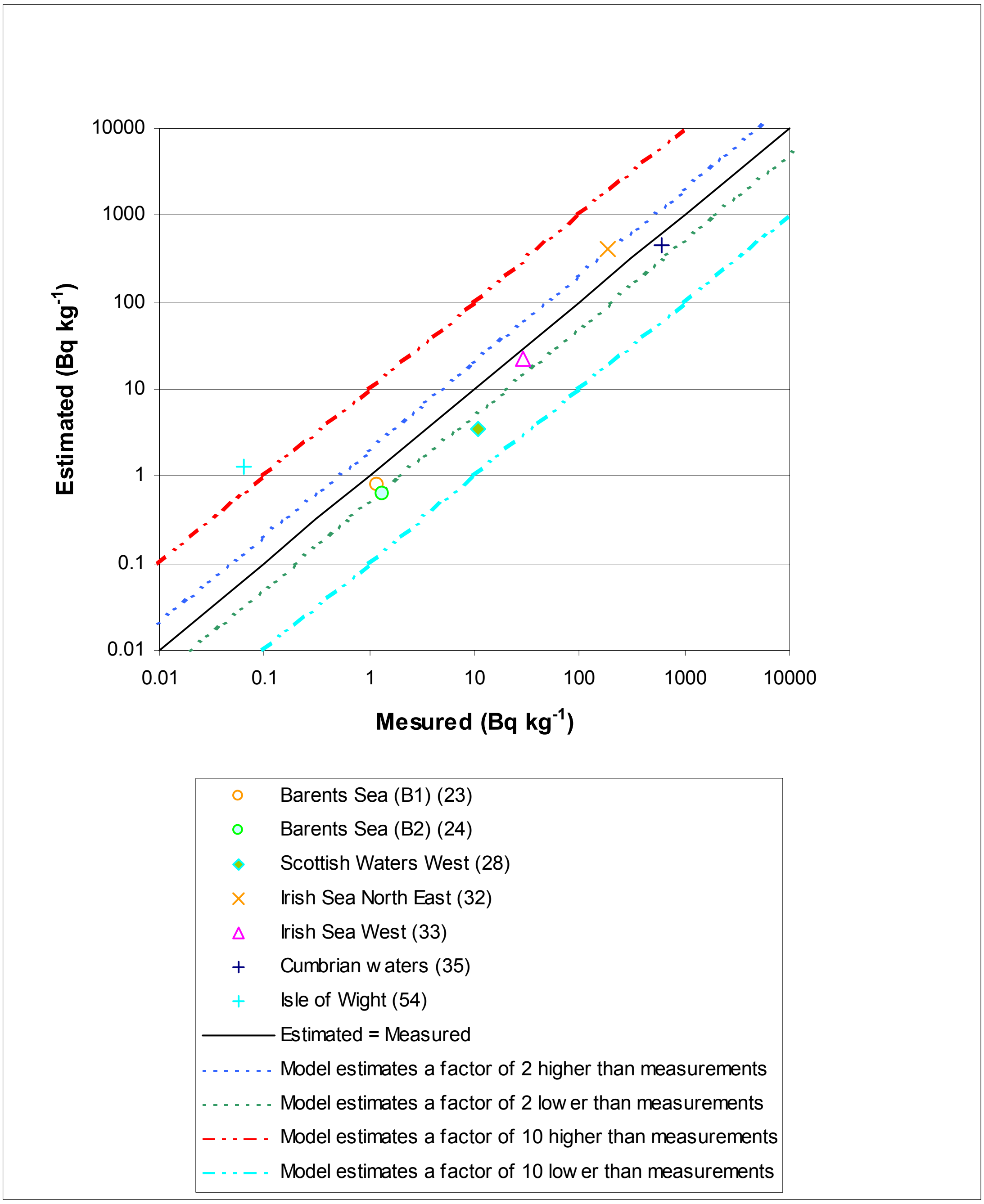


Figure 20: Estimated and measured activity concentrations of plutonium-239 top sediment (dry weight) for Irish Sea north east compartment (32)

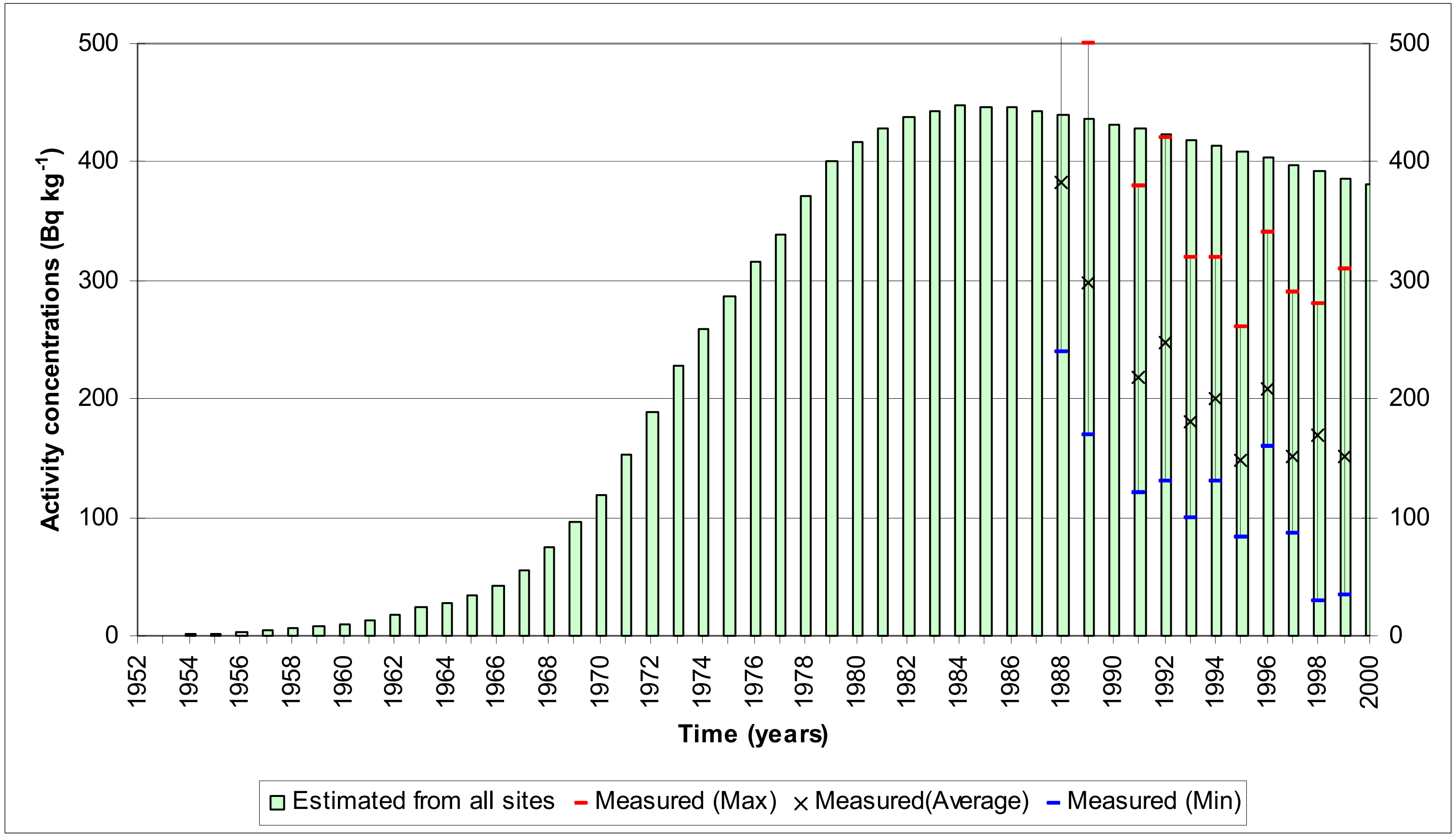


Figure 21: Estimated activity concentrations of americium-241 in filtered seawater for North sea south west compartment (55), showing contributions from different sources.

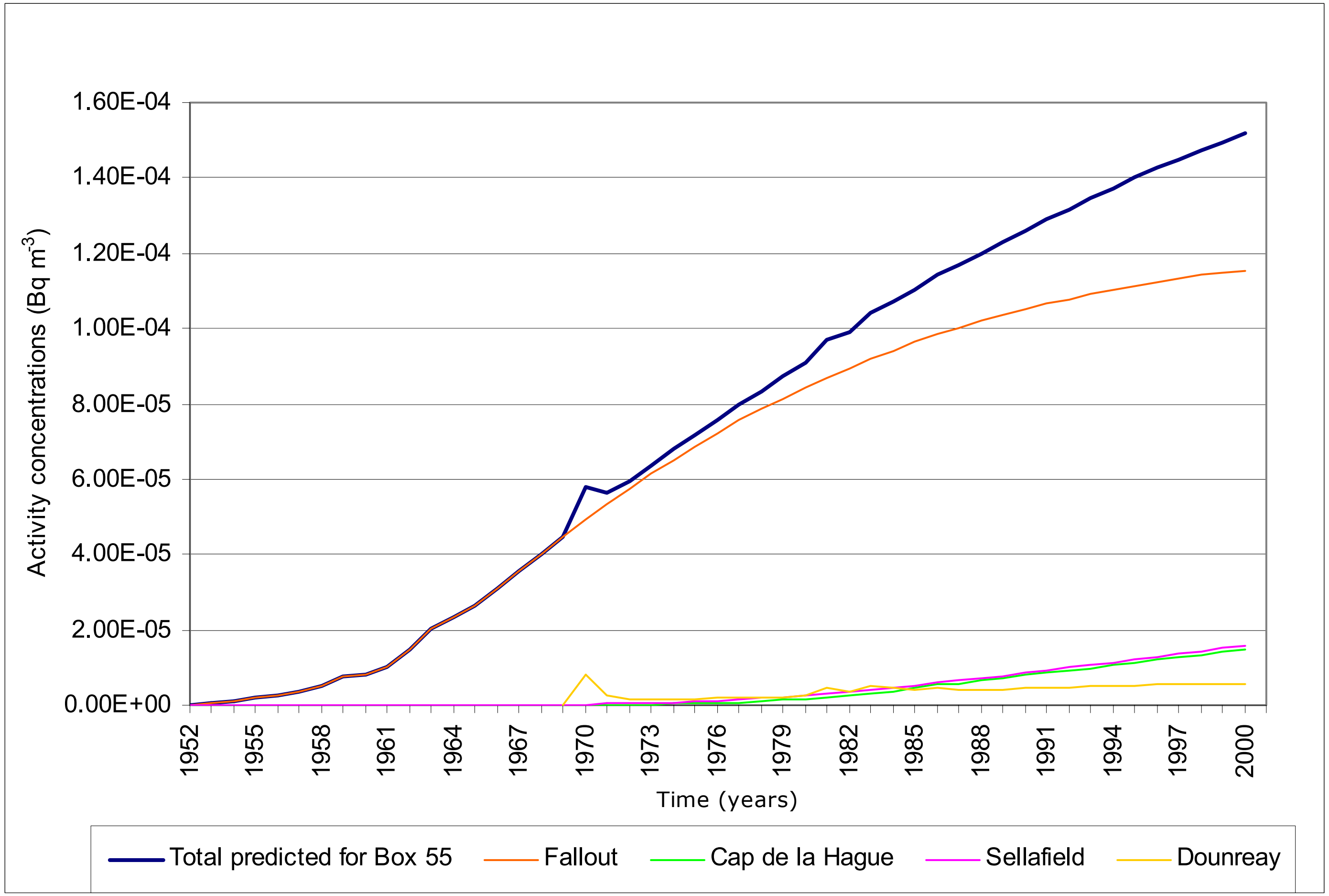


Figure 22: Estimated and measured activity concentrations of americium-241 in fish (wet weight) for selected marine compartments, averaged between 1990 and 2000

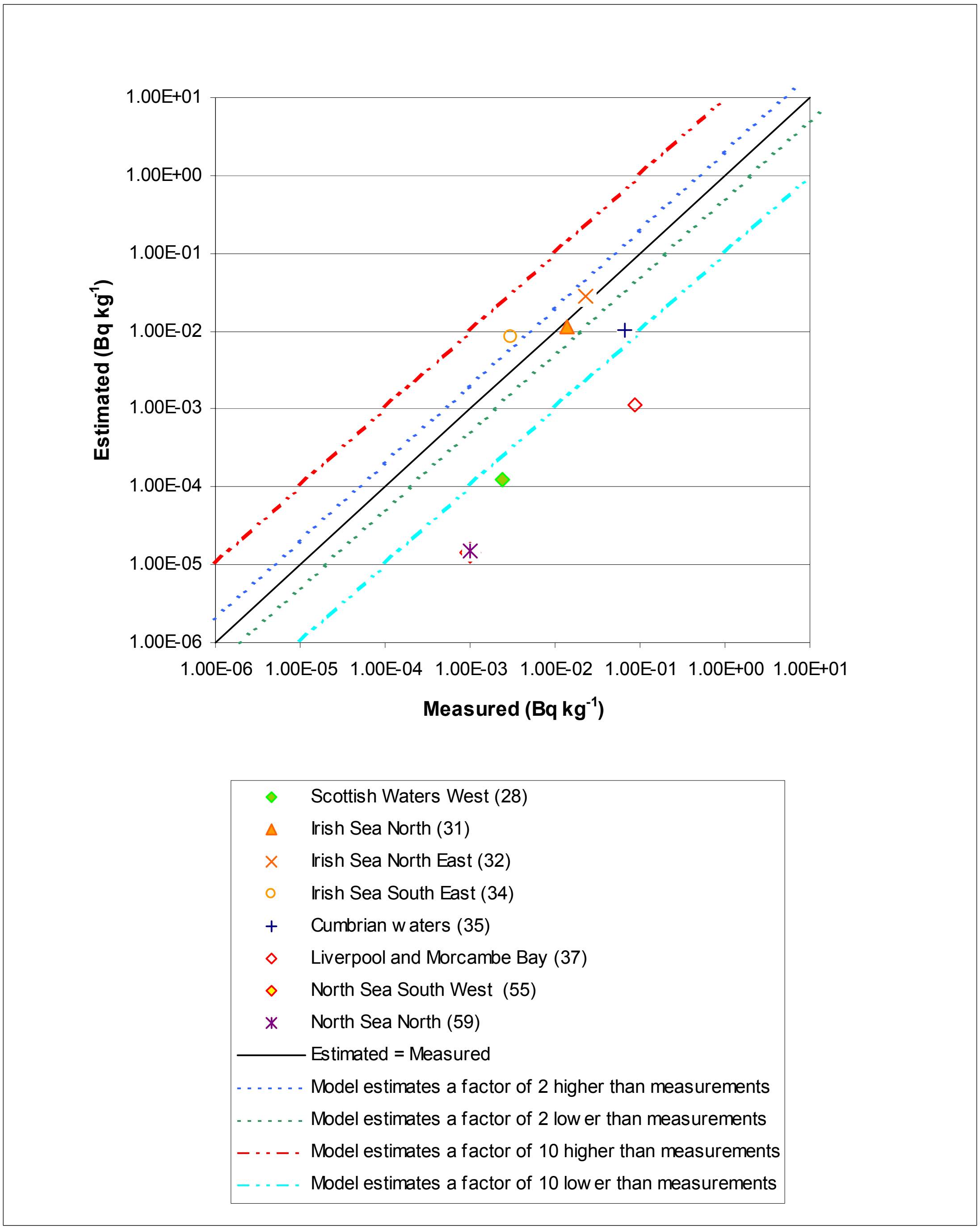


Figure 23: Estimated and measured activity concentrations of americium-241 in molluscs (wet weight) for selected marine compartments, averaged between 1990 and 2000

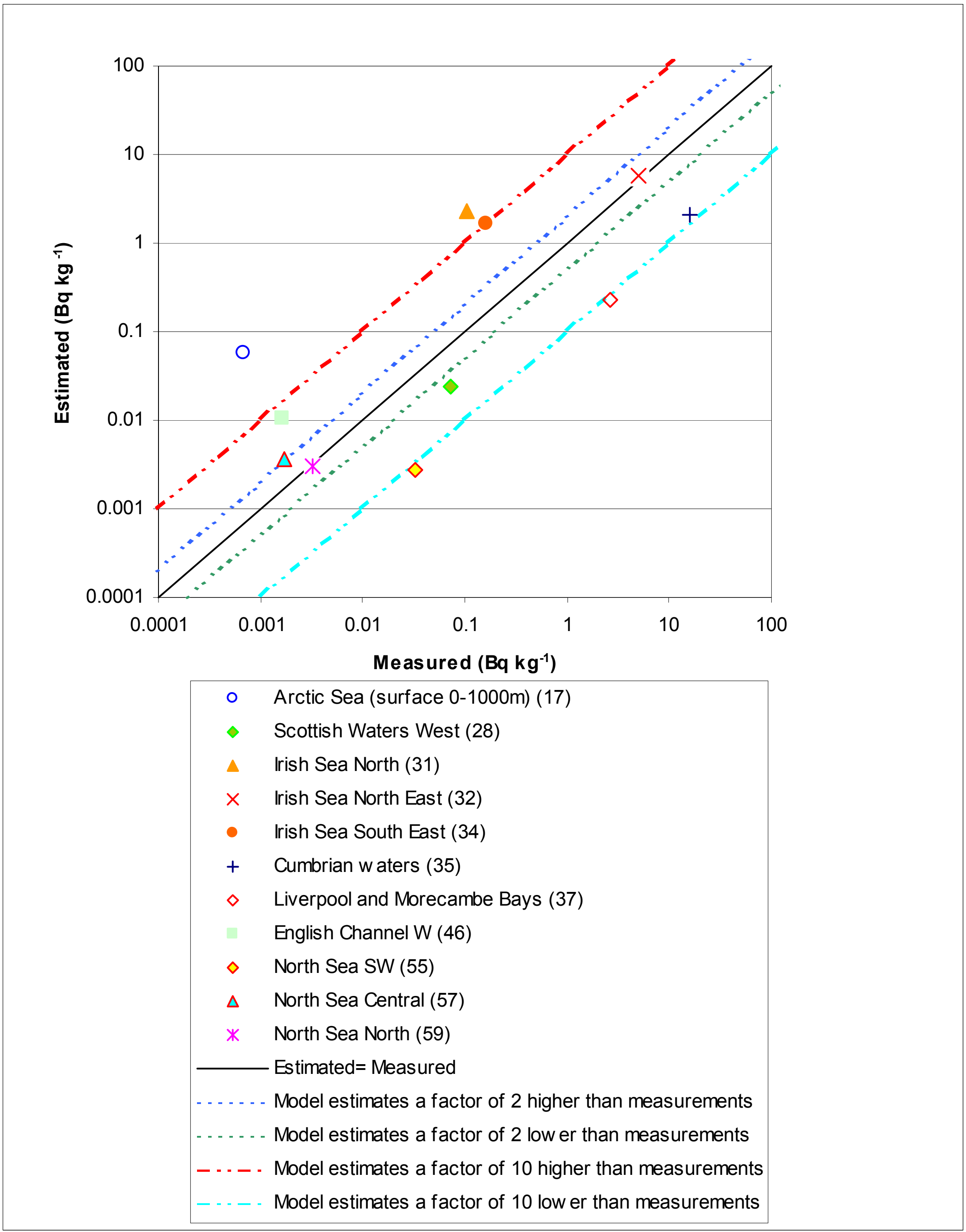


Figure 24: Estimated and measured activity concentrations of americium-241 in molluscs (wet weight) for Irish sea north east compartment (32)

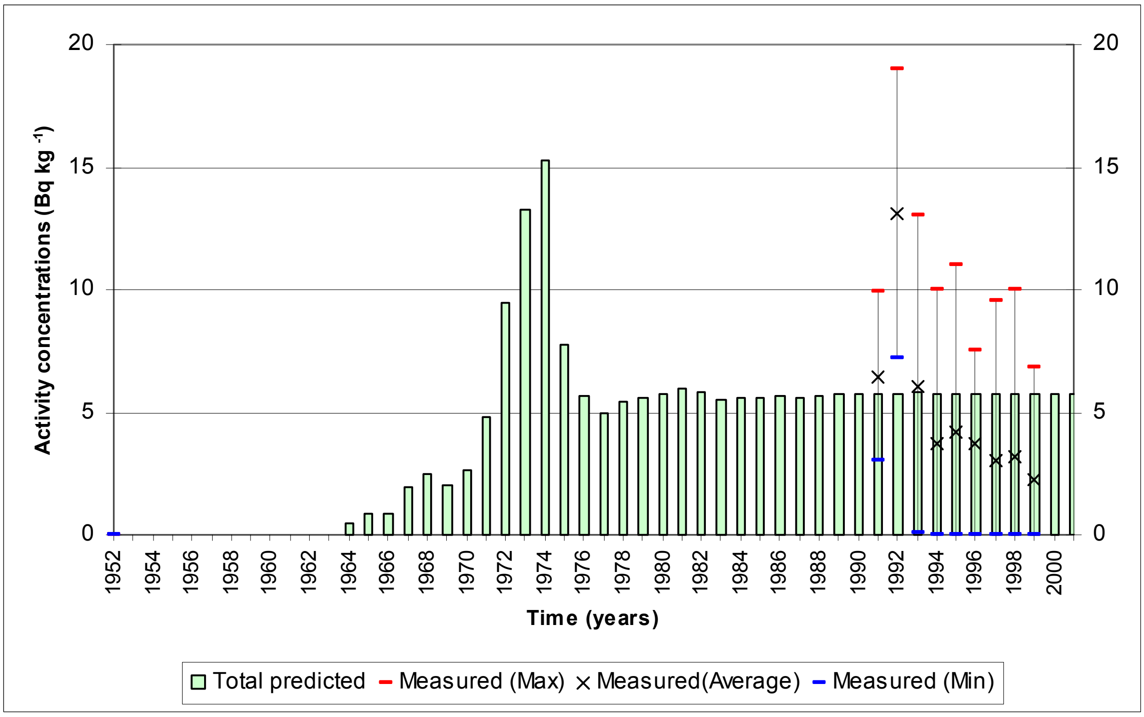


Figure 25: Estimated and measured activity concentrations of americium-241 in top sediment (dry weight) for Cumbrian waters compartment (35)

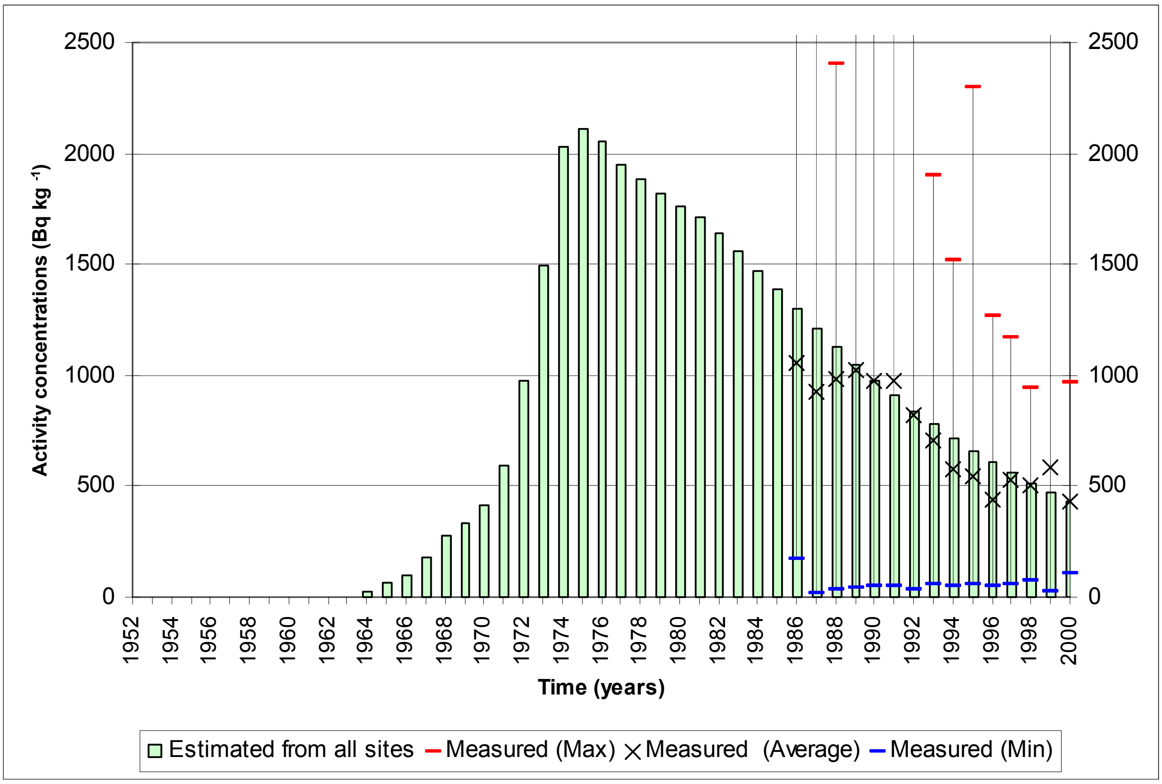


Figure 26: Estimated and measured activity concentrations of tritium in filtered seawater for selected marine compartments, averaged between 1990 and 2000

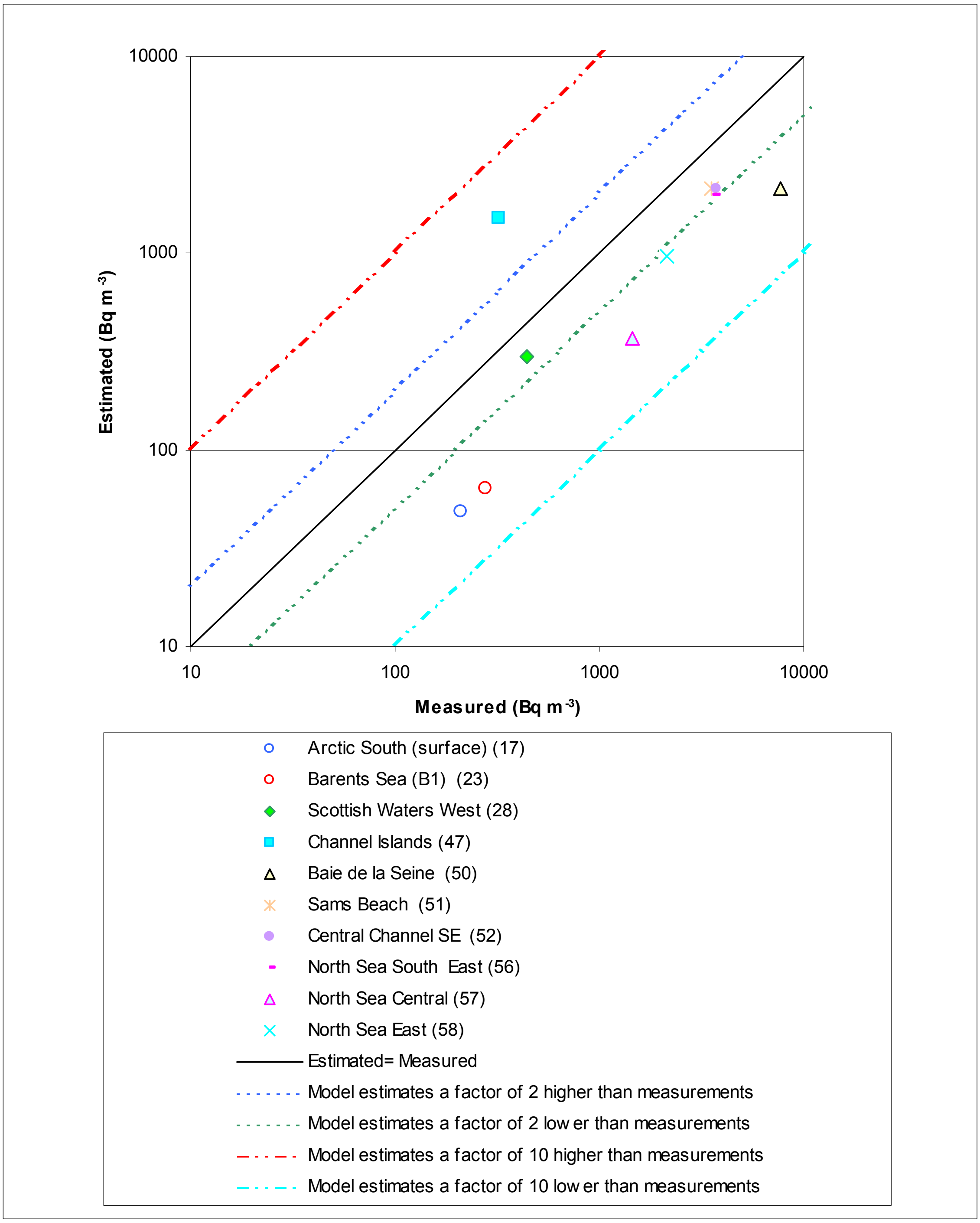


Figure 27: Estimated and measured activity concentrations of tritium in filtered seawater for North sea east compartment (58)

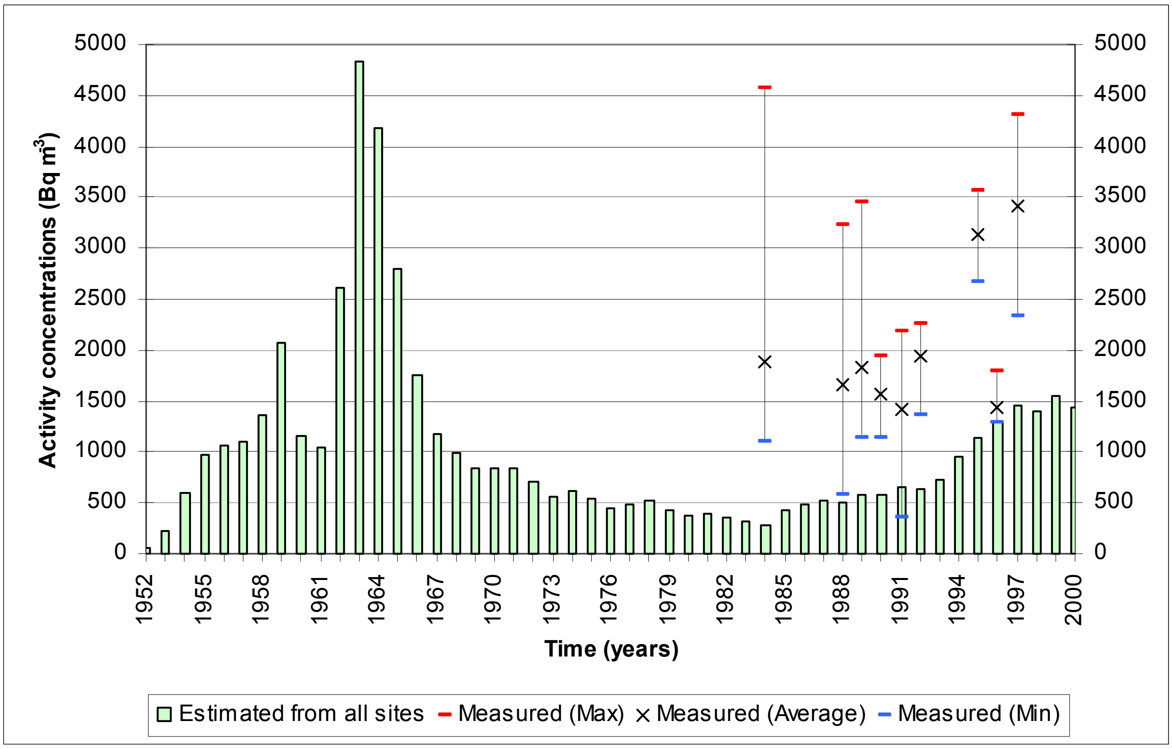


Figure 28: Estimated and measured activity concentrations of tritium in filtered seawater for North sea east compartment (58), showing contributions from different sources

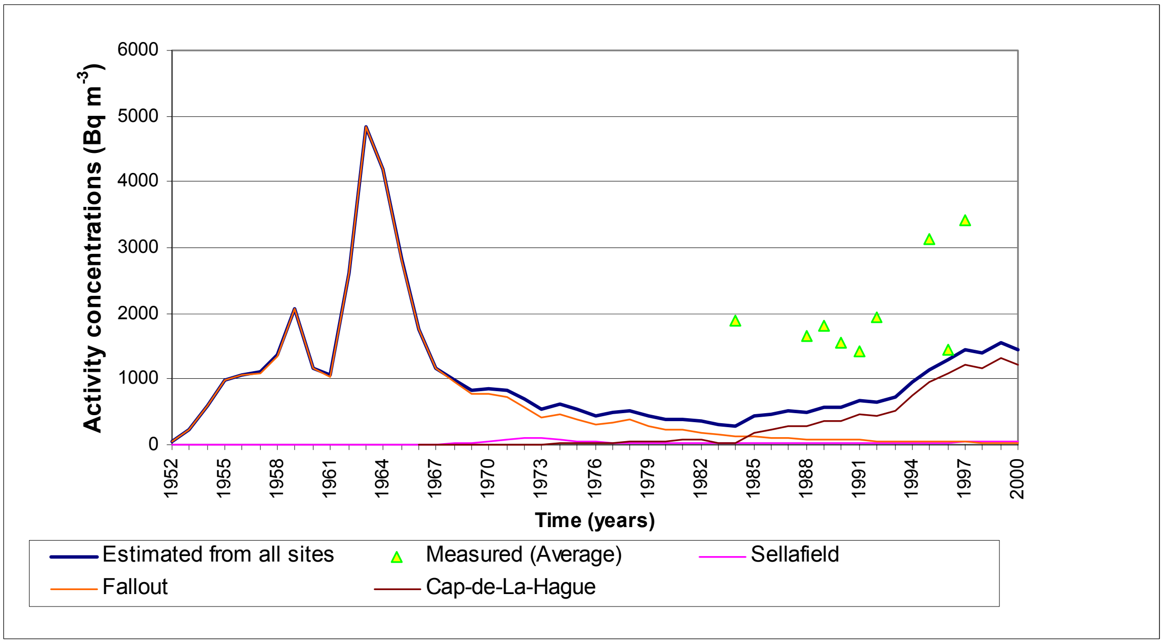


Figure 29: Estimated and measured activity concentrations of carbon-14 in filtered seawater for selected marine compartments, averaged between 1980 and 1990

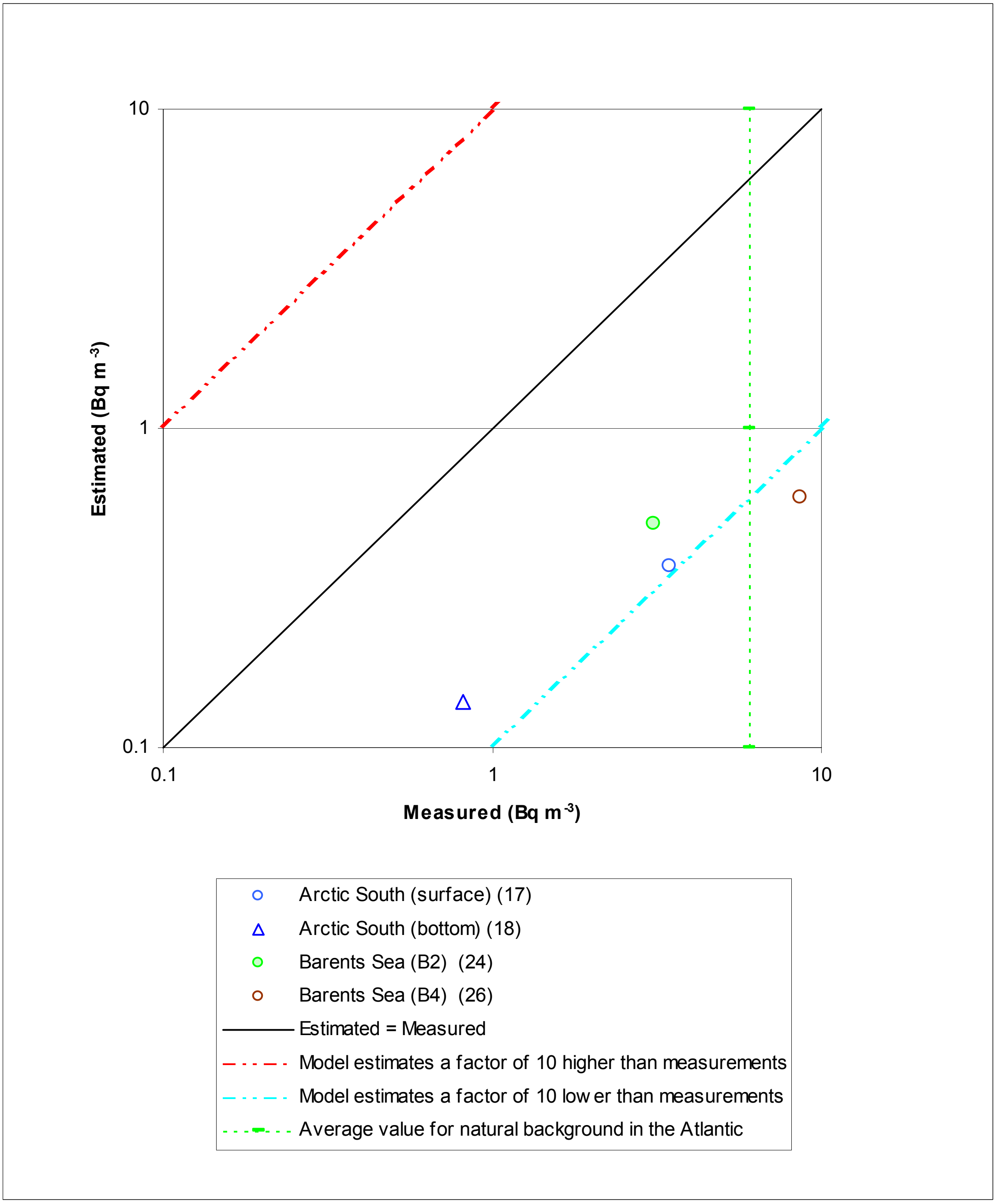


Figure 30: Estimated and measured activity concentrations of carbon-14 in molluscs (wet weight) for selected marine compartments in 1997

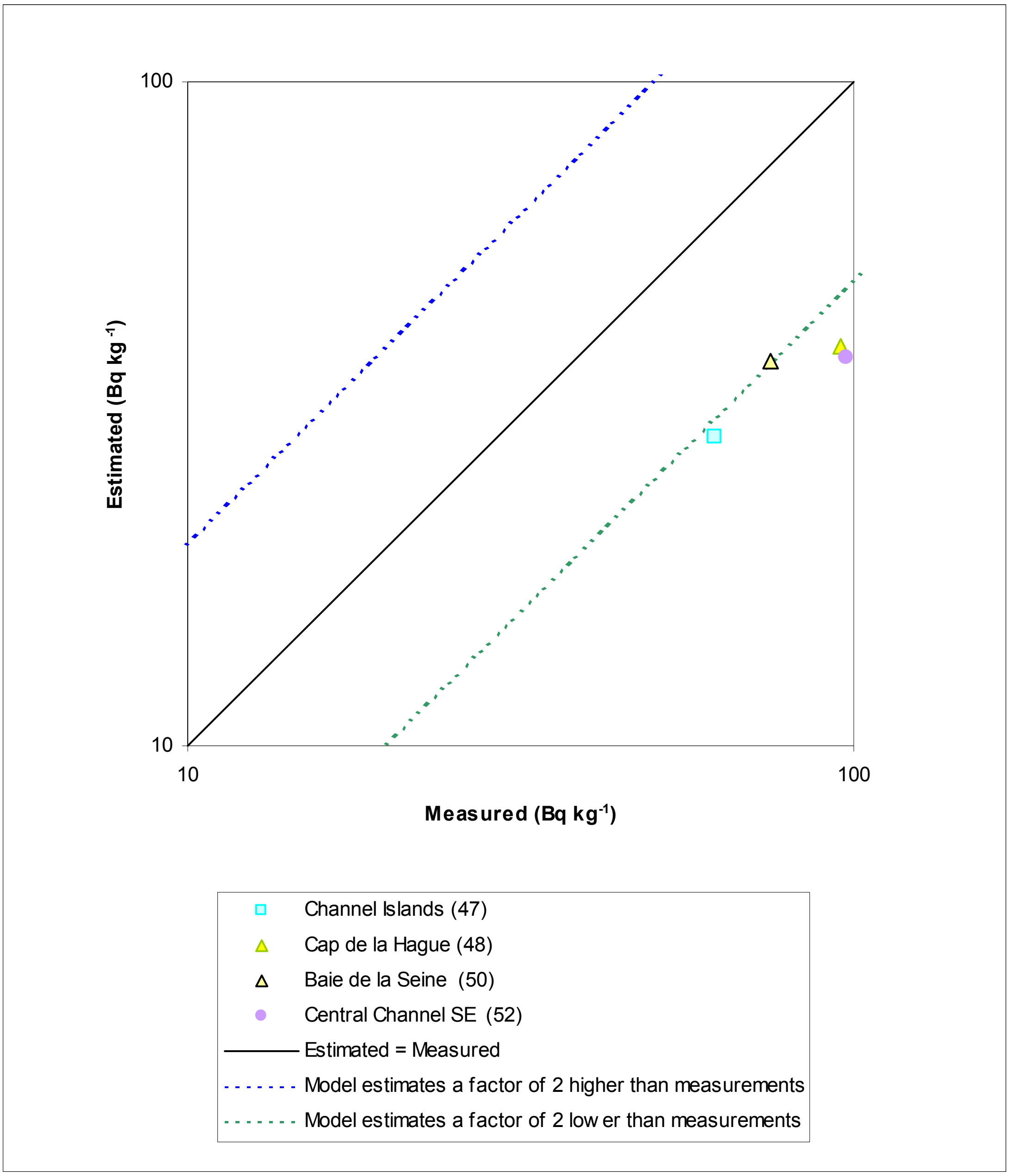


Figure 31: Estimated activity concentrations of carbon-14 in filtered seawater for Baie de la Seine compartment (50), showing contributions from different sources

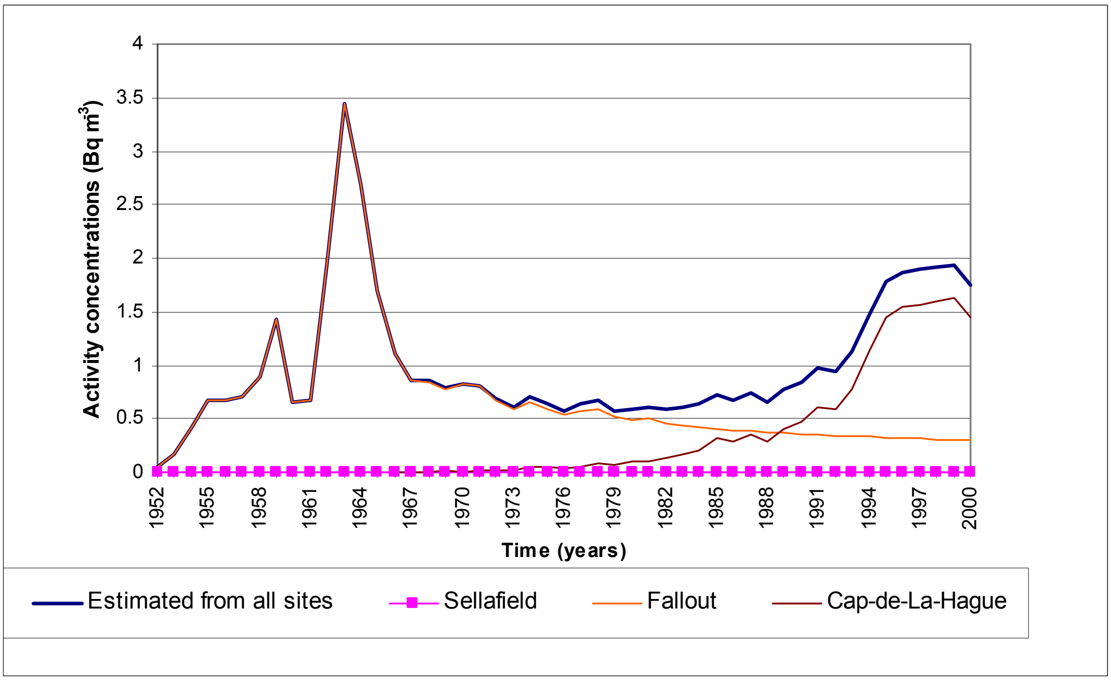


Figure 32: Estimated and measured activity concentrations of polonium-210 in filtered seawater for selected marine compartments, for 1989

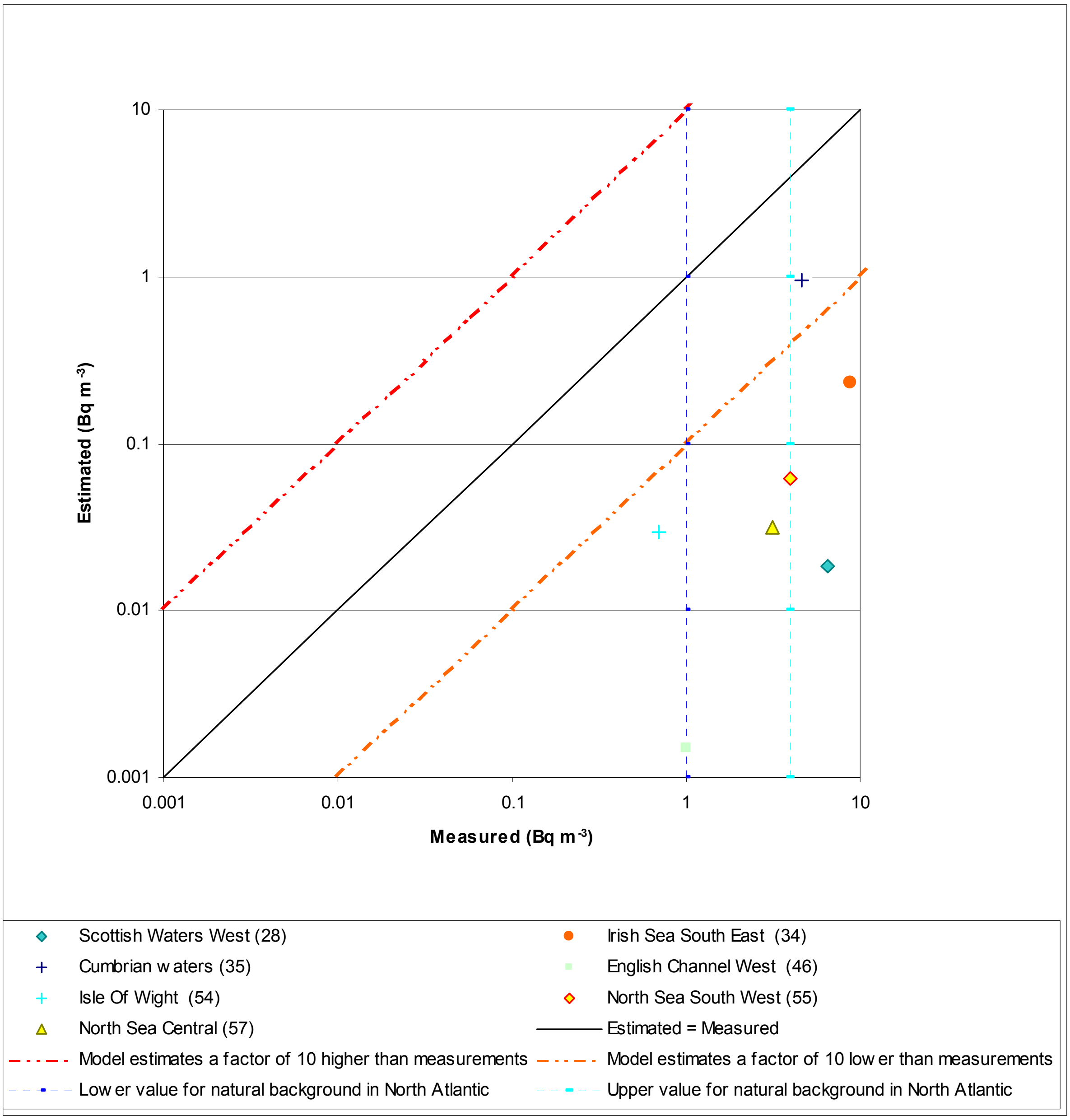


Figure 33: Estimated and measured activity concentrations of polonium-210 in filtered seawater for selected marine compartments, for 1989, showing average background levels.

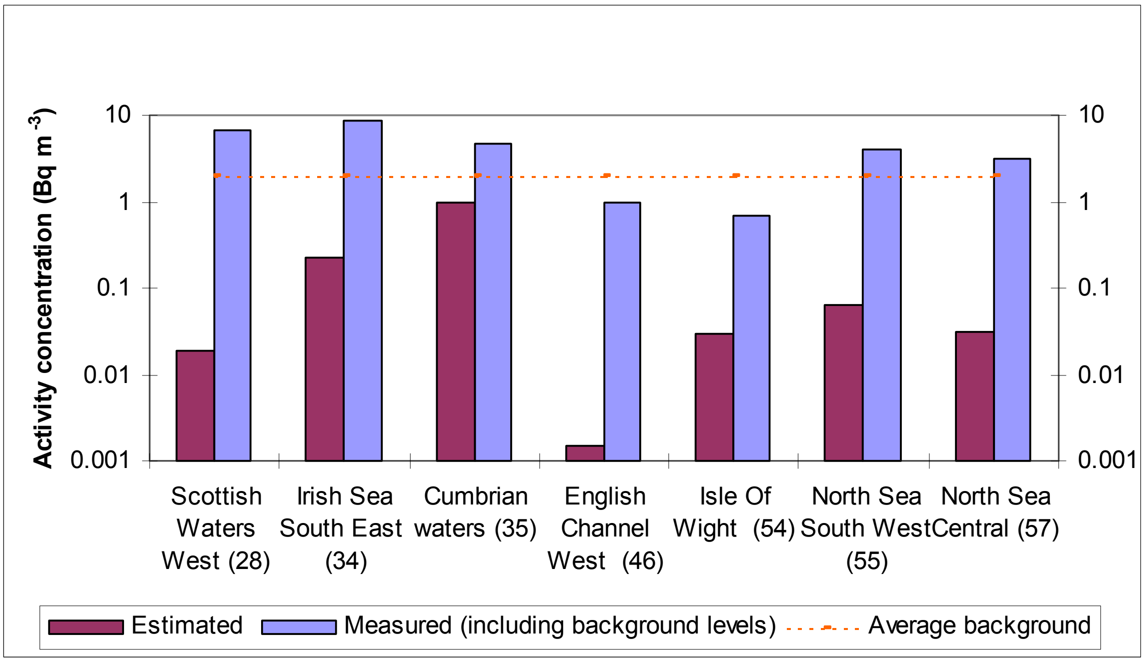


Figure 34: Estimated activity concentrations of polonium-210 in filtered seawater for North sea central compartment (57), showing contributions from different sources.

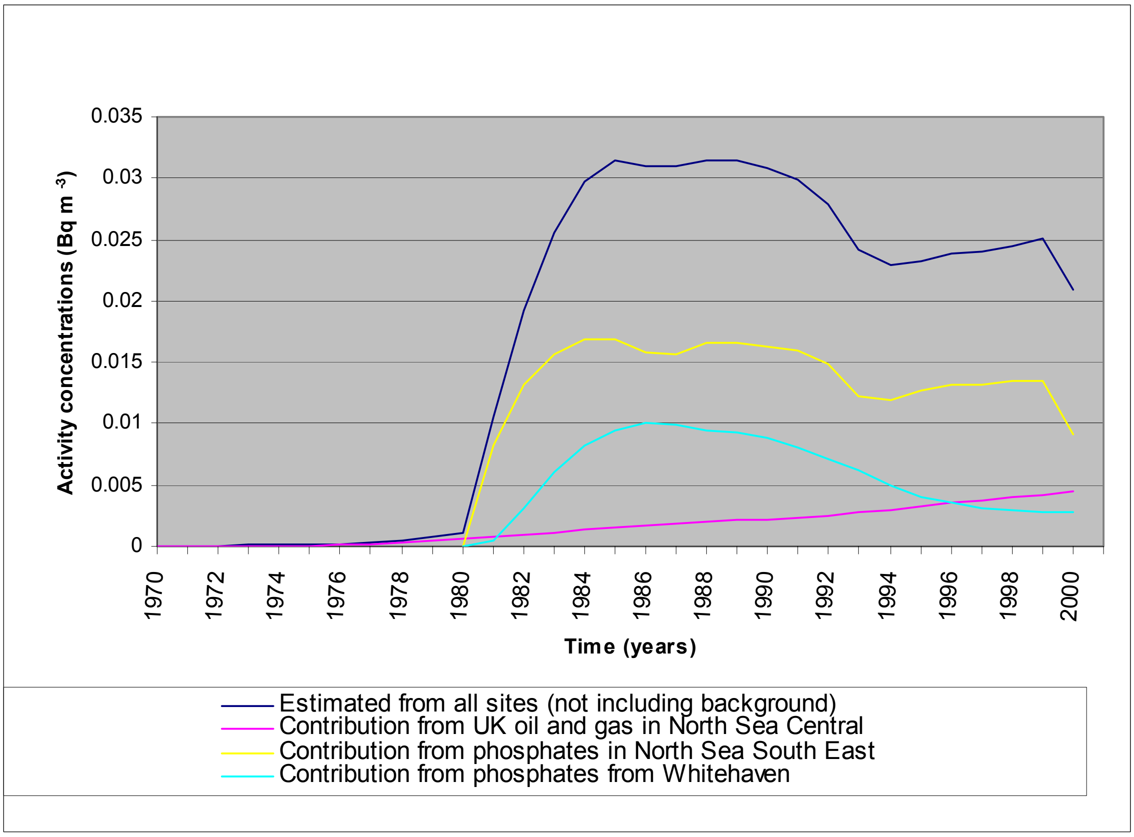


Figure 35: Estimated and measured activity concentrations of cobalt-60 in mollusc (wet weight) in Cap de La Hague compartment (48)

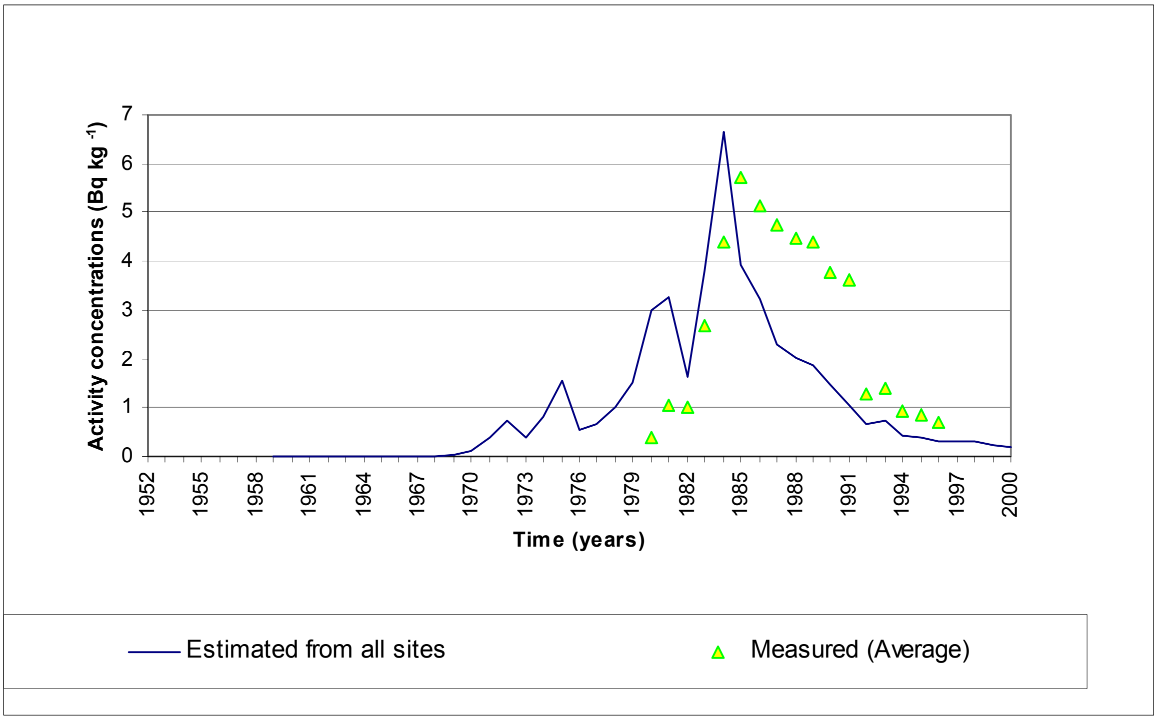


Figure 36: Estimated activity concentrations of cobalt-60 in filtered seawater for Cap de La Hague compartment (48), showing contributions from discharges

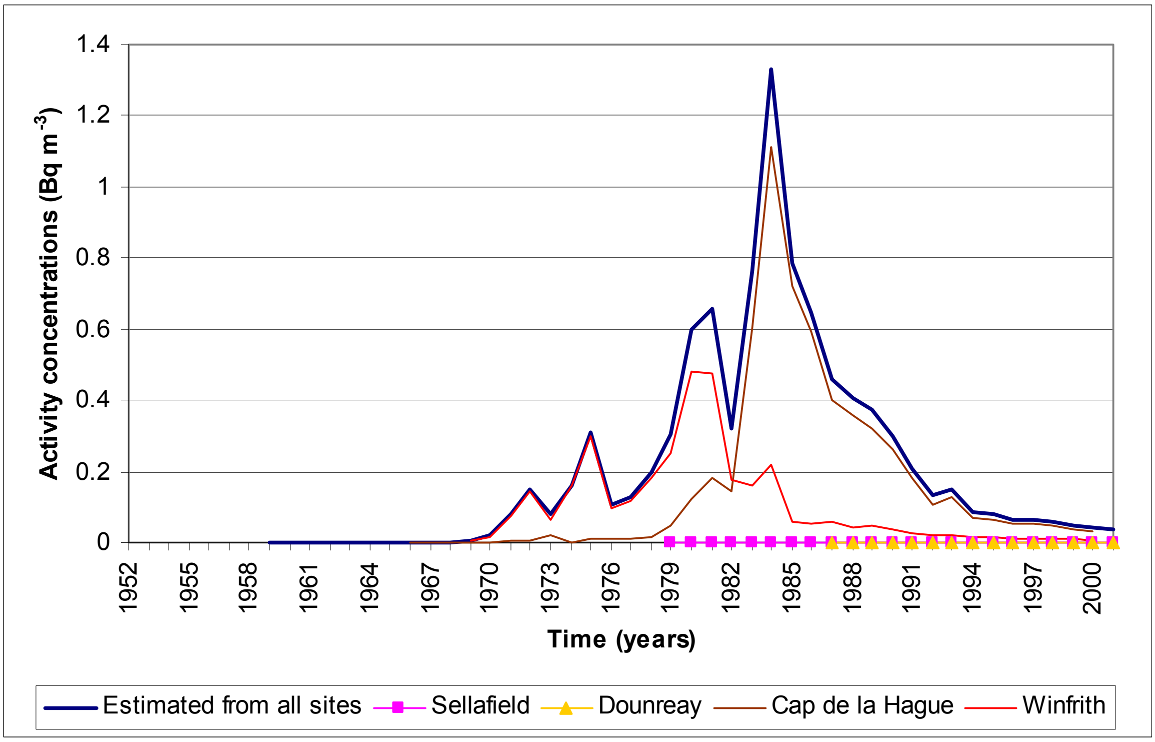


Figure 37: Estimate activity concentrations of cobalt-60 in filtered seawater for North Sea South West compartment (55), showing contributions from discharges

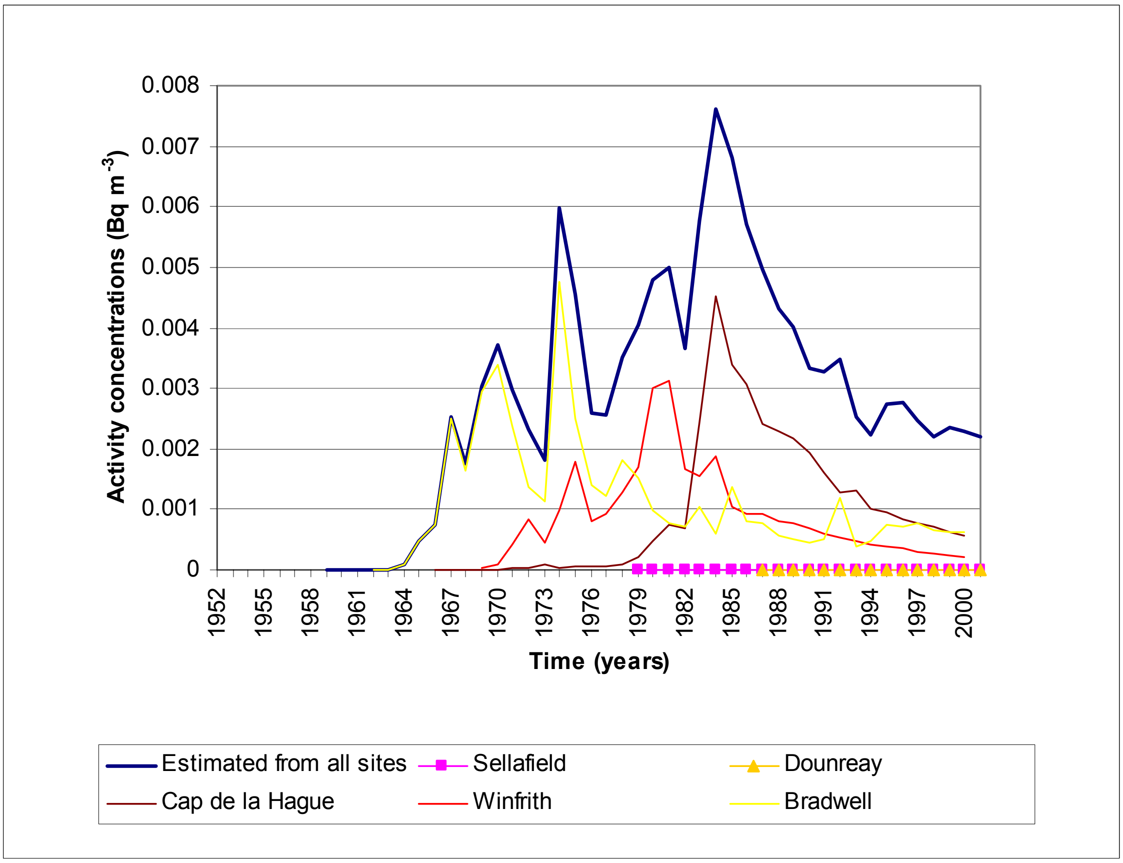


Figure 38: Estimated and measured activity concentrations of ruthenium-106 in molluscs (wet weight) in Cap de La Hague compartment (48)

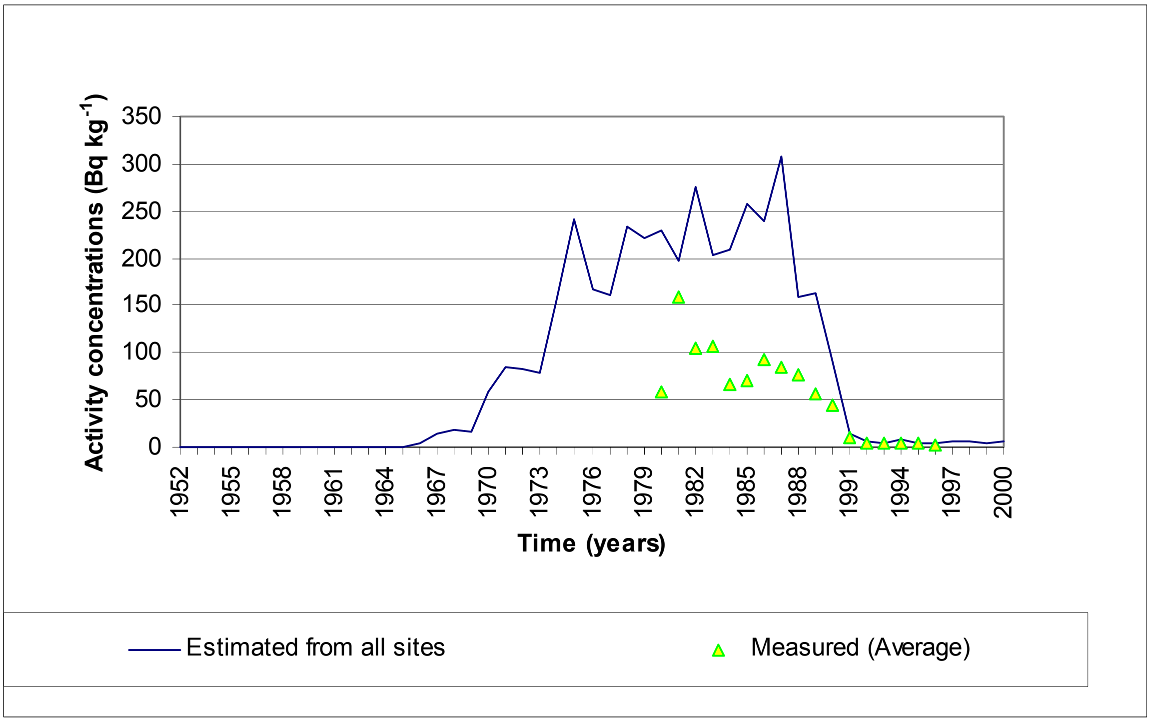
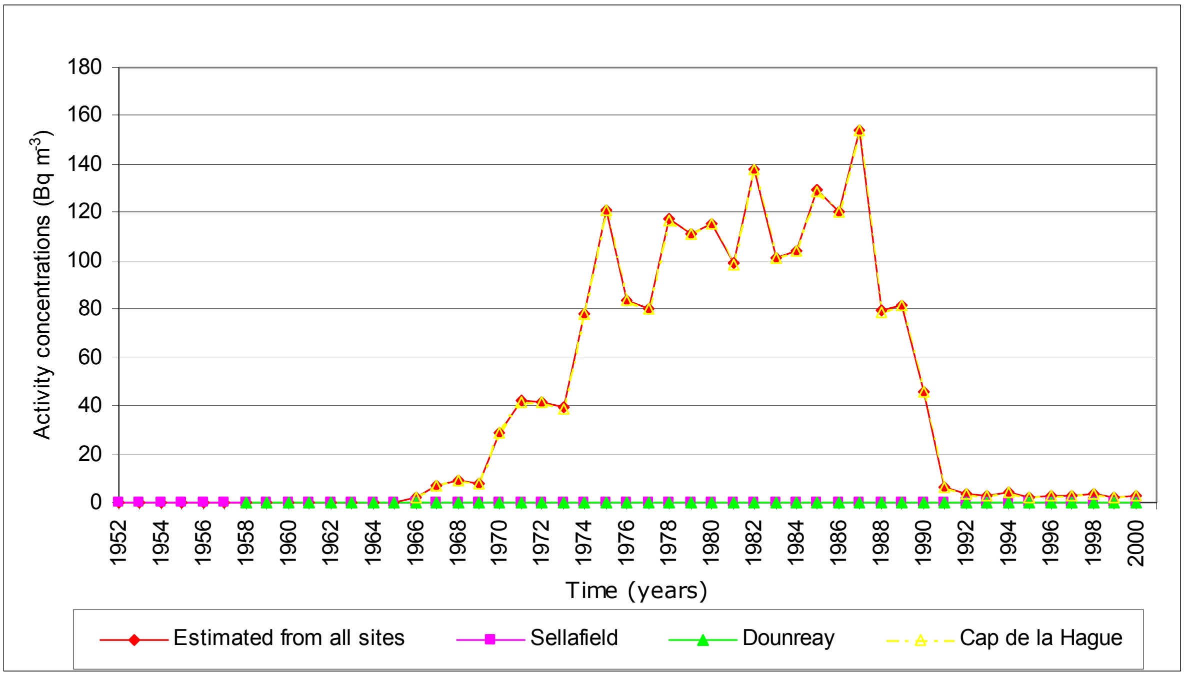


Figure 39: Estimated activity concentrations of ruthenium-106 in filtered seawater for Cap de La Hague compartment (48), showing contributions from different sources



Appendix C - Inputs of radionuclides from rivers

1 Description of approach taken

A large number of the nuclear sites in the European Union are situated at inland locations with the liquid discharges of radionuclides being made to river systems. These river systems subsequently drain into northern European marine waters. Processes such as sedimentation, accumulation by biota and radioactive decay within the river result in a reduced inventory of activity draining from the river than that discharged upstream. These processes have been represented in modelling the total activity discharged to the marine environment from river discharges. Two major European rivers (Rhine and Loire) have been modelled to represent riverine discharges in the European Union. The Schaeffer (Schaeffer, 1976) modelling approach, as described in the EC methodology for routine radioactive discharges (Simmonds et al. 1995) and implemented in the compartmental biosphere transport model, BIOS (Martin et al. 1991), has been used. The two rivers were divided into several river sections for modelling purposes. The relevant inland sites were assumed to either discharge directly to the local marine compartment (in the case of estuarine sites) or to sections of the Rhine or Loire, which are assumed to represent the river the site actually discharges to. The distance between discharge locations and the estuary were estimated. The river sections assumed for the modelling were the same as in a previous study (Smith et al. 2002). Modelling was carried out for all necessary radionuclides for a unit release of 1TBq for 1 year. The concentrations in the local marine compartment following discharge to the river were compared with those assuming the source is discharged directly into the local marine compartment. It should be noted that the local marine compartment is assumed to be the same for all rivers. The results were used to calculate a ratio between discharge to the river and discharge to a local marine compartment for each site. A similar approach was adopted for discharges to Lake Trawsfynydd in the UK, the activity concentrations in the local compartment were compared assuming discharge to Trawsfynydd lake and discharge to the local marine compartment. The calculated ratios were used to scale the river discharges (as provided by Working Group A) to estimate the input to the marine environment. Table 1 provides the calculated ratios that are used to scale the discharge of activity to the riverine environment to estimate the input of activity, from those discharges, to the marine environment.

2 References

Martin, J.S., Barraclough, I.M., Mobbs, S.F., Klos, R.A. and Lawson, G. (1991) User guide for Bios_3A. NRPB-M285, Chilton:

Schaeffer, R. (1976) Conséquences du déplacement des sédiments sur la dispersion des radionucléides. In. Proceedings of the Conference on Impacts of Nuclear Releases into the Aquatic Environment, Otaniemi 1975. IAEA-SM 198/4, Vienna: IAEA.

Simmonds, J.R., Lawson, G. and Mayall, A. (1995) Methodology for assessing the radiological consequences of routine releases of radionuclides to the environment. Radiation Protection 72, EUR 15760, Luxembourg: EC.

Smith, J.G., Bexon, A., Boyer, F.H.C., Harvey, M., Jones, A.L., Kindler, T., Mercer, J., Haywood, S.M., Verhoef, N.B., Haverkate, B.R.W. and Artmann, A. (2002) Assessment of the Radiological Impact on the Population of the European Union of Discharges from European Union Nuclear Sites between 1987 and 1996. Radiation Protection 128, Luxembourg: European Communities.

Table 1: Table of site-specific reduction factors by radionuclide to convert discharges to river to estimate of discharges to the marine environment

	Site							
Radionuclide	Almaraz	Aldermaston	Amersham	Belleville	Beznau	Biblis	Blayais	Brokdorf
Ag-110m	4.08E-01			4.08E-01	2.31E-01	4.96E-01	8.32E-01	8.32E-01
Am-241	4.08E-02		5.00E-01	4.08E-02	6.40E-03	1.08E-01	4.96E-01	4.96E-01
Ba-140	2.78E-01			2.78E-01	1.34E-01	3.61E-01	7.42E-01	7.42E-01
Cd-109	4.08E-01			4.08E-01	2.32E-01	4.92E-01	8.24E-01	8.24E-01
Ce-141	4.04E-02			4.04E-02	6.25E-03	1.04E-01	5.00E-01	5.00E-01
Ce-144	4.04E-02			4.04E-02	6.25E-03	1.04E-01	5.00E-01	5.00E-01
Cm-242	4.09E-02			4.09E-02	6.09E-03	1.09E-01	5.00E-01	5.00E-01
Cm-244	4.09E-02			4.09E-02	6.09E-03	1.09E-01	5.00E-01	5.00E-01
Co-57	4.04E-02			4.04E-02	6.25E-03	1.04E-01	4.96E-01	4.96E-01
Co-58	4.05E-02			4.05E-02	6.19E-03	1.05E-01	5.00E-01	5.00E-01
Co-60	4.08E-02			4.08E-02	6.40E-03	1.04E-01	4.92E-01	4.92E-01
Cr-51	3.88E-02			3.88E-02	5.88E-03	1.00E-01	4.94E-01	4.94E-01
Cs-134	4.04E-01			4.04E-01	2.32E-01	4.88E-01	8.16E-01	8.16E-01
Cs-137	4.12E-01		8.32E-01	4.12E-01	2.36E-01	5.00E-01	8.32E-01	8.32E-01
Cu-64	3.31E-01			0.00E+00	1.73E-01	4.14E-01	7.82E-01	7.82E-01
Eu-155	4.04E-02			4.04E-02	6.40E-03	1.04E-01	4.96E-01	4.96E-01
Fe-55	4.08E-01			4.08E-01	2.32E-01	4.80E-01	8.20E-01	8.20E-01
Fe-59	3.95E-01			3.95E-01	2.16E-01	4.79E-01	8.42E-01	8.42E-01
H-3	9.96E-01	9.96E-01	9.96E-01	9.96E-01	1.00E+00	1.00E+00	9.96E-01	9.96E-01
I-125			9.00E-01					
I-131	2.78E-01			2.78E-01	1.34E-01	3.61E-01	7.42E-01	7.42E-01
I-133	2.78E-01			2.78E-01	1.34E-01	3.61E-01	7.42E-01	7.42E-01
La-140	3.31E-01			3.31E-01	1.73E-01	4.14E-01	7.82E-01	7.82E-01
Mn-54	4.08E-02			4.08E-02	6.25E-03	1.08E-01	5.00E-01	5.00E-01
Mo-99	2.78E-01			2.78E-01	1.34E-01	3.61E-01	7.42E-01	7.42E-01
Na-22	9.96E-01			9.96E-01	1.00E+00	1.00E+00	9.96E-01	9.96E-01
Na-24	2.78E-01			2.78E-01	1.34E-01	3.61E-01	7.42E-01	7.42E-01
Ni-63	4.12E-01			4.12E-01	2.36E-01	5.00E-01	8.32E-01	8.32E-01
P-32	3.31E-01		7.82E-01	3.31E-01	1.73E-01	4.14E-01	7.82E-01	7.82E-01
Pu-239	4.08E-02			4.08E-02	6.40E-03	1.08E-01	5.00E-01	5.00E-01
Ru-103	3.79E-01			3.79E-01	2.11E-01	4.63E-01	8.11E-01	8.11E-01
Ru/Rh-106	4.13E-01			4.13E-01	2.33E-01	5.00E-01	8.38E-01	8.38E-01
S-35	3.95E-01		8.18E-01	3.95E-01	2.23E-01	4.82E-01	8.18E-01	8.18E-01
Sb-122	2.78E-01			2.78E-01	1.34E-01	3.61E-01	7.42E-01	7.42E-01
Sb-124	4.08E-01			4.08E-01	2.32E-01	4.92E-01	8.24E-01	8.24E-01
Sb-125	4.08E-01			4.08E-01	2.32E-01	4.92E-01	8.24E-01	8.24E-01
Sr-89	3.90E-01		8.15E-01	3.90E-01	2.15E-01	4.75E-01	8.15E-01	8.15E-01
Sr-90	4.12E-01			4.12E-01	2.36E-01	5.00E-01	8.32E-01	8.32E-01
Te-123m	4.13E-01			4.13E-01	2.33E-01	5.00E-01	8.38E-01	8.38E-01
Te-125m	4.13E-01			4.13E-01	2.33E-01	5.00E-01	8.38E-01	8.38E-01
Te-127m	4.13E-01			4.13E-01	2.33E-01	5.00E-01	8.38E-01	8.38E-01
Te-132	2.78E-01			2.78E-01	1.34E-01	3.61E-01	7.42E-01	7.42E-01
Y-90	1.42E-01			1.42E-01	5.58E-02	2.14E-01	6.28E-01	6.28E-01
Zn-65	4.04E-01			4.04E-01	2.29E-01	4.88E-01	8.21E-01	8.21E-01
Nb-95/Zr-95	4.04E-02			4.04E-02	6.25E-03	1.04E-01	5.00E-01	5.00E-01
Zr-97					6.25E-04			

Table 1 (cont'd)

Radionuclide	Site							
	Brunsbüttel	Cattenom	Chinon	Chooz	Dampierre	Dodewaard	Emsland	Fessenheim
Ag-110m	8.32E-01	4.96E-01	8.32E-01	4.96E-01	4.08E-01	8.32E-01	8.32E-01	2.31E-01
Am-241	4.96E-01	1.08E-01	4.96E-01	1.08E-01	4.08E-02	4.96E-01	4.96E-01	6.40E-03
Ba-140	7.42E-01	3.61E-01	7.42E-01	3.61E-01	2.78E-01	7.42E-01	7.42E-01	1.34E-01
Cd-109	8.24E-01	4.92E-01	8.24E-01	4.92E-01	4.08E-01	8.24E-01	8.24E-01	2.32E-01
Ce-141	5.00E-01	1.04E-01	5.00E-01	1.04E-01	4.04E-02	5.00E-01	5.00E-01	6.25E-03
Ce-144	5.00E-01	1.04E-01	5.00E-01	1.04E-01	4.04E-02	5.00E-01	5.00E-01	6.25E-03
Cm-242	5.00E-01	1.09E-01	5.00E-01	1.09E-01	4.09E-02	5.00E-01	5.00E-01	6.09E-03
Cm-244	5.00E-01	1.09E-01	5.00E-01	1.09E-01	4.09E-02	5.00E-01	5.00E-01	6.09E-03
Co-57	4.96E-01	1.04E-01	4.96E-01	1.04E-01	4.04E-02	4.96E-01	4.96E-01	6.25E-03
Co-58	5.00E-01	1.05E-01	5.00E-01	1.05E-01	4.05E-02	5.00E-01	5.00E-01	6.19E-03
Co-60	4.92E-01	1.04E-01	4.92E-01	1.04E-01	4.08E-02	4.92E-01	4.92E-01	6.40E-03
Cr-51	4.94E-01	1.00E-01	4.94E-01	1.00E-01	3.88E-02	4.94E-01	4.94E-01	5.88E-03
Cs-134	8.16E-01	4.88E-01	8.16E-01	4.88E-01	4.04E-01	8.16E-01	8.16E-01	2.32E-01
Cs-137	8.32E-01	5.00E-01	8.32E-01	5.00E-01	4.12E-01	8.32E-01	8.32E-01	2.36E-01
Cu-64	7.82E-01	4.14E-01	7.82E-01	4.14E-01	3.31E-01	7.82E-01	7.82E-01	1.73E-01
Eu-155	4.96E-01	1.04E-01	4.96E-01	1.04E-01	4.04E-02	4.96E-01	4.96E-01	6.40E-03
Fe-55	8.20E-01	4.80E-01	8.20E-01	4.80E-01	4.08E-01	8.20E-01	8.20E-01	2.32E-01
Fe-59	8.42E-01	4.79E-01	8.42E-01	4.79E-01	3.95E-01	8.42E-01	8.42E-01	2.16E-01
H-3	9.96E-01	1.00E+00	9.96E-01	1.00E+00	9.96E-01	9.96E-01	9.96E-01	1.00E+00
I-131	7.42E-01	3.61E-01	7.42E-01	3.61E-01	2.78E-01	7.42E-01	7.42E-01	1.34E-01
I-133	7.42E-01	3.61E-01	7.42E-01	3.61E-01	2.78E-01	7.42E-01	7.42E-01	1.34E-01
La-140	7.82E-01	4.14E-01	7.82E-01	4.14E-01	3.31E-01	7.82E-01	7.82E-01	1.73E-01
Mn-54	5.00E-01	1.08E-01	5.00E-01	1.08E-01	4.08E-02	5.00E-01	5.00E-01	6.25E-03
Mo-99	7.42E-01	3.61E-01	7.42E-01	3.61E-01	2.78E-01	7.42E-01	7.42E-01	1.34E-01
Na-22	9.96E-01	1.00E+00	9.96E-01	1.00E+00	9.96E-01	9.96E-01	9.96E-01	1.00E+00
Na-24	7.42E-01	3.61E-01	7.42E-01	3.61E-01	2.78E-01	7.42E-01	7.42E-01	1.34E-01
Ni-63	8.32E-01	5.00E-01	8.32E-01	5.00E-01	4.12E-01	8.32E-01	8.32E-01	2.36E-01
P-32	7.82E-01	4.14E-01	7.82E-01	4.14E-01	3.31E-01	7.82E-01	7.82E-01	1.73E-01
Pu-239	5.00E-01	1.08E-01	5.00E-01	1.08E-01	4.08E-02	5.00E-01	5.00E-01	6.40E-03
Ru-103	8.11E-01	4.63E-01	8.11E-01	4.63E-01	3.79E-01	8.11E-01	8.11E-01	2.11E-01
Ru/Rh-106	8.38E-01	5.00E-01	8.38E-01	5.00E-01	4.13E-01	8.38E-01	8.38E-01	2.33E-01
S-35	8.18E-01	4.82E-01	8.18E-01	4.82E-01	3.95E-01	8.18E-01	8.18E-01	2.23E-01
Sb-122	7.42E-01	3.61E-01	7.42E-01	3.61E-01	2.78E-01	7.42E-01	7.42E-01	1.34E-01
Sb-124	8.24E-01	4.92E-01	8.24E-01	4.92E-01	4.08E-01	8.24E-01	8.24E-01	2.32E-01
Sb-125	8.24E-01	4.92E-01	8.24E-01	4.92E-01	4.08E-01	8.24E-01	8.24E-01	2.32E-01
Sr-89	8.15E-01	4.75E-01	8.15E-01	4.75E-01	3.90E-01	8.15E-01	8.15E-01	2.15E-01
Sr-90	8.32E-01	5.00E-01	8.32E-01	5.00E-01	4.12E-01	8.32E-01	8.32E-01	2.36E-01
Te-123m	8.38E-01	5.00E-01	8.38E-01	5.00E-01	4.13E-01	8.38E-01	8.38E-01	2.33E-01
Te-125m	8.38E-01	5.00E-01	8.38E-01	5.00E-01	4.13E-01	8.38E-01	8.38E-01	2.33E-01
Te-127m	8.38E-01	5.00E-01	8.38E-01	5.00E-01	4.13E-01	8.38E-01	8.38E-01	2.33E-01
Te-132	7.42E-01	3.61E-01	7.42E-01	3.61E-01	2.78E-01	7.42E-01	7.42E-01	1.34E-01
Y-90	6.28E-01	2.14E-01	6.28E-01	2.14E-01	1.42E-01	6.28E-01	6.28E-01	5.58E-02
Zn-65	8.21E-01	4.88E-01	8.21E-01	4.88E-01	4.04E-01	8.21E-01	8.21E-01	2.29E-01
Nb-95/Zr-95	5.00E-01	1.04E-01	5.00E-01	1.04E-01	4.04E-02	5.00E-01	5.00E-01	6.25E-03

Table 1 (cont'd)

Radionuclide	Site							
	Golfech	Gösgen	Grafenrhein-feld	Grohnde	Harwell	Jose Cabrera	Kahl	Karlsruhe
Ag-110m	8.32E-01	2.31E-01	4.96E-01	4.96E-01	8.32E-01	4.08E-01	4.96E-01	4.16E-01
Am-241	4.96E-01	6.40E-03	1.08E-01	1.08E-01	4.96E-01	4.08E-02	1.08E-01	5.60E-02
Ba-140	7.42E-01	1.34E-01	3.61E-01	3.61E-01	7.42E-01	2.78E-01	3.61E-01	2.89E-01
Cd-109	8.24E-01	2.32E-01	4.92E-01	4.92E-01	8.24E-01	4.08E-01	4.92E-01	4.16E-01
Ce-141	5.00E-01	6.25E-03	1.04E-01	1.04E-01	5.00E-01	4.04E-02	1.04E-01	5.42E-02
Ce-144	5.00E-01	6.25E-03	1.04E-01	1.04E-01	5.00E-01	4.04E-02	1.04E-01	5.42E-02
Cm-242	5.00E-01	6.09E-03	1.09E-01	1.09E-01	5.00E-01	4.09E-02	1.09E-01	5.65E-02
Cm-244	5.00E-01	6.09E-03	1.09E-01	1.09E-01	5.00E-01	4.09E-02	1.09E-01	5.65E-02
Co-57	4.96E-01	6.25E-03	1.04E-01	1.04E-01	4.96E-01	4.04E-02	1.04E-01	5.42E-02
Co-58	5.00E-01	6.19E-03	1.05E-01	1.05E-01	5.00E-01	4.05E-02	1.05E-01	5.24E-02
Co-60	4.92E-01	6.40E-03	1.04E-01	1.04E-01	4.92E-01	4.08E-02	1.04E-01	5.60E-02
Cr-51	4.94E-01	5.88E-03	1.00E-01	1.00E-01	4.94E-01	3.88E-02	1.00E-01	5.29E-02
Cs-134	8.16E-01	2.32E-01	4.88E-01	4.88E-01	8.16E-01	4.04E-01	4.88E-01	4.12E-01
Cs-137	8.32E-01	2.36E-01	5.00E-01	5.00E-01	8.32E-01	4.12E-01	5.00E-01	4.20E-01
Cu-64	7.82E-01	1.73E-01	4.14E-01	4.14E-01	7.82E-01	3.31E-01	4.14E-01	3.38E-01
Eu-155	4.96E-01	6.40E-03	1.04E-01	1.04E-01	4.96E-01	4.04E-02	1.04E-01	5.60E-02
Fe-55	8.20E-01	2.32E-01	4.80E-01	4.80E-01	8.20E-01	4.08E-01	4.80E-01	4.12E-01
Fe-59	8.42E-01	2.16E-01	4.79E-01	4.79E-01	8.42E-01	3.95E-01	4.79E-01	4.00E-01
H-3	9.96E-01	1.00E+00	1.00E+00	1.00E+00	9.96E-01	9.96E-01	1.00E+00	9.96E-01
I-131	7.42E-01	1.34E-01	3.61E-01	3.61E-01	7.42E-01	2.78E-01	3.61E-01	2.89E-01
I-133	7.42E-01	1.34E-01	3.61E-01	3.61E-01	7.42E-01	2.78E-01	3.61E-01	2.89E-01
La-140	7.82E-01	1.73E-01	4.14E-01	4.14E-01	7.82E-01	3.31E-01	4.14E-01	3.38E-01
Mn-54	5.00E-01	6.25E-03	1.08E-01	1.08E-01	5.00E-01	4.08E-02	1.08E-01	5.42E-02
Mo-99	7.42E-01	1.34E-01	3.61E-01	3.61E-01	7.42E-01	2.78E-01	3.61E-01	2.89E-01
Na-22	9.96E-01	1.00E+00	1.00E+00	1.00E+00	9.96E-01	9.96E-01	1.00E+00	9.96E-01
Na-24	7.42E-01	1.34E-01	3.61E-01	3.61E-01	7.42E-01	2.78E-01	3.61E-01	1.12E-01
Ni-63	8.32E-01	2.36E-01	5.00E-01	5.00E-01	8.32E-01	4.12E-01	5.00E-01	4.20E-01
P-32	7.82E-01	1.73E-01	4.14E-01	4.14E-01	7.82E-01	3.31E-01	4.14E-01	3.38E-01
Pu-238								5.60E-02
Pu-239	5.00E-01	6.40E-03	1.08E-01	1.08E-01	5.00E-01	4.08E-02	1.08E-01	5.60E-02
Ru-103	8.11E-01	2.11E-01	4.63E-01	4.63E-01	8.11E-01	3.79E-01	4.63E-01	3.84E-01
Ru/Rh-106	8.38E-01	2.33E-01	5.00E-01	5.00E-01	8.38E-01	4.13E-01	5.00E-01	4.17E-01
S-35	8.18E-01	2.23E-01	4.82E-01	4.82E-01	8.18E-01	3.95E-01	4.82E-01	4.00E-01
Sb-122	7.42E-01	1.34E-01	3.61E-01	3.61E-01	7.42E-01	2.78E-01	3.61E-01	2.89E-01
Sb-124	8.24E-01	2.32E-01	4.92E-01	4.92E-01	8.24E-01	4.08E-01	4.92E-01	4.16E-01
Sb-125	8.24E-01	2.32E-01	4.92E-01	4.92E-01	8.24E-01	4.08E-01	4.92E-01	4.16E-01
Sr-89	8.15E-01	2.15E-01	4.75E-01	4.75E-01	8.15E-01	3.90E-01	4.75E-01	3.95E-01
Sr-90	8.32E-01	2.36E-01	5.00E-01	5.00E-01	8.32E-01	4.12E-01	5.00E-01	4.20E-01
Te-123m	8.38E-01	2.33E-01	5.00E-01	5.00E-01	8.38E-01	4.13E-01	5.00E-01	4.17E-01
Te-125m	8.38E-01	2.33E-01	5.00E-01	5.00E-01	8.38E-01	4.13E-01	5.00E-01	4.17E-01
Te-127m	8.38E-01	2.33E-01	5.00E-01	5.00E-01	8.38E-01	4.13E-01	5.00E-01	4.17E-01
Te-132	7.42E-01	1.34E-01	3.61E-01	3.61E-01	7.42E-01	2.78E-01	3.61E-01	2.89E-01
Y-90	6.28E-01	5.58E-02	2.14E-01	2.14E-01	6.28E-01	1.42E-01	2.14E-01	1.63E-01
Zn-65	8.21E-01	2.29E-01	4.88E-01	4.88E-01	8.21E-01	4.04E-01	4.88E-01	4.08E-01
Nb-95/Zr-95	5.00E-01	6.25E-03	1.04E-01	1.04E-01	5.00E-01	4.04E-02	1.04E-01	5.42E-02
Zr-97		6.25E-04						5.42E-03

Table 1 (cont'd)

Radionuclide	Site							
	Krümmel	Leibstadt	Muelheim	Mühleberg	Neckarwest-heim	Nogent	Obrigheim	Philippsburg
Ag-110m	6.72E-01	2.31E-01	6.72E-01	2.31E-01	4.16E-01	5.46E-01	4.16E-01	4.16E-01
Am-241	2.96E-01	6.40E-03	2.96E-01	6.40E-03	5.60E-02	1.12E-01	5.60E-02	5.60E-02
Ba-140	5.82E-01	1.34E-01	5.82E-01	1.34E-01	2.89E-01	4.10E-01	2.89E-01	2.89E-01
Cd-109	6.68E-01	2.32E-01	6.68E-01	2.32E-01	4.16E-01	5.48E-01	4.16E-01	4.16E-01
Ce-141	2.92E-01	6.25E-03	2.92E-01	6.25E-03	5.42E-02	1.08E-01	5.42E-02	5.42E-02
Ce-144	2.92E-01	6.25E-03	2.92E-01	6.25E-03	5.42E-02	1.08E-01	5.42E-02	5.42E-02
Cm-242	2.96E-01	6.09E-03	2.96E-01	6.09E-03	5.65E-02	1.09E-01	5.65E-02	5.65E-02
Cm-244	2.96E-01	6.09E-03	2.96E-01	6.09E-03	5.65E-02	1.09E-01	5.65E-02	5.65E-02
Co-57	2.92E-01	6.25E-03	2.92E-01	6.25E-03	5.42E-02	1.08E-01	5.42E-02	5.42E-02
Co-58	2.95E-01	6.19E-03	2.95E-01	6.19E-03	5.24E-02	1.10E-01	5.24E-02	5.24E-02
Co-60	2.92E-01	6.40E-03	2.92E-01	6.40E-03	5.60E-02	1.08E-01	5.60E-02	5.60E-02
Cr-51	2.88E-01	5.88E-03	2.88E-01	5.88E-03	5.29E-02	1.06E-01	5.29E-02	5.29E-02
Cs-134	6.64E-01	2.32E-01	6.64E-01	2.32E-01	4.12E-01	5.44E-01	4.12E-01	4.12E-01
Cs-137	6.80E-01	2.36E-01	6.80E-01	2.36E-01	4.20E-01	5.60E-01	4.20E-01	4.20E-01
Cu-64	6.17E-01	1.73E-01	6.17E-01	1.73E-01	3.38E-01	4.66E-01	3.38E-01	3.38E-01
Eu-155	2.92E-01	6.40E-03	2.92E-01	6.40E-03	5.60E-02	1.08E-01	5.60E-02	5.60E-02
Fe-55	6.64E-01	2.32E-01	6.64E-01	2.32E-01	4.12E-01	5.44E-01	4.12E-01	4.12E-01
Fe-59	6.74E-01	2.16E-01	6.74E-01	2.16E-01	4.00E-01	5.37E-01	4.00E-01	4.00E-01
H-3	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.96E-01	9.96E-01	9.96E-01	9.96E-01
I-131	5.82E-01	1.34E-01	5.82E-01	1.34E-01	2.89E-01	4.10E-01	2.89E-01	2.89E-01
I-133	5.82E-01	1.34E-01	5.82E-01	1.34E-01	2.89E-01	4.10E-01	2.89E-01	2.89E-01
La-140	6.17E-01	1.73E-01	6.17E-01	1.73E-01	3.38E-01	4.66E-01	3.38E-01	3.38E-01
Mn-54	2.92E-01	6.25E-03	2.92E-01	6.25E-03	5.42E-02	1.10E-01	5.42E-02	5.42E-02
Mo-99	5.82E-01	1.34E-01	5.82E-01	1.34E-01	2.89E-01	4.10E-01	2.89E-01	2.89E-01
Na-22	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.96E-01	9.96E-01	9.96E-01	9.96E-01
Na-24	5.82E-01	1.34E-01	5.82E-01	1.34E-01	1.12E-01	4.10E-01	1.12E-01	1.12E-01
Ni-63	6.80E-01	2.36E-01	6.80E-01	2.36E-01	4.20E-01	5.60E-01	4.20E-01	4.20E-01
P-32	6.17E-01	1.73E-01	6.17E-01	1.73E-01	3.38E-01	4.66E-01	3.38E-01	3.38E-01
Pu-238	2.92E-01		2.92E-01		5.60E-02	1.12E-01	5.60E-02	5.60E-02
Pu-239	2.92E-01	6.40E-03	2.92E-01	6.40E-03	5.60E-02	1.12E-01	5.60E-02	5.60E-02
Ru-103	6.47E-01	2.11E-01	6.47E-01	2.11E-01	3.84E-01	5.16E-01	3.84E-01	3.84E-01
Ru/Rh-106	6.79E-01	2.33E-01	6.79E-01	2.33E-01	4.17E-01	5.54E-01	4.17E-01	4.17E-01
S-35	6.59E-01	2.23E-01	6.59E-01	2.23E-01	4.00E-01	5.36E-01	4.00E-01	4.00E-01
Sb-122	5.82E-01	1.34E-01	5.82E-01	1.34E-01	2.89E-01	4.10E-01	2.89E-01	2.89E-01
Sb-124	6.68E-01	2.32E-01	6.68E-01	2.32E-01	4.16E-01	5.48E-01	4.16E-01	4.16E-01
Sb-125	6.68E-01	2.32E-01	6.68E-01	2.32E-01	4.16E-01	5.48E-01	4.16E-01	4.16E-01
Sr-89	6.55E-01	2.15E-01	6.55E-01	2.15E-01	3.95E-01	5.30E-01	3.95E-01	3.95E-01
Sr-90	6.76E-01	2.36E-01	6.76E-01	2.36E-01	4.20E-01	5.60E-01	4.20E-01	4.20E-01
Te-123m	6.79E-01	2.33E-01	6.79E-01	2.33E-01	4.17E-01	5.54E-01	4.17E-01	4.17E-01
Te-125m	6.79E-01	2.33E-01	6.79E-01	2.33E-01	4.17E-01	5.54E-01	4.17E-01	4.17E-01
Te-127m	6.79E-01	2.33E-01	6.79E-01	2.33E-01	4.17E-01	5.54E-01	4.17E-01	4.17E-01
Te-132	5.82E-01	1.34E-01	5.82E-01	1.34E-01	2.89E-01	4.10E-01	2.89E-01	2.89E-01
Y-90	4.65E-01	5.58E-02	4.65E-01	5.58E-02	1.63E-01	2.44E-01	1.63E-01	1.63E-01
Zn-65	6.67E-01	2.29E-01	6.67E-01	2.29E-01	4.08E-01	5.42E-01	4.08E-01	4.08E-01
Nb-95/Zr-95	2.92E-01	6.25E-03	2.92E-01	6.25E-03	5.42E-02	1.08E-01	5.42E-02	5.42E-02
Zr-97		6.25E-04		6.25E-04	5.42E-03		5.42E-03	5.42E-03

Table 1 (cont'd)

Radionuclide	Site						
	Rheinsberg	St Laurent	Stade	Tihange	Trawsfynydd	Trillo	Würgassen
Ag-110m	6.72E-01	5.46E-01	6.72E-01	4.96E-01	6.67E-01	4.08E-01	4.96E-01
Am-241	2.96E-01	1.12E-01	2.96E-01	1.08E-01		4.08E-02	1.08E-01
Ba-140	5.82E-01	4.10E-01	5.82E-01	3.61E-01		2.78E-01	3.61E-01
C-14					5.20E-01		
Ca-45					5.20E-01		
Cd-109	6.68E-01	5.48E-01	6.68E-01	4.92E-01		4.08E-01	4.92E-01
Ce-141	2.92E-01	1.08E-01	2.92E-01	1.04E-01		4.04E-02	1.04E-01
Ce-144	2.92E-01	1.08E-01	2.92E-01	1.04E-01	8.00E-02	4.04E-02	1.04E-01
Cm-242	2.96E-01	1.09E-01	2.96E-01	1.09E-01		4.09E-02	1.09E-01
Cm-244	2.96E-01	1.09E-01	2.96E-01	1.09E-01		4.09E-02	1.09E-01
Co-57	2.92E-01	1.08E-01	2.92E-01	1.04E-01		4.04E-02	1.04E-01
Co-58	2.95E-01	1.10E-01	2.95E-01	1.05E-01		4.05E-02	1.05E-01
Co-60	2.92E-01	1.08E-01	2.92E-01	1.04E-01	8.00E-02	4.08E-02	1.04E-01
Cr-51	2.88E-01	1.06E-01	2.88E-01	1.00E-01	8.00E-02	3.88E-02	1.00E-01
Cs-134	6.64E-01	5.44E-01	6.64E-01	4.88E-01	5.20E-01	4.04E-01	4.88E-01
Cs-137	6.80E-01	5.60E-01	6.80E-01	5.00E-01	5.20E-01	4.12E-01	5.00E-01
Cu-64	6.17E-01	4.66E-01	6.17E-01	4.14E-01		3.31E-01	4.14E-01
Eu-154					8.00E-02		
Eu-155	2.92E-01	1.08E-01	2.92E-01	1.04E-01	8.00E-02	4.04E-02	1.04E-01
Fe-55	6.64E-01	5.44E-01	6.64E-01	4.80E-01	5.20E-01	4.08E-01	4.80E-01
Fe-59	6.74E-01	5.37E-01	6.74E-01	4.79E-01	5.20E-01	3.95E-01	4.79E-01
H-3	1.00E+00	9.96E-01	1.00E+00	1.00E+00	9.20E-01	9.96E-01	1.00E+00
I-131	5.82E-01	4.10E-01	5.82E-01	3.61E-01		2.78E-01	3.61E-01
I-133	5.82E-01	4.10E-01	5.82E-01	3.61E-01		2.78E-01	3.61E-01
La-140	6.17E-01	4.66E-01	6.17E-01	4.14E-01		3.31E-01	4.14E-01
Mn-54	2.92E-01	1.10E-01	2.92E-01	1.08E-01	8.00E-02	4.08E-02	1.08E-01
Mo-99	5.82E-01	4.10E-01	5.82E-01	3.61E-01		2.78E-01	3.61E-01
Na-22	1.00E+00	9.96E-01	1.00E+00	1.00E+00		9.96E-01	1.00E+00
Na-24	5.82E-01	4.10E-01	5.82E-01	3.61E-01		2.78E-01	3.61E-01
Ni-63	6.80E-01	5.60E-01	6.80E-01	5.00E-01	5.20E-01	4.12E-01	5.00E-01
P-32	6.17E-01	4.66E-01	6.17E-01	4.14E-01	5.20E-01	3.31E-01	4.14E-01
Pm-147					8.00E-02		
Pu-238	2.92E-01	1.12E-01	2.92E-01				
Pu-239	2.92E-01	1.12E-01	2.92E-01	1.08E-01	8.00E-02	4.08E-02	1.08E-01
Ru-103	6.47E-01	5.16E-01	6.47E-01	4.63E-01		3.79E-01	4.63E-01
Ru/Rh-106	6.79E-01	5.54E-01	6.79E-01	5.00E-01	5.20E-01	4.13E-01	5.00E-01
S-35	6.59E-01	5.36E-01	6.59E-01	4.82E-01	5.20E-01	3.95E-01	4.82E-01
Sb-122	5.82E-01	4.10E-01	5.82E-01	3.61E-01		2.78E-01	3.61E-01
Sb-124	6.68E-01	5.48E-01	6.68E-01	4.92E-01	5.20E-01	4.08E-01	4.92E-01
Sb-125	6.68E-01	5.48E-01	6.68E-01	4.92E-01	5.20E-01	4.08E-01	4.92E-01
Sr-89	6.55E-01	5.30E-01	6.55E-01	4.75E-01	5.20E-01	3.90E-01	4.75E-01
Sr-90	6.76E-01	5.60E-01	6.76E-01	5.00E-01	5.20E-01	4.12E-01	5.00E-01
Te-123m	6.79E-01	5.54E-01	6.79E-01	5.00E-01		4.13E-01	5.00E-01
Te-125m	6.79E-01	5.54E-01	6.79E-01	5.00E-01	5.20E-01	4.13E-01	5.00E-01
Te-127m	6.79E-01	5.54E-01	6.79E-01	5.00E-01		4.13E-01	5.00E-01
Te-132	5.82E-01	4.10E-01	5.82E-01	3.61E-01		2.78E-01	3.61E-01
Y-90	4.65E-01	2.44E-01	4.65E-01	2.14E-01	2.60E-01	1.42E-01	2.14E-01
Y-91					5.20E-01		
Zn-65	6.67E-01	5.42E-01	6.67E-01	4.88E-01	5.20E-01	4.04E-01	4.88E-01
Nb-95/Zr-95	2.92E-01	1.08E-01	2.92E-01	1.04E-01	8.00E-02	4.04E-02	1.04E-01

Appendix D - Detailed results

Table 1: Collective dose rates to the European Union population by site/source due to discharges up to 2000 only (man Sv y^{-1})

Operation	Military UK					Nuclear Power Stations							
Year	Aldermaston	Barrow	Devonport	Faslane	Rosyth	Almaraz	Barsebäck	Belleville	Berkeley	Beznau	Biblis	Blayais	Borssele
1952	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1953	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1954	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1955	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1956	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1957	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1958	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1959	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1960	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1961	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1962	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1963	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.09E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1964	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.26E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1965	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.53E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1966	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.26E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1967	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1968	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.64E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1969	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E-02	3.25E-04	0.00E+00	0.00E+00	0.00E+00
1970	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.36E-03	4.32E-04	0.00E+00	0.00E+00	0.00E+00
1971	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.58E-03	4.79E-04	0.00E+00	0.00E+00	0.00E+00
1972	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.64E-03	5.02E-04	0.00E+00	0.00E+00	0.00E+00
1973	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.80E-03	5.14E-04	0.00E+00	0.00E+00	1.67E-04
1974	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.28E-03	5.21E-04	1.09E-05	0.00E+00	5.53E-04
1975	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.70E-06	0.00E+00	1.14E-02	2.15E-04	1.52E-05	0.00E+00	1.72E-03
1976	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.56E-05	0.00E+00	2.31E-02	2.95E-04	2.33E-05	0.00E+00	9.77E-04
1977	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.64E-04	0.00E+00	3.01E-02	2.86E-04	1.84E-05	0.00E+00	5.56E-04
1978	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E-04	0.00E+00	1.15E-02	2.26E-04	3.22E-05	0.00E+00	4.08E-04
1979	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.60E-04	0.00E+00	9.54E-03	1.32E-04	4.12E-05	0.00E+00	4.13E-04

Table 1 (cont'd)

Operation	Military UK					Nuclear Power Stations							
Year	Aldermaston	Barrow	Devonport	Faslane	Rosyth	Almaraz	Barsebäck	Belleville	Berkeley	Beznau	Biblis	Blayais	Borssele
1980	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.91E-04	0.00E+00	9.51E-03	1.88E-04	4.46E-05	0.00E+00	2.19E-04
1981	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.58E-04	3.04E-04	0.00E+00	7.27E-03	1.38E-04	2.89E-05	3.71E-03	4.36E-04
1982	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E-04	7.08E-04	0.00E+00	4.99E-03	1.29E-04	2.68E-05	3.73E-03	3.14E-04
1983	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.15E-05	4.38E-04	0.00E+00	4.94E-03	1.01E-04	2.52E-05	3.74E-03	2.40E-04
1984	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.14E-05	3.90E-04	0.00E+00	2.65E-03	1.01E-04	1.94E-05	3.77E-03	3.76E-04
1985	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.78E-04	1.41E-04	0.00E+00	2.46E-03	1.60E-04	2.03E-05	2.33E-03	3.01E-04
1986	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.05E-04	9.94E-05	0.00E+00	2.42E-03	1.79E-04	1.86E-05	2.68E-03	1.78E-04
1987	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.33E-05	2.29E-04	2.47E-05	2.06E-03	1.86E-04	2.16E-05	4.76E-03	1.35E-04
1988	6.05E-09	0.00E+00	5.77E-05	0.00E+00	5.65E-06	1.57E-04	1.73E-04	1.15E-04	2.27E-03	1.89E-04	1.36E-05	4.00E-03	1.71E-04
1989	1.35E-08	0.00E+00	9.52E-05	1.74E-08	5.73E-06	1.57E-04	1.45E-04	7.48E-04	1.91E-03	1.91E-04	1.32E-05	3.14E-03	1.95E-04
1990	3.66E-07	0.00E+00	4.50E-05	2.11E-08	4.83E-06	2.27E-04	1.74E-04	1.62E-04	1.02E-03	1.92E-04	9.87E-06	3.38E-03	7.04E-05
1991	9.73E-08	0.00E+00	4.13E-05	1.69E-08	5.14E-06	1.50E-04	3.21E-04	1.32E-04	8.39E-04	1.92E-04	9.30E-06	1.13E-03	3.67E-05
1992	5.24E-08	0.00E+00	6.24E-05	1.79E-08	7.67E-06	4.80E-05	3.28E-04	6.73E-05	7.47E-04	1.92E-04	9.84E-06	1.86E-03	6.44E-05
1993	3.72E-08	7.85E-10	4.63E-05	1.04E-06	7.82E-06	5.20E-05	1.67E-04	1.75E-04	6.85E-04	1.92E-04	1.11E-05	7.41E-04	5.27E-05
1994	4.31E-08	9.62E-10	2.08E-05	8.42E-07	7.74E-06	1.19E-03	1.37E-04	7.35E-05	6.33E-04	8.63E-05	1.16E-05	4.54E-04	5.48E-05
1995	3.10E-08	7.49E-10	1.77E-05	2.31E-06	8.05E-06	6.02E-05	1.79E-04	6.31E-05	5.90E-04	5.40E-05	9.88E-06	1.06E-03	3.80E-05
1996	1.59E-08	1.34E-09	1.37E-05	1.68E-06	7.84E-06	6.37E-05	2.51E-04	1.35E-04	5.54E-04	4.09E-05	7.95E-06	3.33E-04	3.36E-05
1997	7.04E-09	7.01E-10	1.20E-05	1.58E-06	7.46E-06	1.02E-04	1.50E-04	5.19E-05	5.20E-04	3.13E-05	6.51E-06	1.39E-04	4.33E-05
1998	4.01E-09	5.14E-10	1.21E-05	7.92E-07	7.67E-06	1.07E-04	1.19E-04	4.40E-05	4.91E-04	2.70E-05	1.13E-05	1.29E-04	2.48E-05
1999	2.61E-09	1.40E-09	1.00E-05	6.44E-07	7.89E-06	1.32E-04	1.17E-04	5.53E-05	4.63E-04	2.44E-05	1.08E-05	1.00E-04	2.14E-05
2000	2.00E-09	1.72E-09	8.99E-06	5.66E-07	7.96E-06	1.32E-04	1.12E-04	5.53E-05	4.38E-04	2.27E-05	1.12E-05	9.69E-05	1.72E-05
2001	1.07E-09	9.19E-10	6.20E-06	4.46E-07	4.64E-06	3.67E-06	6.37E-05	1.35E-06	4.16E-04	1.35E-05	4.16E-06	1.86E-05	9.78E-06
2002	7.55E-10	6.74E-10	5.27E-06	3.76E-07	3.96E-06	3.25E-06	5.29E-05	1.04E-06	3.95E-04	1.08E-05	2.21E-06	1.59E-05	8.33E-06
2003	6.00E-10	4.69E-10	4.47E-06	3.20E-07	3.39E-06	2.89E-06	4.45E-05	8.65E-07	3.75E-04	9.31E-06	1.36E-06	1.37E-05	7.00E-06
2004	5.04E-10	3.17E-10	3.80E-06	2.74E-07	2.90E-06	2.59E-06	3.79E-05	7.43E-07	3.58E-04	8.30E-06	9.47E-07	1.18E-05	5.95E-06
2005	4.37E-10	2.11E-10	3.23E-06	2.34E-07	2.48E-06	2.34E-06	3.22E-05	6.50E-07	3.40E-04	7.54E-06	7.32E-07	1.03E-05	5.08E-06
2006	3.87E-10	1.43E-10	2.76E-06	2.01E-07	2.12E-06	2.12E-06	2.73E-05	5.75E-07	3.25E-04	6.89E-06	6.06E-07	9.02E-06	4.34E-06
2007	3.43E-10	9.86E-11	2.35E-06	1.73E-07	1.82E-06	1.93E-06	2.33E-05	5.10E-07	3.10E-04	6.35E-06	5.24E-07	7.92E-06	3.73E-06
2008	3.07E-10	7.00E-11	2.01E-06	1.49E-07	1.55E-06	1.75E-06	2.00E-05	4.56E-07	2.97E-04	5.85E-06	4.64E-07	6.96E-06	3.22E-06
2009	2.75E-10	5.15E-11	1.71E-06	1.29E-07	1.33E-06	1.60E-06	1.72E-05	4.10E-07	2.84E-04	5.41E-06	4.18E-07	6.16E-06	2.76E-06
2010	2.46E-10	3.91E-11	1.46E-06	1.11E-07	1.14E-06	1.48E-06	1.47E-05	3.68E-07	2.73E-04	4.99E-06	3.77E-07	5.47E-06	2.39E-06

Table 1 (cont'd)

Operation	Military UK					Nuclear Power Stations							
Year	Aldermaston	Barrow	Devonport	Faslane	Rosyth	Almaraz	Barsebäck	Belleville	Berkeley	Beznau	Biblis	Blayais	Borssele
2011	2.21E-10	3.04E-11	1.25E-06	9.51E-08	9.78E-07	1.36E-06	1.27E-05	3.33E-07	2.62E-04	4.62E-06	3.42E-07	4.86E-06	2.06E-06
2012	1.98E-10	2.42E-11	1.06E-06	8.19E-08	8.36E-07	1.25E-06	1.09E-05	3.02E-07	2.51E-04	4.29E-06	3.11E-07	4.35E-06	1.78E-06
2013	1.78E-10	1.95E-11	9.10E-07	7.06E-08	7.17E-07	1.16E-06	9.45E-06	2.75E-07	2.41E-04	3.98E-06	2.85E-07	3.90E-06	1.53E-06
2014	1.60E-10	1.59E-11	7.77E-07	6.08E-08	6.14E-07	1.08E-06	8.18E-06	2.50E-07	2.32E-04	3.69E-06	2.60E-07	3.50E-06	1.33E-06
2015	1.44E-10	1.31E-11	6.64E-07	5.25E-08	5.27E-07	9.99E-07	7.13E-06	2.28E-07	2.24E-04	3.43E-06	2.38E-07	3.17E-06	1.15E-06
2016	1.29E-10	1.09E-11	5.68E-07	4.53E-08	4.51E-07	9.31E-07	6.21E-06	2.10E-07	2.16E-04	3.19E-06	2.18E-07	2.88E-06	1.00E-06
2017	1.16E-10	9.08E-12	4.87E-07	3.90E-08	3.87E-07	8.68E-07	5.41E-06	1.92E-07	2.07E-04	2.97E-06	2.00E-07	2.62E-06	8.69E-07
2018	1.04E-10	7.62E-12	4.17E-07	3.37E-08	3.32E-07	8.12E-07	4.75E-06	1.77E-07	2.00E-04	2.77E-06	1.84E-07	2.39E-06	7.57E-07
2019	9.38E-11	6.41E-12	3.56E-07	2.91E-08	2.84E-07	7.60E-07	4.18E-06	1.64E-07	1.94E-04	2.58E-06	1.69E-07	2.20E-06	6.60E-07
2020	8.45E-11	5.42E-12	3.05E-07	2.51E-08	2.44E-07	7.13E-07	3.70E-06	1.52E-07	1.87E-04	2.41E-06	1.56E-07	2.02E-06	5.77E-07
2025	5.04E-11	2.47E-12	1.42E-07	1.20E-08	1.13E-07	5.29E-07	2.09E-06	1.07E-07	1.60E-04	1.74E-06	1.08E-07	1.39E-06	3.02E-07
2030	3.06E-11	1.21E-12	6.65E-08	5.80E-09	5.29E-08	4.05E-07	1.31E-06	7.82E-08	1.38E-04	1.28E-06	7.73E-08	1.02E-06	1.67E-07
2035	1.89E-11	6.41E-13	3.15E-08	2.81E-09	2.48E-08	3.17E-07	8.99E-07	5.92E-08	1.21E-04	9.75E-07	5.81E-08	7.83E-07	1.01E-07
2040	1.20E-11	3.59E-13	1.50E-08	1.36E-09	1.17E-08	2.53E-07	6.65E-07	4.59E-08	1.07E-04	7.58E-07	4.54E-08	6.18E-07	6.57E-08
2045	7.78E-12	2.12E-13	7.22E-09	6.64E-10	5.52E-09	2.04E-07	5.17E-07	3.63E-08	9.48E-05	6.02E-07	3.68E-08	4.97E-07	4.70E-08
2050	5.16E-12	1.31E-13	3.49E-09	3.26E-10	2.61E-09	1.65E-07	4.17E-07	2.90E-08	8.49E-05	4.88E-07	3.05E-08	4.05E-07	3.60E-08
2055	3.48E-12	8.25E-14	1.70E-09	1.61E-10	1.24E-09	1.36E-07	3.43E-07	2.35E-08	7.64E-05	4.02E-07	2.58E-08	3.34E-07	2.91E-08
2060	2.40E-12	5.37E-14	8.32E-10	7.97E-11	5.95E-10	1.13E-07	2.88E-07	1.91E-08	6.92E-05	3.34E-07	2.22E-08	2.76E-07	2.46E-08
2065	1.67E-12	3.59E-14	4.09E-10	3.99E-11	2.86E-10	9.32E-08	2.43E-07	1.57E-08	6.31E-05	2.81E-07	1.93E-08	2.30E-07	2.11E-08
2070	1.18E-12	2.44E-14	2.02E-10	2.02E-11	1.37E-10	7.75E-08	2.08E-07	1.29E-08	5.75E-05	2.39E-07	1.69E-08	1.92E-07	1.85E-08
2075	8.38E-13	1.68E-14	1.00E-10	1.04E-11	6.65E-11	6.48E-08	1.77E-07	1.07E-08	5.29E-05	2.03E-07	1.50E-08	1.60E-07	1.64E-08
2080	6.01E-13	1.18E-14	5.00E-11	5.41E-12	3.22E-11	5.44E-08	1.52E-07	8.94E-09	4.87E-05	1.73E-07	1.33E-08	1.35E-07	1.46E-08
2085	4.34E-13	8.32E-15	2.50E-11	2.89E-12	1.57E-11	4.57E-08	1.32E-07	7.47E-09	4.51E-05	1.49E-07	1.18E-08	1.14E-07	1.31E-08
2090	3.14E-13	5.91E-15	1.26E-11	1.59E-12	7.66E-12	3.85E-08	1.13E-07	6.26E-09	4.17E-05	1.28E-07	1.06E-08	9.59E-08	1.18E-08
2095	2.28E-13	4.24E-15	6.37E-12	9.05E-13	3.75E-12	3.26E-08	9.78E-08	5.26E-09	3.87E-05	1.11E-07	9.53E-09	8.11E-08	1.06E-08
2100	1.67E-13	3.06E-15	3.26E-12	5.35E-13	1.85E-12	2.76E-08	8.49E-08	4.44E-09	3.61E-05	9.59E-08	8.58E-09	6.87E-08	9.58E-09
2200	3.52E-16	5.97E-18	4.83E-16	5.63E-16	6.37E-17	1.25E-09	8.08E-09	1.95E-10	1.18E-05	5.68E-09	1.50E-09	3.13E-09	1.74E-09
2300	7.92E-19	1.33E-20	1.04E-18	1.27E-18	1.40E-19	7.27E-11	2.71E-09	1.13E-11	4.87E-06	3.65E-10	4.02E-10	1.82E-10	4.84E-10
2400	1.89E-21	3.16E-23	2.47E-21	3.04E-21	3.33E-22	4.89E-12	1.65E-09	7.64E-13	2.28E-06	2.53E-11	1.39E-10	1.24E-11	1.73E-10
2500	4.84E-24	8.18E-26	6.44E-24	7.83E-24	8.55E-25	3.73E-13	1.17E-09	5.84E-14	1.24E-06	1.89E-12	5.87E-11	9.51E-13	7.36E-11

Table 1 (cont'd)

Year	Nuclear Power Stations (continued)											
	Bradwell	Brokdorf	Brunsbüttel	Cattenom	Chapelcross	Chinon	Chooz	Dampierre	Doel	Dodewaard	Dungeness	Emsland	Fessenheim
1952	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1953	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1954	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1955	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1956	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1957	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1958	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1959	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.64E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1960	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.92E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1961	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.08E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1962	5.03E-06	0.00E+00	0.00E+00	0.00E+00	1.50E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1963	1.81E-04	0.00E+00	0.00E+00	0.00E+00	1.18E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1964	3.80E-03	0.00E+00	0.00E+00	0.00E+00	9.23E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1965	1.81E-02	0.00E+00	0.00E+00	0.00E+00	7.61E-03	9.49E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.67E-05	0.00E+00	0.00E+00
1966	3.01E-02	0.00E+00	0.00E+00	0.00E+00	1.38E-02	9.75E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-03	0.00E+00	0.00E+00
1967	9.70E-02	0.00E+00	0.00E+00	0.00E+00	3.11E-02	9.93E-04	2.72E-03	0.00E+00	0.00E+00	0.00E+00	1.79E-02	0.00E+00	0.00E+00
1968	7.29E-02	0.00E+00	0.00E+00	0.00E+00	8.05E-02	1.01E-03	2.88E-03	0.00E+00	0.00E+00	0.00E+00	2.18E-02	3.01E-04	0.00E+00
1969	1.20E-01	0.00E+00	0.00E+00	0.00E+00	6.35E-02	1.02E-03	2.93E-03	0.00E+00	0.00E+00	2.84E-04	8.62E-02	3.31E-04	0.00E+00
1970	1.40E-01	0.00E+00	0.00E+00	0.00E+00	4.86E-02	3.69E-04	4.81E-03	0.00E+00	0.00E+00	1.35E-03	6.36E-02	3.33E-04	0.00E+00
1971	1.02E-01	0.00E+00	0.00E+00	0.00E+00	4.00E-02	3.27E-04	2.51E-02	0.00E+00	0.00E+00	9.26E-04	3.47E-02	1.97E-04	0.00E+00
1972	1.51E-01	0.00E+00	0.00E+00	0.00E+00	2.91E-02	4.48E-04	1.28E-02	0.00E+00	0.00E+00	1.18E-03	2.50E-02	6.18E-05	0.00E+00
1973	7.08E-02	0.00E+00	0.00E+00	0.00E+00	2.17E-02	4.80E-04	7.15E-03	0.00E+00	0.00E+00	1.06E-03	1.84E-02	3.24E-05	0.00E+00
1974	9.42E-02	0.00E+00	0.00E+00	0.00E+00	1.46E-02	1.14E-04	7.37E-03	0.00E+00	5.27E-04	1.42E-03	4.38E-02	2.01E-05	0.00E+00
1975	1.17E-01	0.00E+00	0.00E+00	0.00E+00	1.50E-02	1.36E-04	7.09E-03	0.00E+00	4.85E-03	9.46E-04	5.55E-02	5.37E-05	0.00E+00
1976	9.28E-02	0.00E+00	6.81E-05	0.00E+00	1.98E-02	1.32E-04	2.62E-03	0.00E+00	1.91E-02	4.04E-04	3.80E-02	2.64E-05	0.00E+00
1977	9.93E-02	0.00E+00	6.17E-04	0.00E+00	1.63E-02	7.14E-05	1.60E-03	0.00E+00	1.12E-02	1.66E-03	3.50E-02	1.34E-05	2.36E-04
1978	7.51E-02	0.00E+00	1.21E-03	0.00E+00	4.28E-02	4.21E-05	5.90E-04	0.00E+00	1.01E-02	7.50E-04	3.11E-02	1.44E-05	2.28E-04
1979	6.06E-02	0.00E+00	2.94E-04	0.00E+00	1.07E-01	1.54E-04	8.05E-04	0.00E+00	4.35E-03	8.23E-04	2.62E-02	1.86E-05	4.81E-04
1980	6.57E-02	0.00E+00	2.07E-04	0.00E+00	7.16E-02	1.62E-04	5.98E-04	6.91E-03	3.58E-03	1.93E-04	2.18E-02	1.23E-05	6.27E-04
1981	7.53E-02	0.00E+00	1.23E-04	0.00E+00	5.77E-02	1.61E-04	5.68E-04	6.94E-03	2.21E-03	4.47E-04	2.37E-02	7.24E-06	6.28E-04
1982	5.59E-02	0.00E+00	7.92E-05	0.00E+00	5.32E-02	1.61E-04	5.50E-04	6.94E-03	1.76E-03	4.66E-04	2.11E-02	8.76E-06	6.28E-04
1983	4.16E-02	0.00E+00	3.16E-05	0.00E+00	4.73E-02	1.60E-04	5.38E-04	6.95E-03	6.11E-03	3.69E-04	1.93E-02	5.49E-06	6.29E-04

Table 1 (cont'd)

Year	Nuclear Power Stations (continued)												
	Bradwell	Brokdorf	Brunsbüttel	Cattenom	Chapelcross	Chinon	Chooz	Dampierre	Doel	Dodewaard	Dungeness	Emsland	Fessenheim
1984	3.18E-02	0.00E+00	2.60E-05	0.00E+00	3.55E-02	1.59E-04	5.29E-04	6.95E-03	9.16E-04	2.25E-04	2.94E-02	4.98E-06	6.29E-04
1985	4.21E-02	0.00E+00	7.99E-05	0.00E+00	3.72E-02	1.62E-03	2.51E-03	3.02E-03	1.57E-03	4.29E-04	3.42E-02	3.04E-06	4.77E-03
1986	3.00E-02	0.00E+00	5.03E-05	1.02E-04	2.81E-02	2.37E-03	2.80E-03	1.94E-03	2.07E-03	2.93E-04	4.71E-02	2.56E-06	5.46E-03
1987	2.72E-02	1.93E-05	4.17E-05	6.33E-03	2.43E-02	3.64E-03	4.43E-03	6.08E-03	6.94E-04	3.85E-04	2.41E-02	2.21E-06	5.46E-03
1988	2.09E-02	8.27E-06	1.00E-04	5.56E-03	1.84E-02	2.90E-03	3.25E-03	2.64E-03	1.24E-03	3.12E-04	1.52E-02	4.07E-06	6.09E-03
1989	1.80E-02	1.08E-05	3.57E-05	4.75E-03	1.47E-02	3.23E-03	6.91E-03	1.03E-03	2.08E-03	3.07E-04	9.75E-03	1.23E-05	5.95E-03
1990	1.21E-02	8.19E-06	1.66E-05	2.27E-03	1.08E-02	2.88E-03	5.28E-03	9.95E-04	2.50E-03	1.97E-04	9.25E-03	9.31E-06	5.03E-04
1991	1.57E-02	1.24E-05	4.50E-05	3.70E-03	8.55E-03	2.59E-03	3.87E-03	3.04E-04	2.02E-03	1.94E-04	8.63E-03	8.51E-06	2.37E-03
1992	3.49E-02	1.58E-05	1.84E-05	5.65E-03	6.87E-03	1.06E-03	4.02E-04	3.52E-04	3.63E-04	1.78E-04	9.69E-03	1.18E-05	1.83E-03
1993	2.39E-02	1.22E-05	1.09E-05	4.06E-03	7.09E-03	7.26E-04	2.22E-04	2.12E-04	5.77E-04	5.34E-05	1.52E-02	9.29E-06	9.18E-04
1994	1.89E-02	1.18E-05	4.94E-06	1.03E-02	7.81E-03	5.11E-04	2.59E-04	2.64E-04	8.68E-04	1.63E-04	1.25E-02	1.15E-05	7.78E-04
1995	2.49E-02	1.48E-05	4.19E-06	3.33E-03	7.40E-03	3.12E-04	2.57E-04	2.52E-04	1.82E-03	1.49E-04	1.37E-02	9.51E-06	3.13E-04
1996	2.52E-02	1.24E-05	1.36E-05	7.98E-04	6.79E-03	7.15E-04	6.10E-05	1.77E-04	9.37E-04	1.55E-04	1.46E-02	1.10E-05	2.53E-04
1997	2.71E-02	1.44E-05	4.28E-06	4.48E-04	5.41E-03	2.73E-04	5.84E-04	1.68E-04	2.24E-03	1.60E-04	1.45E-02	1.32E-05	3.29E-04
1998	2.43E-02	1.60E-05	2.47E-05	4.34E-04	4.51E-03	1.37E-04	1.13E-03	7.70E-05	9.81E-04	2.96E-05	1.73E-02	1.33E-05	7.45E-04
1999	2.27E-02	1.55E-05	7.63E-05	5.26E-04	3.95E-03	6.65E-05	6.66E-04	8.27E-05	9.89E-04	2.35E-05	1.51E-02	1.49E-05	4.61E-04
2000	2.21E-02	1.55E-05	7.64E-05	5.27E-04	3.64E-03	6.29E-05	6.64E-04	8.21E-05	9.89E-04	1.97E-05	1.46E-02	1.49E-05	4.61E-04
2001	9.61E-03	1.49E-06	1.98E-06	1.40E-05	2.94E-03	2.03E-05	2.09E-05	6.29E-06	1.50E-04	1.69E-05	6.20E-03	1.82E-06	4.77E-06
2002	6.29E-03	7.76E-07	1.56E-06	7.33E-06	2.42E-03	1.77E-05	1.68E-05	5.49E-06	8.95E-05	1.46E-05	3.58E-03	1.12E-06	2.53E-06
2003	4.92E-03	4.47E-07	1.33E-06	4.53E-06	2.01E-03	1.56E-05	1.47E-05	4.91E-06	6.17E-05	1.27E-05	2.47E-03	7.91E-07	1.71E-06
2004	4.26E-03	2.91E-07	1.18E-06	3.16E-06	1.72E-03	1.38E-05	1.31E-05	4.45E-06	4.67E-05	1.11E-05	1.92E-03	6.18E-07	1.33E-06
2005	3.88E-03	2.12E-07	1.06E-06	2.43E-06	1.52E-03	1.22E-05	1.20E-05	4.05E-06	3.77E-05	9.71E-06	1.63E-03	5.18E-07	1.10E-06
2006	3.64E-03	1.67E-07	9.55E-07	1.99E-06	1.38E-03	1.09E-05	1.10E-05	3.72E-06	3.15E-05	8.53E-06	1.45E-03	4.54E-07	9.53E-07
2007	3.48E-03	1.41E-07	8.65E-07	1.70E-06	1.27E-03	9.74E-06	1.01E-05	3.41E-06	2.68E-05	7.50E-06	1.32E-03	4.06E-07	8.46E-07
2008	3.36E-03	1.22E-07	7.89E-07	1.48E-06	1.19E-03	8.76E-06	9.26E-06	3.15E-06	2.32E-05	6.62E-06	1.23E-03	3.69E-07	7.59E-07
2009	3.24E-03	1.08E-07	7.17E-07	1.30E-06	1.12E-03	7.91E-06	8.55E-06	2.91E-06	2.02E-05	5.85E-06	1.15E-03	3.37E-07	6.84E-07
2010	3.14E-03	9.63E-08	6.57E-07	1.16E-06	1.06E-03	7.17E-06	7.89E-06	2.69E-06	1.76E-05	5.19E-06	1.08E-03	3.09E-07	6.19E-07
2011	3.06E-03	8.64E-08	6.01E-07	1.03E-06	1.01E-03	6.51E-06	7.31E-06	2.49E-06	1.55E-05	4.60E-06	1.02E-03	2.85E-07	5.61E-07
2012	2.97E-03	7.75E-08	5.51E-07	9.22E-07	9.64E-04	5.95E-06	6.77E-06	2.33E-06	1.36E-05	4.09E-06	9.64E-04	2.63E-07	5.11E-07
2013	2.89E-03	6.98E-08	5.09E-07	8.24E-07	9.23E-04	5.45E-06	6.28E-06	2.17E-06	1.20E-05	3.65E-06	9.13E-04	2.43E-07	4.64E-07
2014	2.83E-03	6.28E-08	4.69E-07	7.39E-07	8.84E-04	5.01E-06	5.84E-06	2.03E-06	1.05E-05	3.25E-06	8.69E-04	2.25E-07	4.24E-07

Table 1 (cont'd)

Year	Nuclear Power Stations (continued)												
	Bradwell	Brokdorf	Brunsbüttel	Cattenom	Chapelcross	Chinon	Chooz	Dampierre	Doel	Dodewaard	Dungeness	Emsland	Fessenheim
2015	2.76E-03	5.65E-08	4.33E-07	6.64E-07	8.51E-04	4.62E-06	5.43E-06	1.90E-06	9.32E-06	2.92E-06	8.24E-04	2.08E-07	3.86E-07
2016	2.70E-03	5.10E-08	4.01E-07	5.96E-07	8.19E-04	4.27E-06	5.06E-06	1.78E-06	8.25E-06	2.62E-06	7.84E-04	1.94E-07	3.52E-07
2017	2.63E-03	4.59E-08	3.71E-07	5.37E-07	7.90E-04	3.97E-06	4.73E-06	1.68E-06	7.32E-06	2.35E-06	7.50E-04	1.80E-07	3.22E-07
2018	2.58E-03	4.16E-08	3.44E-07	4.83E-07	7.63E-04	3.70E-06	4.42E-06	1.58E-06	6.50E-06	2.13E-06	7.16E-04	1.68E-07	2.95E-07
2019	2.53E-03	3.75E-08	3.21E-07	4.36E-07	7.38E-04	3.45E-06	4.13E-06	1.49E-06	5.79E-06	1.93E-06	6.84E-04	1.56E-07	2.70E-07
2020	2.47E-03	3.39E-08	2.99E-07	3.94E-07	7.15E-04	3.23E-06	3.87E-06	1.41E-06	5.17E-06	1.76E-06	6.57E-04	1.46E-07	2.48E-07
2025	2.26E-03	2.08E-08	2.16E-07	2.42E-07	6.18E-04	2.39E-06	2.85E-06	1.07E-06	2.99E-06	1.12E-06	5.43E-04	1.06E-07	1.64E-07
2030	2.08E-03	1.31E-08	1.62E-07	1.54E-07	5.48E-04	1.85E-06	2.17E-06	8.40E-07	1.83E-06	7.67E-07	4.63E-04	8.01E-08	1.12E-07
2035	1.94E-03	8.66E-09	1.25E-07	1.02E-07	4.94E-04	1.47E-06	1.68E-06	6.70E-07	1.18E-06	5.54E-07	4.07E-04	6.22E-08	7.89E-08
2040	1.81E-03	5.95E-09	9.97E-08	7.03E-08	4.51E-04	1.19E-06	1.34E-06	5.41E-07	7.94E-07	4.20E-07	3.62E-04	4.96E-08	5.75E-08
2045	1.69E-03	4.27E-09	8.11E-08	5.03E-08	4.15E-04	9.74E-07	1.10E-06	4.41E-07	5.64E-07	3.30E-07	3.28E-04	4.04E-08	4.32E-08
2050	1.59E-03	3.19E-09	6.72E-08	3.73E-08	3.85E-04	8.04E-07	9.05E-07	3.62E-07	4.18E-07	2.66E-07	3.01E-04	3.34E-08	3.34E-08
2055	1.50E-03	2.48E-09	5.66E-08	2.85E-08	3.58E-04	6.68E-07	7.57E-07	2.99E-07	3.22E-07	2.19E-07	2.77E-04	2.79E-08	2.64E-08
2060	1.41E-03	2.00E-09	4.81E-08	2.23E-08	3.35E-04	5.57E-07	6.40E-07	2.49E-07	2.53E-07	1.84E-07	2.58E-04	2.35E-08	2.13E-08
2065	1.33E-03	1.65E-09	4.13E-08	1.79E-08	3.14E-04	4.66E-07	5.44E-07	2.07E-07	2.05E-07	1.55E-07	2.39E-04	2.00E-08	1.75E-08
2070	1.26E-03	1.39E-09	3.56E-08	1.45E-08	2.95E-04	3.92E-07	4.65E-07	1.73E-07	1.69E-07	1.32E-07	2.24E-04	1.70E-08	1.45E-08
2075	1.19E-03	1.20E-09	3.09E-08	1.20E-08	2.78E-04	3.30E-07	4.00E-07	1.45E-07	1.42E-07	1.13E-07	2.09E-04	1.46E-08	1.22E-08
2080	1.12E-03	1.05E-09	2.69E-08	1.00E-08	2.62E-04	2.78E-07	3.45E-07	1.22E-07	1.19E-07	9.71E-08	1.96E-04	1.26E-08	1.03E-08
2085	1.06E-03	9.29E-10	2.36E-08	8.45E-09	2.48E-04	2.34E-07	2.98E-07	1.03E-07	1.01E-07	8.36E-08	1.84E-04	1.08E-08	8.76E-09
2090	1.00E-03	8.30E-10	2.07E-08	7.15E-09	2.34E-04	1.99E-07	2.58E-07	8.68E-08	8.63E-08	7.23E-08	1.73E-04	9.34E-09	7.47E-09
2095	9.46E-04	7.50E-10	1.82E-08	6.09E-09	2.21E-04	1.68E-07	2.23E-07	7.34E-08	7.40E-08	6.25E-08	1.62E-04	8.08E-09	6.41E-09
2100	8.97E-04	6.82E-10	1.61E-08	5.20E-09	2.10E-04	1.43E-07	1.94E-07	6.22E-08	6.37E-08	5.41E-08	1.53E-04	6.98E-09	5.50E-09
2200	3.00E-04	1.86E-10	2.04E-09	2.92E-10	8.26E-05	6.72E-09	1.41E-08	2.85E-09	3.71E-09	3.50E-09	4.87E-05	4.18E-10	3.18E-10
2300	1.06E-04	7.28E-11	5.82E-10	1.88E-11	3.67E-05	3.98E-10	1.84E-09	1.66E-10	2.37E-10	3.24E-10	1.71E-05	2.73E-11	2.05E-11
2400	3.92E-05	3.28E-11	2.47E-10	1.29E-12	1.68E-05	2.74E-11	5.21E-10	1.13E-11	1.63E-11	6.28E-11	6.69E-06	1.95E-12	1.42E-12
2500	1.57E-05	1.66E-11	1.24E-10	9.64E-14	7.80E-06	2.15E-12	2.24E-10	8.70E-13	1.22E-12	2.32E-11	2.93E-06	1.63E-13	1.06E-13

Table 1 (cont'd)

Year	Nuclear Power Stations (continued)												
	Flamanville	Golfech	Gösgen	Grafenrhein-feld	Gravelines	Grohnde	Hartlepool	Heysham	Hinkley	Hunterston	Jose Cabrera	Kahl	Krümmel
1952	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1953	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1954	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1955	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1956	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1957	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1958	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1959	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1960	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.61E-06	0.00E+00
1961	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.11E-05	0.00E+00
1962	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.22E-05	0.00E+00
1963	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.26E-05	0.00E+00
1964	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.43E-02	0.00E+00	1.29E-05	0.00E+00
1965	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.88E-04	3.83E-02	0.00E+00	1.30E-05	0.00E+00
1966	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	2.94E-02	0.00E+00	1.31E-05	0.00E+00
1967	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E-03	4.05E-02	0.00E+00	1.32E-05	0.00E+00
1968	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.17E-03	4.68E-02	7.17E-05	1.33E-05	0.00E+00
1969	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E-02	6.65E-02	7.23E-05	1.33E-05	0.00E+00
1970	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.58E-02	6.38E-02	7.27E-05	1.34E-05	0.00E+00
1971	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-02	4.45E-02	7.31E-05	1.60E-05	0.00E+00
1972	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.68E-02	3.55E-02	7.33E-05	6.98E-06	0.00E+00
1973	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-02	3.07E-02	7.36E-05	3.89E-06	0.00E+00
1974	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.84E-02	4.56E-02	7.39E-05	2.60E-06	0.00E+00
1975	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.34E-02	7.42E-02	7.41E-05	2.45E-06	0.00E+00
1976	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.64E-02	1.09E-01	7.44E-05	3.19E-06	0.00E+00
1977	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.73E-02	1.22E-01	7.45E-05	4.94E-06	0.00E+00
1978	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.58E-02	9.27E-02	7.46E-05	3.83E-06	0.00E+00
1979	0.00E+00	0.00E+00	6.75E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.31E-02	1.03E-01	7.48E-05	3.14E-06	0.00E+00
1980	0.00E+00	0.00E+00	8.05E-07	0.00E+00	8.52E-03	0.00E+00	0.00E+00	0.00E+00	1.97E-02	2.31E-01	7.49E-05	2.34E-06	0.00E+00
1981	0.00E+00	0.00E+00	1.49E-06	0.00E+00	8.81E-03	0.00E+00	0.00E+00	0.00E+00	1.75E-02	2.06E-01	8.94E-05	1.66E-06	0.00E+00
1982	0.00E+00	0.00E+00	2.68E-06	1.42E-06	8.96E-03	0.00E+00	0.00E+00	0.00E+00	1.72E-02	2.08E-01	1.37E-04	1.45E-06	0.00E+00

Table 1 (cont'd)

Year	Nuclear Power Stations (continued)												
	Flamanville	Golfech	Gösgen	Grafenrhein-feld	Gravelines	Grohnde	Hartlepool	Heysham	Hinkley	Hunterston	Jose Cabrera	Kahl	Krümmel
1983	0.00E+00	0.00E+00	1.93E-06	4.36E-06	9.06E-03	0.00E+00	3.41E-05	9.16E-05	8.46E-03	1.36E-01	5.92E-05	1.19E-06	2.18E-04
1984	0.00E+00	0.00E+00	3.90E-06	5.66E-06	9.14E-03	1.33E-07	1.44E-04	1.04E-04	1.07E-02	1.04E-01	1.76E-05	8.92E-07	2.95E-04
1985	0.00E+00	0.00E+00	3.29E-06	6.39E-06	8.35E-03	7.81E-06	1.82E-03	8.58E-04	1.34E-02	9.05E-02	6.88E-05	5.71E-07	2.66E-05
1986	9.06E-04	0.00E+00	3.17E-06	5.41E-06	1.04E-02	6.74E-06	3.30E-03	3.11E-03	6.49E-03	6.68E-02	1.14E-03	4.42E-07	3.99E-06
1987	6.24E-03	0.00E+00	3.14E-06	5.27E-06	1.69E-02	1.46E-05	1.42E-03	2.00E-03	6.06E-03	4.92E-02	8.04E-05	3.68E-07	1.89E-06
1988	1.22E-02	0.00E+00	3.12E-06	4.81E-06	1.51E-02	1.27E-05	8.83E-04	1.93E-03	3.42E-03	3.85E-02	1.37E-04	3.21E-07	5.10E-06
1989	4.23E-03	0.00E+00	3.13E-06	4.72E-06	1.72E-02	1.62E-05	6.55E-04	2.28E-03	5.07E-03	2.94E-02	3.05E-04	2.85E-07	2.21E-06
1990	1.50E-03	7.37E-06	3.13E-06	4.13E-06	1.03E-02	1.25E-05	5.51E-04	2.51E-03	5.03E-03	2.18E-02	3.03E-04	2.57E-07	9.59E-07
1991	1.39E-03	3.25E-06	3.13E-06	4.48E-06	5.61E-03	1.55E-05	6.19E-04	2.19E-03	3.67E-03	1.41E-02	9.70E-05	2.33E-07	1.90E-06
1992	7.01E-04	7.24E-06	3.81E-06	4.39E-06	2.13E-03	1.26E-05	7.66E-04	2.38E-03	4.34E-03	1.21E-02	2.48E-05	2.12E-07	1.40E-06
1993	4.09E-04	5.84E-05	3.96E-06	4.25E-06	1.47E-03	1.38E-05	8.52E-04	2.46E-03	4.43E-03	1.14E-02	1.26E-05	1.94E-07	1.54E-06
1994	3.55E-04	1.02E-04	3.65E-06	4.30E-06	9.43E-04	1.59E-05	4.64E-04	3.11E-03	4.63E-03	1.04E-02	2.21E-05	1.77E-07	8.19E-07
1995	2.22E-04	1.09E-04	4.16E-06	4.24E-06	1.02E-03	1.08E-05	3.67E-04	2.31E-03	5.08E-03	7.90E-03	5.63E-06	1.62E-07	1.03E-06
1996	1.70E-04	2.08E-05	4.11E-06	4.80E-06	9.46E-04	9.03E-06	4.33E-04	2.10E-03	4.09E-03	6.14E-03	5.53E-06	1.49E-07	8.13E-07
1997	1.69E-04	4.87E-05	4.32E-06	5.05E-06	6.51E-04	1.61E-05	3.41E-04	1.92E-03	4.29E-03	5.09E-03	4.97E-06	1.37E-07	4.58E-07
1998	1.48E-04	2.63E-05	4.19E-06	4.90E-06	5.74E-04	1.36E-05	3.05E-04	1.87E-03	4.48E-03	4.52E-03	4.52E-06	1.26E-07	7.39E-07
1999	1.33E-04	2.59E-05	4.16E-06	4.66E-06	5.86E-04	1.60E-05	2.92E-04	1.83E-03	4.31E-03	4.11E-03	7.21E-06	1.16E-07	4.65E-07
2000	1.25E-04	2.61E-05	4.16E-06	4.58E-06	5.66E-04	1.61E-05	2.79E-04	1.81E-03	4.25E-03	3.82E-03	7.00E-06	1.07E-07	4.55E-07
2001	7.46E-05	1.68E-06	1.54E-06	1.71E-06	1.33E-04	1.48E-06	1.45E-04	1.17E-03	2.42E-03	3.38E-03	2.17E-06	9.84E-08	5.14E-08
2002	5.69E-05	1.32E-06	7.59E-07	8.51E-07	1.06E-04	7.68E-07	9.92E-05	8.59E-04	1.98E-03	3.12E-03	2.00E-06	9.08E-08	3.31E-08
2003	4.75E-05	1.08E-06	4.22E-07	4.80E-07	9.01E-05	4.43E-07	7.33E-05	6.20E-04	1.80E-03	2.91E-03	1.85E-06	8.39E-08	2.38E-08
2004	4.10E-05	8.99E-07	2.64E-07	3.06E-07	7.75E-05	2.88E-07	5.78E-05	4.49E-04	1.70E-03	2.73E-03	1.72E-06	7.77E-08	1.86E-08
2005	3.57E-05	7.57E-07	1.87E-07	2.20E-07	6.73E-05	2.10E-07	4.76E-05	3.30E-04	1.62E-03	2.58E-03	1.58E-06	7.20E-08	1.53E-08
2006	3.13E-05	6.39E-07	1.45E-07	1.72E-07	5.85E-05	1.67E-07	4.01E-05	2.46E-04	1.55E-03	2.47E-03	1.48E-06	6.69E-08	1.30E-08
2007	2.76E-05	5.43E-07	1.20E-07	1.44E-07	5.11E-05	1.40E-07	3.44E-05	1.87E-04	1.49E-03	2.35E-03	1.38E-06	6.21E-08	1.13E-08
2008	2.44E-05	4.62E-07	1.04E-07	1.24E-07	4.46E-05	1.22E-07	2.98E-05	1.45E-04	1.44E-03	2.26E-03	1.28E-06	5.76E-08	9.85E-09
2009	2.16E-05	3.96E-07	9.06E-08	1.09E-07	3.90E-05	1.09E-07	2.59E-05	1.15E-04	1.40E-03	2.16E-03	1.20E-06	5.38E-08	8.67E-09
2010	1.91E-05	3.39E-07	8.06E-08	9.72E-08	3.42E-05	9.72E-08	2.27E-05	9.18E-05	1.36E-03	2.08E-03	1.12E-06	5.01E-08	7.66E-09
2011	1.70E-05	2.90E-07	7.21E-08	8.70E-08	3.00E-05	8.74E-08	1.98E-05	7.40E-05	1.32E-03	2.00E-03	1.05E-06	4.69E-08	6.79E-09
2012	1.51E-05	2.50E-07	6.45E-08	7.78E-08	2.64E-05	7.87E-08	1.75E-05	6.02E-05	1.28E-03	1.93E-03	9.91E-07	4.37E-08	6.02E-09
2013	1.34E-05	2.16E-07	5.79E-08	6.99E-08	2.33E-05	7.09E-08	1.54E-05	4.95E-05	1.25E-03	1.86E-03	9.33E-07	4.09E-08	5.36E-09

Table 1 (cont'd)

Year	Nuclear Power Stations (continued)												
	Flamanville	Golfech	Gösgen	Grafenrhein-feld	Gravelines	Grohnde	Hartlepool	Heysham	Hinkley	Hunterston	Jose Cabrera	Kahl	Krümmel
2014	1.19E-05	1.86E-07	5.20E-08	6.28E-08	2.05E-05	6.41E-08	1.36E-05	4.07E-05	1.22E-03	1.80E-03	8.79E-07	3.83E-08	4.77E-09
2015	1.06E-05	1.61E-07	4.67E-08	5.65E-08	1.82E-05	5.80E-08	1.20E-05	3.38E-05	1.19E-03	1.74E-03	8.29E-07	3.60E-08	4.25E-09
2016	9.49E-06	1.41E-07	4.19E-08	5.07E-08	1.61E-05	5.26E-08	1.07E-05	2.81E-05	1.16E-03	1.70E-03	7.84E-07	3.38E-08	3.82E-09
2017	8.48E-06	1.23E-07	3.77E-08	4.57E-08	1.43E-05	4.78E-08	9.47E-06	2.35E-05	1.14E-03	1.65E-03	7.42E-07	3.18E-08	3.41E-09
2018	7.59E-06	1.07E-07	3.39E-08	4.11E-08	1.27E-05	4.33E-08	8.43E-06	1.98E-05	1.11E-03	1.60E-03	7.03E-07	2.99E-08	3.06E-09
2019	6.80E-06	9.36E-08	3.05E-08	3.70E-08	1.13E-05	3.94E-08	7.56E-06	1.68E-05	1.09E-03	1.56E-03	6.66E-07	2.83E-08	2.75E-09
2020	6.10E-06	8.22E-08	2.74E-08	3.33E-08	1.01E-05	3.58E-08	6.77E-06	1.42E-05	1.07E-03	1.52E-03	6.33E-07	2.66E-08	2.47E-09
2025	3.63E-06	4.48E-08	1.64E-08	2.00E-08	5.86E-06	2.29E-08	4.06E-06	6.83E-06	9.65E-04	1.36E-03	4.94E-07	2.03E-08	1.50E-09
2030	2.25E-06	2.63E-08	9.88E-09	1.22E-08	3.60E-06	1.52E-08	2.61E-06	3.71E-06	8.83E-04	1.25E-03	3.93E-07	1.59E-08	9.53E-10
2035	1.47E-06	1.66E-08	6.10E-09	7.73E-09	2.36E-06	1.07E-08	1.80E-06	2.24E-06	8.13E-04	1.17E-03	3.17E-07	1.27E-08	6.33E-10
2040	1.01E-06	1.11E-08	3.86E-09	5.02E-09	1.63E-06	7.86E-09	1.33E-06	1.48E-06	7.54E-04	1.10E-03	2.59E-07	1.03E-08	4.40E-10
2045	7.27E-07	7.85E-09	2.50E-09	3.37E-09	1.19E-06	6.05E-09	1.03E-06	1.03E-06	7.03E-04	1.05E-03	2.12E-07	8.53E-09	3.19E-10
2050	5.45E-07	5.75E-09	1.66E-09	2.33E-09	9.04E-07	4.82E-09	8.38E-07	7.58E-07	6.55E-04	1.00E-03	1.76E-07	7.14E-09	2.40E-10
2055	4.24E-07	4.35E-09	1.14E-09	1.66E-09	7.12E-07	3.98E-09	7.05E-07	5.78E-07	6.15E-04	9.61E-04	1.46E-07	6.02E-09	1.86E-10
2060	3.39E-07	3.34E-09	7.84E-10	1.22E-09	5.75E-07	3.39E-09	6.09E-07	4.53E-07	5.75E-04	9.23E-04	1.22E-07	5.11E-09	1.48E-10
2065	2.77E-07	2.62E-09	5.54E-10	9.18E-10	4.74E-07	2.92E-09	5.36E-07	3.65E-07	5.42E-04	8.88E-04	1.01E-07	4.37E-09	1.20E-10
2070	2.29E-07	2.07E-09	3.97E-10	7.06E-10	3.95E-07	2.57E-09	4.78E-07	2.98E-07	5.10E-04	8.56E-04	8.54E-08	3.74E-09	9.92E-11
2075	1.91E-07	1.66E-09	2.89E-10	5.56E-10	3.33E-07	2.29E-09	4.31E-07	2.48E-07	4.81E-04	8.24E-04	7.19E-08	3.22E-09	8.29E-11
2080	1.62E-07	1.34E-09	2.12E-10	4.44E-10	2.84E-07	2.05E-09	3.91E-07	2.08E-07	4.53E-04	7.95E-04	6.06E-08	2.77E-09	6.99E-11
2085	1.38E-07	1.09E-09	1.58E-10	3.62E-10	2.42E-07	1.86E-09	3.59E-07	1.76E-07	4.28E-04	7.67E-04	5.13E-08	2.39E-09	5.96E-11
2090	1.17E-07	8.95E-10	1.19E-10	3.00E-10	2.08E-07	1.70E-09	3.30E-07	1.51E-07	4.05E-04	7.42E-04	4.33E-08	2.07E-09	5.10E-11
2095	1.00E-07	7.37E-10	9.05E-11	2.52E-10	1.78E-07	1.55E-09	3.05E-07	1.30E-07	3.83E-04	7.16E-04	3.67E-08	1.79E-09	4.39E-11
2100	8.65E-08	6.11E-10	6.97E-11	2.14E-10	1.54E-07	1.43E-09	2.82E-07	1.12E-07	3.63E-04	6.90E-04	3.12E-08	1.55E-09	3.80E-11
2200	4.87E-09	2.40E-11	4.58E-12	2.58E-11	9.04E-09	4.01E-10	8.95E-08	1.02E-08	1.34E-04	3.35E-04	1.46E-09	9.32E-11	3.30E-12
2300	3.09E-10	1.36E-12	1.56E-12	4.96E-12	5.78E-10	1.54E-10	3.63E-08	2.43E-09	5.46E-05	1.54E-04	8.59E-11	6.04E-12	4.73E-13
2400	2.13E-11	9.11E-14	6.37E-13	1.08E-12	3.97E-11	6.91E-11	1.58E-08	9.92E-10	2.44E-05	6.91E-05	5.83E-12	4.20E-13	9.68E-14
2500	1.59E-12	6.90E-15	2.93E-13	2.68E-13	2.94E-12	3.49E-11	7.28E-09	4.58E-10	1.22E-05	3.16E-05	4.48E-13	3.17E-14	2.56E-14

Table 1 (cont'd)

Year	Nuclear Power Stations (continued)											
	Leibstadt	Muelheim	Mühleberg	Neckarwest-heim	Nogent	Obrigheim	Oldbury	Paluel	Penly	Philippsburg	Rheinsberg	Ringhals	Sizewell
1952	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1953	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1954	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1955	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1956	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1957	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1958	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1959	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1960	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1961	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1962	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1963	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1964	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1965	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1966	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.49E-04
1967	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.49E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.72E-03
1968	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.15E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.57E-03
1969	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.78E-06	2.67E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.57E-03
1970	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.33E-06	8.68E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.72E-02
1971	0.00E+00	0.00E+00	2.04E-04	0.00E+00	0.00E+00	2.96E-06	4.12E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.23E-02
1972	0.00E+00	0.00E+00	2.57E-04	0.00E+00	0.00E+00	3.94E-04	6.40E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.31E-02
1973	0.00E+00	0.00E+00	2.79E-04	0.00E+00	0.00E+00	2.85E-04	5.62E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E-02
1974	0.00E+00	0.00E+00	2.88E-04	0.00E+00	0.00E+00	3.08E-04	3.71E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E-05	1.48E-02
1975	0.00E+00	0.00E+00	2.94E-04	0.00E+00	0.00E+00	3.03E-04	4.65E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.95E-04	2.02E-02
1976	0.00E+00	0.00E+00	5.02E-04	6.44E-06	0.00E+00	2.95E-04	6.70E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.04E-03	2.78E-02
1977	0.00E+00	0.00E+00	3.76E-04	7.95E-06	0.00E+00	1.16E-04	1.08E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.78E-03	4.55E-02
1978	0.00E+00	0.00E+00	1.69E-04	3.25E-06	0.00E+00	6.29E-05	7.89E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-03	3.26E-02
1979	0.00E+00	0.00E+00	1.90E-04	6.07E-06	0.00E+00	3.71E-05	2.84E-03	0.00E+00	0.00E+00	7.08E-05	0.00E+00	3.34E-03	4.15E-02
1980	0.00E+00	0.00E+00	1.52E-04	3.08E-06	0.00E+00	2.76E-05	3.68E-03	0.00E+00	0.00E+00	5.30E-05	0.00E+00	2.07E-03	5.44E-02
1981	0.00E+00	0.00E+00	3.47E-04	2.06E-06	0.00E+00	1.76E-05	6.74E-03	0.00E+00	0.00E+00	7.81E-06	0.00E+00	2.63E-03	4.31E-02
1982	0.00E+00	0.00E+00	2.40E-04	2.05E-06	0.00E+00	1.49E-05	1.14E-02	0.00E+00	0.00E+00	1.26E-05	0.00E+00	1.63E-03	3.89E-02

Table 1 (cont'd)

Year	Nuclear Power Stations (continued)												
	Leibstadt	Muelheim	Mühleberg	Neckarwest-heim	Nogent	Obrigheim	Oldbury	Paluel	Penly	Philippsburg	Rheinsberg	Ringhals	Sizewell
1983	0.00E+00	0.00E+00	7.79E-04	3.43E-06	0.00E+00	1.47E-05	1.36E-02	0.00E+00	0.00E+00	2.00E-05	0.00E+00	1.43E-03	3.39E-02
1984	4.66E-08	0.00E+00	2.71E-04	3.74E-06	0.00E+00	1.40E-05	9.43E-03	5.85E-03	0.00E+00	3.61E-05	0.00E+00	1.36E-03	2.90E-02
1985	6.34E-07	0.00E+00	2.41E-04	4.50E-06	0.00E+00	1.01E-05	6.03E-03	5.67E-03	0.00E+00	8.08E-06	2.32E-06	2.82E-04	2.94E-02
1986	7.49E-07	1.37E-06	2.61E-04	3.98E-06	0.00E+00	8.29E-06	4.34E-03	8.64E-03	0.00E+00	9.73E-06	8.66E-07	2.10E-04	2.46E-02
1987	7.99E-07	1.70E-06	2.69E-04	4.01E-06	7.19E-05	7.42E-06	3.58E-03	2.61E-02	0.00E+00	1.13E-05	4.61E-06	7.64E-04	2.22E-02
1988	8.23E-07	3.20E-06	2.72E-04	2.97E-06	2.73E-04	6.52E-06	4.33E-03	1.13E-02	0.00E+00	1.13E-05	3.95E-06	1.27E-03	1.67E-02
1989	8.34E-07	2.73E-06	2.73E-04	4.84E-06	1.39E-03	6.21E-06	2.94E-03	9.51E-03	0.00E+00	1.13E-05	4.08E-06	7.69E-04	1.33E-02
1990	8.43E-07	1.88E-06	2.75E-04	7.15E-06	7.82E-04	6.23E-06	2.78E-03	6.24E-03	1.75E-04	3.24E-05	3.24E-06	1.01E-03	1.29E-02
1991	8.47E-07	8.00E-07	2.76E-04	9.06E-06	2.26E-04	4.23E-06	2.49E-03	4.88E-03	6.52E-05	9.36E-06	1.30E-06	6.37E-04	1.38E-02
1992	8.51E-07	1.36E-06	2.76E-04	7.98E-06	8.78E-05	4.34E-06	2.50E-03	2.49E-03	8.36E-05	8.50E-06	4.21E-08	5.77E-03	1.22E-02
1993	8.54E-07	9.26E-07	2.76E-04	8.94E-06	1.01E-04	4.32E-06	2.76E-03	1.58E-03	1.09E-04	1.14E-05	2.77E-08	1.76E-03	9.78E-03
1994	5.18E-05	8.79E-07	1.96E-04	1.08E-05	4.56E-05	4.37E-06	2.32E-03	1.26E-03	1.30E-04	1.11E-05	2.08E-08	1.91E-03	7.76E-03
1995	9.34E-06	1.78E-07	7.78E-05	1.09E-05	9.10E-05	7.28E-06	2.29E-03	1.33E-03	7.16E-05	1.88E-05	1.68E-08	1.05E-03	1.12E-02
1996	4.83E-06	1.08E-07	8.39E-05	1.11E-05	1.06E-04	6.66E-06	2.25E-03	8.83E-04	5.30E-05	3.14E-05	1.40E-08	7.29E-04	1.57E-02
1997	2.92E-06	7.90E-08	1.30E-04	1.07E-05	6.97E-05	4.42E-06	1.92E-03	8.12E-04	7.40E-05	2.03E-05	1.19E-08	1.20E-03	1.03E-02
1998	1.33E-05	6.32E-08	2.13E-04	9.25E-06	4.60E-05	7.45E-06	1.73E-03	7.57E-04	6.08E-05	1.46E-05	1.02E-08	7.74E-04	8.54E-03
1999	1.35E-05	5.32E-08	2.17E-04	8.35E-06	4.25E-05	6.25E-06	1.68E-03	6.94E-04	4.18E-05	1.11E-05	8.86E-09	5.19E-04	8.38E-03
2000	1.34E-05	4.60E-08	2.18E-04	8.06E-06	4.31E-05	6.03E-06	1.65E-03	6.44E-04	4.07E-05	1.10E-05	7.71E-09	4.68E-04	8.08E-03
2001	8.93E-07	4.03E-08	2.10E-05	3.04E-06	1.14E-05	5.90E-06	7.97E-04	3.75E-04	1.27E-05	3.03E-06	6.74E-09	2.40E-04	2.96E-03
2002	3.47E-07	3.57E-08	1.18E-05	1.51E-06	5.88E-06	3.30E-06	6.43E-04	3.12E-04	6.32E-06	1.50E-06	5.90E-09	1.97E-04	1.81E-03
2003	1.77E-07	3.17E-08	8.52E-06	8.58E-07	3.80E-06	2.74E-06	5.72E-04	2.65E-04	3.88E-06	8.54E-07	5.20E-09	1.65E-04	1.33E-03
2004	1.07E-07	2.83E-08	6.84E-06	5.49E-07	2.79E-06	2.40E-06	5.27E-04	2.26E-04	2.70E-06	5.55E-07	4.59E-09	1.40E-04	1.09E-03
2005	7.48E-08	2.53E-08	5.86E-06	3.95E-07	2.21E-06	2.16E-06	4.94E-04	1.95E-04	2.08E-06	4.05E-07	4.07E-09	1.19E-04	9.51E-04
2006	5.84E-08	2.26E-08	5.20E-06	3.12E-07	1.85E-06	1.96E-06	4.65E-04	1.68E-04	1.69E-06	3.22E-07	3.62E-09	1.01E-04	8.59E-04
2007	4.90E-08	2.03E-08	4.71E-06	2.60E-07	1.60E-06	1.80E-06	4.41E-04	1.44E-04	1.43E-06	2.71E-07	3.24E-09	8.68E-05	7.90E-04
2008	4.26E-08	1.82E-08	4.31E-06	2.26E-07	1.40E-06	1.67E-06	4.20E-04	1.25E-04	1.23E-06	2.36E-07	2.91E-09	7.45E-05	7.37E-04
2009	3.80E-08	1.64E-08	3.97E-06	1.99E-07	1.24E-06	1.54E-06	4.01E-04	1.08E-04	1.07E-06	2.10E-07	2.62E-09	6.40E-05	6.91E-04
2010	3.42E-08	1.48E-08	3.65E-06	1.77E-07	1.10E-06	1.43E-06	3.83E-04	9.31E-05	9.36E-07	1.89E-07	2.37E-09	5.51E-05	6.49E-04
2011	3.10E-08	1.34E-08	3.37E-06	1.59E-07	9.85E-07	1.33E-06	3.67E-04	8.05E-05	8.23E-07	1.70E-07	2.15E-09	4.76E-05	6.14E-04
2012	2.82E-08	1.22E-08	3.12E-06	1.43E-07	8.82E-07	1.24E-06	3.53E-04	6.96E-05	7.24E-07	1.54E-07	1.96E-09	4.11E-05	5.80E-04
2013	2.57E-08	1.11E-08	2.89E-06	1.28E-07	7.90E-07	1.15E-06	3.38E-04	6.02E-05	6.40E-07	1.40E-07	1.79E-09	3.57E-05	5.50E-04

Table 1 (cont'd)

Year	Nuclear Power Stations (continued)												
	Leibstadt	Muelheim	Mühleberg	Neckarwest-heim	Nogent	Obrigheim	Oldbury	Paluel	Penly	Philippsburg	Rheinsberg	Ringhals	Sizewell
2014	2.34E-08	1.01E-08	2.69E-06	1.16E-07	7.10E-07	1.07E-06	3.27E-04	5.22E-05	5.65E-07	1.28E-07	1.65E-09	3.10E-05	5.22E-04
2015	2.14E-08	9.23E-09	2.49E-06	1.04E-07	6.39E-07	1.00E-06	3.15E-04	4.53E-05	4.99E-07	1.17E-07	1.52E-09	2.70E-05	4.97E-04
2016	1.94E-08	8.47E-09	2.30E-06	9.40E-08	5.74E-07	9.35E-07	3.04E-04	3.92E-05	4.43E-07	1.07E-07	1.41E-09	2.36E-05	4.74E-04
2017	1.78E-08	7.78E-09	2.14E-06	8.47E-08	5.19E-07	8.77E-07	2.94E-04	3.40E-05	3.93E-07	9.81E-08	1.31E-09	2.06E-05	4.52E-04
2018	1.63E-08	7.16E-09	1.99E-06	7.66E-08	4.68E-07	8.20E-07	2.84E-04	2.96E-05	3.49E-07	9.00E-08	1.22E-09	1.82E-05	4.33E-04
2019	1.49E-08	6.61E-09	1.85E-06	6.92E-08	4.23E-07	7.70E-07	2.75E-04	2.56E-05	3.09E-07	8.29E-08	1.14E-09	1.60E-05	4.15E-04
2020	1.36E-08	6.13E-09	1.73E-06	6.26E-08	3.83E-07	7.24E-07	2.67E-04	2.23E-05	2.76E-07	7.62E-08	1.07E-09	1.41E-05	3.97E-04
2025	8.88E-09	4.36E-09	1.22E-06	3.84E-08	2.39E-07	5.39E-07	2.31E-04	1.13E-05	1.56E-07	5.21E-08	8.17E-10	7.97E-06	3.29E-04
2030	5.91E-09	3.31E-09	8.92E-07	2.43E-08	1.54E-07	4.12E-07	2.04E-04	5.97E-06	9.18E-08	3.75E-08	6.58E-10	4.90E-06	2.83E-04
2035	4.03E-09	2.64E-09	6.67E-07	1.59E-08	1.04E-07	3.24E-07	1.83E-04	3.30E-06	5.60E-08	2.82E-08	5.52E-10	3.27E-06	2.47E-04
2040	2.82E-09	2.19E-09	5.12E-07	1.09E-08	7.33E-08	2.60E-07	1.65E-04	1.94E-06	3.58E-08	2.21E-08	4.74E-10	2.35E-06	2.22E-04
2045	2.03E-09	1.87E-09	4.02E-07	7.80E-09	5.35E-08	2.12E-07	1.50E-04	1.23E-06	2.39E-08	1.80E-08	4.14E-10	1.77E-06	2.01E-04
2050	1.50E-09	1.64E-09	3.21E-07	5.79E-09	4.04E-08	1.76E-07	1.38E-04	8.35E-07	1.67E-08	1.51E-08	3.66E-10	1.39E-06	1.84E-04
2055	1.14E-09	1.44E-09	2.62E-07	4.47E-09	3.14E-08	1.48E-07	1.27E-04	6.06E-07	1.22E-08	1.30E-08	3.25E-10	1.13E-06	1.71E-04
2060	8.84E-10	1.28E-09	2.17E-07	3.57E-09	2.51E-08	1.25E-07	1.17E-04	4.63E-07	9.21E-09	1.13E-08	2.90E-10	9.36E-07	1.58E-04
2065	7.01E-10	1.15E-09	1.81E-07	2.94E-09	2.03E-08	1.07E-07	1.09E-04	3.68E-07	7.17E-09	1.00E-08	2.60E-10	7.90E-07	1.48E-04
2070	5.65E-10	1.03E-09	1.52E-07	2.46E-09	1.68E-08	9.14E-08	1.01E-04	3.00E-07	5.73E-09	8.93E-09	2.35E-10	6.73E-07	1.38E-04
2075	4.62E-10	9.28E-10	1.30E-07	2.10E-09	1.41E-08	7.86E-08	9.47E-05	2.50E-07	4.65E-09	8.02E-09	2.11E-10	5.80E-07	1.29E-04
2080	3.83E-10	8.39E-10	1.11E-07	1.83E-09	1.18E-08	6.78E-08	8.87E-05	2.10E-07	3.85E-09	7.24E-09	1.91E-10	5.02E-07	1.21E-04
2085	3.20E-10	7.60E-10	9.50E-08	1.61E-09	1.00E-08	5.85E-08	8.31E-05	1.79E-07	3.21E-09	6.57E-09	1.73E-10	4.39E-07	1.13E-04
2090	2.70E-10	6.89E-10	8.17E-08	1.43E-09	8.54E-09	5.07E-08	7.81E-05	1.53E-07	2.71E-09	5.98E-09	1.57E-10	3.85E-07	1.06E-04
2095	2.28E-10	6.24E-10	7.04E-08	1.29E-09	7.31E-09	4.40E-08	7.34E-05	1.32E-07	2.29E-09	5.45E-09	1.42E-10	3.39E-07	1.00E-04
2100	1.95E-10	5.69E-10	6.08E-08	1.16E-09	6.28E-09	3.82E-08	6.92E-05	1.13E-07	1.95E-09	4.99E-09	1.29E-10	3.00E-07	9.44E-05
2200	1.06E-11	9.51E-11	3.59E-09	2.77E-10	3.61E-10	2.58E-09	2.45E-05	6.61E-09	1.07E-10	1.12E-09	2.22E-11	5.52E-08	3.04E-05
2300	6.65E-13	1.84E-11	2.30E-10	9.39E-11	2.32E-11	2.26E-10	9.91E-06	4.24E-10	6.83E-12	3.41E-10	4.57E-12	2.69E-08	1.06E-05
2400	4.48E-14	3.98E-12	1.58E-11	3.72E-11	1.60E-12	2.88E-11	4.42E-06	2.94E-11	4.68E-13	1.27E-10	1.09E-12	1.74E-08	3.98E-06
2500	3.27E-15	9.89E-13	1.18E-12	1.67E-11	1.20E-13	5.50E-12	2.23E-06	2.20E-12	3.45E-14	5.49E-11	3.02E-13	1.25E-08	1.62E-06

Table 1 (cont'd)

Year	Nuclear Power Stations (continued)										Other Nuclear		
	St Laurent	Stade	Tihange	Torness	Trawsfynydd	Trillo	Unterweser	Winfrith	Würgassen	Wylfa	Capenhurst	Dounreay	Harwell
1952	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.36E-03
1953	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.17E-05	0.00E+00	1.47E-03
1954	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.79E-05	0.00E+00	2.14E-03
1955	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.18E-05	0.00E+00	2.65E-03
1956	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.45E-05	0.00E+00	3.15E-03
1957	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.63E-05	0.00E+00	4.13E-03
1958	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.75E-05	1.74E-01	8.72E-03
1959	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.83E-05	3.94E-01	1.71E-02
1960	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E-05	0.00E+00	0.00E+00	4.89E-05	5.14E-01	1.12E-02
1961	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.94E-05	0.00E+00	0.00E+00	4.94E-05	4.00E-01	6.76E-03
1962	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.78E-03	0.00E+00	0.00E+00	4.97E-05	9.91E-01	4.14E-03
1963	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.85E-03	0.00E+00	0.00E+00	5.82E-05	9.31E-01	2.85E-03
1964	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.89E-03	0.00E+00	0.00E+00	5.40E-05	1.66E+00	2.42E-03
1965	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.65E-06	0.00E+00	0.00E+00	5.92E-03	0.00E+00	0.00E+00	4.18E-05	2.46E+00	2.41E-03
1966	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.03E-04	0.00E+00	0.00E+00	1.88E-02	0.00E+00	0.00E+00	4.87E-05	1.97E+00	2.14E-03
1967	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.34E-03	0.00E+00	0.00E+00	2.54E-02	0.00E+00	0.00E+00	4.41E-05	2.97E+00	2.50E-03
1968	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.40E-03	0.00E+00	0.00E+00	4.90E-02	0.00E+00	0.00E+00	5.46E-05	2.72E+00	3.94E-03
1969	3.97E-04	0.00E+00	0.00E+00	0.00E+00	2.46E-03	0.00E+00	0.00E+00	7.11E-02	0.00E+00	0.00E+00	6.15E-05	2.70E+00	4.62E-03
1970	1.19E-04	0.00E+00	0.00E+00	0.00E+00	3.14E-03	0.00E+00	0.00E+00	2.68E-01	0.00E+00	1.44E-03	7.69E-05	2.45E+00	4.61E-03
1971	3.34E-04	0.00E+00	0.00E+00	0.00E+00	4.93E-03	0.00E+00	0.00E+00	8.14E-01	0.00E+00	7.96E-04	5.96E-05	1.97E+00	4.53E-03
1972	1.38E-03	3.35E-05	0.00E+00	0.00E+00	6.86E-03	0.00E+00	0.00E+00	4.29E-01	5.40E-06	6.56E-04	6.11E-05	1.89E+00	4.59E-03
1973	1.08E-03	4.88E-04	0.00E+00	0.00E+00	5.59E-03	0.00E+00	0.00E+00	3.26E-01	8.53E-04	4.90E-04	4.66E-05	2.09E+00	4.32E-03
1974	6.39E-04	5.95E-04	0.00E+00	0.00E+00	4.66E-03	0.00E+00	0.00E+00	3.49E-01	5.38E-03	3.88E-04	4.83E-05	1.50E+00	2.93E-03
1975	7.04E-04	4.83E-04	1.69E-05	0.00E+00	4.46E-03	0.00E+00	0.00E+00	7.41E-01	2.62E-03	1.36E-03	4.12E-05	1.31E+00	3.48E-03
1976	8.93E-05	7.48E-04	1.55E-04	0.00E+00	6.05E-03	0.00E+00	0.00E+00	4.14E-01	1.59E-04	2.12E-03	3.28E-05	8.44E-01	2.72E-03
1977	7.29E-04	3.27E-04	6.12E-04	0.00E+00	3.95E-03	0.00E+00	0.00E+00	3.48E-01	4.76E-03	7.00E-03	2.84E-05	5.71E-01	3.43E-03
1978	1.33E-03	4.10E-04	4.17E-04	0.00E+00	3.38E-03	0.00E+00	6.92E-09	5.22E-01	3.92E-04	1.31E-02	3.66E-05	4.23E-01	2.39E-03
1979	8.58E-04	5.62E-04	3.33E-04	0.00E+00	2.59E-03	0.00E+00	3.40E-06	8.22E-01	1.48E-04	1.60E-02	1.04E-04	4.37E-01	2.63E-03
1980	1.63E-03	9.59E-05	4.92E-04	0.00E+00	4.30E-03	0.00E+00	2.89E-05	1.58E+00	2.11E-04	1.34E-02	1.15E-04	5.08E-01	3.27E-03
1981	1.64E-03	5.73E-05	2.39E-03	0.00E+00	2.66E-03	0.00E+00	1.64E-05	1.18E+00	2.50E-04	1.01E-02	9.51E-05	6.86E-01	2.04E-03
1982	1.64E-03	4.12E-05	1.83E-04	0.00E+00	1.94E-03	0.00E+00	1.79E-05	4.92E-01	2.47E-04	7.65E-03	1.80E-04	6.12E-01	1.66E-03

Table 1 (cont'd)

Year	Nuclear Power Stations (continued)										Other Nuclear		
	St Laurent	Stade	Tihange	Torness	Trawsfynydd	Trillo	Unterweser	Winfrith	Würgassen	Wylfa	Capenhurst	Dounreay	Harwell
1983	1.64E-03	7.24E-05	1.81E-04	0.00E+00	2.51E-03	0.00E+00	2.39E-05	4.78E-01	1.27E-04	5.38E-03	8.69E-05	1.01E+00	1.55E-03
1984	1.65E-03	4.72E-05	1.91E-03	0.00E+00	2.65E-03	0.00E+00	2.22E-05	8.14E-01	2.22E-04	4.00E-03	6.43E-05	7.93E-01	1.50E-03
1985	6.22E-03	4.35E-05	1.95E-03	0.00E+00	2.49E-03	0.00E+00	5.48E-05	1.71E-01	1.03E-04	2.86E-03	3.52E-05	6.20E-01	7.84E-04
1986	1.04E-03	5.16E-05	3.32E-04	0.00E+00	2.16E-03	0.00E+00	2.36E-05	1.32E-01	6.68E-05	2.34E-03	2.36E-05	4.94E-01	7.00E-04
1987	5.83E-04	4.47E-05	2.31E-03	0.00E+00	2.17E-03	0.00E+00	2.30E-05	2.21E-01	3.32E-05	2.03E-03	1.61E-05	4.72E-01	6.56E-04
1988	3.90E-04	3.57E-05	2.49E-03	1.17E-04	2.95E-03	2.44E-05	1.55E-05	1.69E-01	5.92E-05	1.94E-03	1.11E-05	3.96E-01	6.29E-04
1989	5.69E-04	2.19E-05	2.85E-03	1.53E-04	2.92E-03	1.34E-05	2.34E-05	2.15E-01	5.27E-05	1.85E-03	7.88E-06	3.14E-01	6.09E-04
1990	4.41E-05	2.73E-05	3.02E-03	7.23E-05	3.24E-03	1.17E-05	1.34E-05	1.64E-01	9.71E-06	1.84E-03	5.85E-06	2.60E-01	5.94E-04
1991	3.62E-04	1.82E-05	1.65E-03	7.14E-05	3.13E-03	1.38E-05	2.59E-05	1.07E-01	2.98E-05	1.93E-03	4.54E-06	2.45E-01	5.79E-04
1992	2.37E-04	1.82E-05	1.99E-03	1.51E-04	2.76E-03	1.20E-05	1.79E-05	8.35E-02	3.35E-05	1.78E-03	3.69E-06	2.44E-01	5.67E-04
1993	3.76E-04	1.43E-05	1.55E-03	1.65E-04	2.02E-03	1.90E-05	1.82E-05	7.12E-02	2.33E-05	1.75E-03	3.13E-06	2.52E-01	5.55E-04
1994	2.26E-04	5.63E-06	9.45E-04	8.37E-05	1.51E-03	2.18E-05	1.22E-05	6.36E-02	5.32E-05	1.66E-03	2.73E-06	2.65E-01	5.45E-04
1995	8.06E-05	5.94E-05	1.42E-03	9.94E-05	1.07E-03	1.60E-05	9.98E-06	5.80E-02	2.26E-06	1.59E-03	2.43E-06	2.58E-01	5.35E-04
1996	8.00E-05	1.51E-05	2.41E-03	1.11E-04	7.36E-04	2.22E-05	1.74E-05	5.37E-02	1.78E-06	1.56E-03	2.19E-06	2.61E-01	5.25E-04
1997	7.55E-05	1.27E-05	2.60E-03	1.37E-04	5.08E-04	2.55E-05	1.56E-05	5.03E-02	1.51E-06	1.48E-03	2.00E-06	2.05E-01	5.16E-04
1998	3.11E-05	6.75E-06	1.54E-03	1.52E-04	3.56E-04	1.63E-05	8.69E-06	4.73E-02	1.32E-06	1.53E-03	1.84E-06	1.72E-01	5.07E-04
1999	4.08E-05	6.60E-06	4.26E-04	1.48E-04	2.58E-04	1.68E-05	1.04E-05	4.49E-02	1.17E-06	1.30E-03	1.70E-06	1.53E-01	4.98E-04
2000	4.00E-05	6.53E-06	4.21E-04	1.46E-04	1.96E-04	1.68E-05	1.02E-05	4.27E-02	1.04E-06	1.09E-03	1.57E-06	1.44E-01	4.89E-04
2001	7.48E-06	8.08E-07	2.22E-05	7.36E-05	1.57E-04	2.22E-07	1.07E-06	4.08E-02	9.35E-07	8.11E-04	1.47E-06	1.37E-01	4.82E-04
2002	6.70E-06	6.10E-07	1.48E-05	3.90E-05	1.31E-04	1.95E-07	6.84E-07	3.91E-02	8.41E-07	5.86E-04	1.36E-06	1.32E-01	4.74E-04
2003	6.07E-06	5.00E-07	1.12E-05	2.24E-05	1.14E-04	1.73E-07	4.89E-07	3.76E-02	7.57E-07	4.22E-04	1.28E-06	1.28E-01	4.67E-04
2004	5.54E-06	4.28E-07	9.08E-06	1.43E-05	1.02E-04	1.53E-07	3.80E-07	3.64E-02	6.86E-07	3.10E-04	1.20E-06	1.25E-01	4.60E-04
2005	5.07E-06	3.75E-07	7.67E-06	1.02E-05	9.25E-05	1.36E-07	3.11E-07	3.52E-02	6.20E-07	2.34E-04	1.12E-06	1.23E-01	4.53E-04
2006	4.67E-06	3.35E-07	6.61E-06	7.97E-06	8.50E-05	1.21E-07	2.64E-07	3.43E-02	5.64E-07	1.86E-04	1.05E-06	1.21E-01	4.47E-04
2007	4.31E-06	3.00E-07	5.76E-06	6.62E-06	7.87E-05	1.09E-07	2.28E-07	3.34E-02	5.13E-07	1.55E-04	9.87E-07	1.19E-01	4.40E-04
2008	3.99E-06	2.72E-07	5.06E-06	5.71E-06	7.33E-05	9.72E-08	1.99E-07	3.26E-02	4.68E-07	1.34E-04	9.29E-07	1.17E-01	4.35E-04
2009	3.70E-06	2.47E-07	4.47E-06	5.03E-06	6.86E-05	8.71E-08	1.74E-07	3.18E-02	4.27E-07	1.18E-04	8.76E-07	1.15E-01	4.28E-04
2010	3.44E-06	2.24E-07	3.95E-06	4.48E-06	6.43E-05	7.83E-08	1.54E-07	3.12E-02	3.92E-07	1.06E-04	8.25E-07	1.14E-01	4.22E-04
2011	3.21E-06	2.04E-07	3.52E-06	4.03E-06	6.03E-05	7.05E-08	1.36E-07	3.06E-02	3.59E-07	9.73E-05	7.80E-07	1.12E-01	4.17E-04
2012	3.00E-06	1.87E-07	3.12E-06	3.64E-06	5.68E-05	6.36E-08	1.20E-07	3.00E-02	3.30E-07	8.97E-05	7.38E-07	1.11E-01	4.12E-04
2013	2.81E-06	1.72E-07	2.78E-06	3.31E-06	5.36E-05	5.76E-08	1.07E-07	2.95E-02	3.03E-07	8.31E-05	6.98E-07	1.09E-01	4.07E-04

Table 1 (cont'd)

Year	Nuclear Power Stations (continued)										Other Nuclear		
	St Laurent	Stade	Tihange	Torness	Trawsfynydd	Trillo	Unterweser	Winfrith	Würgassen	Wylfa	Capenhurst	Dounreay	Harwell
2014	2.64E-06	1.57E-07	2.49E-06	3.01E-06	5.07E-05	5.22E-08	9.50E-08	2.90E-02	2.80E-07	7.73E-05	6.61E-07	1.08E-01	4.01E-04
2015	2.48E-06	1.44E-07	2.23E-06	2.75E-06	4.80E-05	4.73E-08	8.48E-08	2.85E-02	2.58E-07	7.22E-05	6.27E-07	1.07E-01	3.96E-04
2016	2.34E-06	1.33E-07	2.00E-06	2.52E-06	4.56E-05	4.31E-08	7.56E-08	2.82E-02	2.40E-07	6.75E-05	5.95E-07	1.05E-01	3.91E-04
2017	2.21E-06	1.23E-07	1.80E-06	2.32E-06	4.33E-05	3.93E-08	6.76E-08	2.77E-02	2.22E-07	6.34E-05	5.66E-07	1.04E-01	3.86E-04
2018	2.08E-06	1.14E-07	1.62E-06	2.14E-06	4.13E-05	3.58E-08	6.06E-08	2.74E-02	2.06E-07	5.96E-05	5.38E-07	1.03E-01	3.81E-04
2019	1.97E-06	1.05E-07	1.46E-06	1.98E-06	3.94E-05	3.29E-08	5.44E-08	2.71E-02	1.93E-07	5.62E-05	5.12E-07	1.02E-01	3.76E-04
2020	1.86E-06	9.81E-08	1.32E-06	1.84E-06	3.77E-05	3.01E-08	4.89E-08	2.68E-02	1.79E-07	5.30E-05	4.88E-07	1.01E-01	3.71E-04
2025	1.45E-06	6.97E-08	8.21E-07	1.34E-06	3.09E-05	2.00E-08	2.98E-08	2.54E-02	1.29E-07	4.07E-05	3.89E-07	9.56E-02	3.50E-04
2030	1.15E-06	5.19E-08	5.37E-07	1.05E-06	2.63E-05	1.38E-08	1.91E-08	2.41E-02	9.63E-08	3.26E-05	3.15E-07	9.13E-02	3.30E-04
2035	9.26E-07	4.01E-08	3.69E-07	8.73E-07	2.29E-05	9.79E-09	1.30E-08	2.31E-02	7.44E-08	2.71E-05	2.60E-07	8.73E-02	3.12E-04
2040	7.55E-07	3.18E-08	2.65E-07	7.61E-07	2.05E-05	7.13E-09	9.29E-09	2.21E-02	5.89E-08	2.32E-05	2.19E-07	8.37E-02	2.94E-04
2045	6.20E-07	2.59E-08	1.99E-07	6.87E-07	1.87E-05	5.29E-09	6.94E-09	2.12E-02	4.78E-08	2.04E-05	1.87E-07	8.04E-02	2.77E-04
2050	5.12E-07	2.16E-08	1.54E-07	6.32E-07	1.72E-05	4.00E-09	5.40E-09	2.02E-02	3.95E-08	1.82E-05	1.63E-07	7.73E-02	2.63E-04
2055	4.26E-07	1.81E-08	1.23E-07	5.91E-07	1.61E-05	3.07E-09	4.34E-09	1.93E-02	3.32E-08	1.65E-05	1.44E-07	7.42E-02	2.48E-04
2060	3.54E-07	1.54E-08	1.00E-07	5.56E-07	1.50E-05	2.40E-09	3.55E-09	1.85E-02	2.81E-08	1.51E-05	1.30E-07	7.15E-02	2.34E-04
2065	2.97E-07	1.32E-08	8.32E-08	5.28E-07	1.42E-05	1.88E-09	2.98E-09	1.77E-02	2.40E-08	1.40E-05	1.18E-07	6.88E-02	2.22E-04
2070	2.48E-07	1.14E-08	7.00E-08	5.02E-07	1.34E-05	1.50E-09	2.52E-09	1.69E-02	2.06E-08	1.30E-05	1.08E-07	6.62E-02	2.09E-04
2075	2.09E-07	9.93E-09	5.95E-08	4.78E-07	1.27E-05	1.20E-09	2.17E-09	1.62E-02	1.79E-08	1.22E-05	1.01E-07	6.38E-02	1.98E-04
2080	1.76E-07	8.65E-09	5.11E-08	4.56E-07	1.21E-05	9.68E-10	1.88E-09	1.54E-02	1.55E-08	1.14E-05	9.44E-08	6.14E-02	1.88E-04
2085	1.49E-07	7.57E-09	4.41E-08	4.37E-07	1.15E-05	7.87E-10	1.63E-09	1.47E-02	1.36E-08	1.08E-05	8.92E-08	5.92E-02	1.78E-04
2090	1.26E-07	6.64E-09	3.82E-08	4.17E-07	1.10E-05	6.45E-10	1.43E-09	1.40E-02	1.18E-08	1.02E-05	8.47E-08	5.70E-02	1.68E-04
2095	1.06E-07	5.84E-09	3.32E-08	4.00E-07	1.05E-05	5.32E-10	1.26E-09	1.33E-02	1.04E-08	9.61E-06	8.09E-08	5.49E-02	1.60E-04
2100	9.04E-08	5.13E-09	2.90E-08	3.83E-07	1.01E-05	4.40E-10	1.12E-09	1.27E-02	9.10E-09	9.12E-06	7.77E-08	5.28E-02	1.51E-04
2200	4.20E-09	5.67E-10	2.93E-09	1.63E-07	4.67E-06	1.76E-11	1.43E-10	4.57E-03	1.03E-09	3.84E-06	4.52E-08	2.45E-02	5.07E-05
2300	2.46E-10	1.16E-10	6.48E-10	6.92E-08	2.24E-06	1.01E-12	2.65E-11	1.61E-03	2.65E-10	1.79E-06	3.01E-08	1.14E-02	1.79E-05
2400	1.69E-11	3.78E-11	2.34E-10	3.00E-08	1.07E-06	6.82E-14	6.07E-12	6.04E-04	1.10E-10	8.36E-07	2.13E-08	5.41E-03	6.64E-06
2500	1.30E-12	1.63E-11	1.04E-10	1.37E-08	5.12E-07	5.18E-15	1.67E-12	2.48E-04	5.53E-11	3.95E-07	1.62E-08	2.70E-03	2.67E-06

Table 1 (cont'd)

Year	Other Nuclear (continued) Karlsruhe	Risø	Springfields	La Hague	Sellafield	Isotope Amersham	Cardiff	Baltic Flux	Phosphates Baie de la Seine	Cumbrian Waters	Gulf of Cadiz	Irish Sea NW	Kattegat
1952	0.00E+00	0.00E+00	1.15E-02	0.00E+00	4.69E+00	0.00E+00	0.00E+00	6.18E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1953	0.00E+00	0.00E+00	1.16E-02	0.00E+00	9.66E+00	0.00E+00	0.00E+00	1.55E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1954	0.00E+00	0.00E+00	1.18E-02	0.00E+00	1.48E+01	0.00E+00	0.00E+00	3.53E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1955	0.00E+00	0.00E+00	1.19E-02	0.00E+00	1.30E+01	0.00E+00	0.00E+00	1.26E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1956	0.00E+00	0.00E+00	1.21E-02	0.00E+00	7.53E+01	0.00E+00	0.00E+00	2.30E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1957	0.00E+00	8.36E-07	1.22E-02	0.00E+00	5.88E+01	0.00E+00	0.00E+00	3.54E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1958	0.00E+00	1.02E-06	1.23E-02	0.00E+00	8.61E+01	0.00E+00	0.00E+00	4.54E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1959	0.00E+00	1.09E-06	1.24E-02	0.00E+00	7.67E+01	0.00E+00	0.00E+00	6.01E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1960	0.00E+00	1.15E-06	1.25E-02	0.00E+00	8.38E+01	0.00E+00	0.00E+00	8.17E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1961	7.82E-06	1.17E-06	1.26E-02	0.00E+00	5.95E+01	0.00E+00	0.00E+00	7.55E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1962	1.01E-05	1.19E-06	1.27E-02	0.00E+00	5.28E+01	0.00E+00	0.00E+00	7.72E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1963	1.11E-05	1.21E-06	1.15E-02	0.00E+00	6.70E+01	0.00E+00	0.00E+00	1.09E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1964	1.15E-05	1.22E-06	1.03E-02	0.00E+00	5.66E+01	0.00E+00	0.00E+00	1.80E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1965	1.18E-05	1.23E-06	7.47E-03	0.00E+00	4.93E+01	0.00E+00	0.00E+00	2.06E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1966	1.19E-05	1.25E-06	5.54E-03	5.95E-01	5.75E+01	0.00E+00	0.00E+00	2.03E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1967	1.20E-05	1.26E-06	5.68E-03	2.00E+00	4.86E+01	0.00E+00	0.00E+00	1.95E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1968	1.36E-05	1.26E-06	6.27E-03	2.87E+00	6.51E+01	0.00E+00	0.00E+00	1.82E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1969	1.51E-05	1.27E-06	7.26E-03	2.70E+00	6.87E+01	0.00E+00	0.00E+00	1.71E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1970	1.87E-05	1.28E-06	8.16E-03	8.82E+00	8.93E+01	0.00E+00	0.00E+00	1.52E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1971	2.34E-05	1.29E-06	7.48E-03	1.62E+01	1.28E+02	0.00E+00	0.00E+00	1.20E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1972	5.79E-05	1.29E-06	8.01E-03	1.37E+01	1.30E+02	0.00E+00	0.00E+00	8.70E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1973	6.00E-05	1.29E-06	1.14E-02	1.31E+01	1.50E+02	0.00E+00	0.00E+00	6.51E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1974	9.05E-05	1.30E-06	1.70E-02	2.21E+01	1.71E+02	0.00E+00	0.00E+00	5.03E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1975	8.83E-05	1.31E-06	2.11E-02	3.25E+01	2.00E+02	0.00E+00	0.00E+00	3.33E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1976	9.09E-05	1.32E-06	2.28E-02	2.50E+01	2.22E+02	0.00E+00	0.00E+00	2.59E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1977	1.12E-04	1.32E-06	1.60E-02	2.35E+01	2.36E+02	0.00E+00	0.00E+00	2.19E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1978	7.44E-05	1.50E-06	2.14E-02	3.18E+01	2.48E+02	0.00E+00	0.00E+00	1.94E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1979	7.90E-05	1.54E-06	2.32E-02	3.11E+01	2.12E+02	0.00E+00	0.00E+00	1.75E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1980	5.81E-05	1.49E-06	1.69E-02	3.18E+01	1.88E+02	0.00E+00	0.00E+00	1.61E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1981	5.06E-05	1.84E-06	1.29E-02	2.86E+01	1.79E+02	0.00E+00	0.00E+00	1.48E-02	3.00E+01	1.14E+02	1.16E-01	6.58E+00	2.03E+01
1982	5.58E-05	1.40E-06	1.60E-02	3.75E+01	1.59E+02	0.00E+00	0.00E+00	1.37E-02	3.49E+01	1.78E+02	2.07E-01	1.09E+01	2.46E+01

Table 1 (cont'd)

Year	Other Nuclear (continued)			La Hague	Sellafield	Isotope		Baltic Flux	Phosphates				
	Karlsruhe	Risø	Springfields			Amersham	Cardiff		Baie de la Seine	Cumbrian Waters	Gulf of Cadiz	Irish Sea NW	Kattegat
1983	8.06E-05	7.14E-06	1.75E-02	3.08E+01	1.42E+02	0.00E+00	0.00E+00	1.27E-02	3.65E+01	2.18E+02	2.68E-01	1.41E+01	2.79E+01
1984	7.39E-05	3.17E-06	1.56E-02	3.11E+01	1.09E+02	0.00E+00	0.00E+00	1.18E-02	3.71E+01	2.48E+02	3.45E-01	1.25E+01	3.23E+01
1985	3.43E-03	1.19E-06	1.24E-02	3.64E+01	7.36E+01	0.00E+00	0.00E+00	1.09E-02	3.77E+01	2.46E+02	4.13E-01	8.62E+00	2.87E+01
1986	2.90E-04	6.79E-07	1.24E-02	3.46E+01	5.11E+01	0.00E+00	0.00E+00	4.79E-01	3.81E+01	2.38E+02	4.57E-01	6.30E+00	2.30E+01
1987	9.71E-05	4.64E-07	1.23E-02	4.22E+01	3.65E+01	0.00E+00	0.00E+00	5.95E-01	3.85E+01	2.15E+02	5.10E-01	5.18E+00	2.85E+01
1988	4.67E-05	3.56E-07	1.09E-02	2.57E+01	2.76E+01	1.46E-02	7.11E-02	6.12E-01	3.88E+01	2.18E+02	5.45E-01	3.19E+00	2.47E+01
1989	2.78E-05	2.97E-07	1.08E-02	2.39E+01	2.20E+01	1.16E-02	9.88E-02	5.98E-01	3.92E+01	1.96E+02	5.65E-01	2.01E+00	2.58E+01
1990	1.95E-05	2.59E-07	8.23E-03	1.54E+01	1.81E+01	1.22E-02	1.11E-01	5.67E-01	3.96E+01	1.71E+02	5.65E-01	1.42E+00	1.54E+01
1991	1.53E-05	2.32E-07	5.90E-03	5.28E+00	1.58E+01	1.52E-02	1.03E-01	5.25E-01	4.00E+01	1.44E+02	5.67E-01	1.13E+00	1.44E+01
1992	1.29E-05	2.11E-07	3.96E-03	2.96E+00	1.38E+01	1.46E-02	1.04E-01	4.82E-01	2.52E+01	1.19E+02	6.18E-01	9.93E-01	1.24E+01
1993	1.13E-05	1.94E-07	6.46E-03	2.66E+00	1.32E+01	1.04E-02	9.88E-02	4.38E-01	8.12E+00	8.54E+01	6.14E-01	9.18E-01	1.15E+01
1994	1.01E-05	1.79E-07	8.18E-03	3.51E+00	1.26E+01	1.04E-02	8.73E-02	3.96E-01	5.24E+00	6.55E+01	6.64E-01	8.69E-01	7.00E-02
1995	9.18E-06	1.65E-07	7.79E-03	3.54E+00	1.32E+01	1.03E-02	9.82E-02	3.55E-01	4.43E+00	5.41E+01	6.88E-01	8.31E-01	4.08E-02
1996	8.41E-06	1.54E-07	9.16E-03	3.65E+00	1.33E+01	9.07E-03	1.18E-01	3.19E-01	4.10E+00	4.77E+01	7.47E-01	7.98E-01	3.27E-02
1997	7.74E-06	1.43E-07	8.67E-03	3.82E+00	1.23E+01	3.65E-03	1.03E-01	2.86E-01	3.89E+00	4.38E+01	7.74E-01	7.68E-01	2.89E-02
1998	7.16E-06	1.33E-07	9.28E-03	3.99E+00	1.12E+01	3.65E-03	9.69E-02	2.56E-01	3.73E+00	4.11E+01	7.89E-01	7.40E-01	2.65E-02
1999	6.65E-06	1.24E-07	8.73E-03	3.75E+00	1.07E+01	3.03E-03	9.64E-02	2.29E-01	3.58E+00	3.91E+01	8.23E-01	7.13E-01	2.49E-02
2000	6.18E-06	1.16E-07	8.68E-03	3.65E+00	1.00E+01	3.03E-03	9.67E-02	2.05E-01	3.45E+00	3.73E+01	8.50E-01	6.87E-01	2.36E-02
2001	5.76E-06	1.09E-07	1.85E-03	1.30E+00	9.60E+00	8.60E-06	2.62E-02	1.21E-01	3.33E+00	3.58E+01	7.34E-01	6.62E-01	2.24E-02
2002	5.40E-06	1.01E-07	1.67E-03	6.95E-01	7.82E+00	8.39E-06	1.67E-02	8.65E-02	3.19E+00	3.43E+01	6.77E-01	6.38E-01	2.13E-02
2003	5.07E-06	9.49E-08	1.51E-03	5.01E-01	7.17E+00	8.27E-06	1.35E-02	6.97E-02	3.08E+00	3.29E+01	6.28E-01	6.15E-01	2.02E-02
2004	4.77E-06	8.90E-08	1.40E-03	4.15E-01	6.68E+00	8.18E-06	1.20E-02	5.99E-02	2.96E+00	3.15E+01	5.84E-01	5.93E-01	1.92E-02
2005	4.50E-06	8.34E-08	1.29E-03	3.72E-01	6.31E+00	8.11E-06	1.10E-02	5.36E-02	2.85E+00	3.03E+01	5.45E-01	5.72E-01	1.83E-02
2006	4.24E-06	7.85E-08	1.21E-03	3.46E-01	6.03E+00	8.04E-06	1.03E-02	4.89E-02	2.74E+00	2.92E+01	5.12E-01	5.52E-01	1.74E-02
2007	4.02E-06	7.37E-08	1.14E-03	3.28E-01	5.81E+00	7.98E-06	9.78E-03	4.49E-02	2.64E+00	2.81E+01	4.82E-01	5.31E-01	1.66E-02
2008	3.81E-06	6.94E-08	1.07E-03	3.14E-01	5.60E+00	7.91E-06	9.33E-03	4.15E-02	2.55E+00	2.69E+01	4.58E-01	5.12E-01	1.59E-02
2009	3.63E-06	6.54E-08	1.01E-03	3.01E-01	5.44E+00	7.85E-06	8.93E-03	3.83E-02	2.45E+00	2.59E+01	4.35E-01	4.94E-01	1.51E-02
2010	3.45E-06	6.17E-08	9.62E-04	2.90E-01	5.29E+00	7.79E-06	8.56E-03	3.56E-02	2.36E+00	2.50E+01	4.15E-01	4.76E-01	1.44E-02
2011	3.30E-06	5.82E-08	9.16E-04	2.80E-01	5.14E+00	7.73E-06	8.21E-03	3.31E-02	2.27E+00	2.40E+01	3.98E-01	4.59E-01	1.38E-02
2012	3.15E-06	5.50E-08	8.71E-04	2.70E-01	5.00E+00	7.67E-06	7.90E-03	3.06E-02	2.19E+00	2.32E+01	3.83E-01	4.42E-01	1.32E-02
2013	3.02E-06	5.20E-08	8.31E-04	2.61E-01	4.88E+00	7.60E-06	7.60E-03	2.85E-02	2.10E+00	2.23E+01	3.68E-01	4.27E-01	1.26E-02

Table 1 (cont'd)

Year	Other Nuclear (continued)			La Hague	Sellafield	Isotope		Baltic Flux	Phosphates				
	Karlsruhe	Risø	Springfields			Amersham	Cardiff		Baie de la Seine	Cumbrian Waters	Gulf of Cadiz	Irish Sea NW	Kattegat
2014	2.89E-06	4.94E-08	7.93E-04	2.52E-01	4.77E+00	7.57E-06	7.32E-03	2.65E-02	2.02E+00	2.15E+01	3.55E-01	4.11E-01	1.21E-02
2015	2.77E-06	4.66E-08	7.60E-04	2.43E-01	4.65E+00	7.51E-06	7.05E-03	2.46E-02	1.95E+00	2.07E+01	3.43E-01	3.97E-01	1.16E-02
2016	2.68E-06	4.42E-08	7.28E-04	2.36E-01	4.55E+00	7.45E-06	6.80E-03	2.29E-02	1.88E+00	1.99E+01	3.33E-01	3.82E-01	1.11E-02
2017	2.58E-06	4.20E-08	6.97E-04	2.28E-01	4.46E+00	7.39E-06	6.56E-03	2.13E-02	1.81E+00	1.93E+01	3.23E-01	3.69E-01	1.07E-02
2018	2.48E-06	3.99E-08	6.71E-04	2.22E-01	4.37E+00	7.33E-06	6.33E-03	1.98E-02	1.73E+00	1.86E+01	3.14E-01	3.56E-01	1.03E-02
2019	2.39E-06	3.80E-08	6.46E-04	2.15E-01	4.28E+00	7.27E-06	6.12E-03	1.84E-02	1.67E+00	1.78E+01	3.06E-01	3.43E-01	9.88E-03
2020	2.32E-06	3.62E-08	6.23E-04	2.09E-01	4.20E+00	7.24E-06	5.91E-03	1.72E-02	1.61E+00	1.72E+01	2.98E-01	3.30E-01	9.52E-03
2025	1.98E-06	2.85E-08	5.30E-04	1.82E-01	3.85E+00	6.97E-06	5.03E-03	1.22E-02	1.33E+00	1.44E+01	2.67E-01	2.75E-01	7.95E-03
2030	1.72E-06	2.29E-08	4.68E-04	1.60E-01	3.57E+00	6.68E-06	4.33E-03	8.87E-03	1.10E+00	1.20E+01	2.43E-01	2.30E-01	6.76E-03
2035	1.53E-06	1.87E-08	4.24E-04	1.42E-01	3.33E+00	6.44E-06	3.78E-03	6.60E-03	9.13E-01	1.01E+01	2.23E-01	1.92E-01	5.84E-03
2040	1.36E-06	1.54E-08	3.93E-04	1.28E-01	3.14E+00	6.22E-06	3.33E-03	5.02E-03	7.56E-01	8.47E+00	2.06E-01	1.60E-01	5.13E-03
2045	1.22E-06	1.29E-08	3.72E-04	1.16E-01	2.95E+00	5.98E-06	2.96E-03	3.91E-03	6.27E-01	7.11E+00	1.92E-01	1.34E-01	4.55E-03
2050	1.09E-06	1.08E-08	3.58E-04	1.06E-01	2.80E+00	5.76E-06	2.66E-03	3.11E-03	5.20E-01	5.97E+00	1.79E-01	1.11E-01	4.08E-03
2055	9.80E-07	9.14E-09	3.47E-04	9.81E-02	2.65E+00	5.57E-06	2.40E-03	2.52E-03	4.32E-01	5.01E+00	1.66E-01	9.34E-02	3.71E-03
2060	8.86E-07	7.74E-09	3.39E-04	9.11E-02	2.52E+00	5.36E-06	2.18E-03	2.07E-03	3.59E-01	4.20E+00	1.56E-01	7.80E-02	3.39E-03
2065	8.01E-07	6.60E-09	3.33E-04	8.46E-02	2.41E+00	5.16E-06	2.00E-03	1.72E-03	3.00E-01	3.53E+00	1.46E-01	6.52E-02	3.13E-03
2070	7.26E-07	5.63E-09	3.28E-04	7.94E-02	2.29E+00	4.97E-06	1.84E-03	1.45E-03	2.51E-01	2.96E+00	1.36E-01	5.46E-02	2.90E-03
2075	6.58E-07	4.82E-09	3.24E-04	7.45E-02	2.19E+00	4.78E-06	1.69E-03	1.23E-03	2.10E-01	2.49E+00	1.27E-01	4.58E-02	2.70E-03
2080	5.98E-07	4.13E-09	3.21E-04	7.03E-02	2.09E+00	4.62E-06	1.57E-03	1.04E-03	1.76E-01	2.09E+00	1.20E-01	3.84E-02	2.53E-03
2085	5.42E-07	3.54E-09	3.18E-04	6.65E-02	2.00E+00	4.45E-06	1.46E-03	8.93E-04	1.47E-01	1.76E+00	1.11E-01	3.23E-02	2.38E-03
2090	4.93E-07	3.04E-09	3.16E-04	6.29E-02	1.92E+00	4.29E-06	1.37E-03	7.66E-04	1.24E-01	1.48E+00	1.05E-01	2.72E-02	2.24E-03
2095	4.48E-07	2.61E-09	3.14E-04	5.97E-02	1.83E+00	4.12E-06	1.28E-03	6.59E-04	1.05E-01	1.26E+00	9.84E-02	2.29E-02	2.12E-03
2100	4.09E-07	2.24E-09	3.11E-04	5.66E-02	1.76E+00	3.99E-06	1.21E-03	5.69E-04	8.96E-02	1.05E+00	9.24E-02	1.93E-02	2.01E-03
2200	6.97E-08	1.17E-10	2.66E-04	2.40E-02	7.97E-01	1.87E-06	4.96E-04	3.31E-05	1.10E-02	6.90E-02	3.27E-02	1.57E-03	9.80E-04
2300	1.39E-08	6.72E-12	2.18E-04	1.18E-02	3.85E-01	8.73E-07	2.76E-04	2.09E-06	5.99E-03	2.82E-02	1.61E-02	7.43E-04	6.30E-04
2400	3.19E-09	4.31E-13	1.72E-04	6.28E-03	1.92E-01	4.10E-07	1.81E-04	1.42E-07	4.32E-03	1.99E-02	9.86E-03	5.38E-04	4.51E-04
2500	8.73E-10	3.07E-14	1.32E-04	3.57E-03	9.85E-02	1.95E-07	1.34E-04	1.04E-08	3.34E-03	1.55E-02	6.93E-03	4.23E-04	3.41E-04

Table 1 (cont'd)

Year	Phosphates (continued)	Oil & Gas							Chernobyl fallout	Testing Fallout	**All Sites/ sources**
	North Sea SE	Denmark N. Sea Central	Netherlands N. Sea SE	Norway N. Sea Central	Norway N. Sea North	UK North Sea Central	UK North Sea N	UK North Sea SW			
1952	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.38E-01	**5.24E+00**
1953	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.74E+00	**1.14E+01**
1954	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.65E+00	**1.94E+01**
1955	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.06E+00	**2.11E+01**
1956	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.59E+00	**8.50E+01**
1957	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E+01	**6.95E+01**
1958	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E+01	**9.95E+01**
1959	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.92E+01	**9.64E+01**
1960	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.43E+01	**9.88E+01**
1961	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.35E+01	**7.36E+01**
1962	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.48E+01	**7.87E+01**
1963	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.32E+01	**1.11E+02**
1964	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.32E+01	**1.02E+02**
1965	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.55E+01	**8.76E+01**
1966	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.80E+01	**8.84E+01**
1967	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E+01	**7.70E+01**
1968	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.07E+01	**9.20E+01**
1969	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E+01	**9.38E+01**
1970	0.00E+00	0.00E+00	1.43E-04	0.00E+00	0.00E+00	7.81E-03	3.05E-03	0.00E+00	0.00E+00	1.87E+01	**1.20E+02**
1971	0.00E+00	0.00E+00	9.02E-05	1.00E-02	6.71E-03	8.94E-02	9.58E-03	1.81E-01	0.00E+00	1.81E+01	**1.66E+02**
1972	0.00E+00	0.00E+00	5.72E-05	6.04E-02	3.96E-02	1.77E-01	1.89E-02	3.24E-01	0.00E+00	1.66E+01	**1.64E+02**
1973	0.00E+00	0.00E+00	1.63E-04	8.96E-02	5.49E-02	2.32E-01	2.56E-02	3.97E-01	0.00E+00	1.53E+01	**1.82E+02**
1974	0.00E+00	0.00E+00	3.22E-04	1.09E-01	6.60E-02	2.84E-01	3.15E-02	4.84E-01	0.00E+00	1.54E+01	**2.12E+02**
1975	0.00E+00	0.00E+00	1.75E-02	3.73E-01	2.40E-01	3.74E-01	5.71E-02	5.33E-01	0.00E+00	1.46E+01	**2.51E+02**
1976	0.00E+00	0.00E+00	6.14E-02	6.89E-01	4.29E-01	9.42E-01	2.67E-01	5.79E-01	0.00E+00	1.37E+01	**2.65E+02**
1977	0.00E+00	0.00E+00	1.19E-01	8.77E-01	5.24E-01	2.54E+00	8.56E-01	6.22E-01	0.00E+00	1.37E+01	**2.80E+02**
1978	0.00E+00	0.00E+00	1.54E-01	1.15E+00	6.61E-01	4.24E+00	1.44E+00	6.27E-01	0.00E+00	1.37E+01	**3.03E+02**
1979	0.00E+00	0.00E+00	2.50E-01	1.40E+00	7.85E-01	6.35E+00	2.20E+00	6.44E-01	0.00E+00	1.29E+01	**2.69E+02**
1980	0.00E+00	0.00E+00	3.07E-01	1.78E+00	9.86E-01	7.76E+00	2.64E+00	6.41E-01	0.00E+00	1.23E+01	**2.49E+02**
1981	1.82E+02	1.28E-01	3.23E-01	1.98E+00	1.08E+00	9.03E+00	3.06E+00	6.47E-01	0.00E+00	1.21E+01	**5.91E+02**

Table 1 (cont'd)

Year	Phosphates (continued) North Sea SE	Oil & Gas Denmark N. Sea Central	Netherlands N. Sea SE	Norway N. Sea Central	Norway N. Sea North	UK North Sea Central	UK North Sea N	UK North Sea SW	Chernobyl fallout	Testing Fallout	**All Sites/ sources**
1982	2.15E+02	3.63E-01	3.49E-01	2.16E+00	1.16E+00	1.05E+01	3.58E+00	6.63E-01	0.00E+00	1.15E+01	**6.92E+02**
1983	2.40E+02	5.81E-01	5.95E-01	2.49E+00	1.36E+00	1.22E+01	4.10E+00	6.86E-01	0.00E+00	1.10E+01	**7.44E+02**
1984	2.51E+02	7.37E-01	8.49E-01	2.88E+00	1.57E+00	1.38E+01	4.62E+00	7.01E-01	0.00E+00	1.06E+01	**7.59E+02**
1985	2.39E+02	9.57E-01	1.12E+00	3.30E+00	1.78E+00	1.51E+01	4.98E+00	7.56E-01	0.00E+00	1.03E+01	**7.10E+02**
1986	2.16E+02	1.23E+00	1.40E+00	3.71E+00	2.00E+00	1.62E+01	5.23E+00	8.05E-01	2.21E+01	9.93E+00	**6.72E+02**
1987	2.20E+02	1.58E+00	1.49E+00	4.26E+00	2.30E+00	1.69E+01	5.37E+00	8.53E-01	1.03E+01	9.64E+00	**6.40E+02**
1988	2.35E+02	1.83E+00	1.46E+00	4.89E+00	2.62E+00	1.73E+01	5.38E+00	8.59E-01	5.28E+00	9.37E+00	**6.23E+02**
1989	2.28E+02	2.17E+00	1.45E+00	5.95E+00	3.24E+00	1.68E+01	5.04E+00	8.60E-01	3.00E+00	9.12E+00	**5.87E+02**
1990	2.21E+02	2.48E+00	1.48E+00	6.90E+00	3.75E+00	1.69E+01	4.96E+00	9.17E-01	1.88E+00	8.89E+00	**5.32E+02**
1991	2.13E+02	2.89E+00	1.50E+00	7.95E+00	4.33E+00	1.74E+01	4.99E+00	9.98E-01	1.32E+00	8.66E+00	**4.85E+02**
1992	1.90E+02	3.31E+00	1.40E+00	9.12E+00	4.97E+00	1.82E+01	5.15E+00	1.04E+00	1.02E+00	8.45E+00	**4.19E+02**
1993	1.41E+02	3.69E+00	1.38E+00	1.02E+01	5.50E+00	1.94E+01	5.41E+00	1.16E+00	8.49E-01	8.26E+00	**3.20E+02**
1994	1.53E+02	4.12E+00	1.71E+00	1.15E+01	6.19E+00	2.18E+01	6.11E+00	1.26E+00	7.41E-01	8.07E+00	**3.04E+02**
1995	1.70E+02	4.44E+00	1.74E+00	1.28E+01	6.84E+00	2.37E+01	6.60E+00	1.35E+00	6.66E-01	7.88E+00	**3.13E+02**
1996	1.73E+02	4.92E+00	1.76E+00	1.43E+01	7.64E+00	2.52E+01	6.92E+00	1.54E+00	6.10E-01	7.71E+00	**3.15E+02**
1997	1.70E+02	5.53E+00	1.79E+00	1.55E+01	8.18E+00	2.63E+01	7.14E+00	1.63E+00	5.66E-01	7.54E+00	**3.10E+02**
1998	1.74E+02	6.05E+00	1.75E+00	1.63E+01	8.41E+00	2.76E+01	7.43E+00	1.72E+00	5.29E-01	7.37E+00	**3.13E+02**
1999	1.74E+02	6.96E+00	1.80E+00	1.69E+01	8.62E+00	2.90E+01	7.76E+00	1.80E+00	4.96E-01	7.23E+00	**3.14E+02**
2000	7.69E+01	7.63E+00	1.85E+00	1.76E+01	8.86E+00	3.02E+01	8.00E+00	1.84E+00	4.67E-01	7.07E+00	**2.17E+02**
2001	3.92E+01	5.41E+00	1.15E+00	1.32E+01	5.77E+00	2.45E+01	5.67E+00	8.93E-01	4.41E-01	6.94E+00	**1.55E+02**
2002	3.15E+01	4.18E+00	9.59E-01	1.08E+01	4.36E+00	2.13E+01	4.60E+00	5.86E-01	4.17E-01	6.80E+00	**1.33E+02**
2003	2.86E+01	3.70E+00	9.01E-01	9.93E+00	3.73E+00	2.01E+01	4.12E+00	5.03E-01	3.94E-01	6.66E+00	**1.24E+02**
2004	2.71E+01	3.59E+00	8.87E-01	9.77E+00	3.48E+00	1.99E+01	3.92E+00	4.71E-01	3.74E-01	6.54E+00	**1.19E+02**
2005	2.58E+01	3.62E+00	8.90E-01	9.91E+00	3.38E+00	2.00E+01	3.84E+00	4.55E-01	3.55E-01	6.42E+00	**1.16E+02**
2006	2.49E+01	3.70E+00	8.88E-01	1.01E+01	3.36E+00	2.01E+01	3.81E+00	4.42E-01	3.36E-01	6.30E+00	**1.14E+02**
2007	2.40E+01	3.79E+00	8.90E-01	1.03E+01	3.37E+00	2.04E+01	3.81E+00	4.30E-01	3.20E-01	6.19E+00	**1.12E+02**
2008	2.31E+01	3.87E+00	8.89E-01	1.05E+01	3.39E+00	2.05E+01	3.81E+00	4.20E-01	3.05E-01	6.08E+00	**1.09E+02**
2009	2.22E+01	3.93E+00	8.87E-01	1.07E+01	3.40E+00	2.06E+01	3.80E+00	4.09E-01	2.90E-01	5.96E+00	**1.07E+02**
2010	2.14E+01	3.98E+00	8.82E-01	1.07E+01	3.40E+00	2.07E+01	3.80E+00	3.99E-01	2.77E-01	5.86E+00	**1.05E+02**
2011	2.07E+01	4.02E+00	8.77E-01	1.08E+01	3.41E+00	2.08E+01	3.78E+00	3.88E-01	2.64E-01	5.76E+00	**1.03E+02**

Table 1 (cont'd)

	Phosphates (continued)	Oil & Gas							Chernobyl fallout	Testing Fallout	**All Sites/ sources**
Year	North Sea SE	Denmark N. Sea Central	Netherlands N. Sea SE	Norway N. Sea Central	Norway N. Sea North	UK North Sea Central	UK North Sea N	UK North Sea SW			
2012	1.98E+01	4.04E+00	8.68E-01	1.09E+01	3.40E+00	2.06E+01	3.77E+00	3.79E-01	2.52E-01	5.66E+00	**1.01E+02**
2013	1.91E+01	4.05E+00	8.58E-01	1.09E+01	3.39E+00	2.06E+01	3.75E+00	3.68E-01	2.41E-01	5.57E+00	**9.94E+01**
2014	1.85E+01	4.06E+00	8.50E-01	1.08E+01	3.38E+00	2.04E+01	3.71E+00	3.59E-01	2.30E-01	5.47E+00	**9.74E+01**
2015	1.78E+01	4.05E+00	8.36E-01	1.08E+01	3.36E+00	2.03E+01	3.68E+00	3.48E-01	2.20E-01	5.38E+00	**9.53E+01**
2016	1.72E+01	4.03E+00	8.25E-01	1.08E+01	3.34E+00	2.01E+01	3.66E+00	3.38E-01	2.11E-01	5.30E+00	**9.32E+01**
2017	1.65E+01	4.01E+00	8.12E-01	1.07E+01	3.31E+00	1.99E+01	3.62E+00	3.29E-01	2.01E-01	5.22E+00	**9.12E+01**
2018	1.59E+01	3.97E+00	7.97E-01	1.06E+01	3.29E+00	1.95E+01	3.58E+00	3.19E-01	1.93E-01	5.14E+00	**8.90E+01**
2019	1.54E+01	3.93E+00	7.85E-01	1.05E+01	3.25E+00	1.93E+01	3.54E+00	3.10E-01	1.85E-01	5.06E+00	**8.71E+01**
2020	1.48E+01	3.89E+00	7.69E-01	1.03E+01	3.22E+00	1.90E+01	3.50E+00	3.01E-01	1.78E-01	4.99E+00	**8.50E+01**
2025	1.23E+01	3.61E+00	6.93E-01	9.55E+00	3.03E+00	1.74E+01	3.27E+00	2.58E-01	1.45E-01	4.63E+00	**7.54E+01**
2030	1.02E+01	3.26E+00	6.12E-01	8.65E+00	2.81E+00	1.55E+01	3.02E+00	2.20E-01	1.20E-01	4.32E+00	**6.63E+01**
2035	8.52E+00	2.91E+00	5.35E-01	7.69E+00	2.59E+00	1.38E+01	2.78E+00	1.86E-01	9.97E-02	4.04E+00	**5.82E+01**
2040	7.08E+00	2.56E+00	4.64E-01	6.74E+00	2.38E+00	1.20E+01	2.55E+00	1.58E-01	8.34E-02	3.80E+00	**5.08E+01**
2045	5.91E+00	2.22E+00	3.99E-01	5.85E+00	2.17E+00	1.04E+01	2.33E+00	1.33E-01	7.02E-02	3.58E+00	**4.43E+01**
2050	4.94E+00	1.92E+00	3.43E-01	5.08E+00	1.99E+00	8.94E+00	2.14E+00	1.12E-01	5.93E-02	3.39E+00	**3.87E+01**
2055	4.13E+00	1.65E+00	2.93E-01	4.35E+00	1.82E+00	7.69E+00	1.96E+00	9.38E-02	5.02E-02	3.21E+00	**3.38E+01**
2060	3.45E+00	1.41E+00	2.50E-01	3.72E+00	1.67E+00	6.57E+00	1.79E+00	7.86E-02	4.27E-02	3.04E+00	**2.95E+01**
2065	2.90E+00	1.21E+00	2.13E-01	3.18E+00	1.53E+00	5.61E+00	1.65E+00	6.58E-02	3.63E-02	2.90E+00	**2.59E+01**
2070	2.44E+00	1.03E+00	1.81E-01	2.71E+00	1.41E+00	4.76E+00	1.51E+00	5.50E-02	3.10E-02	2.77E+00	**2.27E+01**
2075	2.06E+00	8.73E-01	1.54E-01	2.30E+00	1.30E+00	4.05E+00	1.40E+00	4.61E-02	2.65E-02	2.64E+00	**2.01E+01**
2080	1.74E+00	7.45E-01	1.32E-01	1.96E+00	1.20E+00	3.45E+00	1.29E+00	3.86E-02	2.27E-02	2.53E+00	**1.78E+01**
2085	1.47E+00	6.32E-01	1.12E-01	1.66E+00	1.11E+00	2.94E+00	1.20E+00	3.24E-02	1.94E-02	2.42E+00	**1.58E+01**
2090	1.26E+00	5.38E-01	9.61E-02	1.42E+00	1.04E+00	2.51E+00	1.13E+00	2.71E-02	1.67E-02	2.32E+00	**1.41E+01**
2095	1.07E+00	4.59E-01	8.23E-02	1.21E+00	9.65E-01	2.14E+00	1.05E+00	2.28E-02	1.43E-02	2.23E+00	**1.27E+01**
2100	9.17E-01	3.91E-01	7.10E-02	1.03E+00	9.03E-01	1.82E+00	9.83E-01	1.91E-02	1.23E-02	2.15E+00	**1.14E+01**
2200	1.38E-01	4.39E-02	1.06E-02	1.18E-01	3.83E-01	2.21E-01	4.25E-01	1.49E-03	6.59E-04	1.13E+00	**3.44E+00**
2300	7.83E-02	2.31E-02	5.99E-03	6.24E-02	2.41E-01	1.20E-01	2.71E-01	7.24E-04	3.94E-05	7.01E-01	**1.97E+00**
2400	5.64E-02	1.65E-02	4.30E-03	4.49E-02	1.74E-01	8.60E-02	1.95E-01	5.23E-04	2.58E-06	4.85E-01	**1.30E+00**
2500	4.35E-02	1.28E-02	3.32E-03	3.47E-02	1.34E-01	6.66E-02	1.50E-01	4.09E-04	1.84E-07	3.72E-01	**9.50E-01**

Table 2: Collective dose rates to the European Union population by site/source assuming discharges continue to 2020 (man Sv y^{-1})

	Military UK					Nuclear Power Stations							
Year	Aldermaston	Barrow	Devonport	Faslane	Rosyth	Almaraz	Barsebäck	Belleville	Berkeley	Beznau	Biblis	Blayais	Borssele
2001	1.71E-09	1.96E-09	8.09E-06	5.01E-07	8.03E-06	1.31E-04	1.07E-04	5.53E-05	4.16E-04	2.16E-05	1.14E-05	9.43E-05	1.54E-05
2002	1.54E-09	2.15E-09	7.33E-06	4.45E-07	8.08E-06	1.31E-04	1.04E-04	5.52E-05	3.95E-04	2.07E-05	1.14E-05	9.20E-05	1.73E-05
2003	1.44E-09	2.28E-09	6.69E-06	3.99E-07	8.12E-06	1.31E-04	1.01E-04	5.52E-05	3.75E-04	1.99E-05	1.15E-05	9.02E-05	1.63E-05
2004	1.37E-09	2.36E-09	6.15E-06	3.59E-07	8.17E-06	1.31E-04	9.90E-05	5.52E-05	3.58E-04	1.93E-05	1.14E-05	8.86E-05	1.54E-05
2005	1.31E-09	2.42E-09	5.68E-06	3.25E-07	8.20E-06	1.31E-04	9.72E-05	5.52E-05	3.40E-04	1.87E-05	1.14E-05	8.72E-05	1.47E-05
2006	1.26E-09	2.45E-09	5.29E-06	2.96E-07	8.23E-06	1.31E-04	9.54E-05	5.51E-05	3.25E-04	1.81E-05	1.14E-05	8.60E-05	1.41E-05
2007	1.23E-09	2.47E-09	4.95E-06	2.71E-07	8.26E-06	1.30E-04	9.40E-05	5.51E-05	3.10E-04	1.77E-05	1.14E-05	8.51E-05	1.35E-05
2008	1.19E-09	2.49E-09	4.67E-06	2.50E-07	8.28E-06	1.30E-04	9.28E-05	5.51E-05	2.97E-04	1.72E-05	1.14E-05	8.42E-05	1.31E-05
2009	1.16E-09	2.50E-09	4.43E-06	2.31E-07	8.30E-06	1.30E-04	9.19E-05	5.51E-05	2.84E-04	1.68E-05	1.14E-05	8.35E-05	1.27E-05
2010	1.13E-09	2.52E-09	4.22E-06	2.15E-07	8.31E-06	1.30E-04	9.09E-05	5.51E-05	2.73E-04	1.65E-05	1.14E-05	8.28E-05	1.24E-05
2012	1.09E-09	2.53E-09	3.89E-06	1.89E-07	8.34E-06	1.30E-04	8.97E-05	5.51E-05	2.51E-04	1.58E-05	1.14E-05	8.18E-05	1.18E-05
2014	1.05E-09	2.53E-09	3.66E-06	1.71E-07	8.36E-06	1.30E-04	8.85E-05	5.51E-05	2.32E-04	1.53E-05	1.14E-05	8.11E-05	1.14E-05
2016	1.02E-09	2.54E-09	3.49E-06	1.57E-07	8.37E-06	1.30E-04	8.78E-05	5.51E-05	2.16E-04	1.48E-05	1.13E-05	8.05E-05	1.12E-05
2018	9.99E-10	2.54E-09	3.36E-06	1.47E-07	8.38E-06	1.30E-04	8.72E-05	5.51E-05	2.00E-04	1.44E-05	1.13E-05	8.01E-05	1.10E-05
2020	9.80E-10	2.55E-09	3.27E-06	1.39E-07	8.39E-06	1.30E-04	8.69E-05	5.50E-05	1.87E-04	1.41E-05	1.13E-05	7.97E-05	1.08E-05
2025	7.09E-11	3.47E-10	7.01E-07	3.60E-08	2.68E-06	1.21E-06	2.11E-05	5.19E-07	1.60E-04	2.32E-06	6.24E-07	2.30E-06	9.39E-07
2030	3.81E-11	7.79E-11	3.17E-07	1.67E-08	1.23E-06	7.82E-07	9.58E-06	2.89E-07	1.38E-04	1.58E-06	3.07E-07	1.46E-06	4.58E-07
2040	1.45E-11	1.28E-11	6.66E-08	3.87E-09	2.64E-07	3.94E-07	2.33E-06	1.16E-07	1.07E-04	8.81E-07	1.24E-07	7.47E-07	1.41E-07
2050	6.06E-12	3.20E-12	1.46E-08	9.26E-10	5.75E-08	2.31E-07	8.24E-07	5.74E-08	8.49E-05	5.44E-07	5.93E-08	4.54E-07	5.99E-08
2060	2.74E-12	1.04E-12	3.33E-09	2.28E-10	1.27E-08	1.47E-07	4.30E-07	3.25E-08	6.92E-05	3.63E-07	3.38E-08	2.98E-07	3.48E-08
2070	1.32E-12	4.02E-13	7.81E-10	5.89E-11	2.86E-09	9.75E-08	2.79E-07	1.98E-08	5.75E-05	2.54E-07	2.21E-08	2.04E-07	2.44E-08
2080	6.68E-13	1.75E-13	1.90E-10	1.66E-11	6.53E-10	6.66E-08	1.97E-07	1.27E-08	4.87E-05	1.84E-07	1.58E-08	1.42E-07	1.86E-08
2090	3.47E-13	8.19E-14	4.78E-11	5.25E-12	1.52E-10	4.64E-08	1.44E-07	8.46E-09	4.17E-05	1.36E-07	1.20E-08	9.99E-08	1.47E-08
2100	1.83E-13	4.04E-14	1.27E-11	1.94E-12	3.57E-11	3.27E-08	1.07E-07	5.77E-09	3.61E-05	1.00E-07	9.34E-09	7.12E-08	1.19E-08
2200	3.84E-16	7.31E-17	3.36E-15	2.48E-15	5.45E-16	1.44E-09	9.20E-09	2.28E-10	1.18E-05	5.93E-09	1.51E-09	3.20E-09	2.07E-09
2300	8.65E-19	1.61E-19	7.17E-18	5.56E-18	1.16E-18	8.28E-11	2.78E-09	1.31E-11	4.87E-06	3.81E-10	4.03E-10	1.86E-10	5.43E-10
2400	2.06E-21	3.80E-22	1.68E-20	1.32E-20	2.73E-21	5.55E-12	1.66E-09	8.81E-13	2.28E-06	2.63E-11	1.40E-10	1.26E-11	1.85E-10
2500	5.28E-24	9.71E-25	4.33E-23	3.37E-23	6.93E-24	4.22E-13	1.18E-09	6.71E-14	1.24E-06	1.96E-12	5.87E-11	9.70E-13	7.65E-11

Table 2 (cont'd)

Year	Nuclear Power Stations (continued)												
	Bradwell	Brokdorf	Brunsbüttel	Cattenom	Chapelcross	Chinon	Chooz	Dampierre	Doel	Dodewaard	Dungeness	Emsland	Fessenheim
2001	2.19E-02	1.56E-05	7.63E-05	5.27E-04	3.45E-03	6.01E-05	6.61E-04	8.16E-05	9.88E-04	1.69E-05	1.43E-02	1.49E-05	4.61E-04
2002	2.17E-02	1.56E-05	7.63E-05	5.27E-04	3.31E-03	5.78E-05	6.60E-04	8.12E-05	9.87E-04	1.46E-05	1.42E-02	1.50E-05	4.61E-04
2003	2.17E-02	1.56E-05	7.62E-05	5.27E-04	3.21E-03	5.58E-05	6.59E-04	8.08E-05	9.86E-04	1.27E-05	1.41E-02	1.49E-05	4.60E-04
2004	2.16E-02	1.56E-05	7.62E-05	5.27E-04	3.11E-03	5.41E-05	6.58E-04	8.04E-05	9.85E-04	1.11E-05	1.41E-02	1.49E-05	4.60E-04
2005	2.15E-02	1.56E-05	7.61E-05	5.27E-04	3.05E-03	5.26E-05	6.57E-04	8.01E-05	9.84E-04	9.71E-06	1.41E-02	1.49E-05	4.60E-04
2006	2.15E-02	1.56E-05	7.61E-05	5.27E-04	2.98E-03	5.14E-05	6.55E-04	7.98E-05	9.83E-04	8.53E-06	1.40E-02	1.48E-05	4.60E-04
2007	2.15E-02	1.56E-05	7.60E-05	5.27E-04	2.93E-03	5.03E-05	6.55E-04	7.96E-05	9.80E-04	7.50E-06	1.40E-02	1.48E-05	4.60E-04
2008	2.13E-02	1.56E-05	7.60E-05	5.27E-04	2.88E-03	4.93E-05	6.54E-04	7.94E-05	9.80E-04	6.62E-06	1.40E-02	1.48E-05	4.60E-04
2009	2.13E-02	1.56E-05	7.60E-05	5.27E-04	2.84E-03	4.85E-05	6.53E-04	7.92E-05	9.80E-04	5.85E-06	1.40E-02	1.48E-05	4.60E-04
2010	2.13E-02	1.56E-05	7.59E-05	5.27E-04	2.79E-03	4.78E-05	6.53E-04	7.90E-05	9.80E-04	5.19E-06	1.40E-02	1.48E-05	4.60E-04
2012	2.12E-02	1.56E-05	7.59E-05	5.27E-04	2.71E-03	4.67E-05	6.52E-04	7.87E-05	9.80E-04	4.09E-06	1.40E-02	1.48E-05	4.60E-04
2014	2.12E-02	1.56E-05	7.58E-05	5.26E-04	2.66E-03	4.58E-05	6.51E-04	7.85E-05	9.79E-04	3.25E-06	1.40E-02	1.48E-05	4.60E-04
2016	2.11E-02	1.57E-05	7.58E-05	5.26E-04	2.60E-03	4.51E-05	6.50E-04	7.83E-05	9.79E-04	2.62E-06	1.40E-02	1.48E-05	4.60E-04
2018	2.10E-02	1.57E-05	7.57E-05	5.26E-04	2.56E-03	4.45E-05	6.49E-04	7.81E-05	9.79E-04	2.13E-06	1.39E-02	1.47E-05	4.60E-04
2020	2.09E-02	1.57E-05	7.57E-05	5.26E-04	2.52E-03	4.41E-05	6.49E-04	7.79E-05	9.79E-04	1.76E-06	1.39E-02	1.47E-05	4.60E-04
2025	3.16E-03	2.71E-07	5.71E-07	2.08E-06	9.11E-04	2.88E-06	3.33E-06	1.57E-06	3.34E-05	1.12E-06	1.42E-03	3.38E-07	5.14E-07
2030	2.53E-03	1.32E-07	3.22E-07	9.92E-07	6.49E-04	2.11E-06	2.39E-06	1.11E-06	1.71E-05	7.67E-07	9.32E-04	1.89E-07	2.67E-07
2040	1.99E-03	4.67E-08	1.38E-07	3.54E-07	5.03E-04	1.28E-06	1.43E-06	6.45E-07	6.17E-06	4.20E-07	5.65E-04	8.71E-08	1.11E-07
2050	1.68E-03	1.81E-08	7.87E-08	1.43E-07	4.19E-04	8.42E-07	9.38E-07	4.11E-07	2.67E-06	2.66E-07	3.97E-04	4.69E-08	5.30E-08
2060	1.45E-03	7.88E-09	5.26E-08	6.65E-08	3.62E-04	5.75E-07	6.55E-07	2.75E-07	1.36E-06	1.84E-07	3.08E-04	2.88E-08	2.92E-08
2070	1.28E-03	3.96E-09	3.80E-08	3.56E-08	3.17E-04	4.01E-07	4.74E-07	1.87E-07	7.95E-07	1.32E-07	2.53E-04	1.93E-08	1.81E-08
2080	1.14E-03	2.27E-09	2.84E-08	2.11E-08	2.81E-04	2.84E-07	3.49E-07	1.31E-07	5.13E-07	9.71E-08	2.14E-04	1.36E-08	1.20E-08
2090	1.01E-03	1.45E-09	2.17E-08	1.37E-08	2.51E-04	2.02E-07	2.61E-07	9.24E-08	3.54E-07	7.23E-08	1.86E-04	9.86E-09	8.39E-09
2100	9.04E-04	1.01E-09	1.68E-08	9.29E-09	2.24E-04	1.45E-07	1.96E-07	6.59E-08	2.53E-07	5.41E-08	1.62E-04	7.24E-09	6.02E-09
2200	3.00E-04	1.89E-10	2.10E-09	4.44E-10	8.80E-05	6.78E-09	1.41E-08	2.97E-09	1.41E-08	3.50E-09	4.91E-05	4.19E-10	3.30E-10
2300	1.06E-04	7.29E-11	5.88E-10	2.82E-11	3.91E-05	4.01E-10	1.85E-09	1.73E-10	8.95E-10	3.24E-10	1.72E-05	2.73E-11	2.12E-11
2400	3.92E-05	3.28E-11	2.48E-10	1.94E-12	1.79E-05	2.76E-11	5.22E-10	1.18E-11	6.09E-11	6.28E-11	6.69E-06	1.95E-12	1.46E-12
2500	1.57E-05	1.66E-11	1.25E-10	1.43E-13	8.29E-06	2.16E-12	2.24E-10	9.04E-13	4.48E-12	2.32E-11	2.93E-06	1.63E-13	1.09E-13

Table 2 (cont'd)

Year	Nuclear Power Stations (continued)												
	Flamanville	Golfech	Gösgen	Grafenrhein-feld	Gravelines	Grohnde	Hartlepool	Heysham	Hinkley	Hunterston	Jose Cabrera	Kahl	Krümmel
2001	1.19E-04	2.63E-05	4.16E-06	4.57E-06	5.49E-04	1.62E-05	2.71E-04	1.79E-03	4.22E-03	3.60E-03	6.82E-06	9.84E-08	4.51E-07
2002	1.13E-04	2.64E-05	4.16E-06	4.56E-06	5.34E-04	1.63E-05	2.63E-04	1.77E-03	4.19E-03	3.40E-03	6.67E-06	9.08E-08	4.48E-07
2003	1.07E-04	2.65E-05	4.16E-06	4.55E-06	5.22E-04	1.63E-05	2.58E-04	1.76E-03	4.16E-03	3.25E-03	6.52E-06	8.39E-08	4.45E-07
2004	1.03E-04	2.66E-05	4.17E-06	4.55E-06	5.12E-04	1.63E-05	2.53E-04	1.75E-03	4.14E-03	3.11E-03	6.39E-06	7.77E-08	4.44E-07
2005	9.84E-05	2.66E-05	4.17E-06	4.55E-06	5.03E-04	1.64E-05	2.48E-04	1.75E-03	4.12E-03	2.98E-03	6.28E-06	7.20E-08	4.42E-07
2006	9.49E-05	2.67E-05	4.17E-06	4.56E-06	4.95E-04	1.64E-05	2.44E-04	1.74E-03	4.09E-03	2.87E-03	6.19E-06	6.69E-08	4.41E-07
2007	9.17E-05	2.67E-05	4.17E-06	4.56E-06	4.89E-04	1.64E-05	2.40E-04	1.74E-03	4.07E-03	2.76E-03	6.09E-06	6.21E-08	4.40E-07
2008	8.89E-05	2.68E-05	4.18E-06	4.56E-06	4.83E-04	1.64E-05	2.38E-04	1.73E-03	4.06E-03	2.66E-03	6.00E-06	5.76E-08	4.39E-07
2009	8.65E-05	2.68E-05	4.18E-06	4.56E-06	4.78E-04	1.64E-05	2.36E-04	1.73E-03	4.03E-03	2.58E-03	5.93E-06	5.38E-08	4.38E-07
2010	8.43E-05	2.69E-05	4.18E-06	4.56E-06	4.74E-04	1.64E-05	2.34E-04	1.73E-03	4.02E-03	2.50E-03	5.86E-06	5.01E-08	4.38E-07
2012	8.07E-05	2.69E-05	4.18E-06	4.56E-06	4.66E-04	1.64E-05	2.30E-04	1.73E-03	3.98E-03	2.36E-03	5.73E-06	4.37E-08	4.36E-07
2014	7.79E-05	2.70E-05	4.19E-06	4.56E-06	4.61E-04	1.64E-05	2.29E-04	1.72E-03	3.95E-03	2.23E-03	5.64E-06	3.83E-08	4.35E-07
2016	7.58E-05	2.70E-05	4.19E-06	4.57E-06	4.57E-04	1.64E-05	2.27E-04	1.72E-03	3.93E-03	2.12E-03	5.55E-06	3.38E-08	4.35E-07
2018	7.41E-05	2.70E-05	4.19E-06	4.57E-06	4.54E-04	1.64E-05	2.25E-04	1.72E-03	3.90E-03	2.04E-03	5.48E-06	2.99E-08	4.34E-07
2020	7.27E-05	2.70E-05	4.19E-06	4.57E-06	4.52E-04	1.64E-05	2.24E-04	1.72E-03	3.88E-03	1.97E-03	5.41E-06	2.66E-08	4.34E-07
2025	7.84E-06	1.21E-06	2.11E-07	2.36E-07	1.23E-05	2.85E-07	2.18E-05	3.03E-04	1.31E-03	1.42E-03	5.92E-07	2.03E-08	7.11E-09
2030	4.34E-06	5.85E-07	9.57E-08	1.07E-07	6.58E-06	1.39E-07	9.93E-06	8.38E-05	1.10E-03	1.29E-03	4.58E-07	1.59E-08	3.60E-09
2040	1.70E-06	1.75E-07	3.31E-08	3.71E-08	2.37E-06	5.00E-08	3.18E-06	1.37E-05	8.66E-04	1.12E-03	2.89E-07	1.03E-08	1.32E-09
2050	8.05E-07	7.26E-08	1.22E-08	1.38E-08	1.11E-06	2.00E-08	1.36E-06	3.86E-06	7.20E-04	1.02E-03	1.92E-07	7.14E-09	5.60E-10
2060	4.55E-07	3.82E-08	4.90E-09	5.67E-09	6.40E-07	9.32E-09	7.79E-07	1.64E-06	6.16E-04	9.34E-04	1.31E-07	5.11E-09	2.76E-10
2070	2.90E-07	2.29E-08	2.16E-09	2.61E-09	4.21E-07	5.13E-09	5.42E-07	8.89E-07	5.37E-04	8.67E-04	9.16E-08	3.74E-09	1.57E-10
2080	1.99E-07	1.47E-08	1.03E-09	1.32E-09	2.96E-07	3.23E-09	4.19E-07	5.50E-07	4.72E-04	8.06E-04	6.47E-08	2.77E-09	9.92E-11
2090	1.42E-07	9.84E-09	5.20E-10	7.31E-10	2.15E-07	2.28E-09	3.43E-07	3.69E-07	4.17E-04	7.50E-04	4.60E-08	2.07E-09	6.71E-11
2100	1.04E-07	6.73E-09	2.75E-10	4.34E-10	1.58E-07	1.73E-09	2.88E-07	2.60E-07	3.71E-04	7.00E-04	3.31E-08	1.55E-09	4.74E-11
2200	5.74E-09	2.60E-10	5.05E-12	2.63E-11	9.23E-09	4.02E-10	8.95E-08	1.75E-08	1.34E-04	3.39E-04	1.53E-09	9.32E-11	3.65E-12
2300	3.62E-10	1.45E-11	1.56E-12	4.96E-12	5.90E-10	1.54E-10	3.63E-08	2.90E-09	5.46E-05	1.56E-04	9.00E-11	6.04E-12	5.20E-13
2400	2.49E-11	9.50E-13	6.37E-13	1.08E-12	4.05E-11	6.91E-11	1.58E-08	1.02E-09	2.44E-05	7.02E-05	6.10E-12	4.20E-13	1.06E-13
2500	1.86E-12	7.11E-14	2.93E-13	2.68E-13	3.00E-12	3.49E-11	7.28E-09	4.61E-10	1.22E-05	3.20E-05	4.68E-13	3.17E-14	2.79E-14

Table 2 (cont'd)

Year	Nuclear Power Stations (continued)												
	Leibstadt	Muelheim	Mühleberg	Neckarwest-heim	Nogent	Obrigheim	Oldbury	Paluel	Penly	Philippsburg	Rheinsberg	Ringhals	Sizewell
2001	1.34E-05	4.03E-08	2.18E-04	7.94E-06	4.32E-05	1.18E-05	1.62E-03	6.02E-04	4.08E-05	1.11E-05	6.74E-09	4.34E-04	7.91E-03
2002	1.34E-05	3.57E-08	2.18E-04	7.90E-06	4.33E-05	1.16E-05	1.60E-03	5.65E-04	4.08E-05	1.11E-05	5.90E-09	4.07E-04	7.81E-03
2003	1.35E-05	3.17E-08	2.18E-04	7.87E-06	4.33E-05	1.14E-05	1.58E-03	5.34E-04	4.09E-05	1.11E-05	5.20E-09	3.85E-04	7.74E-03
2004	1.35E-05	2.83E-08	2.18E-04	7.86E-06	4.32E-05	1.12E-05	1.57E-03	5.07E-04	4.10E-05	1.11E-05	4.59E-09	3.67E-04	7.71E-03
2005	1.35E-05	2.53E-08	2.18E-04	7.85E-06	4.31E-05	1.11E-05	1.56E-03	4.82E-04	4.11E-05	1.11E-05	4.07E-09	3.53E-04	7.69E-03
2006	1.35E-05	2.26E-08	2.17E-04	7.85E-06	4.30E-05	1.09E-05	1.54E-03	4.62E-04	4.10E-05	1.11E-05	3.62E-09	3.39E-04	7.65E-03
2007	1.35E-05	2.03E-08	2.17E-04	7.85E-06	4.30E-05	1.08E-05	1.53E-03	4.44E-04	4.11E-05	1.11E-05	3.24E-09	3.29E-04	7.63E-03
2008	1.35E-05	1.82E-08	2.17E-04	7.85E-06	4.29E-05	1.07E-05	1.52E-03	4.29E-04	4.11E-05	1.11E-05	2.91E-09	3.20E-04	7.58E-03
2009	1.35E-05	1.64E-08	2.17E-04	7.85E-06	4.28E-05	1.06E-05	1.51E-03	4.17E-04	4.11E-05	1.11E-05	2.62E-09	3.12E-04	7.57E-03
2010	1.35E-05	1.48E-08	2.17E-04	7.85E-06	4.28E-05	1.05E-05	1.50E-03	4.05E-04	4.11E-05	1.11E-05	2.37E-09	3.05E-04	7.55E-03
2012	1.35E-05	1.22E-08	2.17E-04	7.85E-06	4.27E-05	1.03E-05	1.49E-03	3.87E-04	4.11E-05	1.11E-05	1.96E-09	2.96E-04	7.52E-03
2014	1.35E-05	1.01E-08	2.16E-04	7.86E-06	4.26E-05	1.02E-05	1.47E-03	3.74E-04	4.12E-05	1.12E-05	1.65E-09	2.88E-04	7.49E-03
2016	1.35E-05	8.47E-09	2.16E-04	7.86E-06	4.25E-05	1.01E-05	1.46E-03	3.64E-04	4.13E-05	1.12E-05	1.41E-09	2.83E-04	7.47E-03
2018	1.35E-05	7.16E-09	2.16E-04	7.87E-06	4.26E-05	9.96E-06	1.45E-03	3.57E-04	4.13E-05	1.12E-05	1.22E-09	2.79E-04	7.45E-03
2020	1.35E-05	6.13E-09	2.16E-04	7.88E-06	4.25E-05	9.88E-06	1.44E-03	3.51E-04	4.13E-05	1.12E-05	1.07E-09	2.76E-04	7.42E-03
2025	9.96E-08	4.36E-09	3.83E-06	4.11E-07	1.55E-06	8.06E-07	3.56E-04	5.52E-05	2.43E-06	4.92E-07	8.17E-10	3.79E-05	6.56E-04
2030	5.20E-08	3.31E-09	2.32E-06	1.91E-07	7.22E-07	5.48E-07	2.81E-04	2.63E-05	1.18E-06	2.50E-07	6.58E-10	1.83E-05	4.47E-04
2040	2.31E-08	2.19E-09	1.14E-06	7.10E-08	2.48E-07	3.20E-07	2.04E-04	6.56E-06	4.01E-07	1.07E-07	4.74E-10	5.54E-06	2.88E-04
2050	1.11E-08	1.64E-09	6.21E-07	2.99E-08	9.95E-08	2.08E-07	1.60E-04	1.92E-06	1.57E-07	5.42E-08	3.66E-10	2.43E-06	2.14E-04
2060	5.92E-09	1.28E-09	3.75E-07	1.50E-08	4.76E-08	1.46E-07	1.31E-04	7.48E-07	7.22E-08	3.25E-08	2.90E-10	1.42E-06	1.74E-04
2070	3.50E-09	1.03E-09	2.46E-07	8.93E-09	2.65E-08	1.07E-07	1.11E-04	3.89E-07	3.88E-08	2.22E-08	2.35E-10	9.67E-07	1.47E-04
2080	2.25E-09	8.39E-10	1.70E-07	6.07E-09	1.66E-08	7.98E-08	9.49E-05	2.47E-07	2.37E-08	1.65E-08	1.91E-10	7.08E-07	1.27E-04
2090	1.55E-09	6.89E-10	1.22E-07	4.53E-09	1.12E-08	6.04E-08	8.23E-05	1.72E-07	1.57E-08	1.28E-08	1.57E-10	5.38E-07	1.11E-04
2100	1.10E-09	5.69E-10	8.98E-08	3.57E-09	7.80E-09	4.60E-08	7.22E-05	1.25E-07	1.09E-08	1.02E-08	1.29E-10	4.21E-07	9.77E-05
2200	5.98E-11	9.51E-11	5.19E-09	8.52E-10	4.02E-10	3.82E-09	2.46E-05	7.16E-09	5.68E-10	1.78E-09	2.22E-11	8.88E-08	3.07E-05
2300	3.76E-12	1.84E-11	3.30E-10	2.96E-10	2.57E-11	4.61E-10	9.92E-06	4.59E-10	3.57E-11	4.57E-10	4.57E-12	4.54E-08	1.06E-05
2400	2.53E-13	3.98E-12	2.26E-11	1.18E-10	1.77E-12	7.86E-11	4.42E-06	3.18E-11	2.42E-12	1.51E-10	1.09E-12	2.92E-08	3.99E-06
2500	1.85E-14	9.89E-13	1.67E-12	5.30E-11	1.32E-13	1.74E-11	2.23E-06	2.37E-12	1.77E-13	6.06E-11	3.02E-13	2.08E-08	1.62E-06

Table 2 (cont'd)

	Nuclear Power Stations (continued)										Other Nuclear		
Year	St Laurent	Stade	Tihange	Torness	Trawsfynydd	Trillo	Unterweser	Winfrith	Würgassen	Wylfa	Capenhurst	Dounreay	Harwell
2001	3.93E-05	6.47E-06	4.19E-04	1.46E-04	1.57E-04	1.68E-05	1.02E-05	4.08E-02	9.35E-07	9.09E-04	1.47E-06	1.38E-01	4.82E-04
2002	3.87E-05	6.42E-06	4.17E-04	1.46E-04	1.31E-04	1.68E-05	1.01E-05	3.91E-02	8.41E-07	7.81E-04	1.36E-06	1.34E-01	4.74E-04
2003	3.82E-05	6.37E-06	4.15E-04	1.45E-04	1.14E-04	1.68E-05	1.01E-05	3.76E-02	7.57E-07	6.91E-04	1.28E-06	1.31E-01	4.67E-04
2004	3.77E-05	6.33E-06	4.15E-04	1.45E-04	1.02E-04	1.68E-05	1.01E-05	3.64E-02	6.86E-07	6.33E-04	1.20E-06	1.29E-01	4.60E-04
2005	3.73E-05	6.30E-06	4.15E-04	1.46E-04	9.25E-05	1.68E-05	1.00E-05	3.52E-02	6.20E-07	5.94E-04	1.12E-06	1.27E-01	4.53E-04
2006	3.70E-05	6.27E-06	4.14E-04	1.46E-04	8.50E-05	1.68E-05	1.00E-05	3.43E-02	5.64E-07	5.69E-04	1.05E-06	1.25E-01	4.47E-04
2007	3.66E-05	6.25E-06	4.14E-04	1.46E-04	7.87E-05	1.68E-05	1.00E-05	3.34E-02	5.13E-07	5.51E-04	9.87E-07	1.23E-01	4.40E-04
2008	3.63E-05	6.23E-06	4.14E-04	1.46E-04	7.33E-05	1.68E-05	9.98E-06	3.26E-02	4.68E-07	5.38E-04	9.29E-07	1.21E-01	4.35E-04
2009	3.61E-05	6.21E-06	4.13E-04	1.46E-04	6.86E-05	1.68E-05	9.97E-06	3.18E-02	4.27E-07	5.29E-04	8.76E-07	1.19E-01	4.28E-04
2010	3.58E-05	6.19E-06	4.13E-04	1.46E-04	6.43E-05	1.68E-05	9.95E-06	3.12E-02	3.92E-07	5.21E-04	8.25E-07	1.18E-01	4.22E-04
2012	3.54E-05	6.16E-06	4.13E-04	1.46E-04	5.68E-05	1.68E-05	9.94E-06	3.00E-02	3.30E-07	5.09E-04	7.38E-07	1.15E-01	4.12E-04
2014	3.51E-05	6.14E-06	4.12E-04	1.46E-04	5.07E-05	1.68E-05	9.93E-06	2.90E-02	2.80E-07	5.00E-04	6.61E-07	1.12E-01	4.01E-04
2016	3.48E-05	6.12E-06	4.12E-04	1.46E-04	4.56E-05	1.68E-05	9.92E-06	2.82E-02	2.40E-07	4.93E-04	5.95E-07	1.09E-01	3.91E-04
2018	3.46E-05	6.10E-06	4.12E-04	1.46E-04	4.13E-05	1.68E-05	9.92E-06	2.74E-02	2.06E-07	4.86E-04	5.38E-07	1.07E-01	3.81E-04
2020	3.44E-05	6.09E-06	4.11E-04	1.46E-04	3.77E-05	1.68E-05	9.91E-06	2.68E-02	1.79E-07	4.82E-04	4.88E-07	1.05E-01	3.71E-04
2025	1.72E-06	1.33E-07	4.18E-06	1.14E-05	3.09E-05	1.41E-07	1.77E-07	2.54E-02	1.29E-07	1.13E-04	3.89E-07	9.60E-02	3.50E-04
2030	1.29E-06	8.29E-08	2.08E-06	5.64E-06	2.63E-05	8.10E-08	8.91E-08	2.41E-02	9.63E-08	5.02E-05	3.15E-07	9.16E-02	3.30E-04
2040	8.05E-07	4.31E-08	6.97E-07	2.78E-06	2.05E-05	3.18E-08	3.23E-08	2.21E-02	5.89E-08	2.93E-05	2.19E-07	8.38E-02	2.94E-04
2050	5.35E-07	2.64E-08	3.01E-07	1.83E-06	1.72E-05	1.50E-08	1.42E-08	2.02E-02	3.95E-08	2.09E-05	1.63E-07	7.75E-02	2.63E-04
2060	3.65E-07	1.79E-08	1.64E-07	1.45E-06	1.50E-05	7.98E-09	7.62E-09	1.85E-02	2.81E-08	1.65E-05	1.30E-07	7.15E-02	2.34E-04
2070	2.55E-07	1.30E-08	1.06E-07	1.25E-06	1.34E-05	4.60E-09	4.77E-09	1.69E-02	2.06E-08	1.38E-05	1.08E-07	6.63E-02	2.09E-04
2080	1.80E-07	9.76E-09	7.48E-08	1.12E-06	1.21E-05	2.81E-09	3.30E-09	1.54E-02	1.55E-08	1.19E-05	9.44E-08	6.15E-02	1.88E-04
2090	1.28E-07	7.48E-09	5.57E-08	1.02E-06	1.10E-05	1.78E-09	2.43E-09	1.40E-02	1.18E-08	1.05E-05	8.47E-08	5.70E-02	1.68E-04
2100	9.16E-08	5.81E-09	4.28E-08	9.29E-07	1.01E-05	1.17E-09	1.85E-09	1.27E-02	9.10E-09	9.33E-06	7.77E-08	5.29E-02	1.51E-04
2200	4.23E-09	7.10E-10	5.94E-09	3.96E-07	4.67E-06	4.13E-11	2.41E-10	4.57E-03	1.03E-09	3.85E-06	4.52E-08	2.46E-02	5.07E-05
2300	2.48E-10	1.66E-10	1.67E-09	1.69E-07	2.24E-06	2.32E-12	4.63E-11	1.61E-03	2.65E-10	1.79E-06	3.01E-08	1.14E-02	1.79E-05
2400	1.70E-11	5.91E-11	6.42E-10	7.28E-08	1.07E-06	1.53E-13	1.06E-11	6.04E-04	1.10E-10	8.36E-07	2.13E-08	5.42E-03	6.64E-06
2500	1.31E-12	2.67E-11	2.87E-10	3.30E-08	5.12E-07	1.15E-14	2.88E-12	2.48E-04	5.53E-11	3.95E-07	1.62E-08	2.71E-03	2.67E-06

Table 2 (cont'd)

	Other Nuclear (continued)			La Hague	Sellafield	Isotope		Baltic Flux*	Phosphates				
Year	Karlsruhe	Risø	Springfields			Amersham	Cardiff		Baie de la Seine	Cumbrian Waters	Gulf of Cadiz	Irish Sea NW	Kattegat
2001	5.76E-06	1.09E-07	8.64E-03	3.61E+00	9.60E+00	3.03E-03	9.72E-02	1.21E-01	3.33E+00	3.58E+01	8.74E-01	6.62E-01	2.24E-02
2002	5.40E-06	1.01E-07	8.60E-03	3.60E+00	9.25E+00	3.03E-03	9.77E-02	8.65E-02	3.19E+00	3.43E+01	8.98E-01	6.38E-01	2.13E-02
2003	5.07E-06	9.49E-08	8.57E-03	3.60E+00	8.97E+00	3.03E-03	9.83E-02	6.97E-02	3.08E+00	3.29E+01	9.21E-01	6.15E-01	2.02E-02
2004	4.77E-06	8.90E-08	8.53E-03	3.60E+00	8.72E+00	3.03E-03	9.88E-02	5.99E-02	2.96E+00	3.15E+01	9.43E-01	5.93E-01	1.92E-02
2005	4.50E-06	8.34E-08	8.51E-03	3.61E+00	8.50E+00	3.03E-03	9.93E-02	5.36E-02	2.85E+00	3.03E+01	9.65E-01	5.72E-01	1.83E-02
2006	4.24E-06	7.85E-08	8.48E-03	3.61E+00	8.32E+00	3.03E-03	9.98E-02	4.89E-02	2.74E+00	2.92E+01	9.85E-01	5.52E-01	1.74E-02
2007	4.02E-06	7.37E-08	8.44E-03	3.62E+00	8.17E+00	3.03E-03	1.00E-01	4.49E-02	2.64E+00	2.81E+01	1.00E+00	5.31E-01	1.66E-02
2008	3.81E-06	6.94E-08	8.43E-03	3.63E+00	8.02E+00	3.03E-03	1.01E-01	4.15E-02	2.55E+00	2.69E+01	1.02E+00	5.12E-01	1.59E-02
2009	3.63E-06	6.54E-08	8.40E-03	3.64E+00	7.87E+00	3.03E-03	1.01E-01	3.83E-02	2.45E+00	2.59E+01	1.04E+00	4.94E-01	1.51E-02
2010	3.45E-06	6.17E-08	8.38E-03	3.65E+00	7.75E+00	3.03E-03	1.02E-01	3.56E-02	2.36E+00	2.50E+01	1.05E+00	4.76E-01	1.44E-02
2012	3.15E-06	5.50E-08	8.34E-03	3.65E+00	7.52E+00	3.03E-03	1.02E-01	3.06E-02	2.19E+00	2.32E+01	1.10E+00	4.42E-01	1.32E-02
2014	2.89E-06	4.94E-08	8.30E-03	3.67E+00	7.33E+00	3.03E-03	1.03E-01	2.65E-02	2.02E+00	2.15E+01	1.13E+00	4.11E-01	1.21E-02
2016	2.68E-06	4.42E-08	8.29E-03	3.68E+00	7.15E+00	3.03E-03	1.04E-01	2.29E-02	1.88E+00	1.99E+01	1.16E+00	3.82E-01	1.11E-02
2018	2.48E-06	3.99E-08	8.26E-03	3.69E+00	7.00E+00	3.03E-03	1.05E-01	1.98E-02	1.73E+00	1.86E+01	1.18E+00	3.56E-01	1.03E-02
2020	2.32E-06	3.62E-08	8.25E-03	3.71E+00	6.86E+00	3.03E-03	1.05E-01	1.72E-02	1.61E+00	1.72E+01	1.21E+00	3.30E-01	9.52E-03
2025	1.98E-06	2.85E-08	1.00E-03	4.88E-01	4.38E+00	1.19E-05	1.85E-02	1.22E-02	1.33E+00	1.44E+01	8.58E-01	2.75E-01	7.95E-03
2030	1.72E-06	2.29E-08	7.77E-04	3.87E-01	3.86E+00	1.14E-05	1.50E-02	8.87E-03	1.10E+00	1.20E+01	6.96E-01	2.30E-01	6.76E-03
2040	1.36E-06	1.54E-08	5.56E-04	2.72E-01	3.30E+00	1.06E-05	1.08E-02	5.02E-03	7.56E-01	8.47E+00	5.32E-01	1.60E-01	5.13E-03
2050	1.09E-06	1.08E-08	4.53E-04	2.01E-01	2.91E+00	9.85E-06	8.20E-03	3.11E-03	5.20E-01	5.97E+00	4.45E-01	1.11E-01	4.08E-03
2060	8.86E-07	7.74E-09	4.05E-04	1.54E-01	2.60E+00	9.14E-06	6.49E-03	2.07E-03	3.59E-01	4.20E+00	3.81E-01	7.80E-02	3.39E-03
2070	7.26E-07	5.63E-09	3.81E-04	1.24E-01	2.35E+00	8.48E-06	5.30E-03	1.45E-03	2.51E-01	2.96E+00	3.32E-01	5.46E-02	2.90E-03
2080	5.98E-07	4.13E-09	3.66E-04	1.03E-01	2.12E+00	7.87E-06	4.44E-03	1.04E-03	1.76E-01	2.09E+00	2.89E-01	3.84E-02	2.53E-03
2090	4.93E-07	3.04E-09	3.58E-04	8.79E-02	1.94E+00	7.29E-06	3.80E-03	7.66E-04	1.24E-01	1.48E+00	2.54E-01	2.72E-02	2.24E-03
2100	4.09E-07	2.24E-09	3.51E-04	7.66E-02	1.77E+00	6.76E-06	3.29E-03	5.69E-04	8.96E-02	1.05E+00	2.23E-01	1.93E-02	2.01E-03
2200	6.97E-08	1.17E-10	3.01E-04	3.13E-02	8.04E-01	3.18E-06	1.27E-03	3.31E-05	1.10E-02	6.90E-02	7.52E-02	1.57E-03	9.80E-04
2300	1.39E-08	6.72E-12	2.46E-04	1.60E-02	3.89E-01	1.49E-06	6.93E-04	2.09E-06	5.99E-03	2.82E-02	3.60E-02	7.43E-04	6.30E-04
2400	3.19E-09	4.31E-13	1.94E-04	9.03E-03	1.94E-01	6.99E-07	4.47E-04	1.42E-07	4.32E-03	1.99E-02	2.16E-02	5.38E-04	4.51E-04
2500	8.73E-10	3.07E-14	1.50E-04	5.49E-03	9.97E-02	3.32E-07	3.28E-04	1.04E-08	3.34E-03	1.55E-02	1.50E-02	4.23E-04	3.41E-04

Table 2 (cont'd)

Year	Phosphates (continued)	Oil & Gas							Chernobyl*	Fallout*	**All sites/ sources**
	North Sea SE	Denmark N. Sea central	Netherlands N. Sea SE	Norway N. Sea central	Norway N. Sea N	UK N. Sea central	UK N. Sea N	UK N. Sea SW			
2001	6.35E+01	8.13E+00	1.89E+00	1.84E+01	9.12E+00	3.13E+01	8.23E+00	1.87E+00	4.41E-01	6.94E+00	**2.04E+02**
2002	5.93E+01	8.52E+00	1.94E+00	1.91E+01	9.37E+00	3.24E+01	8.45E+00	1.90E+00	4.17E-01	6.80E+00	**2.00E+02**
2003	5.75E+01	8.92E+00	1.97E+00	2.00E+01	9.64E+00	3.35E+01	8.64E+00	1.93E+00	3.94E-01	6.66E+00	**2.00E+02**
2004	5.65E+01	9.33E+00	2.02E+00	2.08E+01	9.89E+00	3.46E+01	8.85E+00	1.95E+00	3.74E-01	6.54E+00	**2.00E+02**
2005	5.57E+01	9.73E+00	2.05E+00	2.16E+01	1.02E+01	3.56E+01	9.05E+00	1.99E+00	3.55E-01	6.42E+00	**2.00E+02**
2006	5.51E+01	1.01E+01	2.09E+00	2.25E+01	1.04E+01	3.67E+01	9.25E+00	2.01E+00	3.36E-01	6.30E+00	**2.01E+02**
2007	5.45E+01	1.05E+01	2.12E+00	2.33E+01	1.07E+01	3.77E+01	9.43E+00	2.04E+00	3.20E-01	6.19E+00	**2.01E+02**
2008	5.39E+01	1.10E+01	2.16E+00	2.42E+01	1.10E+01	3.88E+01	9.61E+00	2.06E+00	3.05E-01	6.08E+00	**2.02E+02**
2009	5.34E+01	1.14E+01	2.18E+00	2.50E+01	1.12E+01	3.98E+01	9.82E+00	2.08E+00	2.90E-01	5.96E+00	**2.03E+02**
2010	5.29E+01	1.18E+01	2.21E+00	2.59E+01	1.15E+01	4.08E+01	1.00E+01	2.11E+00	2.77E-01	5.86E+00	**2.04E+02**
2012	5.18E+01	1.26E+01	2.27E+00	2.76E+01	1.20E+01	4.29E+01	1.04E+01	2.15E+00	2.52E-01	5.66E+00	**2.06E+02**
2014	5.08E+01	1.35E+01	2.32E+00	2.92E+01	1.25E+01	4.48E+01	1.07E+01	2.19E+00	2.30E-01	5.47E+00	**2.08E+02**
2016	5.00E+01	1.44E+01	2.36E+00	3.08E+01	1.30E+01	4.67E+01	1.11E+01	2.22E+00	2.11E-01	5.30E+00	**2.11E+02**
2018	4.92E+01	1.52E+01	2.40E+00	3.24E+01	1.35E+01	4.85E+01	1.14E+01	2.26E+00	1.93E-01	5.14E+00	**2.13E+02**
2020	4.84E+01	1.59E+01	2.44E+00	3.40E+01	1.40E+01	5.03E+01	1.18E+01	2.30E+00	1.78E-01	4.99E+00	**2.16E+02**
2025	1.68E+01	1.17E+01	1.37E+00	2.58E+01	8.37E+00	3.87E+01	7.37E+00	8.51E-01	1.45E-01	4.63E+00	**1.38E+02**
2030	1.39E+01	1.18E+01	1.27E+00	2.56E+01	8.10E+00	3.78E+01	7.10E+00	7.42E-01	1.20E-01	4.32E+00	**1.29E+02**
2040	9.67E+00	1.04E+01	1.02E+00	2.24E+01	7.27E+00	3.26E+01	6.32E+00	5.52E-01	8.34E-02	3.80E+00	**1.08E+02**
2050	6.70E+00	8.35E+00	7.84E-01	1.79E+01	6.23E+00	2.58E+01	5.40E+00	4.00E-01	5.93E-02	3.39E+00	**8.52E+01**
2060	4.67E+00	6.39E+00	5.82E-01	1.36E+01	5.25E+00	1.96E+01	4.54E+00	2.85E-01	4.27E-02	3.04E+00	**6.59E+01**
2070	3.29E+00	4.74E+00	4.25E-01	1.01E+01	4.40E+00	1.45E+01	3.83E+00	2.01E-01	3.10E-02	2.77E+00	**5.04E+01**
2080	2.32E+00	3.47E+00	3.09E-01	7.39E+00	3.72E+00	1.06E+01	3.23E+00	1.42E-01	2.27E-02	2.53E+00	**3.86E+01**
2090	1.67E+00	2.51E+00	2.24E-01	5.35E+00	3.16E+00	7.66E+00	2.77E+00	9.91E-02	1.67E-02	2.32E+00	**2.98E+01**
2100	1.22E+00	1.82E+00	1.64E-01	3.88E+00	2.73E+00	5.55E+00	2.38E+00	6.95E-02	1.23E-02	2.15E+00	**2.33E+01**
2200	1.67E-01	1.60E-01	1.98E-02	3.48E-01	1.05E+00	5.24E-01	9.41E-01	4.14E-03	6.59E-04	1.13E+00	**5.37E+00**
2300	9.22E-02	7.58E-02	1.05E-02	1.67E-01	6.47E-01	2.58E-01	5.81E-01	1.73E-03	3.94E-05	7.01E-01	**3.02E+00**
2400	6.61E-02	5.35E-02	7.50E-03	1.19E-01	4.61E-01	1.83E-01	4.17E-01	1.23E-03	2.58E-06	4.85E-01	**2.05E+00**
2500	5.10E-02	4.12E-02	5.76E-03	9.12E-02	3.52E-01	1.41E-01	3.19E-01	9.51E-04	1.84E-07	3.72E-01	**1.52E+00**

Note: * - source continues to 2000 only

Table 3: Integrated Collective doses to the European Union population by site/source due to discharges up to 2000 only (man Sv)

Year	Baltic Flux	Chernobyl	Fallout	Isotope	Phosphates						Oil & Gas		
					Baie de la Seine	Cumbrian Waters	Gulf of Cadiz	Irish Sea NW	Kattegat	North Sea SE	Denmark N. Sea central	Netherlands N. Sea SE	Norway N. Sea central
1952	3.64E-04	0.00E+00	1.05E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1953	1.53E-03	0.00E+00	2.28E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1954	4.24E-03	0.00E+00	5.68E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1955	1.31E-02	0.00E+00	1.22E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1956	3.17E-02	0.00E+00	2.11E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1957	6.19E-02	0.00E+00	3.12E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1958	1.03E-01	0.00E+00	4.32E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1959	1.57E-01	0.00E+00	5.98E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1960	2.30E-01	0.00E+00	7.62E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1961	3.07E-01	0.00E+00	8.99E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1962	3.84E-01	0.00E+00	1.10E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1963	4.80E-01	0.00E+00	1.45E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1964	6.30E-01	0.00E+00	1.87E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1965	8.25E-01	0.00E+00	2.27E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1966	1.03E+00	0.00E+00	2.58E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1967	1.23E+00	0.00E+00	2.83E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1968	1.41E+00	0.00E+00	3.05E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1969	1.59E+00	0.00E+00	3.24E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1970	1.75E+00	0.00E+00	3.43E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.94E-05	0.00E+00
1971	1.88E+00	0.00E+00	3.61E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.94E-04	5.38E-03
1972	1.98E+00	0.00E+00	3.80E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.65E-04	4.25E-02
1973	2.06E+00	0.00E+00	3.95E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.81E-04	1.19E-01
1974	2.11E+00	0.00E+00	4.10E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.33E-04	2.19E-01
1975	2.15E+00	0.00E+00	4.26E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.05E-02	4.70E-01
1976	2.18E+00	0.00E+00	4.39E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.27E-02	1.01E+00
1977	2.21E+00	0.00E+00	4.53E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.47E-01	1.80E+00
1978	2.23E+00	0.00E+00	4.66E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.86E-01	2.83E+00
1979	2.25E+00	0.00E+00	4.80E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.94E-01	4.11E+00
1980	2.26E+00	0.00E+00	4.93E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.76E-01	5.70E+00
1981	2.28E+00	0.00E+00	5.05E+02	0.00E+00	1.93E+01	6.48E+01	7.06E-02	3.36E+00	1.77E+01	1.27E+02	6.84E-02	1.09E+00	7.61E+00

Table 3 (cont'd)

Year	Baltic Flux	Chernobyl	Fallout	Isotope	Phosphates						Oil & Gas		
					Baie de la Seine	Cumbrian Waters	Gulf of Cadiz	Irish Sea NW	Kattegat	North Sea SE	Denmark N. Sea central	Netherlands N. Sea SE	Norway N. Sea central
1982	2.29E+00	0.00E+00	5.17E+02	0.00E+00	5.24E+01	2.13E+02	2.35E-01	1.23E+01	4.18E+01	3.29E+02	3.24E-01	1.44E+00	9.67E+00
1983	2.31E+00	0.00E+00	5.27E+02	0.00E+00	8.81E+01	4.13E+02	4.71E-01	2.49E+01	6.92E+01	5.61E+02	8.05E-01	1.94E+00	1.20E+01
1984	2.32E+00	0.00E+00	5.39E+02	0.00E+00	1.25E+02	6.47E+02	7.80E-01	3.84E+01	1.01E+02	8.07E+02	1.47E+00	2.69E+00	1.47E+01
1985	2.33E+00	0.00E+00	5.49E+02	0.00E+00	1.63E+02	8.93E+02	1.16E+00	4.87E+01	1.31E+02	1.05E+03	2.32E+00	3.70E+00	1.78E+01
1986	2.62E+00	1.26E+01	5.59E+02	0.00E+00	2.00E+02	1.14E+03	1.60E+00	5.61E+01	1.54E+02	1.28E+03	3.43E+00	5.00E+00	2.13E+01
1987	3.16E+00	2.79E+01	5.69E+02	0.00E+00	2.39E+02	1.36E+03	2.08E+00	6.18E+01	1.82E+02	1.49E+03	4.86E+00	6.43E+00	2.54E+01
1988	3.76E+00	3.54E+01	5.79E+02	6.71E-02	2.78E+02	1.58E+03	2.61E+00	6.58E+01	2.07E+02	1.72E+03	6.56E+00	7.90E+00	2.99E+01
1989	4.36E+00	3.94E+01	5.88E+02	1.69E-01	3.16E+02	1.78E+03	3.16E+00	6.84E+01	2.33E+02	1.95E+03	8.57E+00	9.35E+00	3.54E+01
1990	4.94E+00	4.17E+01	5.97E+02	2.88E-01	3.55E+02	1.96E+03	3.72E+00	7.01E+01	2.49E+02	2.17E+03	1.09E+01	1.08E+01	4.19E+01
1991	5.49E+00	4.33E+01	6.05E+02	4.07E-01	3.95E+02	2.12E+03	4.29E+00	7.13E+01	2.64E+02	2.39E+03	1.36E+01	1.23E+01	4.93E+01
1992	5.99E+00	4.44E+01	6.14E+02	5.25E-01	4.26E+02	2.25E+03	4.88E+00	7.24E+01	2.77E+02	2.58E+03	1.67E+01	1.37E+01	5.79E+01
1993	6.44E+00	4.54E+01	6.22E+02	6.35E-01	4.40E+02	2.35E+03	5.50E+00	7.34E+01	2.88E+02	2.75E+03	2.02E+01	1.51E+01	6.76E+01
1994	6.85E+00	4.61E+01	6.30E+02	7.36E-01	4.47E+02	2.42E+03	6.14E+00	7.42E+01	2.90E+02	2.89E+03	2.42E+01	1.67E+01	7.84E+01
1995	7.23E+00	4.69E+01	6.38E+02	8.41E-01	4.52E+02	2.49E+03	6.81E+00	7.51E+01	2.90E+02	3.05E+03	2.84E+01	1.84E+01	9.06E+01
1996	7.56E+00	4.75E+01	6.46E+02	9.63E-01	4.56E+02	2.54E+03	7.53E+00	7.59E+01	2.90E+02	3.23E+03	3.31E+01	2.02E+01	1.04E+02
1997	7.86E+00	4.81E+01	6.53E+02	1.07E+00	4.60E+02	2.58E+03	8.30E+00	7.66E+01	2.90E+02	3.39E+03	3.84E+01	2.19E+01	1.19E+02
1998	8.13E+00	4.86E+01	6.62E+02	1.18E+00	4.63E+02	2.62E+03	9.07E+00	7.75E+01	2.90E+02	3.57E+03	4.41E+01	2.37E+01	1.35E+02
1999	8.37E+00	4.91E+01	6.69E+02	1.28E+00	4.67E+02	2.66E+03	9.89E+00	7.82E+01	2.90E+02	3.74E+03	5.06E+01	2.55E+01	1.52E+02
2000	8.59E+00	4.96E+01	6.75E+02	1.37E+00	4.70E+02	2.70E+03	1.07E+01	7.89E+01	2.90E+02	3.85E+03	5.80E+01	2.73E+01	1.69E+02
2001	8.74E+00	5.00E+01	6.82E+02	1.42E+00	4.74E+02	2.74E+03	1.14E+01	7.95E+01	2.90E+02	3.90E+03	6.45E+01	2.87E+01	1.84E+02
2002	8.84E+00	5.04E+01	6.89E+02	1.44E+00	4.76E+02	2.77E+03	1.22E+01	8.02E+01	2.91E+02	3.94E+03	6.92E+01	2.98E+01	1.96E+02
2003	8.91E+00	5.08E+01	6.96E+02	1.45E+00	4.79E+02	2.80E+03	1.29E+01	8.08E+01	2.91E+02	3.97E+03	7.31E+01	3.07E+01	2.07E+02
2004	8.98E+00	5.12E+01	7.03E+02	1.46E+00	4.83E+02	2.83E+03	1.34E+01	8.14E+01	2.91E+02	3.99E+03	7.67E+01	3.15E+01	2.16E+02
2005	9.04E+00	5.16E+01	7.09E+02	1.48E+00	4.86E+02	2.86E+03	1.40E+01	8.19E+01	2.91E+02	4.02E+03	8.03E+01	3.25E+01	2.26E+02
2006	9.09E+00	5.19E+01	7.16E+02	1.49E+00	4.89E+02	2.89E+03	1.45E+01	8.26E+01	2.91E+02	4.04E+03	8.41E+01	3.33E+01	2.36E+02
2007	9.13E+00	5.23E+01	7.22E+02	1.50E+00	4.91E+02	2.92E+03	1.51E+01	8.31E+01	2.91E+02	4.07E+03	8.77E+01	3.42E+01	2.46E+02
2008	9.18E+00	5.26E+01	7.28E+02	1.51E+00	4.94E+02	2.95E+03	1.55E+01	8.36E+01	2.91E+02	4.09E+03	9.15E+01	3.51E+01	2.56E+02
2009	9.22E+00	5.29E+01	7.34E+02	1.51E+00	4.96E+02	2.98E+03	1.60E+01	8.41E+01	2.91E+02	4.11E+03	9.54E+01	3.60E+01	2.67E+02
2010	9.25E+00	5.31E+01	7.40E+02	1.52E+00	4.99E+02	3.01E+03	1.64E+01	8.46E+01	2.91E+02	4.13E+03	9.94E+01	3.69E+01	2.77E+02
2011	9.29E+00	5.34E+01	7.46E+02	1.53E+00	5.01E+02	3.03E+03	1.68E+01	8.51E+01	2.91E+02	4.16E+03	1.03E+02	3.77E+01	2.89E+02
2012	9.32E+00	5.37E+01	7.51E+02	1.54E+00	5.03E+02	3.06E+03	1.71E+01	8.55E+01	2.91E+02	4.18E+03	1.07E+02	3.86E+01	2.99E+02

Table 3 (cont'd)

Year	Baltic Flux	Chernobyl	Fallout	Isotope	Phosphates						Oil & Gas		
					Baie de la Seine	Cumbrian Waters	Gulf of Cadiz	Irish Sea NW	Kattegat	North Sea SE	Denmark N. Sea central	Netherlands N. Sea SE	Norway N. Sea central
2013	9.35E+00	5.39E+01	7.57E+02	1.55E+00	5.05E+02	3.08E+03	1.76E+01	8.59E+01	2.91E+02	4.20E+03	1.11E+02	3.95E+01	3.11E+02
2014	9.38E+00	5.42E+01	7.62E+02	1.56E+00	5.07E+02	3.10E+03	1.79E+01	8.63E+01	2.91E+02	4.22E+03	1.16E+02	4.04E+01	3.21E+02
2015	9.40E+00	5.44E+01	7.68E+02	1.56E+00	5.09E+02	3.12E+03	1.83E+01	8.67E+01	2.91E+02	4.24E+03	1.20E+02	4.12E+01	3.32E+02
2016	9.43E+00	5.46E+01	7.73E+02	1.57E+00	5.11E+02	3.14E+03	1.86E+01	8.71E+01	2.91E+02	4.26E+03	1.24E+02	4.20E+01	3.43E+02
2017	9.45E+00	5.48E+01	7.78E+02	1.58E+00	5.13E+02	3.16E+03	1.89E+01	8.76E+01	2.91E+02	4.27E+03	1.28E+02	4.29E+01	3.53E+02
2018	9.47E+00	5.50E+01	7.84E+02	1.58E+00	5.15E+02	3.18E+03	1.92E+01	8.79E+01	2.91E+02	4.29E+03	1.32E+02	4.37E+01	3.64E+02
2019	9.49E+00	5.52E+01	7.89E+02	1.59E+00	5.16E+02	3.20E+03	1.95E+01	8.83E+01	2.91E+02	4.30E+03	1.36E+02	4.44E+01	3.75E+02
2020	9.51E+00	5.54E+01	7.94E+02	1.59E+00	5.18E+02	3.21E+03	1.99E+01	8.86E+01	2.91E+02	4.32E+03	1.40E+02	4.52E+01	3.86E+02
2025	9.58E+00	5.62E+01	8.18E+02	1.62E+00	5.26E+02	3.29E+03	2.13E+01	9.01E+01	2.91E+02	4.38E+03	1.58E+02	4.89E+01	4.35E+02
2030	9.63E+00	5.68E+01	8.40E+02	1.65E+00	5.32E+02	3.36E+03	2.26E+01	9.13E+01	2.91E+02	4.44E+03	1.76E+02	5.22E+01	4.80E+02
2035	9.67E+00	5.74E+01	8.61E+02	1.67E+00	5.37E+02	3.41E+03	2.37E+01	9.24E+01	2.91E+02	4.48E+03	1.91E+02	5.50E+01	5.22E+02
2040	9.70E+00	5.78E+01	8.81E+02	1.68E+00	5.41E+02	3.45E+03	2.47E+01	9.33E+01	2.91E+02	4.53E+03	2.04E+02	5.75E+01	5.57E+02
2045	9.72E+00	5.82E+01	8.99E+02	1.70E+00	5.44E+02	3.50E+03	2.58E+01	9.40E+01	2.91E+02	4.56E+03	2.17E+02	5.97E+01	5.88E+02
2050	9.74E+00	5.85E+01	9.17E+02	1.71E+00	5.47E+02	3.53E+03	2.67E+01	9.46E+01	2.91E+02	4.59E+03	2.27E+02	6.15E+01	6.16E+02
2055	9.75E+00	5.88E+01	9.32E+02	1.73E+00	5.49E+02	3.56E+03	2.76E+01	9.51E+01	2.91E+02	4.61E+03	2.36E+02	6.31E+01	6.39E+02
2060	9.76E+00	5.90E+01	9.49E+02	1.74E+00	5.51E+02	3.58E+03	2.84E+01	9.56E+01	2.91E+02	4.63E+03	2.43E+02	6.44E+01	6.60E+02
2065	9.77E+00	5.92E+01	9.63E+02	1.75E+00	5.53E+02	3.60E+03	2.91E+01	9.59E+01	2.91E+02	4.65E+03	2.49E+02	6.56E+01	6.76E+02
2070	9.78E+00	5.94E+01	9.77E+02	1.76E+00	5.54E+02	3.62E+03	2.98E+01	9.62E+01	2.91E+02	4.66E+03	2.56E+02	6.66E+01	6.92E+02
2075	9.79E+00	5.96E+01	9.91E+02	1.77E+00	5.55E+02	3.63E+03	3.05E+01	9.64E+01	2.91E+02	4.67E+03	2.60E+02	6.74E+01	7.04E+02
2080	9.79E+00	5.97E+01	1.00E+03	1.77E+00	5.56E+02	3.64E+03	3.11E+01	9.66E+01	2.91E+02	4.68E+03	2.64E+02	6.81E+01	7.14E+02
2085	9.80E+00	5.98E+01	1.02E+03	1.78E+00	5.57E+02	3.65E+03	3.17E+01	9.68E+01	2.91E+02	4.69E+03	2.68E+02	6.87E+01	7.24E+02
2090	9.80E+00	5.99E+01	1.03E+03	1.79E+00	5.58E+02	3.66E+03	3.22E+01	9.70E+01	2.91E+02	4.69E+03	2.71E+02	6.93E+01	7.31E+02
2095	9.81E+00	6.00E+01	1.04E+03	1.80E+00	5.58E+02	3.67E+03	3.28E+01	9.71E+01	2.91E+02	4.70E+03	2.73E+02	6.97E+01	7.38E+02
2100	9.81E+00	6.00E+01	1.05E+03	1.80E+00	5.60E+02	3.67E+03	3.32E+01	9.72E+01	2.91E+02	4.70E+03	2.75E+02	7.01E+01	7.43E+02
2200	9.83E+00	6.04E+01	1.21E+03	1.88E+00	5.63E+02	3.70E+03	3.88E+01	9.79E+01	2.91E+02	4.74E+03	2.89E+02	7.28E+01	7.79E+02
2300	9.83E+00	6.04E+01	1.30E+03	1.92E+00	5.63E+02	3.71E+03	4.11E+01	9.80E+01	2.92E+02	4.75E+03	2.92E+02	7.35E+01	7.88E+02
2400	9.83E+00	6.04E+01	1.35E+03	1.94E+00	5.64E+02	3.71E+03	4.22E+01	9.80E+01	2.92E+02	4.75E+03	2.94E+02	7.40E+01	7.93E+02
2500	9.83E+00	6.04E+01	1.40E+03	1.95E+00	5.64E+02	3.71E+03	4.31E+01	9.81E+01	2.92E+02	4.76E+03	2.95E+02	7.45E+01	7.97E+02

Table 3 (cont'd)

	Oil & Gas (continued)				Nuclear Power	Other Nucl.	La Hague	Sellafield	UK Military	**All sites**
Year	Norway N. Sea N	UK N. Sea central	UK N. Sea N	UK N. Sea SW	Stations					**/sources**
1952	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.46E-02	0.00E+00	3.07E+00	0.00E+00	**4.19E+00**
1953	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.75E-02	0.00E+00	1.10E+01	0.00E+00	**1.33E+01**
1954	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.12E-02	0.00E+00	2.40E+01	0.00E+00	**2.97E+01**
1955	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.05E-01	0.00E+00	3.75E+01	0.00E+00	**4.98E+01**
1956	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.21E-01	0.00E+00	9.19E+01	0.00E+00	**1.13E+02**
1957	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.36E-01	0.00E+00	1.56E+02	0.00E+00	**1.87E+02**
1958	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.74E-01	0.00E+00	2.33E+02	0.00E+00	**2.76E+02**
1959	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.26E-04	6.15E-01	0.00E+00	3.12E+02	0.00E+00	**3.72E+02**
1960	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E-03	1.11E+00	0.00E+00	3.93E+02	0.00E+00	**4.71E+02**
1961	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.74E-03	1.57E+00	0.00E+00	4.62E+02	0.00E+00	**5.53E+02**
1962	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.28E-02	2.41E+00	0.00E+00	5.17E+02	0.00E+00	**6.29E+02**
1963	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.09E-02	3.33E+00	0.00E+00	5.79E+02	0.00E+00	**7.28E+02**
1964	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.42E-02	4.76E+00	0.00E+00	6.40E+02	0.00E+00	**8.33E+02**
1965	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.36E-01	6.94E+00	0.00E+00	6.92E+02	0.00E+00	**9.26E+02**
1966	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E-01	9.08E+00	3.42E-01	7.46E+02	0.00E+00	**1.01E+03**
1967	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.18E-01	1.16E+01	1.76E+00	7.98E+02	0.00E+00	**1.10E+03**
1968	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.88E-01	1.44E+01	4.29E+00	8.58E+02	0.00E+00	**1.18E+03**
1969	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.09E+00	1.71E+01	7.07E+00	9.25E+02	0.00E+00	**1.28E+03**
1970	0.00E+00	4.17E-03	1.70E-03	0.00E+00	1.69E+00	1.99E+01	1.33E+01	1.01E+03	0.00E+00	**1.39E+03**
1971	3.75E-03	5.01E-02	7.83E-03	9.45E-02	2.69E+00	2.20E+01	2.64E+01	1.12E+03	0.00E+00	**1.54E+03**
1972	2.89E-02	1.86E-01	2.23E-02	3.55E-01	3.52E+00	2.39E+01	4.12E+01	1.25E+03	0.00E+00	**1.70E+03**
1973	7.68E-02	3.94E-01	4.49E-02	7.20E-01	4.09E+00	2.58E+01	5.45E+01	1.40E+03	0.00E+00	**1.88E+03**
1974	1.38E-01	6.52E-01	7.35E-02	1.16E+00	4.67E+00	2.75E+01	7.29E+01	1.55E+03	0.00E+00	**2.07E+03**
1975	3.02E-01	9.85E-01	1.19E-01	1.68E+00	5.62E+00	2.90E+01	1.01E+02	1.73E+03	0.00E+00	**2.30E+03**
1976	6.47E-01	1.67E+00	2.94E-01	2.24E+00	6.48E+00	3.00E+01	1.30E+02	1.95E+03	0.00E+00	**2.56E+03**
1977	1.13E+00	3.46E+00	8.91E-01	2.84E+00	7.22E+00	3.07E+01	1.53E+02	2.17E+03	0.00E+00	**2.83E+03**
1978	1.73E+00	6.93E+00	2.07E+00	3.46E+00	8.07E+00	3.13E+01	1.81E+02	2.41E+03	0.00E+00	**3.12E+03**
1979	2.45E+00	1.23E+01	3.93E+00	4.09E+00	9.18E+00	3.17E+01	2.14E+02	2.64E+03	0.00E+00	**3.40E+03**
1980	3.35E+00	1.94E+01	6.38E+00	4.74E+00	1.11E+01	3.21E+01	2.45E+02	2.84E+03	0.00E+00	**3.66E+03**
1981	4.38E+00	2.79E+01	9.25E+00	5.38E+00	1.28E+01	3.29E+01	2.75E+02	3.02E+03	0.00E+00	**4.14E+03**
1982	5.50E+00	3.76E+01	1.26E+01	6.04E+00	1.39E+01	3.35E+01	3.08E+02	3.19E+03	0.00E+00	**4.78E+03**

Table 3 (cont'd)

	Oil & Gas (continued)				Nuclear Power	Other Nucl.	La Hague	Sellafield	UK Military	**All sites**
Year	Norway N. Sea N	UK N. Sea central	UK N. Sea N	UK N. Sea SW	Stations					**/sources**
1983	6.78E+00	4.92E+01	1.64E+01	6.71E+00	1.48E+01	3.43E+01	3.42E+02	3.33E+03	0.00E+00	**5.50E+03**
1984	8.24E+00	6.21E+01	2.08E+01	7.41E+00	1.59E+01	3.53E+01	3.73E+02	3.46E+03	0.00E+00	**6.26E+03**
1985	9.93E+00	7.67E+01	2.56E+01	8.14E+00	1.65E+01	3.60E+01	4.08E+02	3.55E+03	0.00E+00	**6.99E+03**
1986	1.18E+01	9.24E+01	3.07E+01	8.92E+00	1.69E+01	3.65E+01	4.43E+02	3.61E+03	0.00E+00	**7.68E+03**
1987	1.40E+01	1.09E+02	3.61E+01	9.74E+00	1.74E+01	3.70E+01	4.82E+02	3.65E+03	0.00E+00	**8.33E+03**
1988	1.65E+01	1.26E+02	4.15E+01	1.06E+01	1.78E+01	3.74E+01	5.14E+02	3.68E+03	5.49E-05	**8.95E+03**
1989	1.94E+01	1.43E+02	4.66E+01	1.14E+01	1.81E+01	3.78E+01	5.39E+02	3.72E+03	1.49E-04	**9.58E+03**
1990	2.30E+01	1.60E+02	5.17E+01	1.23E+01	1.85E+01	3.81E+01	5.58E+02	3.74E+03	2.02E-04	**1.01E+04**
1991	2.70E+01	1.77E+02	5.66E+01	1.33E+01	1.87E+01	3.83E+01	5.67E+02	3.74E+03	2.49E-04	**1.06E+04**
1992	3.17E+01	1.95E+02	6.16E+01	1.44E+01	1.89E+01	3.86E+01	5.71E+02	3.76E+03	3.16E-04	**1.11E+04**
1993	3.69E+01	2.14E+02	6.68E+01	1.55E+01	1.91E+01	3.88E+01	5.73E+02	3.78E+03	3.72E-04	**1.14E+04**
1994	4.28E+01	2.35E+02	7.26E+01	1.66E+01	1.93E+01	3.91E+01	5.77E+02	3.79E+03	4.04E-04	**1.17E+04**
1995	4.94E+01	2.57E+02	7.90E+01	1.79E+01	1.94E+01	3.94E+01	5.80E+02	3.81E+03	4.33E-04	**1.20E+04**
1996	5.67E+01	2.82E+02	8.58E+01	1.94E+01	1.96E+01	3.97E+01	5.84E+02	3.81E+03	4.58E-04	**1.24E+04**
1997	6.45E+01	3.07E+02	9.29E+01	2.10E+01	1.97E+01	3.99E+01	5.87E+02	3.82E+03	4.80E-04	**1.27E+04**
1998	7.28E+01	3.34E+02	1.00E+02	2.27E+01	1.98E+01	4.00E+01	5.91E+02	3.84E+03	5.01E-04	**1.30E+04**
1999	8.14E+01	3.63E+02	1.08E+02	2.45E+01	2.00E+01	4.03E+01	5.96E+02	3.85E+03	5.20E-04	**1.33E+04**
2000	9.02E+01	3.92E+02	1.16E+02	2.63E+01	2.01E+01	4.04E+01	6.00E+02	3.86E+03	5.38E-04	**1.35E+04**
2001	9.72E+01	4.19E+02	1.22E+02	2.76E+01	2.01E+01	4.05E+01	6.01E+02	3.86E+03	5.51E-04	**1.37E+04**
2002	1.02E+02	4.42E+02	1.27E+02	2.83E+01	2.02E+01	4.06E+01	6.02E+02	3.87E+03	5.61E-04	**1.38E+04**
2003	1.06E+02	4.62E+02	1.32E+02	2.89E+01	2.03E+01	4.08E+01	6.03E+02	3.89E+03	5.71E-04	**1.40E+04**
2004	1.10E+02	4.83E+02	1.36E+02	2.93E+01	2.03E+01	4.09E+01	6.03E+02	3.89E+03	5.78E-04	**1.41E+04**
2005	1.13E+02	5.02E+02	1.40E+02	2.99E+01	2.04E+01	4.11E+01	6.04E+02	3.90E+03	5.85E-04	**1.42E+04**
2006	1.17E+02	5.22E+02	1.43E+02	3.03E+01	2.04E+01	4.12E+01	6.04E+02	3.90E+03	5.91E-04	**1.43E+04**
2007	1.20E+02	5.43E+02	1.47E+02	3.07E+01	2.05E+01	4.13E+01	6.04E+02	3.91E+03	5.95E-04	**1.44E+04**
2008	1.23E+02	5.64E+02	1.51E+02	3.11E+01	2.05E+01	4.14E+01	6.05E+02	3.91E+03	5.99E-04	**1.46E+04**
2009	1.27E+02	5.83E+02	1.55E+02	3.15E+01	2.06E+01	4.15E+01	6.05E+02	3.92E+03	6.02E-04	**1.47E+04**
2010	1.30E+02	6.04E+02	1.59E+02	3.19E+01	2.06E+01	4.17E+01	6.05E+02	3.92E+03	6.05E-04	**1.48E+04**
2011	1.34E+02	6.25E+02	1.63E+02	3.23E+01	2.06E+01	4.18E+01	6.06E+02	3.92E+03	6.07E-04	**1.49E+04**
2012	1.37E+02	6.47E+02	1.66E+02	3.27E+01	2.07E+01	4.19E+01	6.06E+02	3.93E+03	6.09E-04	**1.50E+04**
2013	1.40E+02	6.67E+02	1.70E+02	3.31E+01	2.07E+01	4.20E+01	6.06E+02	3.94E+03	6.11E-04	**1.51E+04**

Table 3 (cont'd)

Year	Oil & Gas (continued) Norway N. Sea N	UK N. Sea central	UK N. Sea N	UK N. Sea SW	Nuclear Power Stations	Other Nucl.	La Hague	Sellafield	UK Military	**All sites /sources**
2014	1.44E+02	6.87E+02	1.74E+02	3.35E+01	2.08E+01	4.21E+01	6.06E+02	3.95E+03	6.13E-04	**1.52E+04**
2015	1.47E+02	7.08E+02	1.77E+02	3.38E+01	2.08E+01	4.22E+01	6.07E+02	3.95E+03	6.15E-04	**1.53E+04**
2016	1.50E+02	7.28E+02	1.81E+02	3.42E+01	2.08E+01	4.23E+01	6.07E+02	3.96E+03	6.16E-04	**1.54E+04**
2017	1.54E+02	7.48E+02	1.85E+02	3.45E+01	2.09E+01	4.24E+01	6.07E+02	3.96E+03	6.17E-04	**1.55E+04**
2018	1.57E+02	7.67E+02	1.88E+02	3.48E+01	2.09E+01	4.25E+01	6.07E+02	3.96E+03	6.17E-04	**1.56E+04**
2019	1.60E+02	7.87E+02	1.92E+02	3.51E+01	2.10E+01	4.26E+01	6.08E+02	3.97E+03	6.19E-04	**1.56E+04**
2020	1.64E+02	8.06E+02	1.95E+02	3.54E+01	2.10E+01	4.27E+01	6.08E+02	3.97E+03	6.19E-04	**1.57E+04**
2025	1.79E+02	8.97E+02	2.12E+02	3.69E+01	2.11E+01	4.32E+01	6.09E+02	3.99E+03	6.21E-04	**1.61E+04**
2030	1.93E+02	9.79E+02	2.28E+02	3.80E+01	2.13E+01	4.37E+01	6.10E+02	4.01E+03	6.22E-04	**1.65E+04**
2035	2.07E+02	1.05E+03	2.43E+02	3.90E+01	2.15E+01	4.42E+01	6.10E+02	4.02E+03	6.22E-04	**1.68E+04**
2040	2.20E+02	1.12E+03	2.56E+02	3.99E+01	2.16E+01	4.46E+01	6.11E+02	4.04E+03	6.23E-04	**1.70E+04**
2045	2.31E+02	1.17E+03	2.68E+02	4.06E+01	2.17E+01	4.50E+01	6.12E+02	4.06E+03	6.23E-04	**1.73E+04**
2050	2.42E+02	1.22E+03	2.79E+02	4.12E+01	2.18E+01	4.55E+01	6.12E+02	4.07E+03	6.23E-04	**1.75E+04**
2055	2.51E+02	1.27E+03	2.90E+02	4.17E+01	2.20E+01	4.58E+01	6.13E+02	4.08E+03	6.23E-04	**1.77E+04**
2060	2.59E+02	1.30E+03	2.99E+02	4.22E+01	2.21E+01	4.61E+01	6.13E+02	4.09E+03	6.23E-04	**1.78E+04**
2065	2.68E+02	1.33E+03	3.07E+02	4.25E+01	2.22E+01	4.65E+01	6.14E+02	4.11E+03	6.23E-04	**1.80E+04**
2070	2.75E+02	1.35E+03	3.16E+02	4.28E+01	2.23E+01	4.68E+01	6.14E+02	4.13E+03	6.23E-04	**1.81E+04**
2075	2.81E+02	1.38E+03	3.23E+02	4.30E+01	2.24E+01	4.71E+01	6.14E+02	4.14E+03	6.23E-04	**1.82E+04**
2080	2.88E+02	1.39E+03	3.29E+02	4.33E+01	2.25E+01	4.75E+01	6.15E+02	4.15E+03	6.23E-04	**1.83E+04**
2085	2.94E+02	1.41E+03	3.36E+02	4.34E+01	2.26E+01	4.78E+01	6.15E+02	4.16E+03	6.23E-04	**1.84E+04**
2090	2.99E+02	1.42E+03	3.42E+02	4.36E+01	2.27E+01	4.80E+01	6.15E+02	4.17E+03	6.23E-04	**1.85E+04**
2095	3.04E+02	1.43E+03	3.47E+02	4.37E+01	2.28E+01	4.84E+01	6.16E+02	4.18E+03	6.23E-04	**1.85E+04**
2100	3.08E+02	1.44E+03	3.52E+02	4.38E+01	2.28E+01	4.86E+01	6.16E+02	4.19E+03	6.23E-04	**1.86E+04**
2200	3.66E+02	1.51E+03	4.15E+02	4.45E+01	2.38E+01	5.24E+01	6.20E+02	4.31E+03	6.23E-04	**1.92E+04**
2300	3.96E+02	1.52E+03	4.49E+02	4.46E+01	2.41E+01	5.41E+01	6.21E+02	4.36E+03	6.23E-04	**1.95E+04**
2400	4.17E+02	1.53E+03	4.71E+02	4.46E+01	2.43E+01	5.49E+01	6.22E+02	4.39E+03	6.23E-04	**1.96E+04**
2500	4.31E+02	1.55E+03	4.89E+02	4.47E+01	2.43E+01	5.52E+01	6.23E+02	4.41E+03	6.23E-04	**1.97E+04**

Table 4: Integrated collective doses to the European Union population by site/source assuming discharges continue to 2020 (man Sv)

Year	Baltic Flux*	Chernobyl*	Fallout*	Isotope	Phosphates						Oil & Gas		
					Baie de la Seine	Cumbrian Waters	Irish Sea NW	Kattegat	Gulf of Cadiz	North Sea SE	Denmark N. Sea central	Netherlands N. Sea SE	Norway N. Sea central
2001	8.74E+00	5.00E+01	6.82E+02	1.48E+00	4.74E+02	2.74E+03	7.95E+01	2.90E+02	1.16E+01	3.92E+03	6.58E+01	2.91E+01	1.87E+02
2002	8.84E+00	5.04E+01	6.89E+02	1.58E+00	4.76E+02	2.77E+03	8.02E+01	2.91E+02	1.25E+01	3.98E+03	7.42E+01	3.10E+01	2.06E+02
2003	8.91E+00	5.08E+01	6.96E+02	1.67E+00	4.79E+02	2.80E+03	8.08E+01	2.91E+02	1.34E+01	4.04E+03	8.29E+01	3.30E+01	2.25E+02
2004	8.98E+00	5.12E+01	7.03E+02	1.77E+00	4.83E+02	2.83E+03	8.14E+01	2.91E+02	1.43E+01	4.09E+03	9.20E+01	3.50E+01	2.45E+02
2005	9.04E+00	5.16E+01	7.09E+02	1.88E+00	4.86E+02	2.86E+03	8.19E+01	2.91E+02	1.53E+01	4.16E+03	1.02E+02	3.70E+01	2.67E+02
2006	9.09E+00	5.19E+01	7.16E+02	1.98E+00	4.89E+02	2.89E+03	8.26E+01	2.91E+02	1.62E+01	4.21E+03	1.11E+02	3.91E+01	2.88E+02
2007	9.13E+00	5.23E+01	7.22E+02	2.08E+00	4.91E+02	2.92E+03	8.31E+01	2.91E+02	1.72E+01	4.26E+03	1.22E+02	4.12E+01	3.12E+02
2008	9.18E+00	5.26E+01	7.28E+02	2.19E+00	4.94E+02	2.95E+03	8.36E+01	2.91E+02	1.83E+01	4.32E+03	1.33E+02	4.34E+01	3.35E+02
2009	9.22E+00	5.29E+01	7.34E+02	2.29E+00	4.96E+02	2.98E+03	8.41E+01	2.91E+02	1.93E+01	4.37E+03	1.44E+02	4.55E+01	3.60E+02
2010	9.25E+00	5.31E+01	7.40E+02	2.39E+00	4.99E+02	3.01E+03	8.46E+01	2.91E+02	2.03E+01	4.42E+03	1.55E+02	4.78E+01	3.86E+02
2012	9.32E+00	5.37E+01	7.51E+02	2.61E+00	5.03E+02	3.06E+03	8.55E+01	2.91E+02	2.25E+01	4.53E+03	1.80E+02	5.22E+01	4.39E+02
2014	9.38E+00	5.42E+01	7.62E+02	2.81E+00	5.07E+02	3.10E+03	8.63E+01	2.91E+02	2.47E+01	4.63E+03	2.06E+02	5.68E+01	4.95E+02
2016	9.43E+00	5.46E+01	7.73E+02	3.03E+00	5.11E+02	3.14E+03	8.71E+01	2.91E+02	2.69E+01	4.73E+03	2.34E+02	6.15E+01	5.55E+02
2018	9.47E+00	5.50E+01	7.84E+02	3.25E+00	5.15E+02	3.18E+03	8.79E+01	2.91E+02	2.93E+01	4.83E+03	2.63E+02	6.63E+01	6.19E+02
2020	9.51E+00	5.54E+01	7.94E+02	3.46E+00	5.18E+02	3.21E+03	8.86E+01	2.91E+02	3.17E+01	4.93E+03	2.94E+02	7.10E+01	6.85E+02
2025	9.58E+00	5.62E+01	8.18E+02	3.60E+00	5.26E+02	3.29E+03	9.01E+01	2.91E+02	3.67E+01	5.04E+03	3.58E+02	7.90E+01	8.23E+02
2030	9.63E+00	5.68E+01	8.40E+02	3.69E+00	5.32E+02	3.36E+03	9.13E+01	2.91E+02	4.05E+01	5.11E+03	4.16E+02	8.55E+01	9.52E+02
2040	9.70E+00	5.78E+01	8.81E+02	3.81E+00	5.41E+02	3.45E+03	9.33E+01	2.91E+02	4.66E+01	5.22E+03	5.28E+02	9.71E+01	1.19E+03
2050	9.74E+00	5.85E+01	9.17E+02	3.91E+00	5.47E+02	3.53E+03	9.46E+01	2.91E+02	5.14E+01	5.31E+03	6.22E+02	1.06E+02	1.40E+03
2060	9.76E+00	5.90E+01	9.49E+02	3.98E+00	5.51E+02	3.58E+03	9.56E+01	2.91E+02	5.55E+01	5.37E+03	6.95E+02	1.13E+02	1.55E+03
2070	9.78E+00	5.94E+01	9.77E+02	4.04E+00	5.54E+02	3.62E+03	9.62E+01	2.91E+02	5.91E+01	5.41E+03	7.51E+02	1.18E+02	1.67E+03
2080	9.79E+00	5.97E+01	1.00E+03	4.09E+00	5.56E+02	3.64E+03	9.66E+01	2.91E+02	6.22E+01	5.43E+03	7.92E+02	1.22E+02	1.76E+03
2090	9.80E+00	5.99E+01	1.03E+03	4.13E+00	5.58E+02	3.66E+03	9.70E+01	2.91E+02	6.49E+01	5.45E+03	8.21E+02	1.24E+02	1.82E+03
2100	9.81E+00	6.00E+01	1.05E+03	4.16E+00	5.60E+02	3.67E+03	9.72E+01	2.91E+02	6.73E+01	5.47E+03	8.42E+02	1.26E+02	1.87E+03
2200	9.83E+00	6.04E+01	1.21E+03	4.37E+00	5.63E+02	3.70E+03	9.79E+01	2.91E+02	8.04E+01	5.51E+03	9.02E+02	1.32E+02	1.99E+03
2300	9.83E+00	6.04E+01	1.30E+03	4.46E+00	5.63E+02	3.71E+03	9.80E+01	2.92E+02	8.56E+01	5.52E+03	9.12E+02	1.33E+02	2.01E+03
2400	9.83E+00	6.04E+01	1.35E+03	4.52E+00	5.64E+02	3.71E+03	9.80E+01	2.92E+02	8.84E+01	5.53E+03	9.19E+02	1.34E+02	2.03E+03
2500	9.83E+00	6.04E+01	1.40E+03	4.55E+00	5.64E+02	3.71E+03	9.81E+01	2.92E+02	9.02E+01	5.53E+03	9.23E+02	1.35E+02	2.04E+03

Table 4 (cont'd)

Year	Oil & Gas (continued) Norway N. Sea N	UK N. Sea central	UK N. Sea N	UK N. Sea SW	Nuclear Power Stations	Other Nuclear	La Hague	Sellafield	UK Military	**All sites /sources**
2001	9.90E+01	4.24E+02	1.24E+02	2.81E+01	2.02E+01	4.05E+01	6.03E+02	3.86E+03	5.56E-04	**1.37E+04**
2002	1.08E+02	4.55E+02	1.32E+02	3.01E+01	2.03E+01	4.06E+01	6.06E+02	3.87E+03	5.72E-04	**1.39E+04**
2003	1.18E+02	4.88E+02	1.41E+02	3.19E+01	2.04E+01	4.09E+01	6.10E+02	3.89E+03	5.87E-04	**1.41E+04**
2004	1.28E+02	5.23E+02	1.49E+02	3.39E+01	2.05E+01	4.10E+01	6.14E+02	3.90E+03	6.02E-04	**1.43E+04**
2005	1.38E+02	5.57E+02	1.58E+02	3.59E+01	2.06E+01	4.11E+01	6.18E+02	3.90E+03	6.16E-04	**1.45E+04**
2006	1.48E+02	5.93E+02	1.67E+02	3.79E+01	2.07E+01	4.12E+01	6.21E+02	3.91E+03	6.29E-04	**1.47E+04**
2007	1.59E+02	6.31E+02	1.77E+02	3.99E+01	2.08E+01	4.13E+01	6.24E+02	3.92E+03	6.43E-04	**1.49E+04**
2008	1.69E+02	6.69E+02	1.86E+02	4.20E+01	2.09E+01	4.15E+01	6.28E+02	3.92E+03	6.57E-04	**1.51E+04**
2009	1.80E+02	7.08E+02	1.96E+02	4.40E+01	2.10E+01	4.17E+01	6.32E+02	3.93E+03	6.70E-04	**1.53E+04**
2010	1.92E+02	7.48E+02	2.06E+02	4.60E+01	2.11E+01	4.18E+01	6.36E+02	3.95E+03	6.83E-04	**1.56E+04**
2012	2.15E+02	8.31E+02	2.26E+02	5.03E+01	2.12E+01	4.20E+01	6.43E+02	3.96E+03	7.08E-04	**1.60E+04**
2014	2.40E+02	9.20E+02	2.47E+02	5.46E+01	2.14E+01	4.22E+01	6.50E+02	3.97E+03	7.33E-04	**1.64E+04**
2016	2.66E+02	1.01E+03	2.70E+02	5.92E+01	2.16E+01	4.24E+01	6.57E+02	3.98E+03	7.56E-04	**1.68E+04**
2018	2.93E+02	1.11E+03	2.92E+02	6.37E+01	2.18E+01	4.28E+01	6.65E+02	4.01E+03	7.80E-04	**1.72E+04**
2020	3.19E+02	1.20E+03	3.14E+02	6.82E+01	2.20E+01	4.30E+01	6.73E+02	4.02E+03	8.05E-04	**1.76E+04**
2025	3.68E+02	1.41E+03	3.57E+02	7.39E+01	2.22E+01	4.34E+01	6.77E+02	4.05E+03	8.31E-04	**1.84E+04**
2030	4.08E+02	1.61E+03	3.93E+02	7.78E+01	2.24E+01	4.39E+01	6.79E+02	4.07E+03	8.43E-04	**1.91E+04**
2040	4.86E+02	1.96E+03	4.61E+02	8.43E+01	2.26E+01	4.48E+01	6.83E+02	4.11E+03	8.51E-04	**2.03E+04**
2050	5.54E+02	2.25E+03	5.19E+02	8.90E+01	2.29E+01	4.57E+01	6.85E+02	4.14E+03	8.54E-04	**2.12E+04**
2060	6.10E+02	2.47E+03	5.70E+02	9.24E+01	2.31E+01	4.64E+01	6.87E+02	4.16E+03	8.54E-04	**2.20E+04**
2070	6.58E+02	2.65E+03	6.12E+02	9.48E+01	2.34E+01	4.71E+01	6.88E+02	4.19E+03	8.54E-04	**2.26E+04**
2080	6.99E+02	2.77E+03	6.46E+02	9.65E+01	2.36E+01	4.77E+01	6.89E+02	4.21E+03	8.54E-04	**2.30E+04**
2090	7.34E+02	2.86E+03	6.76E+02	9.77E+01	2.38E+01	4.83E+01	6.90E+02	4.23E+03	8.54E-04	**2.33E+04**
2100	7.63E+02	2.93E+03	7.01E+02	9.85E+01	2.39E+01	4.89E+01	6.91E+02	4.25E+03	8.54E-04	**2.36E+04**
2200	9.27E+02	3.11E+03	8.47E+02	1.01E+02	2.49E+01	5.27E+01	6.96E+02	4.37E+03	8.54E-04	**2.47E+04**
2300	1.01E+03	3.14E+03	9.20E+02	1.01E+02	2.52E+01	5.44E+01	6.98E+02	4.43E+03	8.54E-04	**2.51E+04**
2400	1.06E+03	3.16E+03	9.69E+02	1.01E+02	2.53E+01	5.52E+01	6.99E+02	4.45E+03	8.54E-04	**2.53E+04**
2500	1.10E+03	3.18E+03	1.01E+03	1.01E+02	2.54E+01	5.54E+01	7.00E+02	4.47E+03	8.54E-04	**2.55E+04**

Note: * - source continues to 2000 only

Table 5: Collective dose rates by affected country due to discharges up to 2000 only (man Sv y^{-1})

Year	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	U.K.
1952	2.84E-03	9.55E-02	1.02E-01	1.63E-03	1.30E+00	1.34E-01	7.38E-03	6.72E-01	2.48E-01	1.17E-01	3.40E-02	3.90E-01	3.33E-02	2.10E+00
1953	9.31E-03	2.26E-01	2.95E-01	4.74E-03	2.79E+00	4.11E-01	1.75E-02	1.39E+00	5.40E-01	3.05E-01	8.57E-02	8.45E-01	1.03E-01	4.40E+00
1954	2.28E-02	4.33E-01	6.80E-01	1.10E-02	4.58E+00	9.59E-01	3.35E-02	2.15E+00	9.13E-01	6.29E-01	1.89E-01	1.44E+00	2.59E-01	7.17E+00
1955	3.71E-02	5.58E-01	1.09E+00	1.78E-02	4.56E+00	1.52E+00	4.36E-02	1.92E+00	9.59E-01	8.72E-01	3.00E-01	1.58E+00	4.30E-01	7.28E+00
1956	4.90E-02	1.45E+00	1.49E+00	2.56E-02	2.19E+01	2.29E+00	1.20E-01	1.11E+01	4.16E+00	1.96E+00	5.56E-01	6.38E+00	5.86E-01	3.30E+01
1957	5.89E-02	1.31E+00	1.95E+00	3.05E-02	1.71E+01	2.80E+00	1.07E-01	8.40E+00	3.32E+00	1.89E+00	5.98E-01	5.24E+00	6.34E-01	2.62E+01
1958	7.58E-02	1.84E+00	2.54E+00	3.99E-02	2.47E+01	3.70E+00	1.49E-01	1.23E+01	4.77E+00	2.60E+00	7.94E-01	7.49E+00	8.07E-01	3.78E+01
1959	1.03E-01	1.98E+00	3.34E+00	5.25E-02	2.30E+01	4.79E+00	1.61E-01	1.09E+01	4.54E+00	2.99E+00	9.81E-01	7.27E+00	1.11E+00	3.55E+01
1960	8.46E-02	1.80E+00	2.85E+00	4.51E-02	2.42E+01	4.20E+00	1.55E-01	1.18E+01	4.71E+00	2.71E+00	9.48E-01	7.54E+00	8.89E-01	3.70E+01
1961	7.66E-02	1.43E+00	2.67E+00	4.19E-02	1.75E+01	3.83E+00	1.25E-01	8.28E+00	3.44E+00	2.24E+00	8.87E-01	5.73E+00	7.97E-01	2.68E+01
1962	1.17E-01	1.87E+00	3.80E+00	6.16E-02	1.75E+01	5.30E+00	1.56E-01	7.63E+00	3.59E+00	2.97E+00	1.19E+00	6.16E+00	1.31E+00	2.74E+01
1963	1.88E-01	2.85E+00	5.68E+00	9.53E-02	2.42E+01	7.91E+00	2.34E-01	1.02E+01	5.05E+00	4.51E+00	1.80E+00	8.71E+00	2.21E+00	3.80E+01
1964	1.87E-01	2.59E+00	5.80E+00	9.81E-02	2.11E+01	7.98E+00	2.28E-01	8.57E+00	4.49E+00	4.29E+00	1.97E+00	8.15E+00	2.20E+00	3.44E+01
1965	1.57E-01	2.11E+00	5.12E+00	8.75E-02	1.78E+01	6.98E+00	2.01E-01	7.33E+00	3.78E+00	3.59E+00	1.90E+00	7.27E+00	1.82E+00	3.00E+01
1966	1.27E-01	1.93E+00	4.31E+00	7.61E-02	1.91E+01	5.86E+00	1.91E-01	8.39E+00	3.89E+00	3.17E+00	1.82E+00	7.54E+00	1.44E+00	3.10E+01
1967	1.13E-01	1.75E+00	4.08E+00	7.05E-02	1.63E+01	5.48E+00	1.70E-01	6.88E+00	3.31E+00	2.88E+00	1.72E+00	6.69E+00	1.20E+00	2.68E+01
1968	1.11E-01	2.03E+00	4.09E+00	7.07E-02	2.05E+01	5.42E+00	1.86E-01	9.09E+00	4.03E+00	3.10E+00	1.74E+00	7.83E+00	1.15E+00	3.31E+01
1969	1.12E-01	2.06E+00	4.16E+00	7.16E-02	2.05E+01	5.44E+00	1.88E-01	9.26E+00	4.05E+00	3.11E+00	1.72E+00	7.90E+00	1.12E+00	3.46E+01
1970	1.40E-01	3.07E+00	5.49E+00	8.75E-02	2.67E+01	6.85E+00	2.29E-01	1.17E+01	5.11E+00	4.16E+00	1.91E+00	9.82E+00	1.26E+00	4.41E+01
1971	1.90E-01	4.36E+00	7.12E+00	1.11E-01	3.77E+01	9.00E+00	3.03E-01	1.63E+01	7.13E+00	5.79E+00	2.20E+00	1.31E+01	1.57E+00	6.16E+01
1972	2.09E-01	4.35E+00	7.77E+00	1.17E-01	3.54E+01	9.86E+00	3.05E-01	1.56E+01	6.86E+00	5.93E+00	2.21E+00	1.26E+01	1.70E+00	6.16E+01
1973	2.22E-01	4.52E+00	7.82E+00	1.19E-01	4.01E+01	1.03E+01	3.29E-01	1.79E+01	7.77E+00	6.31E+00	2.23E+00	1.38E+01	1.80E+00	6.89E+01
1974	2.77E-01	6.54E+00	1.15E+01	1.59E-01	4.42E+01	1.33E+01	3.91E-01	1.92E+01	8.48E+00	8.00E+00	2.68E+00	1.60E+01	2.08E+00	7.91E+01
1975	3.94E-01	8.74E+00	1.62E+01	2.18E-01	4.90E+01	1.86E+01	4.92E-01	2.03E+01	9.43E+00	1.07E+01	3.29E+00	1.85E+01	2.60E+00	9.31E+01
1976	4.87E-01	8.87E+00	1.80E+01	2.51E-01	4.85E+01	2.13E+01	5.55E-01	2.08E+01	9.77E+00	1.16E+01	3.55E+00	1.89E+01	3.31E+00	1.00E+02
1977	5.61E-01	9.38E+00	1.96E+01	2.79E-01	5.01E+01	2.35E+01	6.03E-01	2.11E+01	1.03E+01	1.27E+01	3.79E+00	1.98E+01	4.09E+00	1.05E+02
1978	6.25E-01	1.04E+01	2.13E+01	3.02E-01	5.55E+01	2.63E+01	6.47E-01	2.18E+01	1.14E+01	1.43E+01	4.00E+00	2.11E+01	4.72E+00	1.11E+02
1979	6.35E-01	9.71E+00	2.08E+01	2.98E-01	4.75E+01	2.64E+01	6.03E-01	1.69E+01	1.00E+01	1.40E+01	3.82E+00	1.85E+01	4.98E+00	9.55E+01
1980	6.14E-01	9.41E+00	2.02E+01	2.90E-01	4.36E+01	2.57E+01	5.67E-01	1.45E+01	9.30E+00	1.35E+01	3.67E+00	1.72E+01	5.01E+00	8.61E+01
1981	1.77E+00	3.38E+01	4.60E+01	7.42E-01	1.04E+02	6.29E+01	1.44E+00	3.08E+01	2.75E+01	4.62E+01	8.33E+00	4.35E+01	2.06E+01	1.64E+02
1982	2.15E+00	3.88E+01	5.52E+01	8.87E-01	1.19E+02	7.71E+01	1.73E+00	3.46E+01	3.19E+01	5.42E+01	9.70E+00	5.01E+01	2.47E+01	1.93E+02
1983	2.40E+00	4.15E+01	6.00E+01	9.72E-01	1.25E+02	8.53E+01	1.89E+00	3.64E+01	3.43E+01	5.89E+01	1.04E+01	5.31E+01	2.76E+01	2.07E+02

Table 5 (cont'd)

Year	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	U.K.
1984	2.52E+00	4.26E+01	6.22E+01	1.02E+00	1.27E+02	8.92E+01	1.95E+00	3.56E+01	3.52E+01	6.12E+01	1.07E+01	5.39E+01	3.06E+01	2.06E+02
1985	2.44E+00	4.08E+01	5.99E+01	9.73E-01	1.18E+02	8.73E+01	1.86E+00	3.04E+01	3.30E+01	5.89E+01	1.02E+01	5.03E+01	2.82E+01	1.88E+02
1986	2.36E+00	3.87E+01	5.78E+01	9.94E-01	1.11E+02	8.46E+01	1.78E+00	2.76E+01	3.14E+01	5.62E+01	9.93E+00	4.78E+01	2.55E+01	1.77E+02
1987	2.31E+00	3.82E+01	5.60E+01	9.47E-01	1.07E+02	8.26E+01	1.71E+00	2.35E+01	3.00E+01	5.55E+01	9.49E+00	4.52E+01	2.75E+01	1.61E+02
1988	2.26E+00	3.78E+01	5.39E+01	8.94E-01	1.03E+02	8.03E+01	1.67E+00	2.41E+01	2.98E+01	5.49E+01	9.33E+00	4.46E+01	2.51E+01	1.57E+02
1989	2.18E+00	3.62E+01	5.15E+01	8.62E-01	9.69E+01	7.73E+01	1.60E+00	2.09E+01	2.81E+01	5.29E+01	8.89E+00	4.18E+01	2.51E+01	1.45E+02
1990	2.04E+00	3.37E+01	4.67E+01	7.67E-01	8.74E+01	7.23E+01	1.48E+00	1.78E+01	2.58E+01	4.97E+01	8.24E+00	3.80E+01	1.88E+01	1.30E+02
1991	1.93E+00	3.14E+01	4.34E+01	7.20E-01	7.86E+01	6.77E+01	1.38E+00	1.49E+01	2.37E+01	4.66E+01	7.68E+00	3.46E+01	1.77E+01	1.16E+02
1992	1.72E+00	2.70E+01	3.84E+01	6.24E-01	6.61E+01	6.04E+01	1.21E+00	1.22E+01	2.05E+01	4.07E+01	6.76E+00	2.89E+01	1.59E+01	1.00E+02
1993	1.37E+00	1.96E+01	3.11E+01	4.97E-01	4.82E+01	4.87E+01	9.44E-01	8.35E+00	1.52E+01	3.07E+01	5.32E+00	2.08E+01	1.39E+01	7.70E+01
1994	1.33E+00	2.05E+01	2.91E+01	4.35E-01	4.74E+01	4.80E+01	9.07E-01	6.86E+00	1.51E+01	3.19E+01	5.18E+00	2.01E+01	7.68E+00	7.13E+01
1995	1.39E+00	2.19E+01	3.00E+01	4.48E-01	4.91E+01	4.99E+01	9.36E-01	6.30E+00	1.57E+01	3.39E+01	5.32E+00	2.06E+01	7.99E+00	7.08E+01
1996	1.41E+00	2.22E+01	3.05E+01	4.54E-01	4.93E+01	5.07E+01	9.44E-01	5.95E+00	1.59E+01	3.44E+01	5.37E+00	2.06E+01	8.16E+00	7.02E+01
1997	1.40E+00	2.18E+01	3.03E+01	4.52E-01	4.83E+01	5.03E+01	9.33E-01	5.58E+00	1.56E+01	3.39E+01	5.30E+00	2.02E+01	8.18E+00	6.86E+01
1998	1.43E+00	2.23E+01	3.08E+01	4.59E-01	4.87E+01	5.13E+01	9.44E-01	5.29E+00	1.58E+01	3.46E+01	5.35E+00	2.03E+01	8.31E+00	6.84E+01
1999	1.44E+00	2.25E+01	3.12E+01	4.64E-01	4.87E+01	5.19E+01	9.52E-01	5.12E+00	1.59E+01	3.48E+01	5.37E+00	2.03E+01	8.41E+00	6.83E+01
2000	9.68E-01	1.23E+01	2.34E+01	3.53E-01	3.15E+01	3.67E+01	6.62E-01	4.64E+00	1.02E+01	2.03E+01	3.96E+00	1.42E+01	6.67E+00	5.26E+01
2001	6.68E-01	7.80E+00	1.68E+01	2.64E-01	2.17E+01	2.58E+01	4.79E-01	4.27E+00	7.11E+00	1.32E+01	2.97E+00	1.07E+01	4.68E+00	3.98E+01
2002	5.67E-01	6.68E+00	1.42E+01	2.27E-01	1.88E+01	2.20E+01	4.14E-01	3.89E+00	6.12E+00	1.13E+01	2.62E+00	9.44E+00	3.74E+00	3.44E+01
2003	5.25E-01	6.22E+00	1.31E+01	2.10E-01	1.76E+01	2.03E+01	3.86E-01	3.71E+00	5.69E+00	1.05E+01	2.45E+00	8.84E+00	3.35E+00	3.20E+01
2004	5.06E-01	6.01E+00	1.25E+01	2.02E-01	1.69E+01	1.96E+01	3.72E-01	3.57E+00	5.49E+00	1.01E+01	2.36E+00	8.47E+00	3.18E+00	3.08E+01
2005	4.96E-01	5.87E+00	1.22E+01	1.96E-01	1.65E+01	1.91E+01	3.64E-01	3.43E+00	5.37E+00	9.90E+00	2.29E+00	8.19E+00	3.09E+00	2.99E+01
2006	4.89E-01	5.78E+00	1.19E+01	1.91E-01	1.61E+01	1.88E+01	3.58E-01	3.31E+00	5.27E+00	9.74E+00	2.24E+00	7.96E+00	3.03E+00	2.92E+01
2007	4.84E-01	5.68E+00	1.17E+01	1.87E-01	1.58E+01	1.86E+01	3.52E-01	3.20E+00	5.18E+00	9.61E+00	2.19E+00	7.75E+00	2.99E+00	2.86E+01
2008	4.78E-01	5.60E+00	1.16E+01	1.83E-01	1.55E+01	1.83E+01	3.47E-01	3.10E+00	5.10E+00	9.47E+00	2.15E+00	7.56E+00	2.95E+00	2.80E+01
2009	4.70E-01	5.51E+00	1.13E+01	1.80E-01	1.52E+01	1.80E+01	3.41E-01	3.01E+00	5.01E+00	9.31E+00	2.11E+00	7.36E+00	2.90E+00	2.74E+01
2010	4.65E-01	5.41E+00	1.11E+01	1.76E-01	1.49E+01	1.78E+01	3.36E-01	2.91E+00	4.93E+00	9.18E+00	2.07E+00	7.19E+00	2.86E+00	2.68E+01
2011	4.58E-01	5.33E+00	1.09E+01	1.73E-01	1.46E+01	1.75E+01	3.30E-01	2.82E+00	4.84E+00	9.03E+00	2.03E+00	7.01E+00	2.81E+00	2.62E+01
2012	4.50E-01	5.22E+00	1.07E+01	1.69E-01	1.43E+01	1.72E+01	3.24E-01	2.73E+00	4.76E+00	8.87E+00	1.98E+00	6.83E+00	2.76E+00	2.56E+01
2013	4.43E-01	5.13E+00	1.05E+01	1.66E-01	1.40E+01	1.69E+01	3.19E-01	2.65E+00	4.66E+00	8.70E+00	1.94E+00	6.67E+00	2.72E+00	2.51E+01
2014	4.35E-01	5.03E+00	1.03E+01	1.62E-01	1.37E+01	1.66E+01	3.13E-01	2.58E+00	4.58E+00	8.54E+00	1.90E+00	6.51E+00	2.67E+00	2.45E+01
2015	4.26E-01	4.92E+00	1.01E+01	1.59E-01	1.34E+01	1.63E+01	3.07E-01	2.50E+00	4.48E+00	8.37E+00	1.86E+00	6.35E+00	2.62E+00	2.39E+01

Table 5 (cont'd)

Year	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	U.K.
2016	4.18E-01	4.83E+00	9.89E+00	1.55E-01	1.31E+01	1.60E+01	3.01E-01	2.42E+00	4.39E+00	8.20E+00	1.83E+00	6.19E+00	2.57E+00	2.34E+01
2017	4.10E-01	4.73E+00	9.69E+00	1.52E-01	1.28E+01	1.56E+01	2.95E-01	2.35E+00	4.30E+00	8.05E+00	1.79E+00	6.03E+00	2.52E+00	2.28E+01
2018	4.01E-01	4.62E+00	9.47E+00	1.48E-01	1.25E+01	1.53E+01	2.88E-01	2.28E+00	4.20E+00	7.87E+00	1.75E+00	5.88E+00	2.46E+00	2.23E+01
2019	3.93E-01	4.52E+00	9.28E+00	1.45E-01	1.22E+01	1.50E+01	2.82E-01	2.22E+00	4.11E+00	7.69E+00	1.71E+00	5.75E+00	2.41E+00	2.18E+01
2020	3.85E-01	4.41E+00	9.06E+00	1.42E-01	1.20E+01	1.47E+01	2.76E-01	2.16E+00	4.01E+00	7.52E+00	1.67E+00	5.60E+00	2.36E+00	2.12E+01
2025	3.42E-01	3.91E+00	8.03E+00	1.26E-01	1.06E+01	1.30E+01	2.46E-01	1.87E+00	3.56E+00	6.68E+00	1.49E+00	4.93E+00	2.10E+00	1.87E+01
2030	3.02E-01	3.43E+00	7.07E+00	1.11E-01	9.35E+00	1.15E+01	2.18E-01	1.64E+00	3.13E+00	5.87E+00	1.33E+00	4.34E+00	1.86E+00	1.64E+01
2035	2.63E-01	2.99E+00	6.20E+00	9.80E-02	8.20E+00	1.01E+01	1.92E-01	1.44E+00	2.74E+00	5.14E+00	1.18E+00	3.81E+00	1.63E+00	1.44E+01
2040	2.29E-01	2.60E+00	5.40E+00	8.61E-02	7.20E+00	8.77E+00	1.69E-01	1.27E+00	2.39E+00	4.47E+00	1.05E+00	3.35E+00	1.42E+00	1.26E+01
2045	1.98E-01	2.25E+00	4.70E+00	7.54E-02	6.31E+00	7.61E+00	1.48E-01	1.12E+00	2.08E+00	3.87E+00	9.34E-01	2.95E+00	1.24E+00	1.10E+01
2050	1.72E-01	1.94E+00	4.09E+00	6.61E-02	5.54E+00	6.61E+00	1.30E-01	1.00E+00	1.81E+00	3.36E+00	8.32E-01	2.60E+00	1.09E+00	9.62E+00
2055	1.48E-01	1.67E+00	3.55E+00	5.80E-02	4.86E+00	5.73E+00	1.14E-01	9.00E-01	1.57E+00	2.91E+00	7.42E-01	2.30E+00	9.44E-01	8.43E+00
2060	1.28E-01	1.44E+00	3.09E+00	5.09E-02	4.28E+00	4.97E+00	1.00E-01	8.11E-01	1.37E+00	2.52E+00	6.64E-01	2.04E+00	8.23E-01	7.41E+00
2065	1.11E-01	1.25E+00	2.69E+00	4.49E-02	3.78E+00	4.32E+00	8.81E-02	7.33E-01	1.19E+00	2.18E+00	5.96E-01	1.82E+00	7.18E-01	6.53E+00
2070	9.58E-02	1.08E+00	2.35E+00	3.95E-02	3.34E+00	3.75E+00	7.77E-02	6.67E-01	1.04E+00	1.89E+00	5.37E-01	1.62E+00	6.29E-01	5.76E+00
2075	8.30E-02	9.32E-01	2.05E+00	3.50E-02	2.97E+00	3.27E+00	6.87E-02	6.09E-01	9.11E-01	1.64E+00	4.85E-01	1.46E+00	5.51E-01	5.11E+00
2080	7.21E-02	8.10E-01	1.81E+00	3.11E-02	2.65E+00	2.86E+00	6.11E-02	5.58E-01	8.01E-01	1.43E+00	4.42E-01	1.31E+00	4.86E-01	4.55E+00
2085	6.29E-02	7.04E-01	1.59E+00	2.78E-02	2.37E+00	2.51E+00	5.47E-02	5.14E-01	7.07E-01	1.25E+00	4.02E-01	1.19E+00	4.29E-01	4.07E+00
2090	5.50E-02	6.17E-01	1.41E+00	2.50E-02	2.14E+00	2.21E+00	4.90E-02	4.75E-01	6.27E-01	1.10E+00	3.69E-01	1.08E+00	3.81E-01	3.67E+00
2095	4.84E-02	5.40E-01	1.26E+00	2.25E-02	1.93E+00	1.96E+00	4.42E-02	4.42E-01	5.57E-01	9.73E-01	3.39E-01	9.87E-01	3.41E-01	3.31E+00
2100	4.28E-02	4.76E-01	1.13E+00	2.04E-02	1.76E+00	1.75E+00	4.00E-02	4.11E-01	4.99E-01	8.63E-01	3.14E-01	9.07E-01	3.05E-01	3.01E+00
2200	1.01E-02	1.08E-01	3.31E-01	6.75E-03	5.53E-01	4.71E-01	1.29E-02	1.53E-01	1.33E-01	2.16E-01	1.24E-01	3.30E-01	8.44E-02	9.52E-01
2300	5.86E-03	6.17E-02	1.95E-01	4.07E-03	3.06E-01	2.77E-01	7.77E-03	7.97E-02	7.41E-02	1.26E-01	7.62E-02	1.94E-01	4.75E-02	5.38E-01
2400	4.01E-03	4.12E-02	1.30E-01	2.77E-03	1.98E-01	1.85E-01	5.49E-03	4.85E-02	4.86E-02	8.49E-02	5.43E-02	1.33E-01	3.12E-02	3.55E-01
2500	2.97E-03	2.99E-02	9.36E-02	2.05E-03	1.42E-01	1.35E-01	4.25E-03	3.33E-02	3.51E-02	6.23E-02	4.28E-02	1.00E-01	2.26E-02	2.57E-01

Table 6: Collective dose rates by affected country assuming discharges continue to 2020 (man Sv y^{-1})

Year	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	U.K.
2001	9.03E-01	1.15E+01	2.21E+01	3.36E-01	2.96E+01	3.43E+01	6.21E-01	4.45E+00	9.59E+00	1.89E+01	3.76E+00	1.34E+01	6.28E+00	4.97E+01
2002	8.89E-01	1.13E+01	2.17E+01	3.32E-01	2.90E+01	3.37E+01	6.11E-01	4.29E+00	9.41E+00	1.86E+01	3.70E+00	1.32E+01	6.21E+00	4.88E+01
2003	8.89E-01	1.13E+01	2.17E+01	3.32E-01	2.88E+01	3.38E+01	6.09E-01	4.17E+00	9.37E+00	1.86E+01	3.68E+00	1.31E+01	6.20E+00	4.83E+01
2004	8.94E-01	1.13E+01	2.18E+01	3.34E-01	2.88E+01	3.40E+01	6.11E-01	4.06E+00	9.39E+00	1.87E+01	3.68E+00	1.31E+01	6.24E+00	4.81E+01
2005	9.01E-01	1.14E+01	2.20E+01	3.36E-01	2.88E+01	3.43E+01	6.14E-01	3.95E+00	9.41E+00	1.88E+01	3.69E+00	1.30E+01	6.28E+00	4.80E+01
2006	9.09E-01	1.14E+01	2.21E+01	3.39E-01	2.88E+01	3.46E+01	6.17E-01	3.86E+00	9.45E+00	1.89E+01	3.70E+00	1.30E+01	6.34E+00	4.79E+01
2007	9.16E-01	1.15E+01	2.23E+01	3.41E-01	2.88E+01	3.48E+01	6.22E-01	3.77E+00	9.49E+00	1.90E+01	3.71E+00	1.30E+01	6.39E+00	4.79E+01
2008	9.25E-01	1.16E+01	2.25E+01	3.44E-01	2.89E+01	3.52E+01	6.25E-01	3.69E+00	9.54E+00	1.92E+01	3.72E+00	1.30E+01	6.45E+00	4.79E+01
2009	9.34E-01	1.16E+01	2.26E+01	3.47E-01	2.89E+01	3.55E+01	6.30E-01	3.61E+00	9.61E+00	1.93E+01	3.74E+00	1.30E+01	6.50E+00	4.79E+01
2010	9.43E-01	1.17E+01	2.28E+01	3.50E-01	2.90E+01	3.58E+01	6.34E-01	3.54E+00	9.66E+00	1.95E+01	3.75E+00	1.31E+01	6.56E+00	4.80E+01
2012	9.61E-01	1.18E+01	2.32E+01	3.55E-01	2.92E+01	3.65E+01	6.43E-01	3.40E+00	9.78E+00	1.98E+01	3.78E+00	1.31E+01	6.67E+00	4.82E+01
2014	9.79E-01	1.20E+01	2.36E+01	3.61E-01	2.94E+01	3.72E+01	6.53E-01	3.29E+00	9.89E+00	2.01E+01	3.82E+00	1.32E+01	6.79E+00	4.84E+01
2016	9.98E-01	1.22E+01	2.40E+01	3.67E-01	2.96E+01	3.79E+01	6.63E-01	3.18E+00	1.00E+01	2.04E+01	3.86E+00	1.32E+01	6.90E+00	4.86E+01
2018	1.02E+00	1.23E+01	2.44E+01	3.73E-01	2.98E+01	3.86E+01	6.73E-01	3.10E+00	1.02E+01	2.07E+01	3.90E+00	1.33E+01	7.01E+00	4.90E+01
2020	1.03E+00	1.25E+01	2.48E+01	3.79E-01	3.01E+01	3.93E+01	6.84E-01	3.02E+00	1.03E+01	2.10E+01	3.94E+00	1.34E+01	7.13E+00	4.93E+01
2025	6.73E-01	7.43E+00	1.60E+01	2.53E-01	1.85E+01	2.58E+01	4.59E-01	2.33E+00	6.57E+00	1.29E+01	2.64E+00	8.79E+00	4.21E+00	3.22E+01
2030	6.39E-01	7.04E+00	1.49E+01	2.34E-01	1.73E+01	2.44E+01	4.34E-01	2.09E+00	6.22E+00	1.22E+01	2.45E+00	8.00E+00	3.95E+00	3.01E+01
2040	5.37E-01	5.88E+00	1.24E+01	1.93E-01	1.45E+01	2.04E+01	3.66E-01	1.68E+00	5.21E+00	1.02E+01	2.04E+00	6.52E+00	3.30E+00	2.49E+01
2050	4.23E-01	4.63E+00	9.76E+00	1.54E-01	1.15E+01	1.61E+01	2.93E-01	1.36E+00	4.11E+00	8.08E+00	1.64E+00	5.17E+00	2.61E+00	1.98E+01
2060	3.23E-01	3.54E+00	7.49E+00	1.20E-01	8.95E+00	1.23E+01	2.29E-01	1.10E+00	3.16E+00	6.19E+00	1.30E+00	4.05E+00	2.00E+00	1.53E+01
2070	2.43E-01	2.66E+00	5.67E+00	9.23E-02	6.92E+00	9.29E+00	1.77E-01	9.11E-01	2.40E+00	4.67E+00	1.03E+00	3.16E+00	1.52E+00	1.19E+01
2080	1.81E-01	1.99E+00	4.28E+00	7.12E-02	5.35E+00	6.99E+00	1.37E-01	7.64E-01	1.81E+00	3.51E+00	8.21E-01	2.49E+00	1.15E+00	9.21E+00
2090	1.36E-01	1.49E+00	3.26E+00	5.55E-02	4.19E+00	5.28E+00	1.07E-01	6.50E-01	1.38E+00	2.65E+00	6.61E-01	1.99E+00	8.78E-01	7.21E+00
2100	1.03E-01	1.12E+00	2.51E+00	4.38E-02	3.32E+00	4.02E+00	8.47E-02	5.61E-01	1.06E+00	2.01E+00	5.41E-01	1.61E+00	6.77E-01	5.73E+00
2200	1.77E-02	1.84E-01	5.29E-01	1.12E-02	8.25E-01	7.79E-01	2.18E-02	2.11E-01	2.10E-01	3.67E-01	1.73E-01	4.76E-01	1.37E-01	1.49E+00
2300	9.82E-03	9.98E-02	3.01E-01	6.58E-03	4.57E-01	4.39E-01	1.29E-02	1.15E-01	1.15E-01	2.05E-01	1.05E-01	2.78E-01	7.38E-02	8.44E-01
2400	6.77E-03	6.79E-02	2.03E-01	4.50E-03	3.05E-01	2.99E-01	9.14E-03	7.41E-02	7.71E-02	1.40E-01	7.44E-02	1.92E-01	4.86E-02	5.72E-01
2500	5.06E-03	5.01E-02	1.48E-01	3.32E-03	2.24E-01	2.21E-01	7.07E-03	5.32E-02	5.69E-02	1.05E-01	5.83E-02	1.45E-01	3.52E-02	4.24E-01

Table 7: Integrated collective doses by affected country due to discharges up to 2000 only (man Sv)

Year	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	U.K.
1952	4.34E-03	9.23E-02	1.30E-01	2.24E-03	9.74E-01	1.80E-01	7.26E-03	4.63E-01	1.93E-01	1.26E-01	4.43E-02	3.15E-01	5.50E-02	1.61E+00
1953	1.07E-02	2.66E-01	3.38E-01	5.60E-03	3.23E+00	4.67E-01	2.08E-02	1.60E+00	6.27E-01	3.54E-01	1.07E-01	9.90E-01	1.28E-01	5.19E+00
1954	2.76E-02	6.18E-01	8.48E-01	1.38E-02	7.16E+00	1.19E+00	4.79E-02	3.48E+00	1.40E+00	8.49E-01	2.49E-01	2.20E+00	3.19E-01	1.13E+01
1955	5.84E-02	1.12E+00	1.76E+00	2.86E-02	1.17E+01	2.45E+00	8.66E-02	5.45E+00	2.32E+00	1.61E+00	4.96E-01	3.70E+00	6.73E-01	1.85E+01
1956	1.02E-01	2.27E+00	3.04E+00	5.04E-02	2.76E+01	4.41E+00	1.80E-01	1.35E+01	5.39E+00	3.18E+00	9.51E-01	8.43E+00	1.19E+00	4.30E+01
1957	1.56E-01	3.60E+00	4.77E+00	7.86E-02	4.62E+01	6.93E+00	2.89E-01	2.27E+01	8.98E+00	5.06E+00	1.52E+00	1.40E+01	1.80E+00	7.11E+01
1958	2.24E-01	5.25E+00	7.04E+00	1.14E-01	6.83E+01	1.02E+01	4.23E-01	3.36E+01	1.32E+01	7.38E+00	2.23E+00	2.07E+01	2.53E+00	1.05E+02
1959	3.15E-01	7.15E+00	1.00E+01	1.61E-01	9.17E+01	1.45E+01	5.78E-01	4.50E+01	1.78E+01	1.02E+01	3.12E+00	2.79E+01	3.50E+00	1.41E+02
1960	4.07E-01	9.03E+00	1.31E+01	2.09E-01	1.15E+02	1.90E+01	7.35E-01	5.65E+01	2.26E+01	1.30E+01	4.08E+00	3.54E+01	4.49E+00	1.77E+02
1961	4.88E-01	1.06E+01	1.58E+01	2.52E-01	1.35E+02	2.30E+01	8.71E-01	6.59E+01	2.64E+01	1.54E+01	4.98E+00	4.18E+01	5.33E+00	2.08E+02
1962	5.87E-01	1.23E+01	1.92E+01	3.05E-01	1.52E+02	2.78E+01	1.01E+00	7.39E+01	2.99E+01	1.81E+01	6.04E+00	4.78E+01	6.42E+00	2.35E+02
1963	7.44E-01	1.47E+01	2.41E+01	3.86E-01	1.75E+02	3.45E+01	1.21E+00	8.31E+01	3.44E+01	2.19E+01	7.55E+00	5.54E+01	8.23E+00	2.69E+02
1964	9.31E-01	1.74E+01	2.98E+01	4.82E-01	1.97E+02	4.24E+01	1.44E+00	9.22E+01	3.90E+01	2.64E+01	9.42E+00	6.36E+01	1.04E+01	3.05E+02
1965	1.10E+00	1.97E+01	3.51E+01	5.74E-01	2.16E+02	4.97E+01	1.65E+00	1.00E+02	4.32E+01	3.02E+01	1.13E+01	7.12E+01	1.24E+01	3.36E+02
1966	1.24E+00	2.17E+01	3.98E+01	6.54E-01	2.34E+02	5.61E+01	1.85E+00	1.08E+02	4.70E+01	3.35E+01	1.32E+01	7.88E+01	1.40E+01	3.67E+02
1967	1.36E+00	2.35E+01	4.39E+01	7.27E-01	2.52E+02	6.17E+01	2.03E+00	1.15E+02	5.06E+01	3.64E+01	1.49E+01	8.58E+01	1.53E+01	3.96E+02
1968	1.47E+00	2.54E+01	4.80E+01	7.98E-01	2.71E+02	6.71E+01	2.21E+00	1.24E+02	5.44E+01	3.95E+01	1.67E+01	9.33E+01	1.65E+01	4.27E+02
1969	1.58E+00	2.75E+01	5.21E+01	8.69E-01	2.92E+02	7.25E+01	2.39E+00	1.33E+02	5.83E+01	4.26E+01	1.85E+01	1.01E+02	1.76E+01	4.61E+02
1970	1.71E+00	3.01E+01	5.69E+01	9.47E-01	3.16E+02	7.86E+01	2.60E+00	1.44E+02	6.31E+01	4.63E+01	2.02E+01	1.10E+02	1.88E+01	5.01E+02
1971	1.87E+00	3.39E+01	6.31E+01	1.05E+00	3.51E+02	8.65E+01	2.87E+00	1.58E+02	6.95E+01	5.14E+01	2.23E+01	1.22E+02	2.02E+01	5.57E+02
1972	2.07E+00	3.82E+01	7.06E+01	1.16E+00	3.86E+02	9.60E+01	3.18E+00	1.75E+02	7.65E+01	5.72E+01	2.45E+01	1.35E+02	2.18E+01	6.19E+02
1973	2.28E+00	4.28E+01	7.85E+01	1.28E+00	4.26E+02	1.06E+02	3.50E+00	1.92E+02	8.39E+01	6.35E+01	2.68E+01	1.48E+02	2.36E+01	6.85E+02
1974	2.53E+00	4.83E+01	8.79E+01	1.42E+00	4.67E+02	1.18E+02	3.85E+00	2.10E+02	9.19E+01	7.05E+01	2.92E+01	1.62E+02	2.55E+01	7.58E+02
1975	2.86E+00	5.59E+01	1.02E+02	1.60E+00	5.13E+02	1.34E+02	4.29E+00	2.29E+02	1.01E+02	7.98E+01	3.21E+01	1.80E+02	2.78E+01	8.43E+02
1976	3.31E+00	6.48E+01	1.19E+02	1.84E+00	5.61E+02	1.54E+02	4.82E+00	2.49E+02	1.10E+02	9.11E+01	3.56E+01	1.98E+02	3.08E+01	9.38E+02
1977	3.83E+00	7.38E+01	1.38E+02	2.11E+00	6.11E+02	1.76E+02	5.39E+00	2.71E+02	1.20E+02	1.03E+02	3.93E+01	2.18E+02	3.45E+01	1.04E+03
1978	4.43E+00	8.39E+01	1.58E+02	2.40E+00	6.65E+02	2.01E+02	6.02E+00	2.92E+02	1.32E+02	1.17E+02	4.31E+01	2.38E+02	3.89E+01	1.15E+03
1979	5.07E+00	9.38E+01	1.79E+02	2.70E+00	7.15E+02	2.28E+02	6.65E+00	3.12E+02	1.42E+02	1.31E+02	4.71E+01	2.58E+02	4.37E+01	1.25E+03
1980	5.69E+00	1.03E+02	2.00E+02	2.99E+00	7.60E+02	2.54E+02	7.23E+00	3.26E+02	1.52E+02	1.45E+02	5.08E+01	2.76E+02	4.88E+01	1.35E+03
1981	7.08E+00	1.30E+02	2.36E+02	3.59E+00	8.43E+02	3.04E+02	8.37E+00	3.51E+02	1.74E+02	1.81E+02	5.76E+01	3.11E+02	6.61E+01	1.48E+03
1982	9.08E+00	1.67E+02	2.88E+02	4.42E+00	9.56E+02	3.74E+02	9.97E+00	3.84E+02	2.03E+02	2.32E+02	6.67E+01	3.58E+02	8.98E+01	1.65E+03
1983	1.14E+01	2.08E+02	3.46E+02	5.35E+00	1.08E+03	4.56E+02	1.18E+01	4.20E+02	2.36E+02	2.90E+02	7.69E+01	4.10E+02	1.17E+02	1.85E+03

Table 7 (cont'd)

Year	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	U.K.
1984	1.39E+01	2.50E+02	4.07E+02	6.36E+00	1.21E+03	5.44E+02	1.37E+01	4.55E+02	2.71E+02	3.50E+02	8.75E+01	4.64E+02	1.47E+02	2.06E+03
1985	1.63E+01	2.92E+02	4.68E+02	7.36E+00	1.33E+03	6.33E+02	1.56E+01	4.87E+02	3.05E+02	4.10E+02	9.80E+01	5.15E+02	1.75E+02	2.25E+03
1986	1.87E+01	3.31E+02	5.26E+02	8.34E+00	1.44E+03	7.17E+02	1.74E+01	5.16E+02	3.37E+02	4.66E+02	1.08E+02	5.63E+02	2.01E+02	2.44E+03
1987	2.11E+01	3.69E+02	5.83E+02	9.32E+00	1.55E+03	8.01E+02	1.92E+01	5.41E+02	3.67E+02	5.22E+02	1.18E+02	6.11E+02	2.29E+02	2.61E+03
1988	2.33E+01	4.07E+02	6.39E+02	1.02E+01	1.65E+03	8.82E+02	2.09E+01	5.66E+02	3.98E+02	5.78E+02	1.27E+02	6.55E+02	2.54E+02	2.76E+03
1989	2.55E+01	4.44E+02	6.91E+02	1.11E+01	1.75E+03	9.61E+02	2.25E+01	5.87E+02	4.27E+02	6.32E+02	1.36E+02	6.97E+02	2.80E+02	2.91E+03
1990	2.76E+01	4.78E+02	7.39E+02	1.19E+01	1.84E+03	1.04E+03	2.40E+01	6.06E+02	4.52E+02	6.82E+02	1.45E+02	7.37E+02	3.00E+02	3.05E+03
1991	2.96E+01	5.11E+02	7.85E+02	1.26E+01	1.92E+03	1.11E+03	2.55E+01	6.22E+02	4.78E+02	7.30E+02	1.52E+02	7.74E+02	3.18E+02	3.17E+03
1992	3.14E+01	5.39E+02	8.25E+02	1.33E+01	2.00E+03	1.17E+03	2.67E+01	6.36E+02	4.99E+02	7.73E+02	1.60E+02	8.05E+02	3.34E+02	3.28E+03
1993	3.29E+01	5.61E+02	8.59E+02	1.38E+01	2.05E+03	1.22E+03	2.78E+01	6.45E+02	5.16E+02	8.06E+02	1.65E+02	8.28E+02	3.48E+02	3.36E+03
1994	3.42E+01	5.81E+02	8.89E+02	1.43E+01	2.10E+03	1.27E+03	2.87E+01	6.53E+02	5.31E+02	8.38E+02	1.71E+02	8.48E+02	3.57E+02	3.44E+03
1995	3.56E+01	6.03E+02	9.18E+02	1.47E+01	2.15E+03	1.32E+03	2.96E+01	6.60E+02	5.47E+02	8.72E+02	1.76E+02	8.68E+02	3.65E+02	3.51E+03
1996	3.70E+01	6.25E+02	9.47E+02	1.52E+01	2.20E+03	1.37E+03	3.05E+01	6.66E+02	5.63E+02	9.06E+02	1.81E+02	8.89E+02	3.73E+02	3.58E+03
1997	3.84E+01	6.47E+02	9.79E+02	1.56E+01	2.24E+03	1.42E+03	3.15E+01	6.72E+02	5.78E+02	9.40E+02	1.87E+02	9.09E+02	3.81E+02	3.65E+03
1998	3.99E+01	6.69E+02	1.01E+03	1.61E+01	2.29E+03	1.47E+03	3.24E+01	6.77E+02	5.95E+02	9.75E+02	1.92E+02	9.29E+02	3.89E+02	3.72E+03
1999	4.12E+01	6.92E+02	1.04E+03	1.65E+01	2.34E+03	1.52E+03	3.33E+01	6.83E+02	6.10E+02	1.01E+03	1.97E+02	9.50E+02	3.98E+02	3.79E+03
2000	4.24E+01	7.06E+02	1.07E+03	1.69E+01	2.38E+03	1.56E+03	3.42E+01	6.87E+02	6.23E+02	1.03E+03	2.02E+02	9.67E+02	4.05E+02	3.85E+03
2001	4.32E+01	7.15E+02	1.09E+03	1.72E+01	2.40E+03	1.59E+03	3.47E+01	6.92E+02	6.29E+02	1.05E+03	2.05E+02	9.78E+02	4.11E+02	3.90E+03
2002	4.14E+01	7.00E+02	1.03E+03	1.58E+01	2.32E+03	1.52E+03	3.20E+01	6.78E+02	6.10E+02	1.01E+03	1.63E+02	8.95E+02	3.85E+02	3.74E+03
2003	4.19E+01	7.06E+02	1.04E+03	1.60E+01	2.34E+03	1.54E+03	3.23E+01	6.83E+02	6.16E+02	1.03E+03	1.66E+02	9.05E+02	3.88E+02	3.78E+03
2004	4.24E+01	7.12E+02	1.05E+03	1.62E+01	2.35E+03	1.56E+03	3.27E+01	6.86E+02	6.21E+02	1.04E+03	1.68E+02	9.13E+02	3.91E+02	3.81E+03
2005	4.29E+01	7.18E+02	1.06E+03	1.64E+01	2.37E+03	1.58E+03	3.31E+01	6.90E+02	6.27E+02	1.05E+03	1.70E+02	9.22E+02	3.94E+02	3.84E+03
2006	4.34E+01	7.24E+02	1.08E+03	1.66E+01	2.39E+03	1.60E+03	3.35E+01	6.92E+02	6.33E+02	1.06E+03	1.73E+02	9.30E+02	3.98E+02	3.86E+03
2007	4.39E+01	7.30E+02	1.09E+03	1.68E+01	2.40E+03	1.62E+03	3.39E+01	6.96E+02	6.37E+02	1.07E+03	1.75E+02	9.37E+02	4.01E+02	3.89E+03
2008	4.44E+01	7.35E+02	1.10E+03	1.69E+01	2.42E+03	1.64E+03	3.42E+01	7.00E+02	6.43E+02	1.08E+03	1.77E+02	9.46E+02	4.03E+02	3.93E+03
2009	4.48E+01	7.41E+02	1.11E+03	1.71E+01	2.43E+03	1.65E+03	3.45E+01	7.02E+02	6.47E+02	1.08E+03	1.79E+02	9.52E+02	4.06E+02	3.95E+03
2010	4.54E+01	7.47E+02	1.12E+03	1.73E+01	2.45E+03	1.67E+03	3.49E+01	7.06E+02	6.53E+02	1.09E+03	1.81E+02	9.59E+02	4.09E+02	3.98E+03
2011	4.58E+01	7.52E+02	1.13E+03	1.75E+01	2.46E+03	1.69E+03	3.52E+01	7.08E+02	6.57E+02	1.10E+03	1.83E+02	9.67E+02	4.12E+02	4.00E+03
2012	4.63E+01	7.57E+02	1.14E+03	1.77E+01	2.48E+03	1.71E+03	3.55E+01	7.11E+02	6.62E+02	1.11E+03	1.85E+02	9.75E+02	4.15E+02	4.03E+03
2013	4.67E+01	7.62E+02	1.15E+03	1.78E+01	2.49E+03	1.72E+03	3.59E+01	7.14E+02	6.66E+02	1.12E+03	1.87E+02	9.81E+02	4.18E+02	4.06E+03
2014	4.71E+01	7.68E+02	1.17E+03	1.80E+01	2.51E+03	1.74E+03	3.62E+01	7.16E+02	6.71E+02	1.13E+03	1.89E+02	9.87E+02	4.20E+02	4.09E+03
2015	4.76E+01	7.72E+02	1.18E+03	1.81E+01	2.52E+03	1.76E+03	3.65E+01	7.19E+02	6.76E+02	1.14E+03	1.91E+02	9.94E+02	4.23E+02	4.10E+03

Table 7 (cont'd)

Year	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	U.K.
2016	4.80E+01	7.77E+02	1.19E+03	1.83E+01	2.53E+03	1.77E+03	3.68E+01	7.20E+02	6.81E+02	1.15E+03	1.93E+02	9.99E+02	4.26E+02	4.13E+03
2017	4.84E+01	7.82E+02	1.19E+03	1.84E+01	2.55E+03	1.79E+03	3.71E+01	7.24E+02	6.85E+02	1.15E+03	1.95E+02	1.01E+03	4.28E+02	4.15E+03
2018	4.88E+01	7.87E+02	1.20E+03	1.86E+01	2.56E+03	1.81E+03	3.74E+01	7.26E+02	6.88E+02	1.16E+03	1.97E+02	1.01E+03	4.30E+02	4.19E+03
2019	4.92E+01	7.92E+02	1.21E+03	1.87E+01	2.57E+03	1.82E+03	3.76E+01	7.28E+02	6.93E+02	1.17E+03	1.98E+02	1.02E+03	4.33E+02	4.20E+03
2020	4.96E+01	7.96E+02	1.22E+03	1.89E+01	2.58E+03	1.83E+03	3.80E+01	7.31E+02	6.97E+02	1.18E+03	2.00E+02	1.02E+03	4.35E+02	4.23E+03
2025	5.14E+01	8.16E+02	1.27E+03	1.96E+01	2.64E+03	1.90E+03	3.93E+01	7.40E+02	7.16E+02	1.21E+03	2.08E+02	1.05E+03	4.47E+02	4.33E+03
2030	5.30E+01	8.35E+02	1.30E+03	2.02E+01	2.69E+03	1.96E+03	4.04E+01	7.48E+02	7.33E+02	1.24E+03	2.15E+02	1.07E+03	4.56E+02	4.41E+03
2035	5.44E+01	8.51E+02	1.34E+03	2.07E+01	2.73E+03	2.02E+03	4.14E+01	7.58E+02	7.47E+02	1.27E+03	2.21E+02	1.09E+03	4.65E+02	4.49E+03
2040	5.56E+01	8.65E+02	1.37E+03	2.11E+01	2.77E+03	2.07E+03	4.24E+01	7.64E+02	7.60E+02	1.30E+03	2.27E+02	1.11E+03	4.73E+02	4.55E+03
2045	5.67E+01	8.77E+02	1.39E+03	2.15E+01	2.80E+03	2.11E+03	4.32E+01	7.70E+02	7.72E+02	1.32E+03	2.32E+02	1.13E+03	4.79E+02	4.61E+03
2050	5.77E+01	8.87E+02	1.41E+03	2.19E+01	2.83E+03	2.14E+03	4.39E+01	7.75E+02	7.80E+02	1.33E+03	2.36E+02	1.14E+03	4.85E+02	4.67E+03
2055	5.85E+01	8.97E+02	1.43E+03	2.22E+01	2.86E+03	2.17E+03	4.44E+01	7.79E+02	7.89E+02	1.35E+03	2.40E+02	1.15E+03	4.91E+02	4.71E+03
2060	5.91E+01	9.04E+02	1.45E+03	2.25E+01	2.88E+03	2.20E+03	4.50E+01	7.85E+02	7.97E+02	1.36E+03	2.43E+02	1.16E+03	4.94E+02	4.75E+03
2065	5.98E+01	9.11E+02	1.46E+03	2.27E+01	2.90E+03	2.22E+03	4.55E+01	7.88E+02	8.03E+02	1.38E+03	2.47E+02	1.17E+03	4.99E+02	4.78E+03
2070	6.02E+01	9.17E+02	1.47E+03	2.29E+01	2.92E+03	2.24E+03	4.58E+01	7.91E+02	8.09E+02	1.39E+03	2.50E+02	1.18E+03	5.02E+02	4.82E+03
2075	6.07E+01	9.22E+02	1.49E+03	2.31E+01	2.94E+03	2.26E+03	4.62E+01	7.94E+02	8.13E+02	1.40E+03	2.52E+02	1.19E+03	5.05E+02	4.84E+03
2080	6.10E+01	9.26E+02	1.50E+03	2.33E+01	2.95E+03	2.28E+03	4.66E+01	7.97E+02	8.18E+02	1.40E+03	2.54E+02	1.20E+03	5.07E+02	4.86E+03
2085	6.14E+01	9.30E+02	1.50E+03	2.34E+01	2.96E+03	2.29E+03	4.68E+01	8.00E+02	8.22E+02	1.41E+03	2.57E+02	1.20E+03	5.10E+02	4.89E+03
2090	6.17E+01	9.33E+02	1.51E+03	2.36E+01	2.97E+03	2.30E+03	4.71E+01	8.03E+02	8.26E+02	1.41E+03	2.58E+02	1.21E+03	5.11E+02	4.90E+03
2095	6.20E+01	9.37E+02	1.52E+03	2.37E+01	2.98E+03	2.31E+03	4.74E+01	8.05E+02	8.28E+02	1.42E+03	2.60E+02	1.21E+03	5.14E+02	4.91E+03
2100	6.22E+01	9.39E+02	1.52E+03	2.38E+01	2.99E+03	2.32E+03	4.76E+01	8.07E+02	8.31E+02	1.42E+03	2.62E+02	1.22E+03	5.16E+02	4.95E+03
2200	6.41E+01	9.60E+02	1.58E+03	2.49E+01	3.09E+03	2.41E+03	4.97E+01	8.32E+02	8.56E+02	1.47E+03	2.81E+02	1.27E+03	5.31E+02	5.11E+03
2300	6.49E+01	9.68E+02	1.61E+03	2.54E+01	3.13E+03	2.44E+03	5.07E+01	8.43E+02	8.65E+02	1.48E+03	2.91E+02	1.30E+03	5.37E+02	5.18E+03
2400	6.54E+01	9.73E+02	1.62E+03	2.57E+01	3.15E+03	2.46E+03	5.13E+01	8.49E+02	8.72E+02	1.49E+03	2.97E+02	1.31E+03	5.40E+02	5.22E+03
2500	6.57E+01	9.77E+02	1.63E+03	2.60E+01	3.17E+03	2.48E+03	5.18E+01	8.53E+02	8.75E+02	1.50E+03	3.02E+02	1.32E+03	5.43E+02	5.25E+03

Table 8: Integrated collective doses by affected country assuming discharges continue to 2020 (man Sv)

Year	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	U.K.
2001	4.33E+01	7.18E+02	1.09E+03	1.73E+01	2.41E+03	1.60E+03	3.48E+01	6.92E+02	6.31E+02	1.05E+03	2.05E+02	9.79E+02	4.12E+02	3.90E+03
2002	4.18E+01	7.07E+02	1.04E+03	1.59E+01	2.33E+03	1.54E+03	3.23E+01	6.79E+02	6.14E+02	1.03E+03	1.65E+02	9.00E+02	3.88E+02	3.76E+03
2003	4.27E+01	7.18E+02	1.06E+03	1.62E+01	2.36E+03	1.57E+03	3.29E+01	6.83E+02	6.24E+02	1.04E+03	1.68E+02	9.14E+02	3.94E+02	3.81E+03
2004	4.36E+01	7.29E+02	1.08E+03	1.65E+01	2.39E+03	1.60E+03	3.34E+01	6.87E+02	6.32E+02	1.06E+03	1.72E+02	9.26E+02	4.00E+02	3.86E+03
2005	4.45E+01	7.40E+02	1.10E+03	1.69E+01	2.42E+03	1.64E+03	3.41E+01	6.91E+02	6.43E+02	1.08E+03	1.76E+02	9.40E+02	4.06E+02	3.90E+03
2006	4.54E+01	7.52E+02	1.12E+03	1.72E+01	2.45E+03	1.67E+03	3.47E+01	6.95E+02	6.52E+02	1.10E+03	1.79E+02	9.52E+02	4.13E+02	3.96E+03
2007	4.63E+01	7.64E+02	1.14E+03	1.76E+01	2.48E+03	1.71E+03	3.54E+01	6.99E+02	6.61E+02	1.12E+03	1.83E+02	9.65E+02	4.19E+02	4.00E+03
2008	4.72E+01	7.76E+02	1.17E+03	1.79E+01	2.50E+03	1.74E+03	3.59E+01	7.03E+02	6.71E+02	1.14E+03	1.87E+02	9.80E+02	4.25E+02	4.04E+03
2009	4.81E+01	7.86E+02	1.19E+03	1.83E+01	2.53E+03	1.78E+03	3.66E+01	7.07E+02	6.80E+02	1.16E+03	1.91E+02	9.92E+02	4.32E+02	4.10E+03
2010	4.91E+01	7.98E+02	1.21E+03	1.86E+01	2.56E+03	1.81E+03	3.72E+01	7.11E+02	6.89E+02	1.18E+03	1.94E+02	1.00E+03	4.38E+02	4.15E+03
2012	5.09E+01	8.22E+02	1.26E+03	1.93E+01	2.62E+03	1.88E+03	3.85E+01	7.17E+02	7.09E+02	1.22E+03	2.02E+02	1.03E+03	4.51E+02	4.24E+03
2014	5.29E+01	8.46E+02	1.31E+03	2.00E+01	2.68E+03	1.96E+03	3.97E+01	7.24E+02	7.30E+02	1.26E+03	2.09E+02	1.06E+03	4.65E+02	4.34E+03
2016	5.49E+01	8.70E+02	1.35E+03	2.08E+01	2.74E+03	2.03E+03	4.11E+01	7.30E+02	7.49E+02	1.30E+03	2.17E+02	1.08E+03	4.79E+02	4.44E+03
2018	5.69E+01	8.95E+02	1.40E+03	2.15E+01	2.80E+03	2.11E+03	4.25E+01	7.36E+02	7.69E+02	1.34E+03	2.25E+02	1.11E+03	4.92E+02	4.54E+03
2020	5.89E+01	9.20E+02	1.45E+03	2.22E+01	2.86E+03	2.19E+03	4.38E+01	7.43E+02	7.89E+02	1.38E+03	2.33E+02	1.14E+03	5.07E+02	4.64E+03
2025	6.27E+01	9.60E+02	1.54E+03	2.37E+01	2.96E+03	2.33E+03	4.63E+01	7.55E+02	8.26E+02	1.45E+03	2.47E+02	1.19E+03	5.31E+02	4.82E+03
2030	6.60E+01	9.97E+02	1.62E+03	2.49E+01	3.05E+03	2.46E+03	4.86E+01	7.66E+02	8.59E+02	1.52E+03	2.60E+02	1.23E+03	5.51E+02	4.97E+03
2040	7.18E+01	1.06E+03	1.75E+03	2.70E+01	3.21E+03	2.68E+03	5.25E+01	7.85E+02	9.15E+02	1.63E+03	2.82E+02	1.30E+03	5.88E+02	5.25E+03
2050	7.67E+01	1.11E+03	1.86E+03	2.87E+01	3.34E+03	2.86E+03	5.59E+01	8.01E+02	9.62E+02	1.72E+03	3.01E+02	1.36E+03	6.18E+02	5.47E+03
2060	8.04E+01	1.15E+03	1.95E+03	3.01E+01	3.44E+03	3.01E+03	5.85E+01	8.14E+02	9.98E+02	1.79E+03	3.16E+02	1.40E+03	6.41E+02	5.65E+03
2070	8.32E+01	1.19E+03	2.02E+03	3.12E+01	3.52E+03	3.11E+03	6.05E+01	8.23E+02	1.03E+03	1.84E+03	3.27E+02	1.44E+03	6.58E+02	5.78E+03
2080	8.53E+01	1.21E+03	2.06E+03	3.20E+01	3.58E+03	3.19E+03	6.20E+01	8.31E+02	1.05E+03	1.88E+03	3.36E+02	1.47E+03	6.71E+02	5.89E+03
2090	8.69E+01	1.23E+03	2.10E+03	3.26E+01	3.63E+03	3.25E+03	6.33E+01	8.39E+02	1.06E+03	1.91E+03	3.44E+02	1.49E+03	6.82E+02	5.96E+03
2100	8.80E+01	1.24E+03	2.13E+03	3.31E+01	3.67E+03	3.30E+03	6.43E+01	8.44E+02	1.07E+03	1.94E+03	3.50E+02	1.51E+03	6.89E+02	6.03E+03
2200	9.23E+01	1.28E+03	2.24E+03	3.52E+01	3.82E+03	3.47E+03	6.82E+01	8.78E+02	1.12E+03	2.02E+03	3.79E+02	1.59E+03	7.19E+02	6.31E+03
2300	9.35E+01	1.30E+03	2.28E+03	3.61E+01	3.88E+03	3.53E+03	7.00E+01	8.94E+02	1.14E+03	2.05E+03	3.92E+02	1.63E+03	7.29E+02	6.42E+03
2400	9.44E+01	1.31E+03	2.30E+03	3.66E+01	3.92E+03	3.56E+03	7.10E+01	9.03E+02	1.14E+03	2.06E+03	4.01E+02	1.65E+03	7.34E+02	6.49E+03
2500	9.48E+01	1.31E+03	2.32E+03	3.70E+01	3.95E+03	3.59E+03	7.18E+01	9.09E+02	1.15E+03	2.08E+03	4.07E+02	1.67E+03	7.39E+02	6.54E+03

Table 9: Collective dose rates by discharging country/source due to discharges up to 2000 only (man Sv y^{-1})

	European Union countries									Other European countries		Other sources		
Year	Belgium	Denmark	France	Germany	Ireland	Netherlands	Spain	Sweden	U.K.	Norway	Switzerland	Baltic Flux	Chernobyl	Fallout
1952	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.70E+00	0.00E+00	0.00E+00	6.20E-04	0.00E+00	5.41E-01
1953	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.67E+00	0.00E+00	0.00E+00	1.56E-03	0.00E+00	1.74E+00
1954	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.48E+01	0.00E+00	0.00E+00	3.55E-03	0.00E+00	4.67E+00
1955	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E+01	0.00E+00	0.00E+00	1.27E-02	0.00E+00	8.11E+00
1956	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.54E+01	0.00E+00	0.00E+00	2.32E-02	0.00E+00	9.64E+00
1957	0.00E+00	8.36E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.88E+01	0.00E+00	0.00E+00	3.57E-02	0.00E+00	1.08E+01
1958	0.00E+00	1.02E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.63E+01	0.00E+00	0.00E+00	4.59E-02	0.00E+00	1.33E+01
1959	0.00E+00	1.10E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.72E+01	0.00E+00	0.00E+00	6.09E-02	0.00E+00	1.93E+01
1960	0.00E+00	1.15E-06	0.00E+00	8.62E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.43E+01	0.00E+00	0.00E+00	8.29E-02	0.00E+00	1.45E+01
1961	0.00E+00	1.18E-06	0.00E+00	1.90E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.00E+01	0.00E+00	0.00E+00	7.69E-02	0.00E+00	1.37E+01
1962	0.00E+00	1.20E-06	0.00E+00	2.23E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.39E+01	0.00E+00	0.00E+00	7.89E-02	0.00E+00	2.50E+01
1963	0.00E+00	1.22E-06	0.00E+00	2.38E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.80E+01	0.00E+00	0.00E+00	1.11E-01	0.00E+00	4.35E+01
1964	0.00E+00	1.24E-06	0.00E+00	2.45E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.83E+01	0.00E+00	0.00E+00	1.83E-01	0.00E+00	4.35E+01
1965	0.00E+00	1.25E-06	9.48E-04	2.49E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.19E+01	0.00E+00	0.00E+00	2.10E-01	0.00E+00	3.60E+01
1966	0.00E+00	1.26E-06	5.96E-01	2.52E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.96E+01	0.00E+00	0.00E+00	2.07E-01	0.00E+00	2.85E+01
1967	0.00E+00	1.27E-06	2.01E+00	2.54E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.17E+01	0.00E+00	0.00E+00	2.00E-01	0.00E+00	2.35E+01
1968	0.00E+00	1.28E-06	2.88E+00	3.29E-04	0.00E+00	0.00E+00	7.17E-05	0.00E+00	6.82E+01	0.00E+00	0.00E+00	1.88E-01	0.00E+00	2.12E+01
1969	0.00E+00	1.29E-06	2.71E+00	3.62E-04	0.00E+00	2.83E-04	7.22E-05	0.00E+00	7.19E+01	0.00E+00	3.25E-04	1.77E-01	0.00E+00	1.95E+01
1970	0.00E+00	1.30E-06	8.83E+00	3.69E-04	0.00E+00	1.49E-03	7.26E-05	0.00E+00	9.25E+01	0.00E+00	4.32E-04	1.58E-01	0.00E+00	1.91E+01
1971	0.00E+00	1.31E-06	1.62E+01	2.41E-04	0.00E+00	1.02E-03	7.30E-05	0.00E+00	1.32E+02	1.73E-02	6.85E-04	1.26E-01	0.00E+00	1.86E+01
1972	0.00E+00	1.32E-06	1.37E+01	5.60E-04	0.00E+00	1.24E-03	7.34E-05	0.00E+00	1.33E+02	1.03E-01	7.61E-04	9.34E-02	0.00E+00	1.71E+01
1973	0.00E+00	1.33E-06	1.31E+01	1.72E-03	0.00E+00	1.40E-03	7.36E-05	0.00E+00	1.53E+02	1.50E-01	7.95E-04	7.12E-02	0.00E+00	1.57E+01
1974	5.26E-04	1.33E-06	2.21E+01	6.41E-03	0.00E+00	2.29E-03	7.39E-05	1.84E-05	1.74E+02	1.82E-01	8.14E-04	5.61E-02	0.00E+00	1.58E+01
1975	4.87E-03	1.34E-06	3.25E+01	3.56E-03	0.00E+00	2.01E-02	7.42E-05	8.01E-04	2.04E+02	6.36E-01	5.13E-04	3.86E-02	0.00E+00	1.50E+01
1976	1.92E-02	1.34E-06	2.51E+01	1.42E-03	0.00E+00	6.28E-02	7.43E-05	1.12E-03	2.26E+02	1.16E+00	8.02E-04	3.08E-02	0.00E+00	1.41E+01
1977	1.19E-02	1.35E-06	2.36E+01	5.97E-03	0.00E+00	1.22E-01	7.45E-05	1.94E-03	2.42E+02	1.46E+00	6.67E-04	2.63E-02	0.00E+00	1.41E+01
1978	1.06E-02	1.52E-06	3.19E+01	2.20E-03	0.00E+00	1.55E-01	7.47E-05	2.08E-03	2.56E+02	1.88E+00	4.01E-04	2.34E-02	0.00E+00	1.41E+01
1979	4.68E-03	1.57E-06	3.11E+01	1.27E-03	0.00E+00	2.52E-01	7.47E-05	3.51E-03	2.23E+02	2.28E+00	3.29E-04	2.12E-02	0.00E+00	1.33E+01
1980	4.08E-03	1.52E-06	3.18E+01	7.48E-04	0.00E+00	3.07E-01	7.49E-05	2.27E-03	2.02E+02	2.88E+00	3.47E-04	1.94E-02	0.00E+00	1.27E+01
1981	4.60E-03	2.04E+01	5.86E+01	5.68E-04	6.57E+00	1.82E+02	1.17E-01	2.93E-03	3.08E+02	3.20E+00	4.91E-04	1.79E-02	0.00E+00	1.25E+01
1982	1.95E-03	2.50E+01	7.25E+01	5.12E-04	1.09E+01	2.16E+02	2.07E-01	2.34E-03	3.54E+02	3.47E+00	3.77E-04	1.65E-02	0.00E+00	1.18E+01

Table 9 (cont'd)

	European Union countries									Other European countries		Other sources		
Year	Belgium	Denmark	France	Germany	Ireland	Netherlands	Spain	Sweden	U.K.	Norway	Switzerland	Baltic Flux	Chernobyl	Fallout
1983	6.30E-03	2.85E+01	6.73E+01	6.32E-04	1.42E+01	2.40E+02	2.68E-01	1.87E-03	3.79E+02	4.03E+00	8.87E-04	1.52E-02	0.00E+00	1.14E+01
1984	2.82E-03	3.31E+01	6.82E+01	7.74E-04	1.25E+01	2.51E+02	3.45E-01	1.76E-03	3.79E+02	4.66E+00	3.80E-04	1.41E-02	0.00E+00	1.10E+01
1985	3.52E-03	2.97E+01	7.41E+01	3.80E-03	8.63E+00	2.39E+02	4.13E-01	4.32E-04	3.42E+02	5.31E+00	4.09E-04	1.30E-02	0.00E+00	1.06E+01
1986	2.39E-03	2.43E+01	7.27E+01	5.48E-04	6.30E+00	2.17E+02	4.59E-01	3.18E-04	3.13E+02	5.99E+00	4.48E-04	4.82E-01	2.22E+01	1.03E+01
1987	3.00E-03	3.00E+01	8.07E+01	3.38E-04	5.19E+00	2.22E+02	5.10E-01	9.98E-04	2.76E+02	6.87E+00	4.63E-04	6.01E-01	1.04E+01	9.95E+00
1988	3.73E-03	2.65E+01	6.47E+01	3.38E-04	3.18E+00	2.36E+02	5.45E-01	1.45E-03	2.70E+02	7.86E+00	4.71E-04	6.20E-01	5.37E+00	9.66E+00
1989	4.93E-03	2.79E+01	6.33E+01	2.54E-04	2.00E+00	2.30E+02	5.65E-01	9.21E-04	2.42E+02	9.61E+00	4.74E-04	6.10E-01	3.07E+00	9.40E+00
1990	5.53E-03	1.79E+01	5.50E+01	1.86E-04	1.42E+00	2.23E+02	5.66E-01	1.19E-03	2.13E+02	1.11E+01	4.76E-04	5.81E-01	1.95E+00	9.15E+00
1991	3.66E-03	1.72E+01	4.53E+01	2.14E-04	1.13E+00	2.15E+02	5.67E-01	9.63E-04	1.84E+02	1.29E+01	4.76E-04	5.41E-01	1.39E+00	8.92E+00
1992	2.36E-03	1.57E+01	2.82E+01	1.82E-04	9.93E-01	1.92E+02	6.18E-01	6.12E-03	1.58E+02	1.47E+01	4.78E-04	4.99E-01	1.08E+00	8.71E+00
1993	2.13E-03	1.52E+01	1.08E+01	1.59E-04	9.17E-01	1.43E+02	6.15E-01	1.94E-03	1.26E+02	1.64E+01	4.77E-04	4.55E-01	9.01E-01	8.49E+00
1994	1.82E-03	4.21E+00	8.78E+00	1.72E-04	8.69E-01	1.55E+02	6.66E-01	2.06E-03	1.08E+02	1.85E+01	3.43E-04	4.14E-01	7.90E-01	8.31E+00
1995	3.25E-03	4.51E+00	8.00E+00	1.75E-04	8.31E-01	1.71E+02	6.89E-01	1.24E-03	1.00E+02	2.05E+01	1.50E-04	3.74E-01	7.09E-01	8.11E+00
1996	3.34E-03	4.98E+00	7.77E+00	1.54E-04	7.98E-01	1.75E+02	7.47E-01	9.89E-04	9.58E+01	2.30E+01	1.38E-04	3.37E-01	6.51E-01	7.93E+00
1997	4.83E-03	5.58E+00	7.73E+00	1.35E-04	7.68E-01	1.71E+02	7.74E-01	1.36E-03	9.23E+01	2.48E+01	1.73E-04	3.04E-01	6.04E-01	7.77E+00
1998	2.51E-03	6.10E+00	7.74E+00	1.41E-04	7.40E-01	1.75E+02	7.89E-01	9.02E-04	9.01E+01	2.59E+01	2.62E-04	2.74E-01	5.63E-01	7.59E+00
1999	1.42E-03	7.02E+00	7.36E+00	1.91E-04	7.12E-01	1.76E+02	8.24E-01	6.44E-04	8.93E+01	2.68E+01	2.63E-04	2.46E-01	5.28E-01	7.43E+00
2000	1.41E-03	7.68E+00	7.12E+00	1.90E-04	6.87E-01	7.88E+01	8.50E-01	5.87E-04	8.84E+01	2.78E+01	2.62E-04	2.22E-01	4.97E-01	7.28E+00
2001	1.76E-04	5.47E+00	4.65E+00	3.49E-05	6.62E-01	4.04E+01	7.33E-01	3.11E-04	7.72E+01	2.01E+01	4.00E-05	1.36E-01	4.68E-01	7.13E+00
2002	1.07E-04	4.22E+00	3.91E+00	2.10E-05	6.39E-01	3.25E+01	6.79E-01	2.56E-04	6.92E+01	1.61E+01	2.66E-05	1.01E-01	4.42E-01	6.99E+00
2003	7.57E-05	3.74E+00	3.60E+00	1.62E-05	6.15E-01	2.95E+01	6.28E-01	2.15E-04	6.54E+01	1.45E+01	2.10E-05	8.27E-02	4.18E-01	6.85E+00
2004	5.84E-05	3.62E+00	3.40E+00	1.35E-05	5.94E-01	2.80E+01	5.83E-01	1.83E-04	6.31E+01	1.40E+01	1.78E-05	7.18E-02	3.96E-01	6.73E+00
2005	4.77E-05	3.66E+00	3.25E+00	1.18E-05	5.72E-01	2.68E+01	5.45E-01	1.56E-04	6.15E+01	1.40E+01	1.58E-05	6.46E-02	3.76E-01	6.60E+00
2006	4.02E-05	3.74E+00	3.11E+00	1.06E-05	5.52E-01	2.58E+01	5.12E-01	1.33E-04	6.02E+01	1.42E+01	1.42E-05	5.87E-02	3.56E-01	6.47E+00
2007	3.45E-05	3.82E+00	2.99E+00	9.66E-06	5.31E-01	2.49E+01	4.83E-01	1.14E-04	5.90E+01	1.44E+01	1.30E-05	5.39E-02	3.39E-01	6.35E+00
2008	3.00E-05	3.90E+00	2.87E+00	8.88E-06	5.13E-01	2.40E+01	4.58E-01	9.79E-05	5.78E+01	1.45E+01	1.19E-05	4.96E-02	3.22E-01	6.24E+00
2009	2.62E-05	3.96E+00	2.77E+00	8.22E-06	4.94E-01	2.31E+01	4.35E-01	8.43E-05	5.67E+01	1.46E+01	1.10E-05	4.58E-02	3.07E-01	6.13E+00
2010	2.30E-05	4.01E+00	2.66E+00	7.63E-06	4.76E-01	2.23E+01	4.16E-01	7.27E-05	5.56E+01	1.48E+01	1.01E-05	4.23E-02	2.92E-01	6.02E+00
2011	2.02E-05	4.05E+00	2.56E+00	7.10E-06	4.59E-01	2.16E+01	3.98E-01	6.28E-05	5.45E+01	1.48E+01	9.32E-06	3.93E-02	2.78E-01	5.91E+00
2012	1.79E-05	4.07E+00	2.47E+00	6.64E-06	4.43E-01	2.08E+01	3.82E-01	5.45E-05	5.33E+01	1.48E+01	8.61E-06	3.62E-02	2.66E-01	5.82E+00
2013	1.58E-05	4.08E+00	2.38E+00	6.21E-06	4.27E-01	2.01E+01	3.68E-01	4.73E-05	5.22E+01	1.48E+01	7.98E-06	3.36E-02	2.53E-01	5.72E+00

Table 9 (cont'd)

	European Union countries									Other European countries		Other sources		
Year	Belgium	Denmark	France	Germany	Ireland	Netherlands	Spain	Sweden	U.K.	Norway	Switzerland	Baltic Flux	Chernobyl	Fallout
2014	1.40E-05	4.08E+00	2.29E+00	5.82E-06	4.11E-01	1.94E+01	3.56E-01	4.12E-05	5.11E+01	1.48E+01	7.39E-06	3.12E-02	2.42E-01	5.63E+00
2015	1.24E-05	4.07E+00	2.20E+00	5.47E-06	3.97E-01	1.87E+01	3.43E-01	3.60E-05	5.00E+01	1.47E+01	6.84E-06	2.89E-02	2.31E-01	5.52E+00
2016	1.10E-05	4.05E+00	2.12E+00	5.15E-06	3.83E-01	1.80E+01	3.33E-01	3.15E-05	4.89E+01	1.46E+01	6.35E-06	2.67E-02	2.21E-01	5.44E+00
2017	9.83E-06	4.02E+00	2.05E+00	4.86E-06	3.69E-01	1.74E+01	3.24E-01	2.76E-05	4.78E+01	1.45E+01	5.89E-06	2.48E-02	2.11E-01	5.35E+00
2018	8.77E-06	3.99E+00	1.97E+00	4.59E-06	3.56E-01	1.67E+01	3.14E-01	2.43E-05	4.67E+01	1.44E+01	5.47E-06	2.30E-02	2.03E-01	5.28E+00
2019	7.83E-06	3.95E+00	1.90E+00	4.34E-06	3.43E-01	1.62E+01	3.06E-01	2.15E-05	4.56E+01	1.42E+01	5.08E-06	2.14E-02	1.94E-01	5.19E+00
2020	7.02E-06	3.90E+00	1.83E+00	4.12E-06	3.31E-01	1.56E+01	2.98E-01	1.90E-05	4.45E+01	1.40E+01	4.73E-06	1.99E-02	1.86E-01	5.11E+00
2025	4.16E-06	3.62E+00	1.52E+00	3.25E-06	2.76E-01	1.30E+01	2.67E-01	1.08E-05	3.94E+01	1.30E+01	3.35E-06	1.40E-02	1.52E-01	4.75E+00
2030	2.59E-06	3.28E+00	1.27E+00	2.64E-06	2.30E-01	1.08E+01	2.43E-01	6.74E-06	3.47E+01	1.18E+01	2.44E-06	1.00E-02	1.25E-01	4.43E+00
2035	1.69E-06	2.91E+00	1.06E+00	2.22E-06	1.92E-01	9.06E+00	2.23E-01	4.52E-06	3.03E+01	1.06E+01	1.82E-06	7.37E-03	1.04E-01	4.14E+00
2040	1.16E-06	2.56E+00	8.88E-01	1.89E-06	1.60E-01	7.55E+00	2.07E-01	3.25E-06	2.65E+01	9.40E+00	1.39E-06	5.53E-03	8.66E-02	3.89E+00
2045	8.29E-07	2.23E+00	7.45E-01	1.64E-06	1.34E-01	6.32E+00	1.92E-01	2.46E-06	2.31E+01	8.26E+00	1.09E-06	4.27E-03	7.28E-02	3.67E+00
2050	6.18E-07	1.93E+00	6.29E-01	1.44E-06	1.12E-01	5.29E+00	1.79E-01	1.93E-06	2.01E+01	7.28E+00	8.72E-07	3.37E-03	6.15E-02	3.47E+00
2055	4.77E-07	1.66E+00	5.32E-01	1.28E-06	9.34E-02	4.42E+00	1.67E-01	1.57E-06	1.75E+01	6.36E+00	7.11E-07	2.71E-03	5.21E-02	3.29E+00
2060	3.78E-07	1.42E+00	4.52E-01	1.14E-06	7.80E-02	3.71E+00	1.56E-01	1.30E-06	1.53E+01	5.55E+00	5.87E-07	2.21E-03	4.42E-02	3.12E+00
2065	3.07E-07	1.21E+00	3.86E-01	1.01E-06	6.52E-02	3.11E+00	1.46E-01	1.09E-06	1.34E+01	4.86E+00	4.90E-07	1.83E-03	3.76E-02	2.97E+00
2070	2.53E-07	1.03E+00	3.31E-01	9.09E-07	5.46E-02	2.62E+00	1.36E-01	9.27E-07	1.17E+01	4.24E+00	4.13E-07	1.53E-03	3.21E-02	2.83E+00
2075	2.12E-07	8.77E-01	2.85E-01	8.17E-07	4.58E-02	2.21E+00	1.27E-01	7.94E-07	1.03E+01	3.71E+00	3.51E-07	1.29E-03	2.74E-02	2.70E+00
2080	1.79E-07	7.48E-01	2.47E-01	7.36E-07	3.84E-02	1.87E+00	1.19E-01	6.86E-07	9.07E+00	3.26E+00	3.00E-07	1.10E-03	2.35E-02	2.59E+00
2085	1.52E-07	6.36E-01	2.15E-01	6.64E-07	3.23E-02	1.59E+00	1.12E-01	5.97E-07	8.03E+00	2.87E+00	2.57E-07	9.36E-04	2.01E-02	2.48E+00
2090	1.30E-07	5.41E-01	1.88E-01	6.00E-07	2.72E-02	1.35E+00	1.05E-01	5.21E-07	7.14E+00	2.53E+00	2.21E-07	8.05E-04	1.73E-02	2.38E+00
2095	1.12E-07	4.62E-01	1.66E-01	5.42E-07	2.29E-02	1.15E+00	9.86E-02	4.57E-07	6.38E+00	2.25E+00	1.90E-07	6.90E-04	1.48E-02	2.28E+00
2100	9.67E-08	3.95E-01	1.47E-01	4.91E-07	1.93E-02	9.92E-01	9.26E-02	4.02E-07	5.72E+00	2.00E+00	1.64E-07	5.95E-04	1.27E-02	2.20E+00
2200	6.86E-09	4.53E-02	3.53E-02	7.99E-08	1.58E-03	1.50E-01	3.27E-02	6.63E-08	1.55E+00	5.23E-01	9.68E-09	3.45E-05	6.83E-04	1.16E+00
2300	9.04E-10	2.39E-02	1.79E-02	1.65E-08	7.49E-04	8.50E-02	1.61E-02	3.11E-08	8.23E-01	3.17E-01	6.21E-10	2.18E-06	4.08E-05	7.18E-01
2400	2.55E-10	1.71E-02	1.07E-02	4.19E-09	5.41E-04	6.11E-02	9.88E-03	2.01E-08	5.03E-01	2.28E-01	4.33E-11	1.47E-07	2.66E-06	4.98E-01
2500	1.08E-10	1.32E-02	6.98E-03	1.34E-09	4.25E-04	4.71E-02	6.95E-03	1.44E-08	3.36E-01	1.75E-01	3.47E-12	1.08E-08	1.90E-07	3.82E-01

Table 10: Per-caput dose rates in European Union member states due to discharges up to 2000 only (Sv y^{-1})

Year	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	U.K.
1952	3.52E-10	9.10E-09	1.94E-08	3.19E-10	2.24E-08	1.63E-09	7.03E-10	1.85E-07	4.32E-09	7.56E-09	3.44E-09	9.84E-09	3.77E-09	3.57E-08
1953	1.15E-09	2.15E-08	5.64E-08	9.24E-10	4.79E-08	5.02E-09	1.67E-09	3.82E-07	9.42E-09	1.97E-08	8.69E-09	2.13E-08	1.16E-08	7.50E-08
1954	2.82E-09	4.13E-08	1.30E-07	2.15E-09	7.87E-08	1.17E-08	3.19E-09	5.92E-07	1.59E-08	4.06E-08	1.92E-08	3.65E-08	2.93E-08	1.22E-07
1955	4.60E-09	5.31E-08	2.07E-07	3.47E-09	7.84E-08	1.85E-08	4.16E-09	5.28E-07	1.67E-08	5.63E-08	3.04E-08	4.00E-08	4.87E-08	1.24E-07
1956	6.06E-09	1.39E-07	2.85E-07	4.99E-09	3.77E-07	2.80E-08	1.14E-08	3.06E-06	7.25E-08	1.26E-07	5.64E-08	1.61E-07	6.64E-08	5.62E-07
1957	7.28E-09	1.25E-07	3.72E-07	5.95E-09	2.93E-07	3.42E-08	1.02E-08	2.31E-06	5.79E-08	1.22E-07	6.06E-08	1.32E-07	7.18E-08	4.46E-07
1958	9.38E-09	1.75E-07	4.85E-07	7.77E-09	4.25E-07	4.52E-08	1.42E-08	3.38E-06	8.32E-08	1.68E-07	8.05E-08	1.89E-07	9.14E-08	6.44E-07
1959	1.28E-08	1.89E-07	6.37E-07	1.02E-08	3.95E-07	5.85E-08	1.53E-08	3.01E-06	7.91E-08	1.93E-07	9.95E-08	1.84E-07	1.25E-07	6.04E-07
1960	1.05E-08	1.72E-07	5.45E-07	8.79E-09	4.15E-07	5.13E-08	1.47E-08	3.25E-06	8.20E-08	1.75E-07	9.61E-08	1.90E-07	1.01E-07	6.30E-07
1961	9.48E-09	1.36E-07	5.09E-07	8.18E-09	3.00E-07	4.68E-08	1.19E-08	2.28E-06	6.00E-08	1.44E-07	8.99E-08	1.45E-07	9.02E-08	4.56E-07
1962	1.45E-08	1.78E-07	7.25E-07	1.20E-08	3.00E-07	6.47E-08	1.48E-08	2.10E-06	6.25E-08	1.92E-07	1.21E-07	1.56E-07	1.49E-07	4.67E-07
1963	2.32E-08	2.71E-07	1.08E-06	1.86E-08	4.17E-07	9.66E-08	2.22E-08	2.80E-06	8.81E-08	2.91E-07	1.82E-07	2.20E-07	2.50E-07	6.48E-07
1964	2.32E-08	2.47E-07	1.11E-06	1.91E-08	3.62E-07	9.74E-08	2.18E-08	2.36E-06	7.82E-08	2.77E-07	1.99E-07	2.06E-07	2.50E-07	5.86E-07
1965	1.94E-08	2.01E-07	9.76E-07	1.70E-08	3.06E-07	8.53E-08	1.91E-08	2.02E-06	6.58E-08	2.31E-07	1.92E-07	1.84E-07	2.06E-07	5.10E-07
1966	1.57E-08	1.84E-07	8.23E-07	1.48E-08	3.28E-07	7.16E-08	1.81E-08	2.31E-06	6.78E-08	2.04E-07	1.85E-07	1.90E-07	1.63E-07	5.29E-07
1967	1.40E-08	1.66E-07	7.79E-07	1.37E-08	2.80E-07	6.69E-08	1.62E-08	1.90E-06	5.76E-08	1.86E-07	1.75E-07	1.69E-07	1.36E-07	4.56E-07
1968	1.38E-08	1.93E-07	7.80E-07	1.38E-08	3.52E-07	6.62E-08	1.77E-08	2.50E-06	7.02E-08	2.00E-07	1.76E-07	1.98E-07	1.31E-07	5.65E-07
1969	1.39E-08	1.96E-07	7.95E-07	1.40E-08	3.52E-07	6.64E-08	1.79E-08	2.55E-06	7.05E-08	2.01E-07	1.75E-07	1.99E-07	1.27E-07	5.89E-07
1970	1.73E-08	2.93E-07	1.05E-06	1.71E-08	4.58E-07	8.37E-08	2.18E-08	3.22E-06	8.91E-08	2.68E-07	1.94E-07	2.48E-07	1.42E-07	7.52E-07
1971	2.35E-08	4.16E-07	1.36E-06	2.16E-08	6.49E-07	1.10E-07	2.88E-08	4.49E-06	1.24E-07	3.74E-07	2.23E-07	3.30E-07	1.78E-07	1.05E-06
1972	2.59E-08	4.14E-07	1.48E-06	2.28E-08	6.09E-07	1.20E-07	2.91E-08	4.28E-06	1.19E-07	3.83E-07	2.24E-07	3.18E-07	1.93E-07	1.05E-06
1973	2.75E-08	4.30E-07	1.49E-06	2.33E-08	6.90E-07	1.25E-07	3.13E-08	4.94E-06	1.35E-07	4.07E-07	2.26E-07	3.47E-07	2.04E-07	1.17E-06
1974	3.42E-08	6.22E-07	2.19E-06	3.10E-08	7.59E-07	1.63E-07	3.73E-08	5.30E-06	1.48E-07	5.16E-07	2.72E-07	4.04E-07	2.35E-07	1.35E-06
1975	4.88E-08	8.32E-07	3.10E-06	4.25E-08	8.42E-07	2.27E-07	4.69E-08	5.60E-06	1.64E-07	6.90E-07	3.33E-07	4.67E-07	2.94E-07	1.59E-06
1976	6.02E-08	8.44E-07	3.44E-06	4.90E-08	8.34E-07	2.60E-07	5.28E-08	5.73E-06	1.70E-07	7.51E-07	3.60E-07	4.78E-07	3.75E-07	1.71E-06
1977	6.94E-08	8.94E-07	3.74E-06	5.45E-08	8.61E-07	2.87E-07	5.74E-08	5.82E-06	1.80E-07	8.20E-07	3.84E-07	4.99E-07	4.64E-07	1.79E-06
1978	7.73E-08	9.93E-07	4.06E-06	5.89E-08	9.54E-07	3.21E-07	6.16E-08	6.01E-06	1.99E-07	9.25E-07	4.06E-07	5.32E-07	5.34E-07	1.89E-06
1979	7.86E-08	9.25E-07	3.97E-06	5.81E-08	8.16E-07	3.23E-07	5.74E-08	4.66E-06	1.75E-07	9.02E-07	3.88E-07	4.67E-07	5.64E-07	1.63E-06
1980	7.60E-08	8.96E-07	3.86E-06	5.65E-08	7.50E-07	3.14E-07	5.40E-08	4.00E-06	1.62E-07	8.73E-07	3.73E-07	4.34E-07	5.67E-07	1.47E-06
1981	2.19E-07	3.22E-06	8.77E-06	1.45E-07	1.78E-06	7.68E-07	1.37E-07	8.49E-06	4.79E-07	2.98E-06	8.45E-07	1.10E-06	2.33E-06	2.80E-06
1982	2.66E-07	3.70E-06	1.05E-05	1.73E-07	2.05E-06	9.42E-07	1.64E-07	9.53E-06	5.55E-07	3.50E-06	9.84E-07	1.26E-06	2.80E-06	3.29E-06
1983	2.97E-07	3.95E-06	1.14E-05	1.90E-07	2.16E-06	1.04E-06	1.80E-07	1.00E-05	5.98E-07	3.80E-06	1.06E-06	1.34E-06	3.13E-06	3.52E-06
1984	3.12E-07	4.06E-06	1.19E-05	1.98E-07	2.18E-06	1.09E-06	1.86E-07	9.81E-06	6.14E-07	3.95E-06	1.09E-06	1.36E-06	3.47E-06	3.51E-06

Table 10 (cont'd)

Year	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	U.K.
1985	3.02E-07	3.89E-06	1.14E-05	1.90E-07	2.03E-06	1.07E-06	1.77E-07	8.38E-06	5.75E-07	3.80E-06	1.04E-06	1.27E-06	3.19E-06	3.20E-06
1986	2.91E-07	3.68E-06	1.10E-05	1.94E-07	1.91E-06	1.03E-06	1.70E-07	7.60E-06	5.47E-07	3.62E-06	1.01E-06	1.21E-06	2.88E-06	3.02E-06
1987	2.86E-07	3.63E-06	1.07E-05	1.85E-07	1.84E-06	1.01E-06	1.62E-07	6.49E-06	5.23E-07	3.58E-06	9.63E-07	1.14E-06	3.12E-06	2.74E-06
1988	2.79E-07	3.60E-06	1.03E-05	1.74E-07	1.76E-06	9.80E-07	1.59E-07	6.63E-06	5.20E-07	3.54E-06	9.46E-07	1.13E-06	2.84E-06	2.67E-06
1989	2.70E-07	3.45E-06	9.84E-06	1.68E-07	1.66E-06	9.44E-07	1.53E-07	5.77E-06	4.89E-07	3.41E-06	9.02E-07	1.06E-06	2.84E-06	2.46E-06
1990	2.53E-07	3.21E-06	8.91E-06	1.49E-07	1.50E-06	8.83E-07	1.41E-07	4.92E-06	4.50E-07	3.21E-06	8.35E-07	9.61E-07	2.13E-06	2.22E-06
1991	2.39E-07	2.99E-06	8.28E-06	1.40E-07	1.35E-06	8.26E-07	1.32E-07	4.11E-06	4.13E-07	3.01E-06	7.79E-07	8.74E-07	2.01E-06	1.98E-06
1992	2.12E-07	2.57E-06	7.33E-06	1.22E-07	1.14E-06	7.37E-07	1.15E-07	3.36E-06	3.57E-07	2.63E-06	6.85E-07	7.30E-07	1.80E-06	1.71E-06
1993	1.69E-07	1.87E-06	5.94E-06	9.68E-08	8.28E-07	5.94E-07	8.99E-08	2.30E-06	2.65E-07	1.98E-06	5.40E-07	5.26E-07	1.58E-06	1.31E-06
1994	1.64E-07	1.95E-06	5.55E-06	8.48E-08	8.14E-07	5.87E-07	8.63E-08	1.89E-06	2.63E-07	2.06E-06	5.25E-07	5.08E-07	8.69E-07	1.22E-06
1995	1.72E-07	2.09E-06	5.73E-06	8.74E-08	8.44E-07	6.09E-07	8.91E-08	1.74E-06	2.74E-07	2.19E-06	5.40E-07	5.20E-07	9.05E-07	1.21E-06
1996	1.75E-07	2.12E-06	5.82E-06	8.85E-08	8.47E-07	6.19E-07	8.99E-08	1.64E-06	2.77E-07	2.22E-06	5.44E-07	5.21E-07	9.24E-07	1.20E-06
1997	1.73E-07	2.08E-06	5.78E-06	8.81E-08	8.29E-07	6.14E-07	8.89E-08	1.54E-06	2.72E-07	2.18E-06	5.37E-07	5.09E-07	9.26E-07	1.17E-06
1998	1.77E-07	2.12E-06	5.88E-06	8.94E-08	8.37E-07	6.26E-07	8.99E-08	1.46E-06	2.76E-07	2.23E-06	5.42E-07	5.13E-07	9.41E-07	1.17E-06
1999	1.78E-07	2.14E-06	5.95E-06	9.04E-08	8.37E-07	6.33E-07	9.06E-08	1.41E-06	2.77E-07	2.25E-06	5.45E-07	5.12E-07	9.52E-07	1.16E-06
2000	1.20E-07	1.18E-06	4.47E-06	6.89E-08	5.40E-07	4.48E-07	6.31E-08	1.28E-06	1.78E-07	1.31E-06	4.02E-07	3.59E-07	7.56E-07	8.95E-07
2001	8.26E-08	7.43E-07	3.20E-06	5.14E-08	3.73E-07	3.16E-07	4.56E-08	1.18E-06	1.24E-07	8.51E-07	3.01E-07	2.70E-07	5.30E-07	6.78E-07
2002	7.01E-08	6.36E-07	2.71E-06	4.43E-08	3.23E-07	2.68E-07	3.94E-08	1.07E-06	1.07E-07	7.28E-07	2.65E-07	2.38E-07	4.24E-07	5.86E-07
2003	6.50E-08	5.93E-07	2.49E-06	4.10E-08	3.02E-07	2.48E-07	3.68E-08	1.02E-06	9.92E-08	6.77E-07	2.48E-07	2.23E-07	3.79E-07	5.46E-07
2004	6.26E-08	5.72E-07	2.39E-06	3.93E-08	2.91E-07	2.39E-07	3.54E-08	9.82E-07	9.56E-08	6.53E-07	2.39E-07	2.14E-07	3.60E-07	5.24E-07
2005	6.14E-08	5.59E-07	2.32E-06	3.82E-08	2.83E-07	2.34E-07	3.47E-08	9.44E-07	9.36E-08	6.39E-07	2.32E-07	2.07E-07	3.50E-07	5.09E-07
2006	6.06E-08	5.51E-07	2.28E-06	3.73E-08	2.77E-07	2.30E-07	3.41E-08	9.13E-07	9.19E-08	6.28E-07	2.27E-07	2.01E-07	3.44E-07	4.98E-07
2007	5.99E-08	5.41E-07	2.24E-06	3.65E-08	2.72E-07	2.27E-07	3.35E-08	8.83E-07	9.03E-08	6.20E-07	2.23E-07	1.96E-07	3.38E-07	4.87E-07
2008	5.91E-08	5.33E-07	2.20E-06	3.57E-08	2.67E-07	2.24E-07	3.31E-08	8.55E-07	8.89E-08	6.11E-07	2.18E-07	1.91E-07	3.34E-07	4.77E-07
2009	5.82E-08	5.24E-07	2.16E-06	3.50E-08	2.61E-07	2.20E-07	3.25E-08	8.28E-07	8.74E-08	6.01E-07	2.14E-07	1.86E-07	3.28E-07	4.66E-07
2010	5.75E-08	5.16E-07	2.13E-06	3.43E-08	2.56E-07	2.17E-07	3.20E-08	8.01E-07	8.59E-08	5.92E-07	2.10E-07	1.82E-07	3.24E-07	4.57E-07
2011	5.66E-08	5.07E-07	2.09E-06	3.36E-08	2.51E-07	2.14E-07	3.15E-08	7.77E-07	8.44E-08	5.82E-07	2.06E-07	1.77E-07	3.19E-07	4.47E-07
2012	5.56E-08	4.97E-07	2.05E-06	3.29E-08	2.46E-07	2.10E-07	3.09E-08	7.53E-07	8.29E-08	5.73E-07	2.01E-07	1.73E-07	3.13E-07	4.37E-07
2013	5.48E-08	4.89E-07	2.01E-06	3.23E-08	2.41E-07	2.06E-07	3.03E-08	7.31E-07	8.12E-08	5.61E-07	1.97E-07	1.69E-07	3.08E-07	4.27E-07
2014	5.38E-08	4.79E-07	1.97E-06	3.16E-08	2.36E-07	2.03E-07	2.98E-08	7.09E-07	7.97E-08	5.51E-07	1.93E-07	1.64E-07	3.02E-07	4.18E-07
2015	5.28E-08	4.68E-07	1.93E-06	3.09E-08	2.31E-07	1.99E-07	2.92E-08	6.88E-07	7.80E-08	5.40E-07	1.89E-07	1.60E-07	2.97E-07	4.08E-07
2016	5.18E-08	4.60E-07	1.89E-06	3.02E-08	2.26E-07	1.95E-07	2.86E-08	6.67E-07	7.64E-08	5.29E-07	1.85E-07	1.56E-07	2.91E-07	3.98E-07
2017	5.08E-08	4.50E-07	1.85E-06	2.96E-08	2.20E-07	1.91E-07	2.81E-08	6.48E-07	7.49E-08	5.19E-07	1.81E-07	1.52E-07	2.85E-07	3.89E-07

Table 10 (cont'd)

Year	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	U.K.
2018	4.97E-08	4.40E-07	1.81E-06	2.89E-08	2.15E-07	1.87E-07	2.75E-08	6.29E-07	7.31E-08	5.08E-07	1.77E-07	1.49E-07	2.79E-07	3.80E-07
2019	4.87E-08	4.30E-07	1.77E-06	2.83E-08	2.10E-07	1.83E-07	2.69E-08	6.11E-07	7.15E-08	4.96E-07	1.74E-07	1.45E-07	2.73E-07	3.71E-07
2020	4.76E-08	4.20E-07	1.73E-06	2.77E-08	2.06E-07	1.79E-07	2.63E-08	5.95E-07	6.99E-08	4.85E-07	1.70E-07	1.41E-07	2.67E-07	3.62E-07
2025	4.23E-08	3.72E-07	1.53E-06	2.46E-08	1.82E-07	1.59E-07	2.35E-08	5.16E-07	6.20E-08	4.31E-07	1.52E-07	1.24E-07	2.38E-07	3.18E-07
2030	3.73E-08	3.27E-07	1.35E-06	2.17E-08	1.61E-07	1.40E-07	2.08E-08	4.51E-07	5.46E-08	3.79E-07	1.35E-07	1.09E-07	2.10E-07	2.80E-07
2035	3.26E-08	2.85E-07	1.18E-06	1.91E-08	1.41E-07	1.23E-07	1.83E-08	3.96E-07	4.78E-08	3.32E-07	1.20E-07	9.62E-08	1.85E-07	2.45E-07
2040	2.83E-08	2.47E-07	1.03E-06	1.68E-08	1.24E-07	1.07E-07	1.61E-08	3.49E-07	4.17E-08	2.88E-07	1.07E-07	8.46E-08	1.61E-07	2.14E-07
2045	2.46E-08	2.14E-07	8.97E-07	1.47E-08	1.08E-07	9.29E-08	1.41E-08	3.10E-07	3.62E-08	2.50E-07	9.48E-08	7.45E-08	1.41E-07	1.87E-07
2050	2.13E-08	1.85E-07	7.80E-07	1.29E-08	9.51E-08	8.07E-08	1.24E-08	2.76E-07	3.15E-08	2.17E-07	8.44E-08	6.57E-08	1.23E-07	1.64E-07
2055	1.84E-08	1.59E-07	6.77E-07	1.13E-08	8.35E-08	7.00E-08	1.08E-08	2.48E-07	2.74E-08	1.88E-07	7.53E-08	5.81E-08	1.07E-07	1.44E-07
2060	1.59E-08	1.37E-07	5.89E-07	9.93E-09	7.35E-08	6.06E-08	9.53E-09	2.23E-07	2.39E-08	1.62E-07	6.74E-08	5.15E-08	9.32E-08	1.26E-07
2065	1.37E-08	1.19E-07	5.13E-07	8.74E-09	6.49E-08	5.27E-08	8.39E-09	2.02E-07	2.08E-08	1.41E-07	6.04E-08	4.59E-08	8.14E-08	1.11E-07
2070	1.19E-08	1.03E-07	4.48E-07	7.71E-09	5.74E-08	4.57E-08	7.40E-09	1.84E-07	1.82E-08	1.22E-07	5.45E-08	4.09E-08	7.12E-08	9.81E-08
2075	1.03E-08	8.87E-08	3.92E-07	6.83E-09	5.10E-08	3.99E-08	6.55E-09	1.68E-07	1.59E-08	1.06E-07	4.92E-08	3.68E-08	6.25E-08	8.71E-08
2080	8.93E-09	7.71E-08	3.45E-07	6.07E-09	4.55E-08	3.49E-08	5.82E-09	1.54E-07	1.40E-08	9.25E-08	4.48E-08	3.31E-08	5.51E-08	7.76E-08
2085	7.78E-09	6.71E-08	3.04E-07	5.42E-09	4.08E-08	3.06E-08	5.21E-09	1.42E-07	1.23E-08	8.09E-08	4.08E-08	3.00E-08	4.86E-08	6.94E-08
2090	6.81E-09	5.87E-08	2.70E-07	4.87E-09	3.67E-08	2.70E-08	4.67E-09	1.31E-07	1.09E-08	7.12E-08	3.74E-08	2.73E-08	4.32E-08	6.25E-08
2095	5.99E-09	5.15E-08	2.41E-07	4.39E-09	3.32E-08	2.39E-08	4.21E-09	1.22E-07	9.71E-09	6.28E-08	3.44E-08	2.49E-08	3.86E-08	5.64E-08
2100	5.29E-09	4.54E-08	2.15E-07	3.98E-09	3.02E-08	2.13E-08	3.81E-09	1.13E-07	8.69E-09	5.57E-08	3.18E-08	2.29E-08	3.46E-08	5.12E-08
2200	1.25E-09	1.03E-08	6.32E-08	1.32E-09	9.51E-09	5.76E-09	1.22E-09	4.22E-08	2.32E-09	1.39E-08	1.25E-08	8.32E-09	9.56E-09	1.62E-08
2300	7.25E-10	5.88E-09	3.72E-08	7.93E-10	5.25E-09	3.38E-09	7.40E-10	2.20E-08	1.29E-09	8.11E-09	7.72E-09	4.90E-09	5.38E-09	9.17E-09
2400	4.96E-10	3.93E-09	2.47E-08	5.40E-10	3.40E-09	2.26E-09	5.23E-10	1.33E-08	8.47E-10	5.48E-09	5.51E-09	3.35E-09	3.54E-09	6.04E-09
2500	3.68E-10	2.85E-09	1.79E-08	3.99E-10	2.44E-09	1.64E-09	4.05E-10	9.17E-09	6.12E-10	4.02E-09	4.34E-09	2.53E-09	2.55E-09	4.39E-09

Table 11: Per-caput dose rates in European Union member states assuming discharges continue to 2020 (Sv y^{-1})

Year	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	U.K.
2001	1.12E-07	1.10E-06	4.21E-06	6.55E-08	5.08E-07	4.19E-07	5.92E-08	1.22E-06	1.67E-07	1.22E-06	3.81E-07	3.39E-07	7.11E-07	8.47E-07
2002	1.10E-07	1.08E-06	4.15E-06	6.48E-08	4.99E-07	4.12E-07	5.81E-08	1.18E-06	1.64E-07	1.20E-06	3.75E-07	3.33E-07	7.03E-07	8.31E-07
2003	1.10E-07	1.08E-06	4.15E-06	6.48E-08	4.96E-07	4.13E-07	5.80E-08	1.15E-06	1.63E-07	1.20E-06	3.74E-07	3.31E-07	7.03E-07	8.23E-07
2004	1.11E-07	1.08E-06	4.16E-06	6.51E-08	4.94E-07	4.15E-07	5.82E-08	1.12E-06	1.64E-07	1.20E-06	3.74E-07	3.30E-07	7.07E-07	8.19E-07
2005	1.12E-07	1.08E-06	4.19E-06	6.56E-08	4.94E-07	4.19E-07	5.85E-08	1.09E-06	1.64E-07	1.21E-06	3.74E-07	3.29E-07	7.12E-07	8.17E-07
2006	1.12E-07	1.09E-06	4.22E-06	6.60E-08	4.95E-07	4.22E-07	5.88E-08	1.06E-06	1.65E-07	1.22E-06	3.75E-07	3.29E-07	7.18E-07	8.17E-07
2007	1.13E-07	1.09E-06	4.25E-06	6.65E-08	4.95E-07	4.26E-07	5.92E-08	1.04E-06	1.65E-07	1.23E-06	3.76E-07	3.29E-07	7.24E-07	8.17E-07
2008	1.15E-07	1.10E-06	4.29E-06	6.70E-08	4.96E-07	4.30E-07	5.96E-08	1.02E-06	1.66E-07	1.24E-06	3.78E-07	3.29E-07	7.30E-07	8.16E-07
2009	1.16E-07	1.11E-06	4.32E-06	6.76E-08	4.97E-07	4.33E-07	6.00E-08	9.95E-07	1.67E-07	1.25E-06	3.79E-07	3.29E-07	7.36E-07	8.16E-07
2010	1.17E-07	1.11E-06	4.36E-06	6.81E-08	4.98E-07	4.38E-07	6.03E-08	9.74E-07	1.68E-07	1.26E-06	3.81E-07	3.30E-07	7.43E-07	8.17E-07
2012	1.19E-07	1.13E-06	4.43E-06	6.92E-08	5.01E-07	4.46E-07	6.12E-08	9.38E-07	1.70E-07	1.28E-06	3.84E-07	3.31E-07	7.56E-07	8.20E-07
2014	1.21E-07	1.14E-06	4.51E-06	7.04E-08	5.05E-07	4.54E-07	6.22E-08	9.08E-07	1.72E-07	1.29E-06	3.88E-07	3.32E-07	7.68E-07	8.24E-07
2016	1.24E-07	1.16E-06	4.58E-06	7.16E-08	5.09E-07	4.63E-07	6.31E-08	8.77E-07	1.75E-07	1.32E-06	3.91E-07	3.34E-07	7.82E-07	8.29E-07
2018	1.26E-07	1.17E-06	4.66E-06	7.27E-08	5.13E-07	4.71E-07	6.41E-08	8.53E-07	1.77E-07	1.34E-06	3.95E-07	3.36E-07	7.94E-07	8.35E-07
2020	1.28E-07	1.19E-06	4.73E-06	7.39E-08	5.17E-07	4.80E-07	6.51E-08	8.32E-07	1.79E-07	1.36E-06	3.99E-07	3.38E-07	8.07E-07	8.40E-07
2025	8.33E-08	7.07E-07	3.05E-06	4.93E-08	3.17E-07	3.15E-07	4.37E-08	6.41E-07	1.15E-07	8.33E-07	2.68E-07	2.22E-07	4.77E-07	5.48E-07
2030	7.91E-08	6.70E-07	2.85E-06	4.55E-08	2.98E-07	2.98E-07	4.14E-08	5.76E-07	1.08E-07	7.88E-07	2.48E-07	2.02E-07	4.48E-07	5.12E-07
2040	6.64E-08	5.60E-07	2.37E-06	3.77E-08	2.48E-07	2.49E-07	3.49E-08	4.64E-07	9.07E-08	6.60E-07	2.07E-07	1.65E-07	3.73E-07	4.24E-07
2050	5.24E-08	4.41E-07	1.86E-06	2.99E-08	1.98E-07	1.96E-07	2.79E-08	3.74E-07	7.16E-08	5.21E-07	1.67E-07	1.30E-07	2.95E-07	3.37E-07
2060	3.99E-08	3.37E-07	1.43E-06	2.33E-08	1.54E-07	1.50E-07	2.18E-08	3.04E-07	5.50E-08	3.99E-07	1.32E-07	1.02E-07	2.27E-07	2.61E-07
2070	3.00E-08	2.53E-07	1.08E-06	1.80E-08	1.19E-07	1.13E-07	1.68E-08	2.51E-07	4.17E-08	3.01E-07	1.05E-07	7.99E-08	1.72E-07	2.02E-07
2080	2.24E-08	1.89E-07	8.17E-07	1.39E-08	9.20E-08	8.53E-08	1.30E-08	2.11E-07	3.16E-08	2.27E-07	8.33E-08	6.29E-08	1.31E-07	1.57E-07
2090	1.68E-08	1.42E-07	6.21E-07	1.08E-08	7.19E-08	6.45E-08	1.02E-08	1.79E-07	2.40E-08	1.71E-07	6.70E-08	5.01E-08	9.94E-08	1.23E-07
2100	1.27E-08	1.07E-07	4.78E-07	8.54E-09	5.70E-08	4.91E-08	8.07E-09	1.55E-07	1.85E-08	1.30E-07	5.48E-08	4.06E-08	7.67E-08	9.77E-08
2200	2.19E-09	1.75E-08	1.01E-07	2.19E-09	1.42E-08	9.52E-09	2.08E-09	5.81E-08	3.66E-09	2.37E-08	1.75E-08	1.20E-08	1.56E-08	2.54E-08
2300	1.21E-09	9.51E-09	5.74E-08	1.28E-09	7.85E-09	5.36E-09	1.23E-09	3.18E-08	2.00E-09	1.32E-08	1.06E-08	7.03E-09	8.36E-09	1.44E-08
2400	8.38E-10	6.46E-09	3.88E-08	8.77E-10	5.24E-09	3.65E-09	8.70E-10	2.04E-08	1.34E-09	9.05E-09	7.55E-09	4.85E-09	5.50E-09	9.74E-09
2500	6.27E-10	4.78E-09	2.83E-08	6.48E-10	3.85E-09	2.69E-09	6.73E-10	1.46E-08	9.90E-10	6.75E-09	5.91E-09	3.65E-09	3.99E-09	7.22E-09

Appendix E - Collective doses from naturally occurring radionuclides

1 Introduction

Collective dose rates have been calculated for typical levels of naturally occurring radionuclides in North European waters, covering the OSPAR area. The radionuclides considered are tritium, carbon-14, potassium-40, rubidium-87, polonium-210, lead-210, radium-226, uranium-234, uranium-235 and uranium-238. Four exposure pathways have been considered: the ingestion of radionuclides in fish, crustacea and molluscs, and external irradiation from radionuclides in sediment. The collective dose rate per year for each pathway is given in Table 1, together with the total summed over all radionuclides and pathways.

2 Results

The collective doses were calculated using the same methodology as used for the main study but based on measured activity concentrations in marine foods (Pentreath, 1988) rather than predicted values. For tritium and uranium-235, the concentration in seafood was estimated from the measured concentration in water (Pentreath, 1988) and the marine food concentration factors used in this study (Table 2 in the main text). The collective doses due to external irradiation during beach residency were calculated using measurements of activity concentrations in coastal sediment (dry weight) for the UK (McDonald 1991).

Table 1 shows that the total collective dose rate to the population of the EU from naturally occurring radionuclides in the marine environment is $1.7\ 10^{4}$ man Sv y^{-1}. This rate will be constant over time, assuming that the concentration of naturally occurring radionuclides remains the same and the seafood harvest data remain constant over time. Most of the dose is from the consumption of fish (43%) and molluscs (36%) with most of the remaining dose from the consumption of crustacea (16%). The most important radionuclide is polonium-210, which contributes nearly 80% of the total collective dose rate.

3 Discussion

The concentrations of polonium-210 in seafood used in the assessment were based on measurements reported by Pentreath, 1988. The average values used were 1.5 Bq kg^{-1} for fish, 25 Bq kg^{-1} for crustacea and 50 Bq kg^{-1} for molluscs (wet weight). These are within the ranges of concentrations of polonium recently measured in seafood around the UK (Young, 2002). These are: fish 0.22 to 4.4 Bq kg^{-1}, median 0.78 Bq kg^{-1} (cod, whiting and plaice); crustacea 2 to 35 Bq kg^{-1}, median 8 Bq kg^{-1} and for molluscs 4 to 52 Bq kg^{-1}, median 20 Bq kg^{-1}, (wet weight). Pelagic fish (those that live and feed in the water column such as mackerel) were not considered in this study. Shannon (1973) reported that pelagic fish contain roughly five times more polonium-210 than demersal species (those that live and feed on the bottom such as plaice).

The above figure is for natural radioactivity in the marine environment only. There are other sources of exposure from natural radioactivity and an estimate has been made of the annual collective dose to the population of the EU from all natural background radiation. A value for the total collective dose rate for all natural sources of $8.44\ 10^{5}$ man Sv y^{-1} for the EU was obtained by scaling from the estimated UK per caput dose (Hughes, 1999). The fraction of the annual collective dose resulting from natural radioactivity in the marine environment is about 2%. This is consistent with the contribution of the collective dose from polonium-210 in seafood of 1.1% given by Hughes, 1999.

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Table 1. Collective dose rate (man Sv y^{-1}) to the population of the European Union from naturally occurring radionuclides in the marine environment.

Radionuclide	Dose from the ingestion of radionuclides in fish	Dose from the ingestion of radionuclides in crustacea	Dose from the ingestion of radionuclides in molluscs	External dose from beach occupancy
Tritium	$5.21\ 10^{-3}$	$1.55\ 10^{-4}$	$1.72\ 10^{-4}$	0
Carbon-14	$2.52\ 10^{1}$	$7.51\ 10^{-1}$	$8.32\ 10^{-1}$	0
Potassium-40	$1.79\ 10^{3}$	$5.35\ 10^{1}$	$5.93\ 10^{1}$	$5.81\ 10^{2}$
Rubidium-87	$4.34\ 10^{0}$	$1.29\ 10^{-1}$	$1.44\ 10^{-1}$	0
Polonium-210	$5.21\ 10^{3}$	$2.59\ 10^{3}$	$5.74\ 10^{3}$	$7.97\ 10^{-4}$
Lead-210	$7.99\ 10^{1}$	$1.19\ 10^{1}$	$1.98\ 10^{2}$	$3.11\ 10^{-1}$
Radium-226	$8.10\ 10^{1}$	$4.83\ 10^{-1}$	$8.03\ 10^{0}$	$1.87\ 10^{2}$
Uranium-234	$1.70\ 10^{0}$	$5.07\ 10^{-1}$	$1.41\ 10^{0}$	1.83E-01
Uranium-235	$2.99\ 10^{-1}$	$8.92\ 10^{-2}$	$2.97\ 10^{-1}$	$8.45\ 10^{-1}$
Uranium-238	$1.43\ 10^{0}$	$4.27\ 10^{-1}$	$1.16\ 10^{0}$	$3.64\ 10^{0}$
Total	$7.20\ 10^{3}$	$2.66\ 10^{3}$	$6.01\ 10^{3}$	$7.73\ 10^{2}$

The total collective dose rate summed over radionuclides and exposure pathways is $1.7\ 10^{4}$ man Sv y^{-1}

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MARINA II

Update of the MARINA Project on the radiological exposure of the European Community from radioactivity in North European marine waters

Annex E: Critical Group Exposure

CRITICAL GROUP EXPOSURE

Report of Working Group B

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1 Introduction

The aim of this report is to identify existing assessments of radiological exposures from marine pathways to critical groups in the OSPAR region, and to examine the assumptions included in these calculations. Table 1 summarises the habit data used in the various projects discussed here. Uncertainty assessments of these doses are also considered where available. The sources of radioactivity include civil nuclear site discharges, solid waste disposal in the Northwest Atlantic, fallout from the Chernobyl accident, fallout from nuclear weapons testing and naturally occurring radionuclides. The dose limit for a member of the general public is 1 mSv a^{-1}, and in most regions the main anthropogenic contributor to dose from marine pathways is ^{137}Cs. Below, sources of dose estimations are identified for critical groups in different geographical regions, and the assumptions and some key dose rates are recorded. After these summaries, there is a more general discussion concerning the different approaches used and possibilities for the future of dose assessment.

2 Northern Europe

The Marina Project (1990) examined doses to a variety of critical groups using data available from reports and publications. The critical groups considered were those living near nuclear facilities and those exposed to solid waste disposal in the north-east Atlantic, fallout from the Chernobyl accident, and naturally-occurring radionuclides. The habit data used in the calculations varies according to the source of the information, and is therefore difficult to summarise here. Monitoring programs provided the data for levels of radioactivity in the food and sediments of the different areas.

The highest critical group doses from a nuclear installation were found near Sellafield where, in the period between 1980-86, exposures were estimated by MAFF to be as high as 3.5 mSv a^{-1}. These doses do not agree with more recent retrospective assessments (see below; Hunt, 1997) largely because of a change in the gut transfer factor used for the transuranics. The older calculations use a gut transfer factor of 0.0005 and the newer calculations use a factor of 0.0002 for transuranics in winkles, which deliver a large proportion of the dose in this area. In the following period, doses were calculated to fall following changes in waste management practices.

All critical group doses from waste disposal at sea were calculated to be less than 0.002 mSv a^{-1}. These calculations used a hypothetical pathway in which the critical groups consumed 600 g d^{-1} of fish muscle. The highest dose from the Chernobyl accident was delivered to the critical group in the Baltic Sea region (which does not fall within OSPAR), who received a maximum dose of 0.08 mSv during 1986.

Naturally occurring radionuclides deliver maximum critical group doses of 2 mSv a^{-1}, with ^{210}Po being the most important radionuclide.

2.1 Cap de la Hague

In the Nord-Cotentin radioecology group report (1999), realistic estimates were made of doses to the most-exposed group of individuals in the Beaumont-Hague Canton region of France. The sources of exposure were nuclear facilities, medical and natural radiation, fallout from weapons testing and the Chernobyl accident. The local nuclear facilities are the COGEMA Cap de la Hague reprocessing plants, ANDRA's shallow-land radioactive waste repository at Cap de la Hague, EDF's nuclear power station in Flamanville and the French Navy Arsenal in Cherbourg. Dietary and dose-relevant habits were included in the dose assessment along with data on the geographic areas of these groups. Monitoring programs supplied the activity data and activities were converted into doses using factors recommended by international organisations. The dose relevant habits used were the worst case habits, with exposure arising from particular behaviour or location, but they were kept within realistic limits. Effective doses were calculated, which are doses to the whole body.

The highest doses from marine and terrestrial pathways (outside the near field) were calculated to be received by the fishermen of Huquets and the farmers of Pont-Durand, who received 0.23 and 0.053 mSv a^{-1} in 1985 and 0.026 and 0.059 mSv a^{-1} in 1996, respectively (see Figure 1). These calculated doses were significantly higher than those received by the 'critical groups' used by COGEMA, the fishermen of Goury and the inhabitants of Digulleville, who were reported by COGEMA to receive 0.041 and 0.014 mSv a^{-1} in 1985 and 0.005 and 0.006 mSv a^{-1} in 1996, respectively. The differences in critical group dose assessments are a result of the choices of habit data, and the report suggests that these results may be considered as a test of the sensitivity of these factors. The doses can be compared with the natural radioactivity dose of 2.4 mSv a^{-1}. The habits of the fishermen of Huquets can be summarised as consumption of 67 kg a^{-1} of fish, 61 kg a^{-1} crustaceans and 31 kg a^{-1} molluscs, and 2400 h a^{-1} spent outdoors, 20 h a^{-1} bathing, 100 h a^{-1} on the beach and 2400 h a^{-1} handling fishing equipment. This list excludes the terrestrial pathways included in the assessment. The report recommends that uncertainty studies be carried out in the future on dose calculations.

An incident occurred at COGEMA in 1979/1980 when the sea release pipe was damaged, creating a hole about 1 m long and 4 cm wide. This was located approximately 200 m from the shore. The perforation is estimated to have occurred between September and the end of November 1979. The radiological impact of this incident was reconstructed. COGEMA used very conservative assumptions of seafood consumption and measurements of the activity of a number of radionuclides in the marine fauna (^{106}Ru-Rh, ^{144}Ce-Pr, ^{137}Cs, ^{125}Sb, ^{110m}Ag) and estimated activities of ^{90}Sr, which was not measured at the time. The doses were calculated to be 0.12 mSv in 1979 and 0.10 mSv in 1980 for the reference group (children from 7 to 12 years old). Complementary estimates were further completed by the Nord Cotentin Working group GT4, leading to individual doses (critical group) of 0.086 mSv in 1979 and 0.27 mSv in 1980 for an average adult and 0.21 mSv in 1979 and 0.66 mSv in 1980 for a fisherman. Since these are conservative doses, they cannot be directly compared with the doses plotted in Figure 1.

2.2 Sellafield

The area surrounding Sellafield is by far the most studied area in terms of doses to critical groups. MAFF conduct detailed and lengthy surveys of behaviour patterns in the area, and so the critical groups are well characterised. The environment and foodstuffs are also monitored closely. The main dose-delivering radioisotopes have changed over time, as have the main pathways, and remobilisation of elements such as Cs is considered along with direct discharges. This has been reviewed extensively in the literature (Hunt, 1991; Hunt, 1997; Hunt *et al.,* 1998, Hunt and Smith, 1999). There are also historical reassessments of doses, comparing exposure with the new limits and using ICRP 60 methodology (Hunt, 1997).

Briefly, until the early 1970's, the critical pathway was the consumption of *Porphyra umbilicalis* in the foodstuff laverbread, with the dose arising from ^{106}Ru. The peak effective dose rates fluctuated around the 1 mSv a^{-1} level from 1952-1970. Laverbread was mostly eaten in South Wales and this pathway became less important as rail transport between Cumbria and Wales was reduced. Emissions of ^{106}Ru also decreased from the mid-1970's, again reducing the importance of this pathway. The critical pathway for 1972-1973 became external exposure over mud in the Ravenglass estuary, due to the growing importance of ^{95}Zr/Nb and ^{144}Ce. Following this, due to an increase in radiocaesium emissions, the consumption of fish and shellfish was reported as the most important pathway, and this caused the highest internal doses to a critical group in the area, of 1.9 mSv a^{-1} in 1975 (Hunt, 1997). As caesium emissions declined, external radiation again became the most important pathway to the critical groups in 1985 because the external doses decrease more slowly than seafood concentrations in response to the lower discharges. Figure 2 shows the doses to the three main critical groups from 1988-1999, the consumers in the local fishing community, the houseboat dwellers on the river Ribble who have a relatively high external exposure from the long times spent over the contaminated sediment, and local fishermen who experience skin exposure via the handling of fishing gear. External exposure remained a key pathway, but from 1988, the local consumers again became the group receiving the highest dose. The higher external doses received by fishermen handling fishing gear in 1993 was attributed to an increase in exposure time. Figure 3 shows the changes in the consumption habits of the local consumers from 1988-1999, demonstrating the high variability of habit data from year to year.

For most of the period shown in Figure 2, the main contribution to the doses delivered by ingestion to consumers in the local fishing community came from ^{239,240}Pu and ^{241}Am. In the review by Hunt and Smith (1999), it is shown that this critical group would have experienced a peak effective dose in 1976 of about 2 mSv, of which about 30% was due to actinides. By the early 1990s, the overall dose had decreased to about 0.1 mSv a^{-1}, but the actinide component had increased to 80% prior to the introduction of Enhanced Actinide Removal Plant (EARP) in 1994. From this time, ^{99}Tc became an important contributor. Figure 4 shows the dose delivered from the most important isotopes to the critical group of consumers of fish and shellfish in the local community in 1993, 1997 and 1999. Doses to the critical group from ^{99}Tc peaked in 1997 at 0.053 mSv a^{-1}, and in this year ^{99}Tc was the largest contributor, with doses from ^{241}Am at 0.021 mSv a^{-1}. By 1999, ^{239,240}Pu and ^{241}Am were again the most important contributors to the exposure of this critical group, giving doses of 0.046 and 0.082 mSv a^{-1} respectively, compared to 0.016 mSv a^{-1} from ^{99}Tc.

Certain additional critical groups have appeared in the MAFF reports and these are outlined here. In 1993, fishermen on the Scottish coast were found to experience higher doses than the local Sellafield fishermen, receiving a dose of 0.11 mSv a^{-1}

using ICRP-60 methodology, through the consumption of 38 kg fish, 13 kg crustaceans and 16 kg molluscs in that year. In the 1990's, anglers who dig for bait were also found to experience high external doses through skin contact with intertidal sediment. Their doses have been as high as 0.88 mSv a^{-1} in 1997. In 1998, the highest internal dose pathway was through the consumption of fishing by-catches by a family of local consumers, who received 0.33 mSv each in the year. Seafood by-catches include seamice which are not normally eaten by humans. This critical group consumed 8.3 kg a^{-1} seamice, 19 kg a^{-1} crab, 22 kg a^{-1} whelks, 1.7 kg a^{-1} lobster and 7.5 kg a^{-1} plaice.

Doses as a result of contact with, or ingestion of, fragments of irradiated nuclear fuel of a similar size to grains of sand, known as hot particles, are currently being investigated. In the 1998 Scottish Environment Protection Agency (SEPA) report, the risks associated with ingesting or direct skin contact with one of the hot particles found in the vicinity of Dounreay were assessed. The presence of these particles has been explained by the United Kingdom Atomic Energy Authority by the fracturing of a plastic pipe which was used to transfer demineralised water to the Dounreay Materials Testing Reactor fuel element pond water. This caused the pond water to be siphoned out, contaminating an area of about 78 m^2. Attempts to clean the area involved removing contaminated grit and then hosing the area into a storm drain. UKAEA propose that some of these particles were transported to a cliff, where they remained until a severe storm in 1983 caused erosion and their release. An alternative theory (COMPARE/RWMAC, 1995) is that the area around the waste disposal shaft was contaminated, either by debris or by an explosion in 1977 or by accidental spillage, and that erosion of this area is the mechanism transferring the particles to the foreshore. The number of metallic particles found per annum is variable, ranging randomly between 4-26 in the period 1984 and 1994, and is not showing an appreciable decline. The doses from these particles could be significant. Ingestion of one of the highest activity particles (2×10^8 Bq; mainly from enriched uranium and fission products) could give a dose equivalent to the intestine of tens of sieverts and the dose to red bone marrow would be in the region of hundreds of millisieverts. Even the particles in the most probable activity range ($10^6 – 10^7$ Bq) would give an equivalent dose to bone marrow of tens of millisieverts. In 1997 the detection of pieces of irradiated fuel off shore resulted in a two-kilometre fishing exclusion zone.

3 The Baltic Sea

Marina-Balt (2000) examined doses to the Baltic critical groups on a regional scale, encompassing 9 geographic divisions. Of these, only the Kattegat falls within the OSPAR region. In the critical dose assessment, marine pathways that are known to be most important when radiocaesium is a major contributor were considered. These pathways include ingestion of fish, crustaceans and molluscs, inhalation of contaminated sediment and sea spray, and external exposure from occupancy on contaminated coastal areas. The habit data collected was highly variable and not easily divided into national habits. The upper end of the data was therefore combined and used for critical groups in all countries, as a conservative estimate. The habits of the critical groups were therefore assumed to include the consumption of 90 kg a^{-1} of fish, 10 kg a^{-1} of crustaceans and 10 kg a^{-1} of molluscs, and beach occupancy of 700 h a^{-1}. Assumptions on inhalation rates and concentrations of resuspended airborne particulates and seaspray were adapted from IAEA (1986). ^{137}Cs concentrations of fish and shellfish in the Baltic sea were used in conjunction with catch statistics and gut transfer units taken from IAEA (1996).

The doses to the critical groups from Chernobyl fallout, weapons testing fallout, nuclear reprocessing facilities, nuclear power plants, nuclear research facilities and sea dumpings in the 1960's were considered individually for each region, along with the does from natural radioactivity. Fallout from the Chernobyl accident dominates the annual dose in every critical group in the Baltic region, and the peak doses from the different sources are shown for the Kattegat region in Table 2. Naturally occurring radioactivity was considered from ^{210}Po, using typical Baltic Sea concentrations of 0.8 Bq kg^{-1} for fish, 20 Bq kg^{-1} for crustaceans and 30 Bq kg^{-1} for molluscs. The dose to critical groups from marine exposure pathways involving naturally occurring radionuclides is 0.7 mSv a^{-1}, a factor of 3-4 higher than any maximum dose rate from anthropogenic radioactivity in the Baltic region.

4 The Arctic Ocean

The Arctic Monitoring and Assessment Programme (AMAP) has looked in detail at Arctic sensitivity and the critical groups living in the Arctic. Information has been gathered on population characteristics such as occupation, housing and food consumption in 8 Arctic countries and the critical groups have been defined as those groups of people expected to receive higher doses of radiocaesium, as shown in Table 3. ^{90}Sr was considered for a few countries, but it is less significant than ^{137}Cs, particularly for the critical groups. The critical groups are of variable size and the Greenland group is hypothetical. Estimates of external dose have, where appropriate, taken account of the shielding effects of different types of dwelling. The data are based on environmental measurements and, where the habit data used are those collected specifically, the assessments are realistic.

The overall findings were that the major dose to the average population is from radon (0.5-4 mSv a^{-1}) giving a lifetime dose of 30-300 mSv. Anthropogenic radionuclides give average lifetime doses of 2-15 mSv, but the selected 'critical' groups receive total committed doses in the region of 145-160 mSv. The main source of dose from anthropogenic radionuclides is reindeer/caribou consumption, and so not from marine pathways. The uncertainty assessments for the general populations were made by comparison with whole body gamma measurements, which showed a general tendency for overestimation of dose via consumption pathways, with the exception of Northern Russia. They show the importance of including countermeasures in dose assessments, and the uncertainties that can arise from the averaging of national data. Whole body measurements to the critical groups were not discussed.

The European Commission Kara Sea report (1997) calculated the doses to critical groups from the dumping of radioactive waste in the Kara Sea using the IAEA assumptions of ingestion of 110 kg a^{-1} fish, 11 kg a^{-1} crustaceans and 8 kg a^{-1} molluscs, inhalation of 1 m^3 h^{-1} for 1000 h a^{-1} at a loading of 10g sea spray and 0.25 μg marine sediment per cubic metre of air, and external gamma-ray exposure from 1000 h a^{-1} occupancy of coastal beaches where coastal sediments have radionuclide concentrations 10 times lower than fine-grained marine sediments. The best-estimate scenarios show that dose rates to the critical group in Iceland peak in 3700 at 8 x 10^{-12} Sv a^{-1}, with contributions from ^{239}Pu and ^{240}Pu of 74% and 24%, respectively, predominantly through the consumption of molluscs. In Norway, the maximum annual dose of 1 x 10^{-11} Sv a^{-1} arose almost immediately from short-lived corrosion products (mostly ^{55}Fe) through ingestion pathways. In the Kola peninsula the maximum annual dose occurred in 1974 at a level of 9 x 10^{-11} Sv a^{-1}, with ^{55}Fe contributing 99.6% of the dose. Secondary maxima are also observed when Pu isotopes are released, and these dose rates are maintained over a longer period. Uncertainties were assessed and were found to be large however, even within the uncertainty of the predictions, the doses to critical groups did not exceed a few micro sieverts a year. The predictions were particularly sensitive to sedimentation processes that remove radionuclides from the water column.

The International Arctic Sea Assessment Project (IASAP) report (1998) examined the doses to critical groups from the dumping of radioactive waste in the Arctic seas. Only one of the critical groups falls within the OSPAR region – the group representative of the average local Russian population located on the Kola peninsula. Consumption of fish, assumed to be caught in the Barent's Sea, was taken as 50 kg a^{-1}, in addition to 0.5 kg a^{-1} of molluscs and 1 kg a^{-1} of crustaceans. Seaweed and sea mammal consumption were not included, nor was an external exposure pathway. Exposure was calculated for 3 exposure pathways: scenario A looks at the 'best estimate' assuming release is governed solely by corrosion processes, scenario B considers the 'worst possible case' where a collision or explosion causes a complete breach of the containment of the waste in the year 2050 and scenario C addresses 'climate change', where glaciation and subsequent warming cause release in the year 3000. All models assumed that all corroded material was immediately released to the environment, making these highly conservative estimates. All of the radionuclide inventories were included. Under scenario A, the relevant critical group was found to experience a maximum individual dose rate in the region of 5 x 10^{-12} – 2 x 10^{-9} Sv a^{-1} in the years 2000 - 2400, with the highest exposure arising from the Abrosimov fjord sources through ingestion of ^{137}Cs and $^{239,240}Pu$. Under Scenario B and considering only the Tsivolka fjord sources, this increased to 1 x 10^{-10} – 2 x 10^{-8} Sv a^{-1} in the years 2100-2200, through ingestion of ^{239}Pu and ^{137}Cs. Under Scenario C, the maximum individual dose rates of 6 x 10^{-10} – 6 x 10^{-9} Sv a^{-1} would be experienced in the years 3000-3089 through ingestion of $^{239,240}Pu$. Therefore, under any of the scenarios considered, the doses from these sea dumpings are negligible.

5 The Mediterranean

The Marina Med project (1994) assessed doses to the critical group in the Mediterranean region. The critical group considered was a generalised group with high fish and shellfish consumption rates, 73 kg a^{-1} and 35 kg a^{-1}, respectively. Average consumption rates were 5 kg a^{-1} of fish and 2 kg a^{-1} of shellfish. Doses from ^{137}Cs and ^{210}Po were considered, calculating the isotope concentrations in the fish and shellfish in two different ways. Firstly, the overall mean measured concentrations in fish and shellfish from the Mediterranean sea were used, and then the concentrations were calculated using measured seawater concentrations and the known biota concentration factors (IAEA, 1985). The mean of each pair of these values was used in the dose calculation, along with the fishing catch statistics and import/export for each region, and with Cs considered to have a 70 day half-life in the body.

It was calculated that the critical group received doses of 0.0005 mSv a^{-1} from ^{137}Cs and 0.54 mSv a^{-1} from ^{210}Po in 1990. The Po dose was half the annual dose from natural background excluding radon. The critical Mediterranean group may get an integrated effective dose from Chernobyl ^{137}Cs in marine food of about 0.0075 mSv, which is approximately 5 times lower than the Black Sea critical group and 2 times lower than Baltic critical group (Marina Project, 1990).

6 Estimated Doses in the OSPAR Region

Annual doses have been calculated for generic critical groups in the OSPSAR region in the period 1988-2000. Average consumption rates were based on the MAFF habit studies from 1988-1999 for the Sellafield critical group of local consumers in the fishing community:

- Fish – 34 kg a^{-1}
- Crustaceans – 12 kg a^{-1}
- Molluscs – 11 kg a^{-1}

This is considered the best estimate available for this generalised critical group, as it is the most detailed survey of actual habits. All exposure has been assumed to result from consumption of seafood, considering the isotopes ^{137}Cs, ^{90}Sr, ^{99}Tc and $^{239,240}Pu$. The activity concentration of each type of seafood was calculated from the maximum seawater concentration in each area in each year (see sections 2-5), using concentration factors taken from IAEA (1985). This approach was used because seawater data are the most abundant. The doses were calculated using dose factors recommended by the European Council (Directive 96/29 Euratom of 13 May 1996).

The results from this calculation show maximum annual doses in the range 0.01-0.2 mSv to individuals from critical groups in the Irish Sea region due to Sellafield discharges to sea. The doses are predominantly due to ^{137}Cs and $^{239,240}Pu$. For the remaining areas of the OSPAR region the maximum annual doses to individuals of the critical groups are below 0.01 mSv.

7 Discussion

The level of detail included in habit assessment varies very significantly depending on proximity to a recognised source term and the perceived risk to a critical group, as shown in Table 1. There is a very significant variation in critical group habits between the studies and Table 1 shows how there is at least a factor of 2 between the lowest and highest frequency of each habit. In order to make the most accurate assessment it is necessary to carry out detailed habit studies on a regular basis. The patterns emerging from the MAFF assessments of doses to the Sellafield critical groups shows how sensitive the data is both to fluctuations in discharges and the particular consumption or habit of the critical group over time (e.g. Figure 3). However, increasing the level of detail in these studies may not be particularly useful, or may be too complex to be of any practicable benefit. For example, although cooking practices will affect the dose received, including them will not aid the dose assessment without further information such as whether the cooking water is consumed in addition to the food (Jackson and Rickard, 1998). Factors such as size of organisms consumed are also of limited use because of lack of real information on where the seafood was caught and the cooking procedure used. Moreover, for a reasonable sized critical group, there may be some variation in these preferences, adding further to the complexity of how they can helpfully be used. In general, the level of detail that is useful is related to the risk to the group, the ability to define a critical group and the homogeneity of that group. Many studies of communities away from a particularly dominant source do not have a defined critical group, making specific habit studies impossible to carry out. Equally, the habit data of the critical group may be too disperse, such as that collected in the Marina-Balt project which could not be used to define regional critical groups.

The general consensus in dose assessment is for realistic rather than conservative assessments, based on habit data for the population of interest and including uncertainty assessment of the numbers reached. Arguably, it is not relevant to put uncertainties on intentionally conservative estimates, or for predictive calculations, which tend to be for the worst-case scenarios. The current reality is that uncertainty assessments are rarely given, and when they are, they are quite vague rather than being carefully derived numbers. Examples of attempts to include an uncertainty assessment are the Nord-Cotentin project (2000) where the groups identified as critical in the area of COGEMA reprocessing plant differed in the studies by COGEMA and Nord-Cotentin. The Nord-Cotentin study suggested that this was an indication of the sensitivity of the choice of habit data. Another approach, when calculating uncertainties on internal doses, is to carry out whole body measurements and contrast these with the calculated dose, as done in the AMAP project for doses to the general population. If an uncertainty has to be derived from the assumptions included in the dose calculation, it must include considerations such as whether the data is generic, or from habit studies for that area. What time scale/how often/how detailed were the habit studies? How many radionuclides are included? How accurate are the gut transfer factors[1]? How homogenous is the critical group?

Since uncertainty assessments are difficult to derive in the absence of an 'experimental' check, such as thorough whole body gamma counting, they will tend to be large. They will be particularly large when doses are very low, and when a definable, homogenous critical group is not available. In the absence of a relevant habit study for a critical group, consumer data can be used to calculate hypothetical critical groups through consumption pathways, as there are accepted relationships between critical consumers and average consumers. For example, in the UK critical consumers tend to eat 10 times more of a particular foodstuff than average consumers. While realistic data are generally more preferable than worst case estimates, in many regions of low anthropogenic input worst case estimates still give sufficient

[1] Hunt (1991) discusses using gut transfer factors of 0.0002 and 0.0005 for Pu and Am as realistic and cautious approaches.

confidence that it is a very low risk area. The choice of a very inaccurate 'realistic' dose assessment over a conservative one may be of marginal, if any, actual benefit, and the 'fitness for purpose' of the assessment should be considered.
Since 1983 fragments of irradiated nuclear fuel of a similar size to grains of sand have been found in the marine environment around the Dounreay Research facility, Scotland. The radiation doses as a result of human contact with, or ingestion of, these hot particles could be significant. SEPA carry out a beach monitoring program, aimed at removing the particles, but Day (2001) argues that the program is inadequate and estimates that less than 1% of the particles which may be on, or in, the beach over the course of time will be detected and removed. Further work is on-going and information can be found on the SEPA website (http://www.sepa.org.uk).

The Nord-Cotentin report looks in detail at public health issues, addressing the effect of nuclear facilities on the likelihood of leukaemia in young people living in the area. The data could not explain the cases of leukaemia occurring in the area, and they suggest other sources of radioactivity be monitored more closely.

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Table 1 Summary of habit data

Study (Year)	Habit Assessment	Consumption (kg a^{-1})			Beach Occupancy (h a^{-1})
		Fish	Crustaceans	Molluscs	
Marina (1990)	From literature and reports	Varied according to the information available for each location			
Marina Med (1994)	Assumption	73	35		
EC Kara Sea (1997)	IAEA assumptions	110	11	8	1000
IASAP (1998)	Estimated to be representative of the average local Russian population	50	1	0.5	Not considered
MAFF/SEPA (1998)	Realistic, from detailed habit studies	45	28	15	‡1100
Nord-Cotentin (1999)	Realistic worst case estimates – 95 percentile of seafood consumers	†67	†61	†31	†*100
Marina Balt (2000)	Realistic estimate from habit data collected in the region	90	10	10	700

†These data are for the most exposed group in this study – the fishermen of Huquets

*N.B. the fishermen of Huquets also spend 2400 h yr^{-1} outside and 2400 hr a^{-1} handling fishing equipment.

‡The critical group is the local fishermen who spend this time over intertidal sediments.

Table 2 Peak annual doses to the critical group in the Kattegat from different sources (Marina-Balt, 2000)

Source	Region	Year of Peak Dose Rate (1950-2000)	Peak Annual Dose (mSv a^{-1})
Weapons Fallout	All	1965	0.01
European Reprocessing Facilities	Kattegat	1980	0.02
Chernobyl Fallout (70% of the maximum dose in the Kattegat)	Kattegat	1986	0.04

Table 3 Critical Group Descriptions in AMAP report (1998)

Region	Critical Group	Habits
Finnish Lapland	Adult Saami reindeer herders	Dwellings and food consumption are specifically assessed and monitored over time
Greenland	Hypothetical group	Assumed to consume only reindeer meat (not imported meat or lamb), only freshwater fish (not marine) and locally collected berries (not imported fruit)
Northern Russia	Reindeer herders	Dwellings, movement and food assessed. Food studied carefully since the 1960’s.
Northern Norway	Males and females associated with reindeer breeding	National data
Iceland	Over 50 age group (highest fish consumption)	National data
Arctic Sweden	Reindeer herders	Relatively high consumption of reindeer meat and fish from the region

Figure 1 Variation of the annual total effective dose to fishermen in the Huquets area (Nord-Cotentin, 2000)

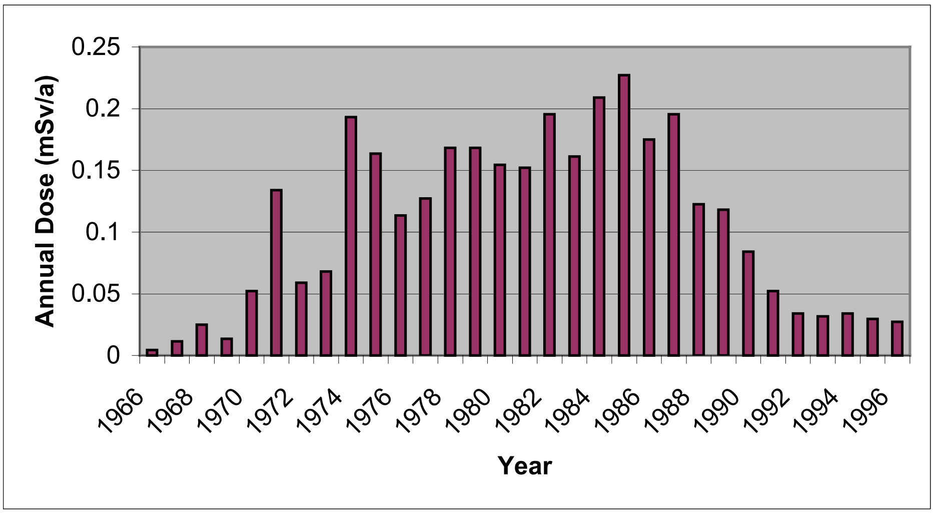
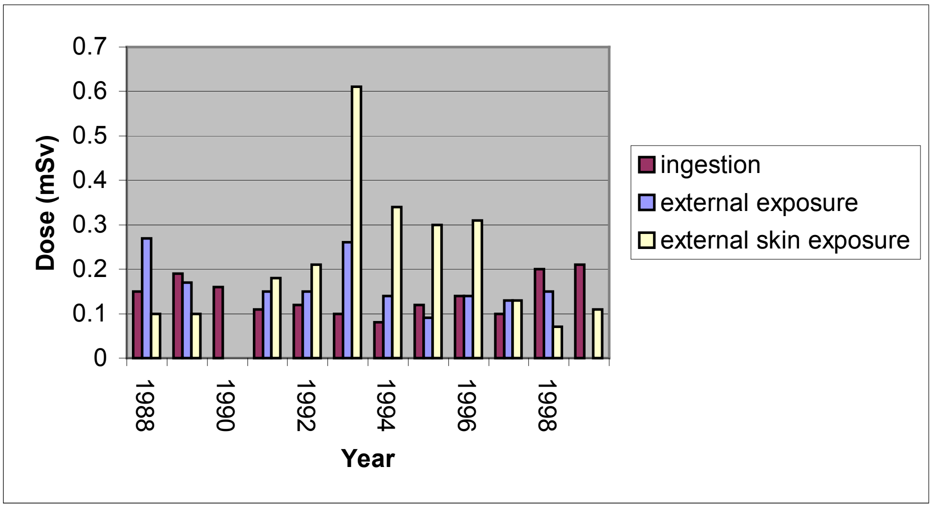


Figure 2 Doses to the Sellafield critical groups over time (MAFF/SEPA reports 1988-1999, except for 1990 data which comes from BNFL and only considers the local consumer critical group).



The doses to the consumers in the local fishing community are internal doses, using the accepted gut transfer factors for transuranics of 0.0002 for winkles caught in the Irish Sea and 0.0005 in other cases. 1999 is an exception as it includes a contribution from the external dose. Doses to the houseboat dwellers on the River Ribble are external doses. Those to the local fishing community from handling fishing gear are doses to skin, and should be compared with the ICRP-recommended dose limit of 50 mSv a^{-1}.

Figure 3 Consumption of fish, crustaceans and molluscs by the critical group of consumers in the local fishing community near Sellafield (MAFF/SEPA reports, 1988-1999)

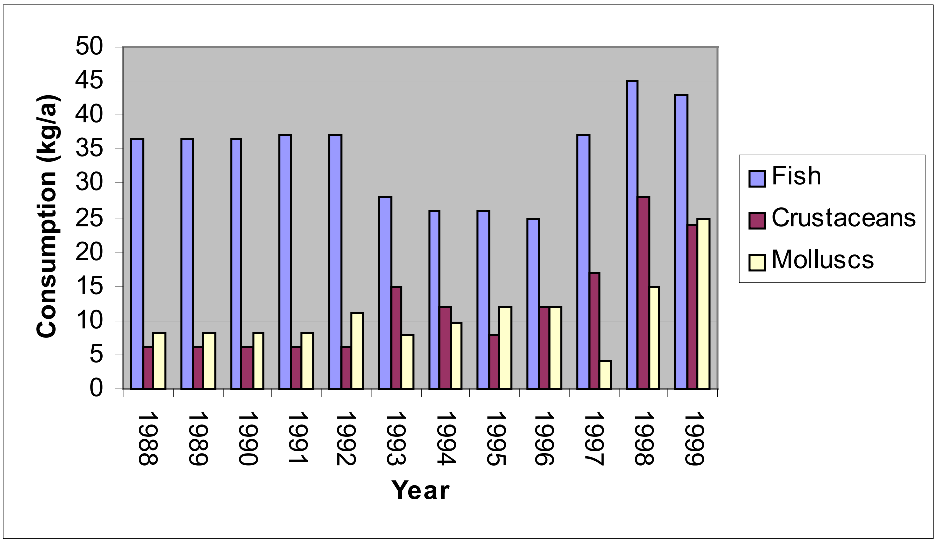
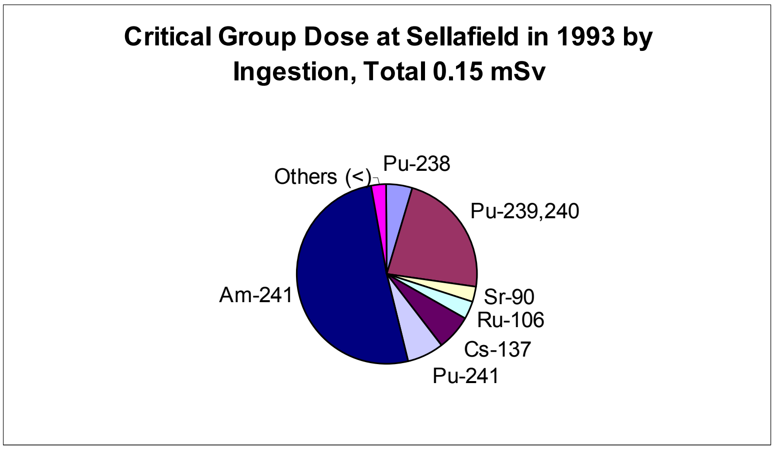
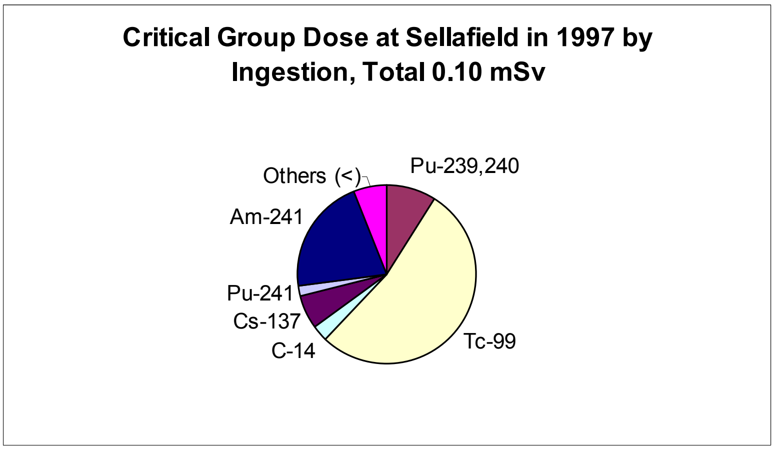


Figure 4 Dose distribution by nuclide to the fishing community critical group at Sellafield by ingestion. 1999 includes an external exposure component, which was not considered in 1993 or 1997 (MAFF/SEPA reports, 1993, 1997 and 1999).





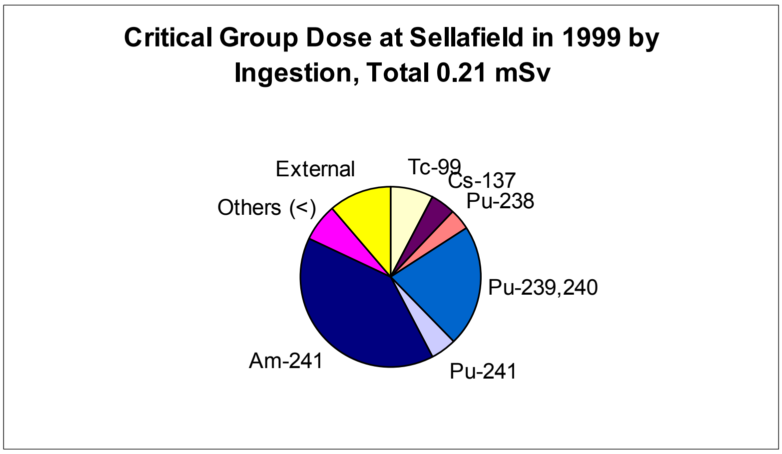
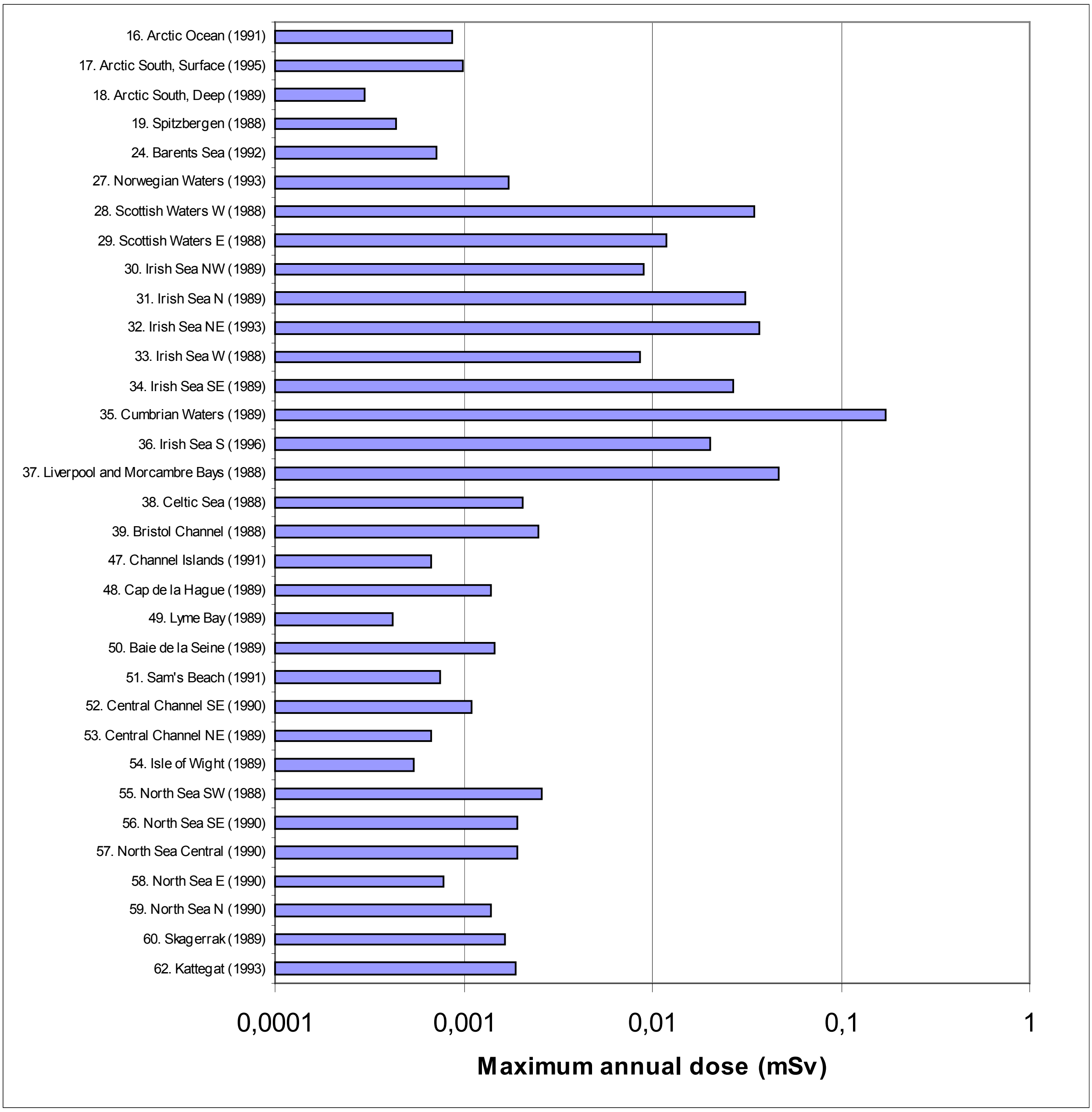


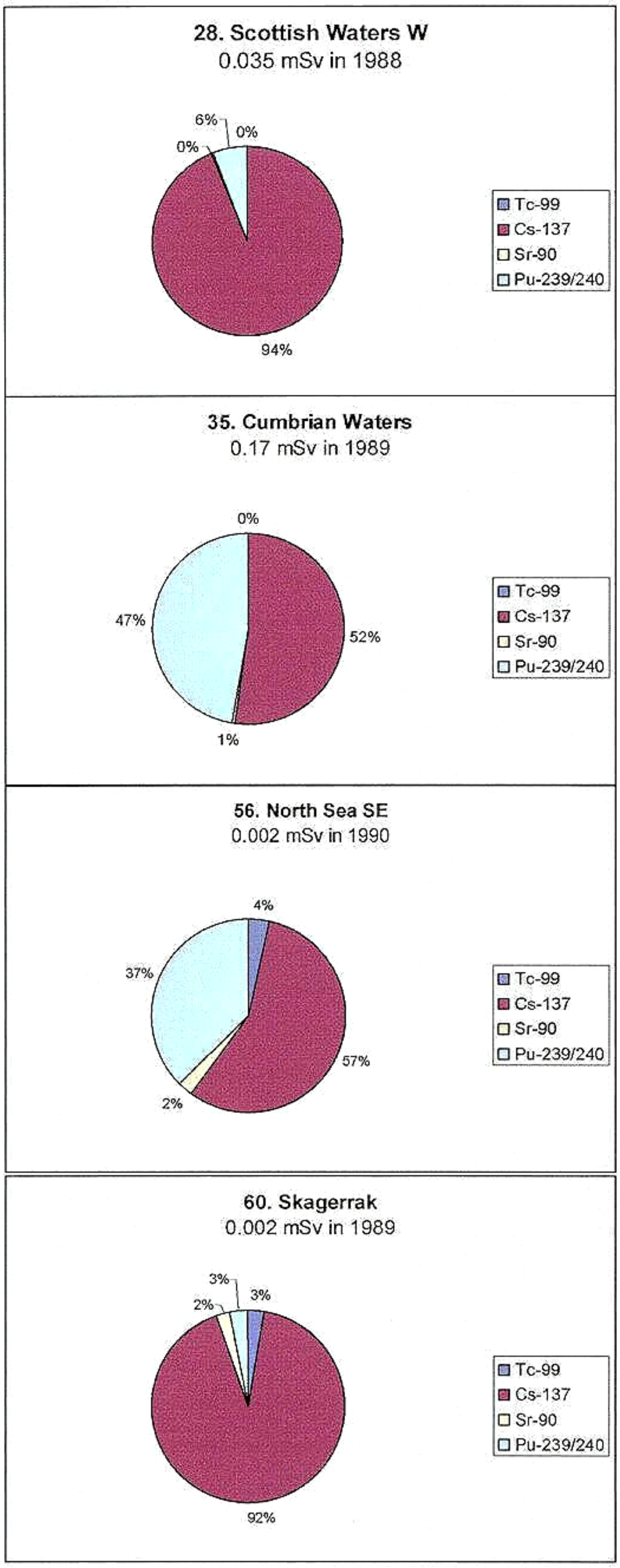
Figure 5 Maximum[2] annual doses in the OSPAR region from marine pathways (mSv) calculated from observed concentrations of man-made radionuclides in the water



The figure shows for each sub-region the compartment number, the compartment name and in brackets the year in which the maximum dose occurs.

[2] These are the maximum annual doses based on normalised consumption rates and not the actual maximum doses measured.

Figure 6 Maximum annual doses from marine pathways in selected OSPAR regions (compartment number, compartment name) shown by contribution from man-made radionuclides



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European Commission

MARINA II

Update of the MARINA Project on the radiological exposure of the European Community from radioactivity in North European marine waters

Annex F: Assessment of the Impact of Radioactive Substances on Marine Biota of North European Waters

Marina II

ASSESSMENT OF THE IMPACT OF RADIOACTIVE SUBSTANCES ON MARINE BIOTA OF NORTH EUROPEAN WATERS

Report of Working Subgroup D*

By

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This report, nevertheless, remains the responsibility of the authors.

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Glossary of Terms

The following terms have been adopted or modified from: IAEA International basic safety standards (1996), IAEA Safety Glossary (2000), NRPB (1998), Environment Agency (2001), Berkeley National Laboratory glossary and ecological literature.

Absorbed dose. Quantity of energy imparted by *ionising radiation* to unit mass of matter such as tissue. Unit *gray,* symbol Gy. 1 Gy = 1 joule per kilogram; also 1 rad = 0.01 Gray.

Activity. Attribute of an amount of a *radionuclide.* Describes the rate at which transformations occur in it. Unit *Becquerel,* symbol Bq. 1 Bq =1 transformation per second.

Acute exposure. Exposure received within a short period of time. Normally used to refer to exposure of sufficiently short duration that the resulting *dose* can be treated as instantaneous (e.g. less than an hour). Usually contrasted with *chronic exposure.*

Alpha particle (alpha radiation). A positively charged particle (a ^{4}He nucleus) made up of two neutrons and two protons. It is the least penetrating of the three common forms of radiation, being stopped by a sheet of paper.

Aquatic Biota. Plant or animal life living in or on water.

Background radiation. The exposure of organisms to radiation naturally existing in the environment.

Becquerel (Bq). See *activity.*

Benthic organisms. Animals and plants living on or within the bottom sediments of an aquatic ecosystem.

Beta particle. An electrically charged elementary particle (electron or positron), emitted during the decay of some radioactive elements. The mass of electron is 1/1836 of that of a proton.

Bioaccumulation. The capacity of organisms to accumulate in their bodies some contaminants in higher concentrations through dietary intake or directly from the environment.

Biota. Plant and animal life of a particular region.

Chronic exposure. Exposure persisting in time.

Community. An assemblage of populations of different species within a specified location in space and time.

Concentration factor for aquatic organism. The ratio of radionuclide concentration in an aquatic organism to that in water.

Cosmic Rays. High energy *ionising radiation* from space.

Cytogenetic damage. Damage to chromosomes that can be detected on the microscopic level.

Decay of a radionuclide. The process of spontaneous transformation of a *radionuclide.* The decrease in the activity of a radioactive substance.

Demersal fish. Fish inhabiting the deeper layers of water column.

Deterministic effect. A *radiation* effect for which generally a threshold level of dose exists, above which the severity of the effect is greater for a higher dose.

Dose assessment. Assessment of the *dose(s)* to an individual or group of organisms.

Dose. A measure of the energy deposited by *radiation* in a target.

Dose rate. Dose delivered over a specified unit of time.

Electron. An elementary particle with low mass, 1/1836 that of a *proton,* and unit negative electric charge. Positively charged *electrons,* called positrons, also exist. See also *beta particle.*

Equivalent dose. The quantity obtained by multiplying the *absorbed dose* by a radiation weighting factor to allow for the differing effectiveness of the various types of *ionising radiation* in causing harm to organism.

Fertility. The number of fertilized eggs produced in a given time in sexually reproducing plants and animals.

Gamma ray. A discrete quantity of electromagnetic energy without mass or charge emitted by a *radionuclide.* Gamma rays are high-energy electromagnetic photons similar to X-rays. They are highly penetrating and several inches of lead or several feet of concrete are necessary to shield against them.

Gray (Gy). See absorbed dose.

Ion. Electrically charged atom or grouping of atoms.

Ionisation. The process by which a neutral atom or molecule acquires an electric charge and become an ion.

Ionising radiation. *Radiation* that produces *ionisation* in matter. Examples are *alpha particles, beta-particles, gamma rays, X-rays* and *neutrons.*

Linear energy transfer (LET). A measure of how, as a function of distance, energy is transferred from radiation to the exposed matter. *Radiation* with high LET is normally assumed to comprise of protons, neutrons and alpha particles (or other particles of similar or greater mass). *Radiation* with low LET is assumed to comprise of photons (including *X-rays* and *gamma rays*), electrons and positrons.

Morbidity. A decline in well-being due to a worsening of the physiological characteristics of the organism, e.g. effects on the immune system, blood system, nervous system, etc.

Naturally occurring radionuclides. *Radionuclides* that occur naturally in significant quantities on Earth.

Pelagic organisms. Animals and plants living in water column of marine ecosystem. Pelagic organisms are distinct from *benthic* organisms. Phytoplankton, zooplankton, planktivorous fish are examples of pelagic organisms.

Phytoplankton. Passive or weakly motile suspended small plants (mostly microscopic algae). The plant subgroup of plankton.

Plankton. Small organisms which are passively suspended in water column.

Poikilotermic animals. Animals, which are unable to maintain the body temperature at a constant level. The body temperature of a poikilotermic animal follows the temperature of the environment. E.g. fish, molluscs, crustaceans, frogs are poikilotermic organisms.

Population. Group of individuals of a particular species inhabiting a specified territory.

Proton. An elementary particle with unit positive charge, stable nucleus of a hydrogen atom.

Rad. Unit of absorbed dose of ionising radiation equal to an energy of 100 ergs per gram of irradiated material.

Radiation (ionising). Refers to alpha particles, beta particles, photons (gamma rays or x-rays), high-energy electrons, and any other particles capable of producing ions.

Radiation weighting factors (w_r). Defined as multipliers of absorbed dose used to account for the relative effectiveness of different types of radiation in inducing health effects.

Radioecological assessment. Includes the analysis of radionuclide accumulation and transfer in the biotic components of the environment. Complex radioecological assessment includes also *radiological assessment* for non-human organisms.

Radiological assessment for non-human organisms. Includes assessment of doses received by organisms and analysis of biological effects of radiation. Assessment is aimed at providing information that forms the basis of a decision whether the radiological situation is satisfactory or not.

Relative Biological Effectiveness (RBE). Ratio of the absorbed dose of a reference radiation (normally gamma rays or X rays) required to produce a level of biological response to the absorbed dose of the radiation of concern required to produce the same level of biological response, all other conditions being kept constant.

Stochastic Effects. Effects for which the probability of occurrence is a function of dose, without threshold, but the severity of the effects is independent of dose.

Zooplankton. Weakly motile suspended small animals (mostly invertebrates). The animal subgroup of plankton.

Executive Summary

The objectives of work

The primary objective of the MARINA II study is to provide input from the European Commission to the work of OSPAR RSC in implementing the OSPAR Strategy with regard to radioactive substances and the work of the European Commission in respect of this Strategy. The OSPAR Strategy places particular emphasis on the radiological impacts on man and biota and requires contracting parties to develop further scientific tools for assessing radiation exposure and risk especially to marine organisms. Consequently a sub-group in the MARINA II Study was established to address the radiological aspects relating to biota and this chapter presents the results of the work of that sub-group.

Methodology for assessing doses and radiation impact on marine biota

At present, no internationally agreed criteria, or guidance, exist for assessing the impact of environmental radiation on flora and fauna.

An assessment methodology has been identified, in the present report, for the estimation of doses and radiation impact on marine biota, based on the current 'state-of-the-art' in the dosimetry of non-human organisms, and available information of the effects of chronic radiation exposure on aquatic organisms. The methodology includes the following components: identification of biological endpoints of concern; selection of region-specific organisms for assessment; adaptation of dosimetric models for dose calculations and, radiological assessment for marine biota.

The biological endpoints of concern

There are significant differences between the radiation protection of man, and the non-human biotic environment, in relation to the definition of the biological endpoints of concern. For humans the concern is on the potential impairment of health in any individual resulting from inherited or somatically acquired mutations. In the environment the concern is on the maintenance of the integrity of ecosystems and component populations of different species, which, in turn, depends on the survival and reproduction of individual organisms in the populations.
Four umbrella endpoints have been proposed to be inclusive of relevant effects at the level of individual organisms (FASSET Project, 2001):

- **Morbidity** (a decline in well-being due to a worsening of the physiological characteristics of the organisms, e.g., effects on the immune system, blood system, nervous system, etc.);

- **Reproduction** (negative changes in fertility and fecundity resulting in reduced reproductive success, i.e. reduced production of reproductively competent individuals in the following generations);

- **Cytogenetic effects** (cytological and genetic changes in tissues) and,

- **Mortality** (shortening of lifetime because of the combined effects on different organs and tissues of the organism).

During normal operating conditions, both in the nuclear industry and in other industries dealing with natural radionuclides, the radioactive waste management activities (inclusive of authorised releases directly to the environment) are associated with chronic exposure of flora and fauna at comparatively low dose rates.

Dose-effect relationships

To evaluate the possible harm to biota, the dose rates to organisms inhabiting the industry-impacted marine areas in the OSPAR region, have been compared with the available information on the effects of radiation in aquatic organisms.

Comprehensive reviews on the effects of ionising radiation on non-human organisms provide the following general conclusions on the range of chronic dose rates, which are of practical interest in the radiological assessment for aquatic and coastal organisms (including sea birds and marine mammals):

NCRP report (1991):

"It appears that a chronic dose rate of no greater than 10 mGy day^{-1} (1 rad day^{-1}) to the maximally exposed individual in a population of aquatic organisms would ensure protection for the population. If modeling and/or dosimetric measurements indicate a level of 2.5 mGy day^{-1}, then a more detailed evaluation of the potential ecological consequences to the endemic population should be conducted" (page 62, conclusions);

IAEA report (1992):

"*In the aquatic environment it would appear that limiting chronic dose rates to 10 mGy day^{-1} or less to the maximally exposed individuals in a population would provide adequate protection for the population"* (page 53, summary);

UNSCEAR report (1996):

*"Overall consideration of the data available for the effects of chronic irradiation on aquatic organisms has led to the conclusion that dose rates up to 10 mGy day^{-1} to a small proportion of the individuals in aquatic populations (and, therefore, lower average dose rates to the whole population) would not have any detrimental effects at the population level"***(**para 176);

"*For the most sensitive animal species, mammals, there is little indication that dose rates of 10 mGy day^{-1} to the most exposed individual would seriously affect mortality in the population. For dose rates up to an order of magnitude less (1-2.4 mGy day^{-1}), the same statement could be made with respect to reproductive effects" (conclusions, p.59)* .

In the terrestrial environment harmful effects to animals are not expected at dose rates below 1 mGy day^{-1}.

None of the above cited dose rate levels were intended as recommendations for radiation protection criteria although they clearly could have implications for the development of such criteria.

To provide an understanding of natural normal levels of radiation exposure of marine biota, the natural background exposure has been estimated for the representative marine organisms.

Selection of region-representative marine organisms

It is practically impossible to perform radioecological assessment for every species from the thousands inhabiting the waters of the North-East Atlantic. This problem has been solved by selecting a limited set of region-specific organisms, which have been used as representative marine organisms in this radioecological assessment. The report presents the criteria for, and a selection of, the region-specific organisms for the OSPAR marine region. The selected representative species satisfy most, or all, of the selection criteria; they form large populations, and their natural areas of geographical distribution cover the whole or the greater part of the OSPAR region.

The set of region-representative organisms includes molluscs (mussel and winkle/limpet), large crustaceans (crab and lobster), fish (cod and plaice). The contamination of the region-specific species is studied within radioecological monitoring/research programmes; databases on the concentrations of radionuclides are available for these organisms. Some preliminary assessments were made for seafood-eating coastal birds and seals; however, these organisms are not the subjects of systematic radioecological monitoring.

In the radiological assessment, the use of region-specific organisms throughout the whole OSPAR region offers the possibility to compare the doses to biota at different locations of the North-East Atlantic. However, there are some shortcomings that may affect the comparisons, such as: the representativeness of organisms within the existing monitoring programs; frequency of sampling and differences in type of exposures among the organisms.

Dose assessment to marine biota in the OSPAR region

In the MARINA II Update study, dose rates to representative marine organisms have been calculated using the existing dosimetric approaches; adaptations were made to take into account the sizes and habits of the region-specific organisms. Doses from both external and internal pathways have been estimated, as well as total dose rates to the representative organisms.

To account the differences in the relative biological efficiency of α-, β-, and γ- radiation, a radiation weighting factor (w_r) of 20 has been selected for α-emitting radionuclides as a very conservative assumption, and a factor of 1 for other radionuclides.

Dose assessments to marine biota have been made for the selected representative areas of the OSPAR region:

- Coastal areas in the vicinity of nuclear reprocessing plants (Sellafield, UK; Cap de la Hague, France);
- Near coastal zone of nuclear power plant (Ringhals NPP in Sweden);
- Coastal zones in the vicinity of non-nuclear plants, characterized by discharges of enhanced levels of natural radionuclides (phosphate plant at Whitehaven, UK; offshore oil installations in the North Sea);

- Remote marine areas with low levels of man-made radioactivity, which are considered as relatively non-contaminated waters in the OSPAR region (Barents Sea, North-Norwegian coastal waters).

Real data of measurements of radionuclide concentrations in the marine biota, seawater and sediments have been used for 'dose-to-biota' estimates. This information has been obtained in the course of routine/research monitoring programmes. The environmental data for dose assessment has been compiled by the Working Group B within the frame of the MARINA II Project; these include databases from BNFL and MAFF/CEFAS; Nord-Cotentin database; data from the AMAP programme, and journal publications. The assessments were made for the periods extending from the early 1980s to the late 1990s.

Average dose rates (in Gray per day) to site-specific organisms have been calculated for each year of observations, using a computer code linked with databases. Uncertainties in dose rates associated with the scattering of monitoring data were estimated to be about one order of magnitude.

The results of dose assessment to marine biota

During the assessment period, dose rates to representative organisms within the OSPAR region varied within a very broad range from about 10^{-9} Gy day^{-1} in the remote, relatively 'clean' areas up to about 10^{-4} Gy day^{-1} in the industry-impacted zones (values weighted by w_r).

Among the marine zones affected by the nuclear industry, the highest dose rates to marine biota were estimated for the **Sellafield coastal area** impacted by the BNFL nuclear reprocessing plant. The dose rates to representative organisms that inhabit the Sellafield coastal waters are shown in Figure 1, demonstrating the gradual decrease of radiation exposure to biota during the assessment period (1986-2001).

Molluscs (mussel, winkle) were found to be the most exposed group among the assessed marine organisms, as a result of high accumulation of many radionuclides in their tissues. The contribution of different radionuclides to the dose rates to molluscs is shown in Figure 2.

Crustaceans (crab, lobster) were found to receive somewhat lower radiation exposures than molluscs; dose rates to fish were lower than those to crustaceans. The contribution of different radionuclides to the dose rates to fish is given in Figure 3.

Preliminary estimations of the exposure of seafood-eating birds, inhabiting the vicinity of Sellafield, have revealed that dose rates to this group of near-sea organisms were closer to those to molluscs and higher than those to fish. Preliminary estimations for grey seals indicated that dose rates were approximately the same as for large fish.

During the assessment period (1986-2001), the estimated dose rates to marine biota in the vicinity of Sellafield were found to be even lower than the levels suggested in the literature at which effects on aquatic organisms at a population level would be unlikely (UNSCEAR 1996, IAEA 1992). A gradual decrease in dose rates was found during the assessment period, although the exposure to marine organisms at Sellafield from man-made sources remained

higher than that of the same species in the remote, relatively 'clean' areas within the OSPAR region (Barents Sea).
Doses to marine biota at the **Cap de la Hague coastal area** in France, affected by the nuclear reprocessing plant, were somewhat lower than those at Sellafield, with a gradual decrease in the dose rates throughout the assessment period 1982-1997 (see Figure 4).

Estimated dose rates to marine biota due to artificial radionuclides in the vicinity of a nuclear power plant (**Ringhals NPP in Sweden**) were very low during recent years (1997-2000), amounting to a minor addition to natural background.

Regarding non-nuclear industry-impacted zones, the radiation exposure to marine biota in 1991-1999 was estimated in the vicinity of the phosphate plant at **Whitehaven (UK**) where raw minerals with enhanced levels of naturally occurring radioactive material (NORM) were processed until 1992. At the beginning of the assessment period, the estimated radiological impact to marine biota from a big phosphate plant was found to be comparable with that from a large nuclear reprocessing plant at Sellafield. In the recent years the additional dose rates to marine biota at Whitehaven (from NORM) were of the same order of magnitude as the natural background.

The radiation impact on marine biota in the vicinity of **offshore oil installations in the North Sea** is associated mainly with the elevated concentrations of radium isotopes released with produced waters[1] from oil platforms. Presently there exist no monitoring data but model estimations indicate that the radiation exposure of marine biota in the immediate proximity of oil platforms may be enhanced, especially in the local zones with slow water currents. Accurate evaluation of this impact is a task for further investigation.

Dose rates due to man-made radionuclides in the marine areas of the OSPAR region remote from sources of radionuclide discharges (e.g. **Barents Sea**) are negligible compared with the natural background.

Radioecological situation in marine ecosystems of the OSPAR region

Figure 5 shows the estimated dose rates to molluscs from exposure to radionuclides at the selected locations within the OSPAR region.

All estimated dose rates to marine biota within the OSPAR region are below the lower boundary of the zone of deterministic effects on the health and reproduction of marine organisms.

Conclusion

According to the **available information** and the dose assessment for the selected industry-impacted locations in the OSPAR region, there is no identifiable impact on populations of marine biota from radioactive discharges.

The methodology for determining the impact of radioactivity on marine biota is still under development. In the future, the methodology of radiological assessment to natural biota will

[1] Produced water is the description given to the large quantity of contaminated water produced when pumping oil and gas from the wells.

be improved following the development of scientific knowledge on the dose-effect relationships in marine organisms.

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UNSCEAR. United Nations Scientific Committee on the Effects of Atomic Radiation. (1996). *Effects of Radiation on the Environment,* Annex to *Sources and Effects of Ionising Radiation* (1996 Report to the General Assembly, with one Annex), Scientific Committee on the Effects of Atomic radiation, UN, New York

Figure 1 **Radiation exposure of marine biota in the Sellafield coastal area (Cumbrian waters, UK). Man-made radionuclides**

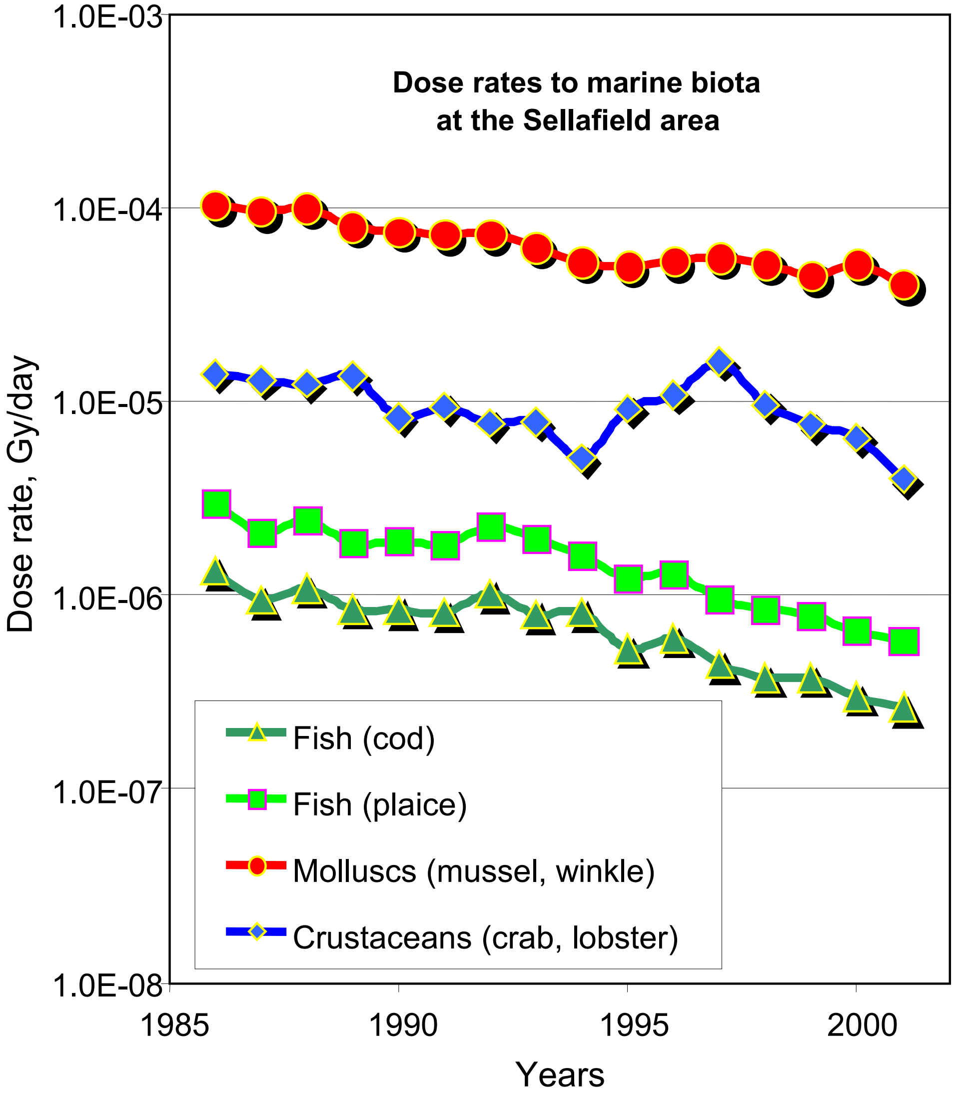


Figure 2 **Sellafield coastal area, UK. Contribution of different radionuclides to the radiation exposure of molluscs in 1986-2001; detailed figure for the year 1999**

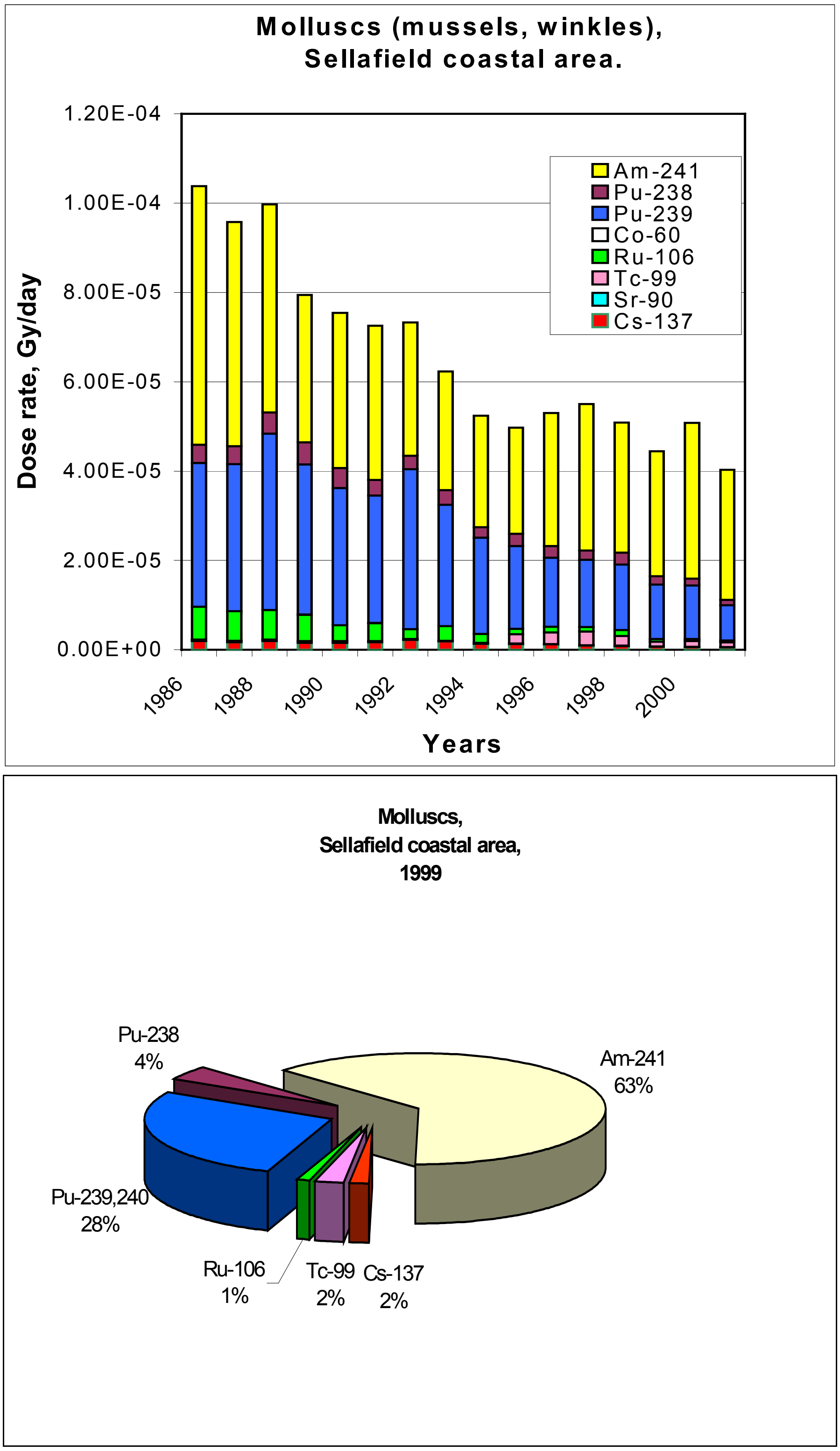


Figure 3 **Sellafield coastal area, UK. Contribution of different radionuclides to the radiation exposure of fish (cod) in 1986-2001; detailed figure for the year 1999**

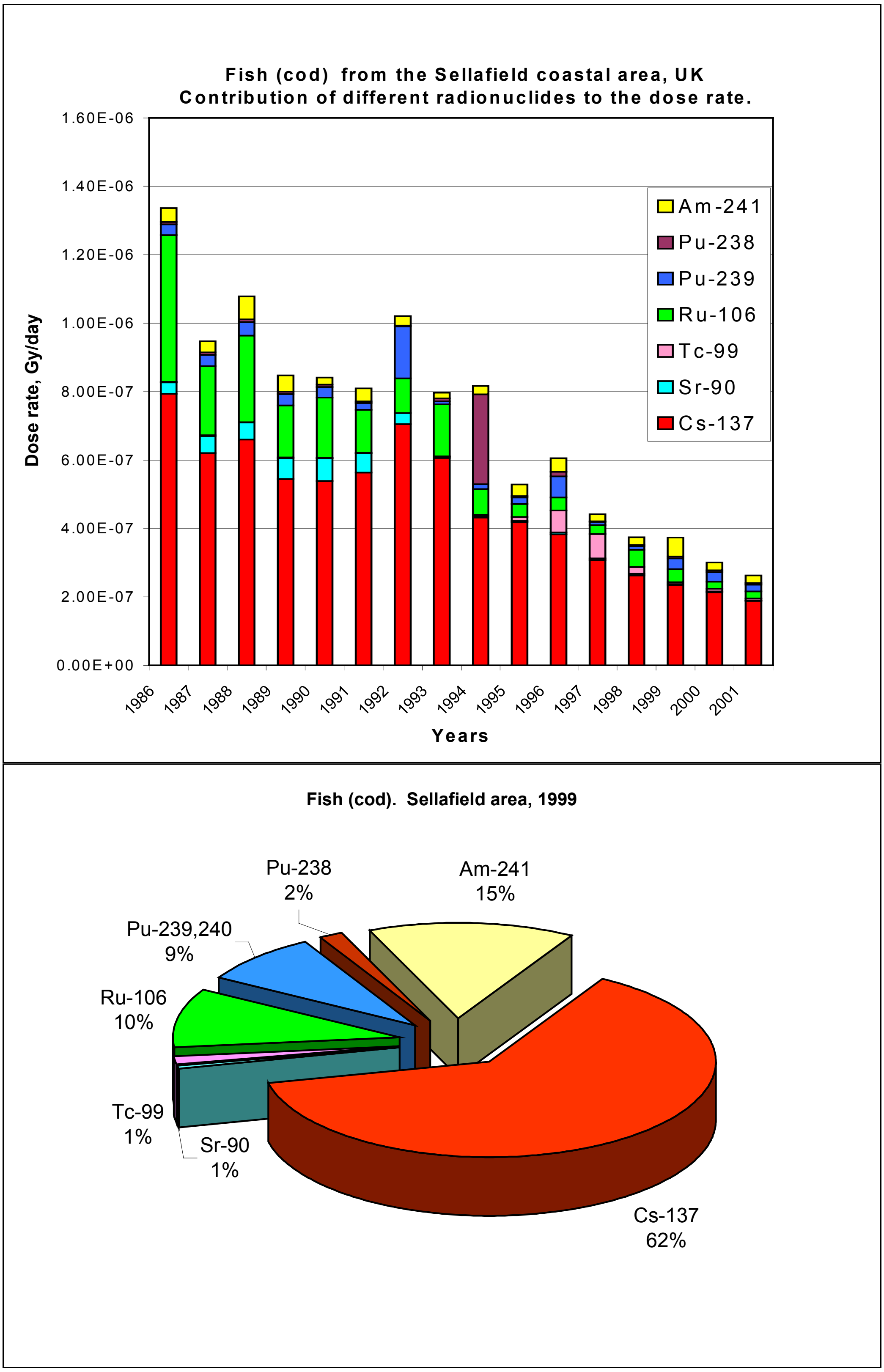


Figure 4 **Radiation exposure of marine biota at the Cap de la Hague coastal area (France) due to man-made radionuclides. *Data on alpha-emitters were available only for Patella molluscs (limpets)**

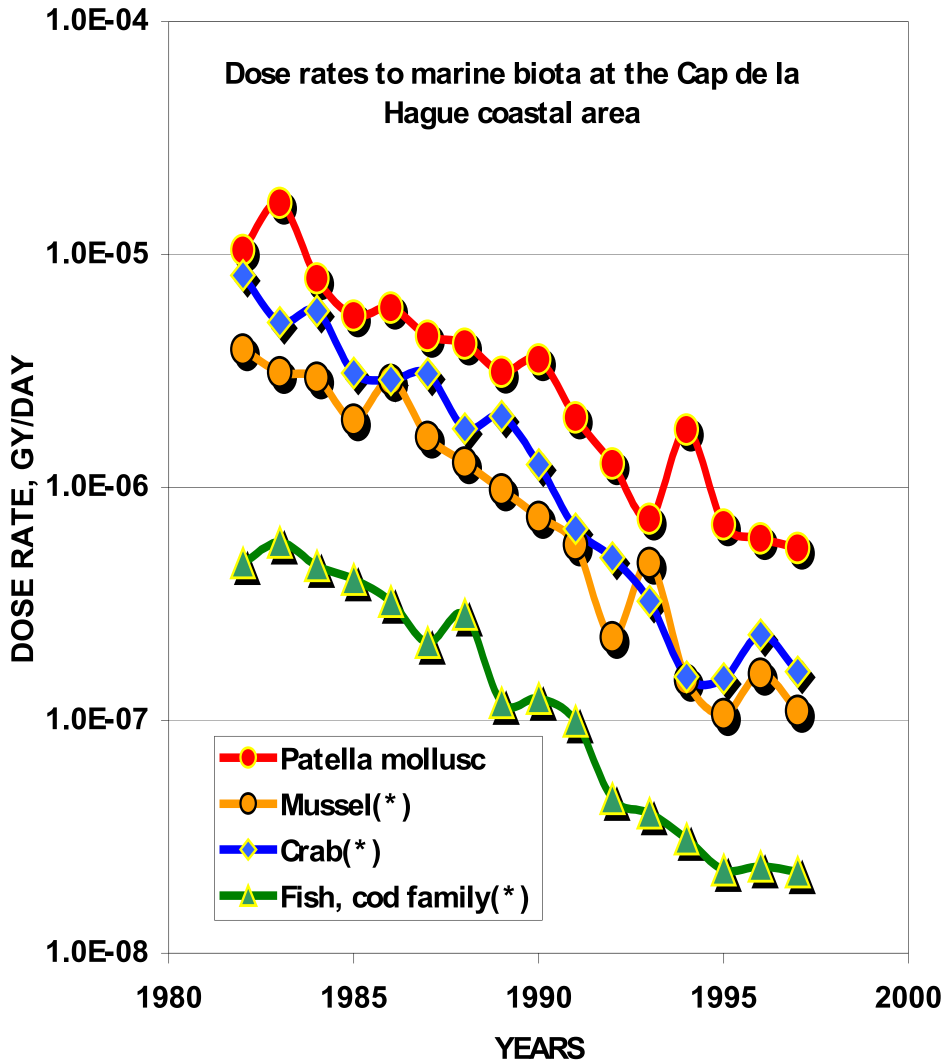
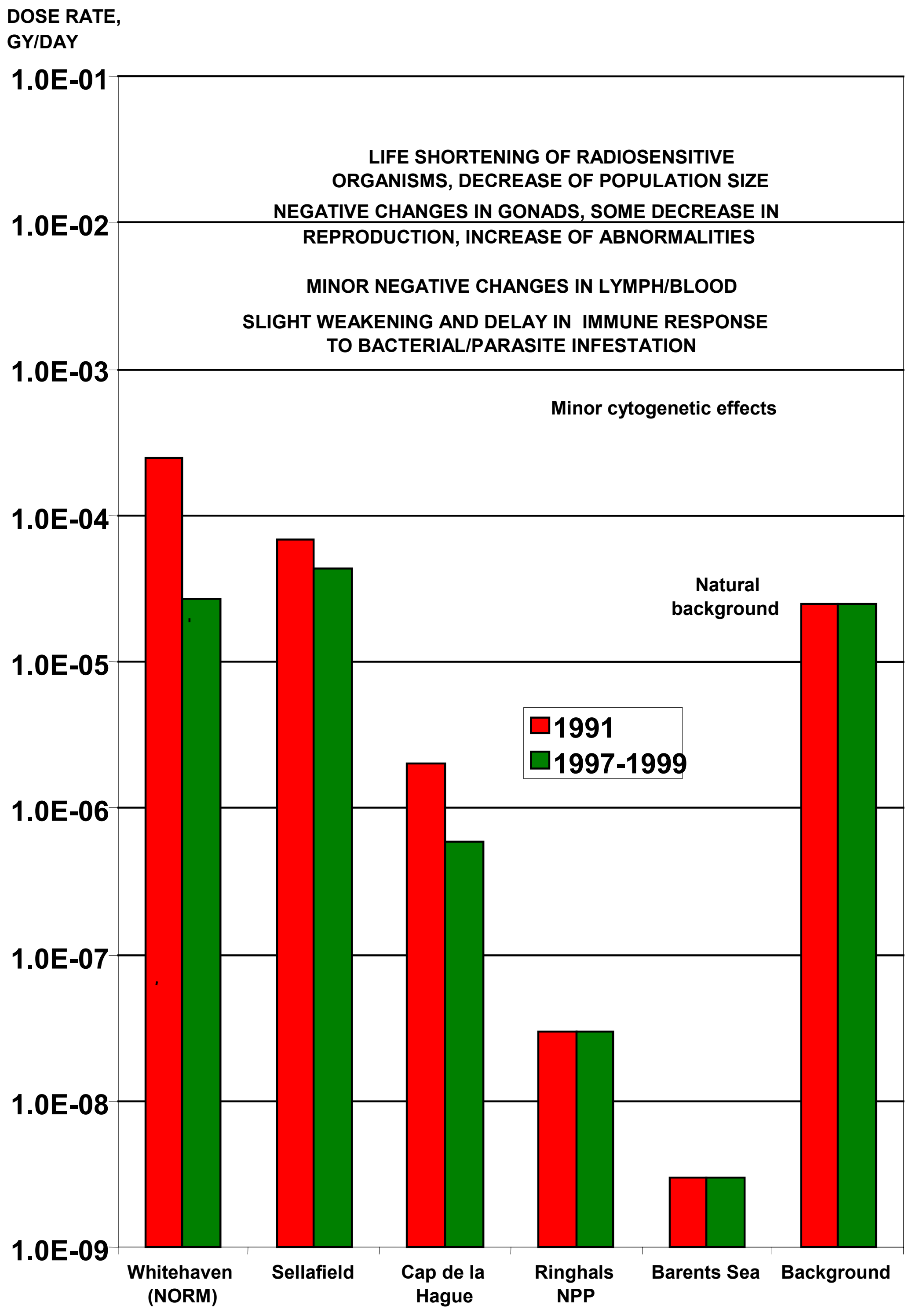


Figure 5 **Radiation exposure of molluscs in the OSPAR region (additional exposure above natural radiation background)**



Note: Presented are annual average values of dose rates to molluscs at different locations of the OSPAR region; values for molluscs near Ringhals NPP are upper estimates of dose rates.

1 Introduction

There is a growing international interest of specialists and the public in establishing a regulatory framework for protection of the environment from the effects of ionising radiation. Until the recently, the international position concerning the radiation protection of biota was based on the ICRP statement that "… if man is adequately protected then other living things are also likely to be sufficiently protected" (ICRP, 1977. 1991). However, *Homo sapiens* represents only one biological species, whereas the biosphere consists of millions of species, differing considerably from man by their size, lifespan, habitat, habits and radiosensitivity. The living conditions for non-human organisms in the natural ecosystems are not comparable with the conditions of human life, and the radiation doses to non-human organisms may be orders of magnitude different from the exposure of humans.

The Rio Declaration on Environment and Development (UNCED, 1992a) and the Convention on Biological Diversity (UNCED, 1992b) provided an internationally agreed concept of "sustainable development", including requests for environmental protection, the conservation of biodiversity, and the maintenance of ecosystems and the ecological processes essential for the healthy functioning of the biosphere. For industries, which may release hazardous wastes to the environment, an environmental impact assessment for both humans and the environment is an established practice (EIA Directive 85/337/EEC amended by 97/11/EC). There is a growing consensus that from ethical, legal and scientific perspectives, specific radiation protection standards are needed for the environment *per se*, with a focus on the ecological consequences from detrimental effects of ionising radiation.

The problems of the radiation exposure of marine biota in northern European waters, and the possible consequent biological impacts, were not addressed in the report of the original MARINA project (MARINA I, 1990). The subject did arise, however, at the associated seminar held in Bruges, Belgium in June 1989, and a short paper, outlining the, then, state-of-the-art in the approach to dose assessment for aquatic organisms, was included in the seminar proceedings (Woodhead & Pentreath, 1989).

The new MARINA Update project, besides dealing with the assessment of radiation exposure to the human population, established a subgroup (subgroup D[*]) with the specific task of assessing the dose rates to, and estimating the possible radiobiological effects on, representative non-human organisms, inhabiting the marine waters of the North-East Atlantic within the OSPAR area. The present report summarizes the methodology and results of this radiological assessment.

2 Approaches for protecting flora and fauna from ionising radiation

At present, the European Union regulations (Directive 96/29/EURATOM Basic Safety Standards) regarding the protection of the environment from ionising radiation are based on the ICRP approach (ICRP, 1977, 1990) and Basic Safety Standards (IAEA, 1996) with exclusive consideration of protection of humans from exposure. The environment is mainly considered as a pathway for radionuclide transfer to man. No internationally agreed criteria, or guidance, exist for assessing the impact of environmental radiation on flora and fauna.

In recent years, considerable international efforts have been undertaken to develop scientifically correct and practically acceptable methodologies for assessing the possible impact on the environment from the effects of increased exposure to ionising radiation, and, thus, to provide a basis for the protection of the non-human biotic environment.

Several relevant international documents have been prepared: OSPAR Strategy with regard to Radioactive substances (1998); UNSCEAR Report (1996), IAEA TECDOC 1091 (1999), and others. Preliminary ideas and views on the problem have been discussed in recent publications (Larsson et al., 1996; Pentreath, 1998, 1999; Pentreath and Woodhead, 2000; Howard, 2000; Strand et al., 2000; Kryshev, Sazykina, 1998; Sazykina, Kryshev, 1999a,b); publications and reports of the EULEP/EURADOS/UIR Joint Concerted Action (1997-1999). Two special International Congresses have been organized in Stockholm (1996) and Ottawa (1999). In addition, the IAEA has organized several specialists' meetings to discuss the principles of the protection of the environment from the effects of ionising radiation (IAEA, working materials, 1997-2001).

Two innovative EC projects commenced in 2000: FASSET (Framework for Assessment of Environmental Impact) and EPIC (Environmental Protection from Ionising Contaminants in the Arctic), which are directed towards the development of appropriate methodologies to provide for environmental protection from radiation; the project activities include the preparation of databases on dose-effect relationships, the selection of reference biota, and the development of dose assessment models, as well as the application of the methodologies to the extreme Arctic environment.

In 2000, the ICRP organized a special Task Group with the aim to develop a policy and suggest a framework for the environmental protection from radiation hazards based on scientific and ethical principles. The new policy, and the conceptual framework, should feed into the ICRP's next set of recommendations. The Task Group will report their findings in 2003.

The U.S. Department of Energy (DOE) has been active in developing frameworks and guidance for demonstrating protection of the environment from the effects of ionising radiation. DOE currently has in place an interim standard approach for the protection of aquatic organisms (U.S. DOE, 2000), and has considered dose rate standards for both aquatic and terrestrial biota. The DOE technical standard assumes upper limits for the protection of plants and animals at the following absorbed dose rates: for aquatic animals, 1 rad day^{-1} (10 mGy day^{-1}); for terrestrial plants, 1 rad day^{-1} (10 mGy day^{-1}); and for terrestrial animals, 0.1 rad day^{-1} (1 mGy day^{-1}). The approach used in the U.S. technical standard applies these dose limits to representative, rather than maximally exposed, individuals in given populations of plants and animals.

2.1 Existing scientific recommendations for protecting the aquatic wildlife from the effects of ionising radiation

During normal operating conditions, in both the nuclear industry and other industries dealing with natural radionuclides, the radioactive waste management activities (inclusive of authorised releases directly to the environment) are associated with a consequent chronic exposure of flora and fauna at comparatively low dose rates (with accumulated doses well below those likely to lead to increased mortality) (IAEA, 1976). Even in the areas contaminated by radiation accidents, high dose rates leading to the lethal exposure of the flora and fauna have only been observed within a short period immediately after the release of the radionuclides.

There have been many reviews of the available radiobiological literature from the viewpoint of its utility for providing a basis for assessing the possible impacts of chronic, low-level irradiation arising from radionuclide contamination of the environment (see, e.g., Polikarpov, 1966; Turner, 1975; IAEA, 1976; 1988; 1992; Blaylock & Trabalka, 1978; Woodhead, 1984; Anderson & Harrison, 1986; NCRP, 1991; Rose, 1992; UNSCEAR, 1996). In most cases, the declared intention was to concentrate on the data generated by studies at chronic, low dose rates, but this relevant material was found to be rather limited. Inevitably, therefore, the reviews included some data obtained from experiments to determine the acute effects of short-term exposures at high dose rates (and usually, therefore, high doses); while not directly relevant to the majority of environmental concerns, these data were used as a basis for informed extrapolations.

The later and the most comprehensive reviews on the effects of ionising radiation on non-human organisms provided the following general conclusions on the range of chronic dose rates which provide adequate protection for populations of aquatic organisms:

NCRP report (1991):

"It appears that a chronic dose rate of no greater than 10 mGy day^{-1} (1 rad day^{-1}) to the maximally exposed individual in a population of aquatic organisms would ensure protection for the population. If modeling and/or dosimetric measurements indicate a level of 2.5 mGy day^{-1}, then a more detailed evaluation of the potential ecological consequences to the endemic population should be conducted" (page 62, conclusions).

IAEA report (1992):

"*In the aquatic environment it would appear that limiting chronic dose rates to 10 mGy day^{-1} or less to the maximally exposed individuals in a population would provide adequate protection for the population"* (page 53, summary);

UNSCEAR report (1996, para 176):

"Overall consideration of the data available for the effects of chronic irradiation on aquatic organisms has led to the conclusion that dose rates up to 10 mGy day^{-1} to a small proportion of the individuals in aquatic populations (and, therefore, lower average dose rates to the whole population) would not have any detrimental effects at the population level".

"For the most sensitive animal species, mammals, there is little indication that dose rates of 10 mGy day $^{-1}$ to the most exposed individual would seriously affect mortality in the population. For dose rates up to an order of magnitude less (1-2.4 mGy day $^{-1}$),

the same statement could be made with respect to reproductive effects" (conclusions, p.59).
In the terrestrial environment the harmful effects to animals are not expected at dose rates below 1 mGy day^{-1}.

None of these dose rate levels were intended as recommendations for radiation protection criteria although they clearly could have implications for the development of such criteria.

The above-cited conclusions of the NCRP, IAEA and UNSCEAR make it possible to evaluate a range of chronic dose rates, which are of practical interest in the radiological assessment of marine organisms:

- Dose rates in the range 1-10 mGy day^{-1} are considered as the levels at which minor radiation effects on the morbidity, fertility and fecundity of individual aquatic animals begin to become apparent first in laboratory studies, and, at higher exposure, in natural populations;

- At average dose rates above 2.5 mGy day^{-1} to aquatic organisms NCRP recommended to consider a more detailed evaluation for the most vulnerable populations;

- Average dose rates higher than 10 mGy day^{-1} are assumed to be harmful to populations of aquatic organisms.

In this report the recommendations of the NCRP (1991), IAEA (1992) and UNSCEAR (1996) reports are used for the evaluation of the possibility of detrimental effects of radiation on populations of marine organisms within the OSPAR area.

It should be noted, however, that the currently available information concerning the effects of chronic exposure on aquatic wildlife is very limited; for instance, there is no data on marine mammals, which probably are the most radiosensitive animals in marine ecosystems. The marine mammals can be considered in the same way as the great majority of terrestrial mammals, i.e. by informed extrapolation from the available data on effects in mammals.

Polikarpov (1977, 1998, 2001) has generalized the available information into a conceptual scheme of the effects of chronic exposures to ionising radiation, based on changes in the most radiosensitive organisms, populations and ecosystems. The scheme includes the following categories:

(a) the 'Uncertainty' zone (below the lowest natural ionising radiation background level);
(b) the 'Radiation well-being zone' (natural ionising radiation background range);
(c) the 'Physiological masking zone' (0.005–0.1 Gy y^{-1}); in this zone minor cytogenetic, physiological and morbid effects can be observed; however the scale of effects does not significantly exceed the natural range of variability in physiological functions of organisms;

(d) the 'Ecological masking zone' (0.1-0.4 Gy y^{-1}); in this zone a variety of radiation effects can be registered on the organism's level; significant masking of these effects in ecosystems occurs due to natural selection, variability of ecological conditions etc.;

(e) the 'Zone of damage to communities/ecosystems' (>>0.4 Gy y^{-1}); in this zone obvious radiation effects are registered, including increased mortality of organisms, elimination of some species, impoverishment of ecosystems;

(f) the 'Radiation threshold for lethality of the biosphere' (>>MGy y^{-1}).

The scheme, as proposed by Polikarpov, provides a general view on the range of bio-ecological effects of radiation; it allows any estimate of the incremental dose rate from contamination in the environment to be placed into context so that an approximate indication of its significance may be obtained.

Estimates of the dose rates to aquatic biota in the most contaminated sites of the world (areas of Kyshtym and Chernobyl radiation accidents; areas of historical releases of radionuclides) demonstrate that dose rates about 10 mGy day^{-1} were characteristic for the exposure of biota in these highly contaminated water bodies (Blaylock, Trabalka, 1978; Sokolov et al., 1994; UNSCEAR, 1996; Kryshev et al., 1998; Kryshev & Sazykina, 1995, 1998).

2.2 RBE and radiation weighting factors

The magnitude of harmful effects, caused by ionising radiation depends not only on absorbed dose, but also on the type of ionising particles, produced by the decay of a radionuclide. The α-, β-, and γ-radiation differ from each other by penetrating capacity, particle size, energy, and by their ability to produce ions in biological tissues. The alpha particles are known to have the highest ionising effect in biological tissues per unit of absorbed dose.

To account for the different quality of radiation the concept of relative biological effectiveness is employed. The relative biological effectiveness (RBE) is defined as the ratio of dose required to achieve a specific biological effect from a standard radiation (typically gamma rays) to that required for the same end point from different types of radiation. The value of the RBE is thus expressed as a ratio of two different radiation doses required to producing the same effect.

$$RBE = D_l/D_h;$$

where *D* is the adsorbed dose in tissue to produce a specific effect and *l* and *h* refer to the low-LET standard and the test high-LET radiation. This interpretation tacitly assumes that the energy distribution throughout the irradiated system is uniform, and has no consequence on the measurement of effects.

The values of RBE can be experimentally estimated for different types of radiation. It is practically impossible to obtain experimental values of RBE for a great number of possible endpoints and every type of organisms. Instead, a simple set of radiation weighting factors is employed. The radiation weighting factors (w_r) are defined as multipliers of absorbed dose used to account for the relative effectiveness of different types of radiation in inducing health effects (ICRP, 1991; IAEA, 1996). The value of

w_r for a given type of radiation is derived from available values of RBE. The equivalent dose is calculated by multiplying the absorbed dose by the radiation weighting factor.

A special problem in radiobiology of non-human organisms is the establishment of appropriate radiation weighting factors between equal absorbed doses of α-, β,- and γ-radiation. Up to now, there are no officially established values for the radiation weighting factors for organisms other than man.

UNSCEAR (1996) has proposed that a radiation weighting factor (w_r) of 5 for alpha particles is, perhaps, appropriate for non-human biota, based on the approach that deterministic effects are of greater importance for wildlife than stochastic effects. Based on experimental data, Kocher and Trabalka (2000) suggested that the weighting factors for deterministic effects of alpha radiation are within the range from 5 to 10. A weighting factor of 20 for alpha particles is suggested in a number of publications (e.g., Woodhead, 1984; Blaylock et al., 1993; Environment Agency, 2001).

Regarding beta radiation, a radiation weighting factor of 3 has been proposed for tritium (Environment Canada, 2000; Environment Agency, 2001); UNSCEAR (1996) has made a general recommendation to use a radiation weighting factor of 1 for all beta emitters.

Efforts are being undertaken within current EC Projects (FASSET and EPIC) to evaluate experimentally derived RBE values for various relevant endpoints and dose rates for biota in order to develop radiation weighting factors appropriate for environmental protection.

As a very conservative default for the purpose of this assessment, it seems reasonable to apply a radiation weighting factor of 20 to the absorbed dose from α-particles and a factor of 1 for beta- and gamma- radiation, and to quantify the biologically equivalent dose in the unit of Gy, weighted by w_r.

3 Endpoints of concern in radiation protection of wildlife

There are some significant differences between the radiation protection of man on one hand, and the biotic environment on the other, in relation to the definition of the biological endpoints of concern. Besides taking into account deterministic effects for humans the concern is on the potential impairment of health in any individual resulting from inherited or somatically acquired mutations.

Human ethics requires, that each individual person should be protected, and the dose limit established for the general public (1 mSv $year^{-1}$) is assumed to provide an acceptable degree of protection for individual members of the human population.

Within the biosphere, populations of individual wild organisms (more or less self-sustaining sub-sets of individual species) become grouped together as interacting communities that, together with the inanimate physical and chemical components of the environment, constitute ecosystems. Natural ecosystems are complex organizations, in which (usually) many individual plant and animal species combine to accumulate solar energy and facilitate the circulation of the essential chemical elements that are required for the continued existence of themselves and their ecosystem. The maintenance of the integrity of ecosystems, in turn, depends on the survival and reproduction of healthy component populations.

The natural law is not focused on the survival of an individual wild organism, i.e., the survival of biological species, communities and ecosystems is generally not dependent on the survival of single plants or animals. It may be concluded, therefore, that protection of the environment means the protection of the normal overall functioning of populations, communities and natural ecosystems, even if a few individual organisms are damaged by radiation.

The damage produced by radiation in wild plants and animals can be registered, in principle, at each of the increasingly complex levels of the biological hierarchy: atoms, molecules, cells, tissues/organs, organisms, populations, ecosystems, and the biosphere. This immediately raises the question: what level of biological hierarchy is to be selected as the most appropriate, or representative, for the purpose of assessing harm to the natural environment from the effects of ionising radiation?

Initially, all of the known effects of radiation occur at the atomic level within molecules. The numerous molecular effects of ionisation are accumulated and possibly amplified by biochemical pathways and may lead to the damage of genetic information, cells, tissues/organs, and abnormalities in metabolism; these effects may then express themselves at the level of individual organism. If the radiation damage results in a decrease in the survival potential of organisms (life shortening, a reduction of the reproductive success, a reduction of competitive activity, etc.), this could in turn influence the maintenance of the exposed population as a whole. The scale of population effects is strongly dependent on the number of damaged individuals in the population. Effects at the population level can, in turn, be transformed to effects at the community and ecosystem level via disturbances in the evolutionary balance in the trophic relations between species.

Because it is impossible to consider every radiation effect in all of the extant species of plant and animal, some broad (umbrella) endpoints have to be selected; indeed, not all of the available radiobiological information is relevant to the evaluation of the possible environmental consequences of any incremental radiation exposure arising from human activities.

The initial effects of radiation, as observed at the molecular level, are generally of little use for decision makers because it is difficult to interpret them in terms of their consequent effects at the organism level. However, the mechanistic information on radiation effects at the molecular and cellular level is important and, in addition to the epidemiological studies, can facilitate the interpretation of effects occurring at the organism level.

On the other hand, a quantitative evaluation of dose-effect relationships at the population, community and ecosystem levels is also a difficult task because there exist strong (presently unquantified) and complex non-linear interactions between the

biological components, as well as special compensatory mechanisms for maintaining the integrity of the system.
From the practical point of view, the most applicable information for which dose-effect relationships could be derived is that which relates to the level of individual organism. The term "individual organism" here refers to a typical "reference" organism of a given type/species, whose response to radiation exposure is to be assessed.

A radiobiological endpoint has been defined as a consequence of the absorption of radiation that has relevance for the health of the individual organism and that may, therefore, have implications for the population (FASSET, 2001).

The biological endpoints are to be measurable at an organism level. The endpoints of special importance are those referring to key characteristics of the survival capacity of the population, i.e., mortality and reproduction.

According to the suggestions of the FASSET Project (FASSET, 2001), four umbrella endpoints are assumed to be inclusive of all relevant effects at the level of individual organisms:

- Morbidity (a decline in well-being due to a worsening of the physiological characteristics of the organism, e.g., effects on the immune system, blood system, nervous system, etc.);

- Reproduction (negative changes in fertility and fecundity resulting in reduced reproductive success, i.e. reduced production of reproductively competent individuals in the following generations);

- Cytogenetic effects (cytological and genetic changes in tissues (including the gonads of the organisms); and,

- Mortality (shortening of lifetime because of combined effects on different organs and tissues of the organism).

It should be understood, that these defined categories of umbrella endpoints are mutually dependent, e.g. effects on morbidity can lead to worsening of reproduction success, to early death, etc.

4 The procedure for assessing the radiological impact on marine biota

The procedure for radioecological assessment for biota includes the following steps:

- Selection of region-representative organisms for a given geographical area;

- Estimation of dosimetric factors (normalized dose rates) for representative organisms resulting from a unit contaminaton of organisms, and also from a unit contamination of environment (seawater and sediments);

- Assessment of actual/potential doses to representative organisms of a given geographic area, based on actual/predicted data of environmental contamination with radionuclides;
- Comparison of actual/potential dose rates to representative organisms with existing data on harmful effects of radiation, using such endpoints as morbidity, mortality, reproduction and cytogenetic effects;

- Conclusions on the radioecological state of biota in a given geographical area.

5 Selection of region-specific organisms for radioecological assessment (North-European waters)

It is practically impossible to perform radioecological assessment for every species from the thousands of species inhabiting the waters of the North-East Atlantic. This problem can be solved by selecting a limited set of region-specific organisms, which are to be used as representative marine organisms in radioecological assessment.

This section presents the criteria for, and a preliminary selection of, the region-specific organisms for the OSPAR marine region.

5.1 Criteria for selecting region-specific organisms in a given geographical area

The selection of region-specific organisms in a given geographical area for the radioecological assessment is based on the following basic criteria (EPIC, 2001b):

- Ecological (position in ecosystem);
- Availability for monitoring;
- Dosimetric (critical pathways of exposure);
- Radiobiological (sensitivity to radiation) and,
- Recovery potential of populations.

5.1.1 Ecological criteria

The ecological criteria allow the selection of the region-specific organisms among the dominant species at each trophic level of the ecosystem.

The ecological criteria are based on the statement that the appropriate reference organisms for assessment are the dominant representatives of basic trophic levels of the marine ecosystem. These species carry out the major energy/material flows in the ecosystem, and the well-being of dominant species is vitally important for the well-being of the whole ecosystem (Begon et al., 1986). As a rule, one reference organism per trophic level may be selected.

5.1.2 Monitoring criteria

The monitoring criteria allow the selection of the region-specific organisms among the wide spread species available for radionuclide analysis.

Radioecological assessment is closely linked with the monitoring of the region-specific organisms, including measurements of radionuclide concentrations in the organisms.

Taking into account the monitoring purposes, it is practical to select the region-specific organisms (within each trophic level) from the following groups of species:

- Typical, numerous and wide spread species in the investigated area;
- Species which can be easily collected (microscopic-size organisms are not suitable);
- Species which can be easily identified; and,
- Species of commercial importance which are monitored because of importance to man.

The dominant representatives of basic food chains selected from ecological criteria, satisfy most monitoring conditions. Also organisms, which are known to be natural accumulators of radionuclides, are the most suitable for radioecological assessment because they demonstrate the highest levels of biological transfer of radionuclides and would, therefore, be likely to receive the highest dose rates from internal sources.

The only exceptions are phytoplankton and bacteria, which are too small to be properly collected for radionuclide analysis. Endangered or rare species are also not suitable for the screening assessment, because they are not available for routine radionuclide analysis.

5.1.3 Dosimetric criteria

The dosimetric criteria provide a set of characteristic types of region-specific organisms, based on critical pathways of radiation exposure.

Radiation exposure of biota in the contaminated marine environment is associated with the following major pathways:

- internal exposure from radionuclides incorporated within organisms;
- external exposure from water, bottom sediments, and biofoulings;
- external exposure from radionuclides adsorbed on the organism's surfaces.

It is proposed to define a "critical group" of organisms for each possible pathway of exposure. Representatives from each "critical group" may be selected as the region-specific organisms. The following critical groups of organisms can be distinguished in the aquatic ecosystem:

- bottom-dwelling organisms (critical pathway - external exposure);
- organisms, accumulating specific radionuclides (critical pathway - internal exposure).

In the dosimetric calculations it is essential to estimate the contribution of α-, β-, and γ-emitters to the dose to the whole organism, as well as to the dose to its organs and tissues. Taking into account the differences in penetration capacity for α-, β- and γ-

radiation, the dosimetric calculations are to be performed for region-specific organisms of different size groups. The set of region-specific organisms should include both relatively small organisms (critical group for α- and β-emitters), whose organs may be comparable in size to the path lengths of α- and β-particles, as well as relatively large organisms (critical group for γ-emitters), which can absorb higher γ-radiation doses.

5.1.4 Biological radiosensitivity criterion

The biological radiosensitivity criterion allows the selection of the region-specific organisms among the sensitive species in the ecosystem and excludes from consideration the most radioresistant organisms.

The biological species forming the ecosystem vary considerably in respect to their sensitivity to ionising radiation. It is well known that many lower organisms are rather resistant to radiation. For example, bacteria, planktonic algae, bottom invertebrates are several orders of magnitude less sensitive to radiation exposure as compared with fish or mammals (IAEA, 1976, 1979; NCRP,1991; UNSCEAR, 1996).

It is inexpedient to select the organisms for radioecological assessment among very radioresistant species, because they certainly will not be damaged at the radiation levels, which may be expected in the marine environment from authorized releases. For the purposes of radioecological assessment the region-specific organisms should be chosen among relatively radiosensitive groups of organisms in an ecosystem.

5.1.5 Criterion of the recovery potential of populations

Biological species differ considerably in their capacity to recover at the population level when some individual organisms are damaged. In general, the recovery capacity depends on the number of progeny produced by individual organisms per unit of time, and also on the period of development of the organisms (time to reproductive maturity).

It is not sensible to perform a detailed radiological assessment for species with very high recovery potential. This is because, if such organisms were to be damaged by radiation, the losses would be rapidly recovered by the reproduction of remaining organisms. Instead, the species with relatively low recovery potential are good candidates for the region-specific organisms in radioecological assessment. So, the low recovery potential can be used as a criterion for revealing the most vulnerable species of biota in a given geographical area.

If a biological species satisfies all, or most, of the above criteria, such a species could be considered as a candidate for the list of region-specific organisms in a given geographical area.

For the purposes of radioecological assessment it is proposed to exclude some groups of marine organisms from the list of region-specific organisms. These are:

- Bacteria;
- Phytoplankton;

- Small zooplankton.

It is assumed, that the above listed groups of organisms are not suitable for the specific purposes of the radioecological assessment because of: a) difficulties in sampling very small organisms of one species for the radionuclide analyses; b) relatively high resistance to radiation when compared with other species (UNSCEAR, 1996); c) small sizes and short individual lifetimes, which prevent organisms from receiving high doses of radiation; and, d) high biological productivity, which means rapid recovery of populations. Thus, these groups of organisms are unlikely to be damaged at existing/expected levels of radioactive contamination of the OSPAR region. It should be stressed, however, that the above listed groups of organisms play a great role in the functioning of marine ecosystems, and their damage by any toxicant can have serious implications for the whole ecosystem.

The potential candidates for the region-specific organisms can be selected from the following broad categories of marine biota:

- Fish;
- Molluscs;
- Large crustaceans;
- Soft benthos;
- Seabirds;
- Marine mammals;
- Macrophytes.

In the present report, macrophytes are not considered: aquatic plants are known to be more radioresistant than animals, and dose assessment for plants is reasonable only in case of accidental contamination. Soft benthos is not considered in the present report because of non-sufficient data on benthos contamination, and lack of detailed information on radionuclides distribution within bottom sediments.

5.2 Region-specific marine organisms in the OSPAR region

Among thousands of biological species inhabiting the marine waters of the North-East Atlantic, only a few species, listed below, were selected as region-specific representative organisms for radiological assessment.

The selected species satisfy all/most of the selection criteria, they form large populations, and their natural areas of geographical distribution cover the whole or the greater part of the OSPAR region.

The contamination of the selected species is studied within radioecological monitoring/research programmes, so databases on the concentrations of radionuclides are available for most of the selected organisms.

In the radiological assessment, the use of region-specific organisms throughout the whole OSPAR region provides an advantageous possibility to compare on a unified basis the doses/effects to biota in different local sites of the North-East Atlantic region.

5.2.1 Region-specific fish in the OSPAR marine region

In the present study (MARINA II Update) it is proposed to consider a set of region-specific fish species, representing the most typical commercial fish in the OSPAR region. Region-specific fish species are divided into several groups according to their trophic/size/habitat type, see Table 1.

A few typical representatives in each trophic/size/habitat group are listed in the column 'Representative species' (Table 1); one species of each type is a recommended representative organism for dose assessments, see column 'Recommended organism'.

Size/weight characteristics of the region-specific fish given in Table 1 refer to a typical adult specimen of the recommended organism. It should be noted, however, that in the absence of the recommended organism in any local place within the OSPAR region, the assessment can be made for other representative species of the same trophic/size/habitat type.

The proposed list of fish covers almost all typical geometrical forms of fish inhabiting the OSPAR marine region. The proposed forms allow the calculation of dosimetric factors (dose rates per unit concentration of radionuclide) applicable to any specific radiological assessment of fish exposure in the OSPAR region. They also, incidentally and quite usefully, show the influence of fish size on the dose rate received from internal sources and the influence of the external sources, particularly the sediments.

For the assessment of external radiation exposure additional information is needed on the environmental behaviour of fish. The default values of percentage of time, which fish spend near the sea bottom or in the water column are presented in Table 2.

5.2.2 Region-specific molluscs in the OSPAR region

Molluscs are important representatives of the marine biota in dose assessment due to the fact that they:

- accumulate many radionuclides with high concentration factors;
- have close contact with bottom sediments where a number of radionuclides are accumulated and provide a source of external exposure; and,
- have natural shielding covers, which in some cases provide protection from external exposure, but in other cases the shells themselves may become an additional source of radiation exposure to organisms due to high accumulation of radionuclides.

Two types of commercially important molluscs are typical for the OSPAR region: Bivalve molluscs and Gastropod molluscs.

The characteristics of the region-specific molluscs are given in Table 3.

5.2.3 Region-specific crustaceans in the OSPAR region

Large crustaceans are a commercially important group of marine biota in the OSPAR region.

Two main types of crustaceans can be considered as region-specific organisms – crabs and pelagic shrimps. These organisms are exposed to radiation from different pathways, thus providing a range of possible dose rates from each pathway of exposure.

Table 4 presents the main size/weight characteristics of the region-specific large crustaceans.

5.2.4 Region-specific marine mammals and seabirds in the OSPAR region

Marine mammals and seabirds belong to the radiosensitive types of biota in the marine environment.

The common seal (*Phoca vitulina*) is recommended as the region-specific sea mammal in the OSPAR region, with a typical ellipsoidal size of 150 x 40 x 40 cm, and a weight of 120 kg.

A seabird of the *Larus* genus (common gull) is recommended as the region-specific seabird, with a typical ellipsoidal body size of 15 x 11 x 8 cm, overall dimensions (including feather) 21 x 16 x 11 cm, average density of body tissues 0.8 g cm^{-3}, density of feather layer 0.33 g cm^{-3}, and weight 0.6 kg (Woodhead, 1986).

5.3 Ecological links of region-specific organisms with other species in the marine ecosystems of the OSPAR region

Biological species in the marine ecosystems represent an evolutionary selected set of inter-linked organisms.

Populations of different species form trophic chains, where organisms of higher trophic levels feed on organisms of lower trophic levels. In general, the dose assessment for biota does not require a detailed knowledge of the trophic position of reference organisms.

However, in the assessment of radiation effects in biota, it is necessary to consider the possibility of indirect effects of radiation associated with a distortion of the ecological balance (or trophic links) between species in the ecosystem. Simple examples of indirect effects of radiation are as follows: a) a ‘prey’ population is more seriously damaged by radiation than a ‘predator’ population, the number of prey organisms decreases, and, as a consequence, the number of predators also decreases because of lack of food; b) a ‘predator’ population is more seriously damaged by radiation than the ‘prey’ population, the number of predators decreases, and as a consequence, the population of prey rapidly increases in number, this results in the depression of other prey species competing for the same food and space resources.

6 Methods for dose assessment to region-specific marine biota

The assessment of dose rates to marine biota (both pelagic and benthic) is an important, and necessary, tool in the evaluation of the impact of radionuclides released into the environment.

In the marine environment, dose rates to biota originate from external irradiation due to the presence of radionuclides in the water column and bottom sediments, and from internal irradiation owing to the uptake and assimilation of radionuclides by the biota.

6.1 The 'state-of-the-art' in the dose assessment to aquatic organisms

Initially, the development of dose assessment methods for marine biota was closely linked with the management of deep sea disposals of radioactive wastes, estimation of the potential damage from the underwater nuclear tests, and evaluation of damage to biota associated with historical releases from nuclear fuel reprocessing plants into the marine environment.

These considerations drove the dosimetric approach in the direction of a generic assessment using reference organisms that: showed a range of size forms; showed a range of radiosensitivities (on the basis of the available information); showed a range of bio-accumulation capacities; and, occupied different environmental niches.

The reference organisms, although they might bear a resemblance, were not meant to represent particular, identifiable species. It was assumed that this approach would provide a reasonable assessment of the general range of dose rates that would be experienced in a contaminated environment. In order to simplify the dosimetric calculations, the target geometries were reduced to spheres, or ellipsoids with differing ratios between the axes. The characteristics of the reference organisms, used in previous assessments, are set out in Table 5, and the basis for their selection is given in more detail in (Pentreath & Woodhead, 1988).

With the assumptions of uniform radionuclide distribution in the bodies of the organisms at levels defined by equilibrium concentration factors (CF), and uniform distributions of radionuclides in the sediments at levels defined by equilibrium distribution coefficients (k_d), these models were used to estimate the dose rate factors per unit concentration in water (Bq m^{-3}) for a wide range of radionuclides that might be present in radioactive wastes (Pentreath & Woodhead, 1988). These dose rate factors were not, however, applied to the estimation of the dose rates that might have existed in the marine waters of northern Europe at the time of the original MARINA I assessment (MARINA I, 1990).

A similar set of reference geometries and environmental niches was considered in (Blaylock et al., 1993) with the following modifications: small crustaceans were replaced by small insects/ larvae of the same size; large crustaceans were replaced by small fish, again of the same size.

Amiro (1997) proposed an even more conservative dosimetric approach of assuming some generic, non-identified organisms to be exposed to maximum possible levels from potential internal and external sources. This approach is intended for simple screening of potential exposure for assessments where consideration of specific target organisms is either impossible or not required.

Mathematical methods for dosimetry in non-human organisms were developed based on achievements in medical dosimetry (Radiation Dosimetry, 1956; Brownell et al., 1968; Berger, 1968, 1971; Ellet & Humes, 1971), and also on methods developed in the engineering dosimetry of radiation shielding (Engineering, 1968; Gusev et al., 1989). The adaptation of dosimetric models for calculating doses to aquatic organisms has been made in a number of publications (Adams, 1968; Woodhead, 1970, 1973a, 1979, 1984; IAEA, 1976, 1979,1988; Pentreath & Woodhead, 1988).

6.2 Adaptation of dosimetric methods to regional dose assessment for marine biota

For the specific purposes of the OSPAR regional radioecological assessment, a generic approach with the use of non-identified reference organisms is not suitable; in the regional assessment the actual doses and effects are estimated for real organisms based on site-specific data on the environmental contamination in the investigated region.

Dose calculations have been carried out for the selected region-specific representatives of the marine biota in the North European marine waters – the OSPAR marine region. Doses from both external and internal pathways are estimated, as well as total dose rates to the representative organisms.

In the MARINA Update report, dose rates to marine organisms are calculated using the existing dosimetric approaches, outlined in the above listed publications; adaptations were made to take into account the sizes and habits of the region-specific organisms.

6.2.1 Input data in the dose assessment for biota

Input data are required for the calculation of doses to biota; in particular, the concentrations of radionuclides in the biota and the abiotic marine environment (water, sediments). These data are derived using the datasets from both analyses of the monitoring information, and radionuclide transport modeling in marine ecosystems.

In some cases, the available monitoring data on radionuclide distribution are not sufficient for dose assessment for biota. Some data have, therefore, to be reconstructed from the well-known correlations between the activity levels in water and consequent equilibrium concentrations in the sediments (K_d) and biota (CF).

6.2.2 Quantities and units in the dose assessment for biota

Marine organisms have great differences in their average lifetimes, so the most appropriate quantity in any dose assessment is the estimation of dose rates (dose per unit time). If required, one can switch to doses by integrating the dose rate over the lifespan or some other relevant period of the life of the organism (e.g. the period of embryonic development).

Taking into account the fact that the lifespans of the selected reference organisms range from months to years, the appropriate units for dose rates are in Gy day^{-1}.

The activity concentrations of radionuclides in water are given in Bq m^{-3} or in Bq L^{-1}; in organisms, in Bq kg^{-1} of fresh weight; and, in bottom sediments, in Bq kg^{-1} of natural (wet) weight.

6.2.3 Calculation of radiation doses to marine organisms from incorporated radionuclides

An important characteristic in calculations of internal dose to marine organisms is the relation between the linear dimensions of organisms and maximum path lengths of ionising particles in tissues (IAEA, 1976). This characteristic enables one to estimate the relative importance of alpha, beta and gamma radiation from internal and external sources.

Assessment of dose from incorporated alpha emitters

Most alpha emitters are sources of non-relativistic energies (up to 10 MeV). Alpha particles are characterized by high ionising, and low penetrating, power - their paths in materials are essentially straight. The path lengths of alpha particles in air and biological tissue are of the order of a few centimeters and several tens of micrometers, respectively.

Since the dimensions of the reference marine organisms are large compared with the path lengths of alpha particles, the actual body shapes become unimportant for dosimetric calculations. The dose rate to a larger aquatic organism (and component organs and tissues with dimensions greater than ~0.5 mm) is then effectively equal to $D_\alpha(\infty)$, the specific dose rate within the infinite volume of a uniformly contaminated absorbing material, and the value of $D_\alpha(\infty)$ (Gy day^{-1}) can be found using the following formula (IAEA, 1976; Loevinger et al., 1956)

$$D_\alpha(\infty) = 1.38 \cdot 10^{-8} \cdot \overline{E}_\alpha C_{org} , \qquad (1)$$

where $\overline{E}_\alpha$ is the average energy of alpha particles per decay of the particular radionuclide (MeV), and C_{org} is the activity concentration of the radionuclide within the organism, organ or tissue (Bq kg^{-1} wet weight).

Assessment of dose from incorporated beta emitters

Beta radiation is electron/positron radiation arising from the decay of nuclei. As beta particles interact with matter, they lose energy, decelerate and scatter. A special feature of the beta radiation from a particular radionuclide is the continuous character of its spectrum, because beta particles emitted by nuclei possess different initial energies from zero to a certain maximum value. A significant characteristic of the beta spectrum is the average energy of beta particles per decay.

Fast beta particles lack a strongly defined path, but can be characterized by the maximum path corresponding to the maximum energy E_0 of the beta spectrum. The highest-energy particles with an energy of about 3.5 MeV, can travel a distance of ≥10 mm in biological tissue. The average range for the beta particles from the decay of a particular radionuclide is approximately 20% of the maximum range corresponding to the beta particles with the maximum energy, E_0.

In the region-specific representative organisms considered here, such as molluscs, crustaceans, fish, etc. (i.e., with size greater than 1 cm), the contribution to the dose rate due to uniformly distributed beta emitters is taken to be equal to $D_\beta(\propto)$, which is the dose rate within an infinite volume of an absorbing material uniformly contaminated with the beta emitter (IAEA, 1976, 1979):

$$D_\beta(\infty) = 1.38 \cdot 10^{-8} \cdot \overline{E}_\beta C_{org}\ , \tag{2}$$

where $D_\beta(\propto)$ is dose rate in Gy day^{-1}; $\overline{E}_\beta$ is the average energy of beta particles per decay of the particular radionuclide (MeV), and, C_{org} is the concentration of the beta emitter in the organism, (Bq kg^{-1} wet weight).

In some special cases, the dose to small critical organs within the organisms need to be calculated, and detailed dose rate distribution is required. The basic equation in the dosimetry of beta radiation is the Loevinger formula for the distribution of dose around a point source, derived from a mathematical analysis of experimental data (Loevinger et al.,1956; Engineering, 1968; Gusev et al., 1989; IAEA, 1979). The determination of dose from incorporated beta emitters breaks down into two stages. At the first stage, the dose from a point source of beta particles is determined and at the second stage the distribution of dose from volume sources of beta radiation is obtained by integrating the doses from elementary point sources. The beta-radiation dose rate distribution in aquatic organisms of arbitrary shape is rather difficult to determine by direct integration of the dose function from a point source. Consequently, the organisms/organs are approximated by spheres, cylinders, or other elementary geometric figures in the dose calculations (IAEA, 1976, 1979). For the purpose of evaluating the possible radiobiological effects in some organisms (especially small fish and molluscs), the considerable extent of accumulation of certain radionuclides in organs/tissues should be taken into account, as this may lead to a non-uniform distribution of dose rate within the body resulting in higher exposure of critical organs (e.g., gonads, liver). For a restricted number of region-specific organisms, detailed calculations of dose rate distribution can be performed provided that additional experimental information on the radionuclide distribution in different organs is available.

Assessment of dose from incorporated gamma emitters

The average dose rate from incorporated gamma emitters can be calculated using the following equation (Loevinger et al., 1956; Engineering, 1968; Gusev et al., 1989)

$$\overline{D}_{\gamma,\text{int}} = 8.64 \cdot 10^4 \cdot C_{org} \cdot \rho \cdot \Gamma_\delta \cdot \overline{g};$$
$$\overline{g} = \frac{1}{V}\int_V g_P dV; \quad where \quad g_P = \int_V \frac{\exp(-\mu_{eff} r)}{r^2} dV; \tag{3}$$

where $\overline{D}_{\gamma,\text{int}}$ is the dose rate , Gy day^{-1}; Γ_δ is the kerma radiation constant of a radionuclide, (Gy m^2)(s Bq)$^{-1}$; C_{org} is the concentration of the radionuclide in the organism, Bq kg^{-1} wet weight; ρ is the density of the biological material, kg m^{-3}; $\overline{g}$ is the average geometric factor, m; g_P is the geometric factor at point *P*; V is the body volume, m^3; μ_{eff} is the effective attenuation factor of the biological tissue/water, m^{-1}; coefficient 8.64x10^4 is the number of seconds in a day.

In radiation dosimetry, the kerma Γ_δ (Gy m^2 s^{-1}Bq^{-1}) is a standard dose constant, characteristic for each radionuclide; it is defined by the formula (Engineering, 1968; Gusev et al., 1989):

$$\Gamma_\delta = \frac{1.602 \cdot 10^{-13}}{4\pi \cdot w} \cdot \sum_{i=1}^{m} E_{0i} \cdot n_{\gamma i} \cdot \mu_{tr,i}^{air}(E_{0i}); \tag{4}$$

where E_{0i} is the energy of photon of the i-th energy group emitted by the radionuclide, MeV (1 MeV=1.602x10^{-13} J); *m* – total number of energy groups of photons emitted by the radionuclide; $n_{\gamma i}$ is the fraction of photons emitted with energy E_{oi}; $\mu_{tr,i}^{air}(E_{0i})$ is the energy absorption coefficient in the standard media (air) , m^2 kg^{-1}; w=1 J kg^{-1} Gy^{-1}. Standard Γ_δ values are tabulated for a point source in the air, for biological tissues and water $\Gamma_\delta^{wat} = \frac{\mu_{tr}^{wat}}{\mu_{tr}^{air}}\Gamma_\delta \approx 1.09 \cdot \Gamma_\delta$.

The value of the geometric factor $\overline{g}$, appearing in the Eq.(3), can be calculated analytically for simple symmetrical figures, such as sphere, plate, cylinder, truncated cone, etc. (Loevinger et al., 1956; Engineering, 1968; IAEA, 1976; Gusev et al., 1989).

For a sphere, the average geometric factor throughout the spherical volume accounts for 0.75 of the geometric factor g_o at the center of the sphere, i.e.

$$\overline{g}_{sph} = \frac{3}{4} g_0 = \frac{3}{4} \cdot \frac{4\pi}{\mu_{eff}}(1 - \exp(-\mu_{eff} R)); \tag{5}$$

where R is the radius of the sphere, m.

For cylinders of different size, the average geometric factors are tabulated in (Loevinger et al., 1956; IAEA, 1976).

The calculation of geometric factors for volumes of arbitrary shape is a complicated task and it is solved with the use of computer codes.

For the purposes of medical dosimetry, detailed numerical calculations have been performed by the Monte-Carlo method, which provided values of the absorbed fractions of energy in different volumes containing gamma-emitting radioactive substances (Brownell, Ellet & Reddy, 1968; Ellet & Humes, 1971). In these calculations the following modification of the Eqs.(3) and (4) was used:

$$\overline{D}_{\gamma,\text{int}} = 1.38 \cdot 10^{-8} \cdot C_{org} \sum_i E_i n_i \Phi_i (E_i) \approx 1.38 \cdot 10^{-8} \cdot C_{org} \cdot \overline{E}_\gamma \cdot \Phi(\overline{E}_\gamma); \quad (6)$$

where $\Phi(E) = \dfrac{\textit{photon energy absorbed in the volume}}{\textit{photon energy emitted by the source}}$ is the photon absorbed fraction within a target volume.

The $\Phi(E_\gamma)$ values were obtained for a range of emitted photon energies E_γ from 0.02 to 2.75 MeV; geometrical models considered were spheres and ellipsoids of different shapes (flat, thick and elongated ellipsoids) with masses ranging from 1 g up to 200 kg, (unit density tissue), containing the uniformly distributed gamma-emitter (Brownell et al., 1968; Ellet & Humes, 1971).

The approach (6) was successfully adopted for the dosimetry of aquatic biota (IAEA, 1988; Pentreath & Woodhead, 1988; Blaylock et al., 1993; Woodhead, 2000).

For very large organisms (walrus, whale) a simplified assumption can be used, i.e., that the dose rate within the organism is equal to $D_\gamma(\infty)$, the dose rate within the infinite volume of an absorbing material uniformly contaminated with the gamma emitter. The value of $D_\gamma(\infty)$, Gy day^{-1} can be calculated from formula (6), taking Φ=1 (Brownell et al., 1968; Ellet & Humes, 1971; Pentreath & Woodhead, 1988; Blaylock et al., 1993):

$$D_\gamma(\infty) = 1.38 \cdot 10^{-8} \overline{E}_\gamma \cdot C_{org}. \quad (7)$$

6.2.4 External irradiation

The sources of external irradiation of marine biota are as follows:

- irradiation from contaminated water and bottom sediments;
- irradiation from contaminated overgrowths of macroalgae or accumulations of molluscs; and,
- irradiation from radionuclides adsorbed onto the surfaces of organisms.

For large organisms the predominant external irradiation pathway can be from gamma-radiation, and to a lesser extent from beta-particles. For small organisms (phytoplankton, small zooplankton, fish eggs), the doses from alpha- and beta-emitters adsorbed on their surfaces may be important in the external dosimetry.

Exposure from water

In the assessment of external dose, water is considered as an infinite source of uniformly distributed radionuclides.

External exposure from alpha and beta emitters uniformly distributed in the water column may be significant only for the outer surfaces of the selected region-specific marine organisms because of short paths of α- and β- particles in water and biological tissues.

The dose rate to the surface layer (skin) of organisms from alpha and beta emitters distributed in water column can be estimated as 0.5 $D_\alpha(\infty)$ (for alpha emitters) and 0.5 $D_\beta(\infty)$ (for beta emitters), where $D(\infty)$ is calculated from Eqs. (1) or (2) at the radionuclide concentration in water.

External gamma-radiation dose rate $D^{W}_{\gamma,ext}$ to aquatic organisms from a gamma emitter of average energy E_γ uniformly distributed in the water column is calculated as:

$$D^{wat}_{\gamma,ext} = D^{wat}_{\gamma}(\infty) - D^{wat}_{\gamma}(V_{org}); \qquad (8)$$

where $D^{wat}_{\gamma}(\infty)$ and $D^{wat}_{\gamma}(V_{org})$ are calculated from Eq. (7) and Eq. (3) or Eq. (6) respectively; both values are calculated from the radionuclide concentration in water.

External exposure from bottom sediments

The bottom sediments are represented as a layer of infinite thickness with uniformly distributed activities of radionuclides.
The dose rate at the surface of bottom sediments from γ-radiation can be estimated as $0.5\,D_\gamma(\infty)$ (IAEA, 1976).

6.2.5 Calculation of total dose rates to the region-specific organisms

Radiological dose conversion factors (internal and external exposure) were calculated with a computer code for each of the region-specific organisms, represented by the appropriate geometric model, for different radionuclides, see Appendix A. The radioactive decay data used in calculations were taken from the ICRP Publication 38 (ICRP, 1983).

Dose conversion factors for internal exposure are calculated on the assumption of a unit radionuclide concentration in the organism 1 Bq kg^{-1} wet weight. Dose conversion factors for external exposure from water are calculated, using a unit radionuclide concentration in the water 1 Bq L^{-1}. Dose conversion factors for external exposure from sediments are calculated, using a unit radionuclide concentration in sediments 1 Bq kg^{-1} wet weight.

The total dose rate to the i-th region-specific organism from a given radionuclide can be calculated by the formula:

$$D^{i}_{tot} = w_r \cdot [DCF^{i}_{\text{int}} \cdot C^{i}_{org} + DCF^{i}_{wat} \cdot C_{wat} + DCF^{i}_{sed} \cdot C_{sed}]; \qquad (9)$$

where D^{i}_{tot} is the total dose rate to reference organism;

w_r is the radiation weighting factor for the given radiation (alpha, beta or gamma exposure);

$DCF_{int}^{i}, DCF_{wat}^{i}, DCF_{sed}^{i}$ are calculated dose conversion factors for internal and external exposure; $C_{org}^{i}, C_{wat}, C_{sed}$ are the radionuclide concentrations in the i-th organism, water, and sediments, respectively.

In an ideal situation, measured concentrations of the radionuclides are available for the organism, water and sediment; this makes it possible to use Eq. (9) directly. In the worst case, when only data on radionuclide concentrations in water are available, the radionuclide concentrations in the organism and sediments can be reconstructed using appropriate concentration factors (CF) and K_d values (IAEA, 1985). It should be noted, however, that concentration factors and K_d values are variable from site to site, and the uncertainty associated with employing default values of CF and K_d can be rather large.

In the present approach, the radiation weighting factors for α- and β-radiation are not included in the tabulated dose conversion factors (see Appendix A), the reason being that the values of these factors for non-human biota are not yet established in the official documents.

7 Dose assessment to marine biota in the industry-impacted zones of the North-East Atlantic

This chapter presents the results of dose assessment to natural marine biota in some representative, industry-impacted sites of the OSPAR region.

Assessment of radiation exposure to marine organisms has been performed, based on the methodology and dose conversion factors outlined in the previous sections of this report. Real data on the radioactive contamination of the marine environment were used for dose estimates, which were obtained in the course of routine/research monitoring programmes carried out in 1980s-1990s. The input data on the radioactivity of marine environment in the OSPAR region has been compiled by the Working Group B within the present MARINA II study ; the sources of data included databases from BNFL and MAFF/CEFAS, the Nord-Cotentin database; data from the AMAP programme; and, journal publications.

The following data were used as input information in the dose assessment to marine biota:

- Measured activity concentrations of artificial or natural radionuclides in the key representatives of marine organisms in a particular marine area;

- Measured activity concentrations of radionuclides in sea water and sediments in a particular marine area.

As far as possible, site-specific species of organisms were considered; however, the existing monitoring databases are not specially adapted for the dose-to-biota assessment, therefore some data in the databases represent values averaged by broad categories of organisms (e.g. ‘fish’, ‘shellfish’), and for some organisms data are missing. As a rule, the routine monitoring measurements include the radionuclide analysis of edible parts of organisms only, without consideration of different organs and tissues.

The dose assessment to marine biota has been performed based on the assumption of a uniform distribution of radionuclides within organism; the results, therefore, are averaged dose rates to the whole body of the organism.

Dose assessments to marine biota have been made for the following industry-impacted areas of the OSPAR region:

- Coastal areas in the vicinity of nuclear reprocessing plants (Sellafield, UK; Cap de la Hague, France);

- Near coastal zone of nuclear power plant (Ringhals NPP in Sweden);

- Coastal zones in the vicinity of non-nuclear plants, characterized by discharges of enhanced levels of natural radionuclides (phosphate plant at Whitehaven, UK; oil fields in the North Sea);
- Remote marine areas with low levels of man-made radioactivity, which are considered as relatively 'clean' waters (Barents Sea, Norwegian coastal waters).

Dose rates to site-specific organisms were calculated for each year of observations, using a computer code connected with databases.

To provide a basis for comparison in this dose assessment, estimated values for natural background exposure of the selected organisms have been taken from literature. Taking into account that living organisms have been exposed to natural background radiation during the entire period of biological evolution, the background dose rates to biota are considered as normal, i.e. not having a negative impact on the safety of organisms.

To evaluate the possible harm to biota, the dose rates to organisms, inhabiting the industry-impacted marine areas were compared with the available information on the 'dose-effect' relationships for aquatic organisms.

7.1 Background exposure of marine organisms from natural sources of radiation

The background exposure of marine organisms comprises cosmic radiation and exposure from natural radionuclides dispersed in water, present in sediments, and accumulated in living organisms.

The typical concentrations of natural radionuclides in sea water and representative organisms are summarized in Table 6. The summary of dose rates to marine organisms from natural background radiation is presented in Table 7.

7.2 Contamination in the remote marine areas of the OSPAR region

In addition to the natural radioactivity of seawater, there exists some global contamination of the World Ocean with artificial radionuclides.

Two main sources are fallout from nuclear weapon tests, and the operation of nuclear reactors including the concomitant processing of the spent fuel. The contamination of the remote zones in the OSPAR region provides an indication of the levels of man-made background within the OSPAR area.

The Barents Sea and the northern part of the Norwegian Sea can be considered as relatively clean areas in the OSPAR region remote from intensive industrial activity.

The current man-made radioactivity in the Barents Sea is characterized by trace concentrations of ^{137}Cs, ^{90}Sr, ^{99}Tc, $^{239,240}Pu$.

The activity concentrations of artificial radionuclides and dose rates to representatives of marine biota in the Barents Sea are summarized in Table 8 and Table 9.

The additional dose rates to marine biota from artificial radionuclides in the Barents Sea are extremely low in comparison with the exposure from natural radioactivity, so no harm can be expected from those minor dose rates.

8 Radiological impact on marine biota from nuclear industry

8.1 Sellafield area: dose rates to marine biota

The coastal area impacted by the Sellafield nuclear reprocessing plant is located at the east coast of the Irish Sea, UK. The scheme of the Sellafield coastal area is shown in Figure1.

The 'Sellafield Coastal Area' extends 15 km north and south of Sellafield from St. Bees Head to Selker and 11 km offshore; most of the fish and shellfish consumed by the most exposed group is taken from this area. Specific surveys are carried out in the smaller 'Sellafield Offshore Area' where experience has shown that good catch rates may be obtained. This area consists of a rectangle, one nautical mile (1.8 km) wide by two nautical miles (3.6 km) long, situated south of the pipelines with the long side parallel to the shoreline; it averages about 5 km from the pipeline outlet (MAFF & SEPA, 1999).

The dose assessment to marine biota in the vicinity of Sellafield was performed, using monitoring data on the environmental contamination for the period 1986-2001 compiled by the Working Group B of the MARINA II study from the BNFL and MAFF/CEFAS databases (see report on environmental data in the present study).

8.1.1 Fish, molluscs, crustaceans

The aquatic monitoring programmes carried out by BNFL and MAFF include sampling/measurements of the following components of the marine environment:

- Sea water;
- Sediments;

- Fish (mostly cod *Gadus morhua* and plaice *Pleuronectus platessa*, with some samples of other fish species, e.g. whiting, haddock, bass);

- Molluscs (mostly mussels *Mytilus edulis* and winkles *Littorina littorea*, with some samples of whelks and limpets);

- Crustaceans (crabs and lobsters).

The averaged annual results of monitoring are usually presented for broad categories of biota, e.g. 'fish', 'molluscs', 'crustaceans', and not for individual species; in this context for the purpose of dose calculations the 'fish' data refers directly to cod and plaice as site-specific fish species; 'molluscs' data refers to mussels and winkles, and 'crustaceans' data refers to crabs and lobsters. Calculations of doses to other fish species (herring, haddock, etc.) were made from the general data set on 'fish' contamination.

A number of radionuclides have been measured in the environmental samples in the Sellafield marine area, including ^{137}Cs, ^{90}Sr, ^{99}Tc, ^{241}Am,^{239,240}Pu, ^{238}Pu, ^{60}Co and^{106}Ru. The dose rates to marine biota were calculated, using dose conversion factors, from data on concentrations of radionuclides in organisms and in the biotic environment.

Dose rates to representatives of marine biota in the vicinity of Sellafield are shown in Figure 2 (see also Appendix B, Table B1).

The highest dose rates were estimated for molluscs: annual average dose rates to mussels and winkles varied within the range from $1{\cdot}10^{-4}$ to $4{\cdot}10^{-5}$ Gy day^{-1} (weighted by w_r), see Figure 3. Molluscs feed on suspended matter; these organisms accumulate in their bodies radionuclides which are adsorbed on suspended particles in sea water. Molluscs are also known to bioassimilate some trace elements from seawater, such as cobalt, manganese, zinc, etc. As a general rule, molluscs tend to contain higher levels of radionuclides than crustaceans, which in turn tend to contain more than fish. According to monitoring data, molluscs contain considerably higher concentrations of radionuclides as compared with fish. The major contributors to dose rates to molluscs are incorporated ^{241}Am and ^{239,240}Pu, see Figure 3.

Dose rates to crustaceans (crabs and lobsters) were somewhat lower than those to molluscs, average values vary within the range from $1.4{\cdot}10^{-5}$ to $4{\cdot}10^{-6}$ Gy day^{-1} (weighted by w_r), see Figure 4. Having close contact to bottom sediments, crustaceans are contaminated with radionuclides accumulated in sediment. Also, lobsters are specific accumulators of some particular radionuclides, e.g. ^{99}Tc, probably because of some peculiarities in metabolism. In 1996-2000, ^{99}Tc and ^{241}Am were the major contributors to the dose rate to crustaceans, in the previous period (1986-1993) the most significant contributor was ^{106}Ru, see Figure 4.

Dose rates to fish were lower than those to molluscs and large crustaceans. Typical dose rates to larger fish (cod, plaice) were about $3{\cdot}10^{-6}$-$2.6{\cdot}10^{-7}$ Gy day^{-1} (weighted by w_r) during the assessment period (1986-2001), see Figure 5. Fish can move some tens of kilometers through the concentration gradients in seawater; the resulting level of fish contamination therefore represents an average over a large area. In contrast to molluscs and crustaceans, the main contributor to dose rates to fish was ^{137}Cs, see Figure 5.

Dose rates estimated for smaller planktivorous fish (herring, sardine) were somewhat lower ($8.5 \cdot 10^{-7}$- $7 \cdot 10^{-8}$ Gy day^{-1} (weighted by w_r)) than those for large fish, reflecting lower exposure from sediments, as well as lower absorption of gamma-energy from incorporated radionuclides within small bodies. Contamination of small fish was not studied within monitoring programmes in the Sellafield coastal area, so the data on radionuclide concentrations in this group of fish were not available. The preliminary dose estimates to small fish were performed using general data on fish contamination.

There are some variations in dose rates to biota between years, resulting from changes in the spectrum of radionuclides discharged to the marine environment, which in turn correlates with changes in technologies at the reprocessing plant. For example, the increase in dose rates to crustaceans in the period 1995-2000 correlates with the increase in the releases of ^{99}Tc. In general, the dose rates to marine biota in the Sellafield coastal waters slowly decreased in the period 1986-2000, the current dose rates amount to about 20-40% of the dose rates to biota in 1986-1987.

During the assessment period, the dose rates to biota at Sellafield exceeded the natural background radiation exposure up to 2–4 times for different organisms. The exposure in this industrial area due to artificial radionuclides was several orders of magnitude higher than such exposure of marine organisms in the remote, relatively ’clean’ areas within the OSPAR region.

Nevertheless, throughout the assessment period 1986-2001, the estimated dose values were all below the levels of deterministic effects of radiation, so it is unlikely any radiation effects will appear in marine organisms.

Some assessments of dose rates to marine biota at Sellafield were made in the earlier period of the operation of the reprocessing plant. The dose rate to hypothetical local plaice resting stationary on the site calculated from conservative assumptions by Woodhead, was estimated to be as high as $1.4 \cdot 10^{-3}$ Gy day^{-1} in late 1960s. Long-term studies with in situ measurements of dose rates to plaice were carried out in 1967-1969 (Woodhead, 1973b). About 3500 plaice were caught in the area 1-2 km south of the Sellafield effluent discharge point. Small dosimeters were attached to fish before releasing them back into the sea. About 1000 fish were recaptured in the subsequent period. The average dose rates to plaice registered with dosimeters were $8.4 \cdot 10^{-5}$ Gy day^{-1} with occasional dosimeters registering dose rates up to $6 \cdot 10^{-4}$ Gy day^{-1}. These dose rates were mainly due to exposure from radionuclides in the contaminated seabed.

8.1.2 Sea birds in the vicinity of the Sellafield

In the early 1980s, concern was expressed about the decline in numbers of waterfowl, waders and gulls in the Ravenglass estuary about 10 km to the south-west from the Sellafield nuclear reprocessing plant. In particular, the colony of black-headed gulls had fallen from over 10 000 pairs before 1976 to about 1500 pairs in 1984, when they bred on the Drigg dunes for the last time. Suggestions have been made that the decline might be due to radioactive contamination of bird's food and their general environment.

Ninety six bird specimen, of 15 different species, were sampled between 1980 and 1984, mainly from Ravenglass; these included black-headed gull (*Larus ridibundus*), greater black-backed gull (*Larus marines*), lesser black-backed gull (*Larus fuscus*), herring gull (*Larus argentatus*), oystercatcher (*Haematopus ostralegus*), bar-tailed godwit (*Limosa lapponica*), shelduck (*Tadorna tadorna*), wigeon (*Anas penelope*), and some others (Lowe, 1991). Most of the birds were shot, but some were natural deaths; all the black-headed gulls samples were from the carcasses of individuals killed on their nests by foxes.

The highest concentrations of radiocaesium were found (in the breast muscles) in oystercatcher (maximum value ^{137}Cs = 636.8 Bq kg^{-1} fresh weight) and bar-tailed godwit (maximum value ^{137}Cs = 478.1 Bq kg^{-1} fresh weight).

Of the other species, only shelduck, wigeon and curlew occasionally reached or came close to 300 Bq kg^{-1}. Among birds, the black-headed gulls had the lowest concentrations of radiocesium, with maximum ^{137}Cs concentration of 45.5 Bq kg^{-1} fresh weight in breast muscles.

The highest concentration of plutonium radionuclides were found in shellduck (max values in liver $^{239,240}Pu = 12.3 \pm 1.9$(n=2) Bq kg^{-1} and ^{238}Pu = 2.7(n=1) Bq kg^{-1} fresh weight) and wigeon (max values in liver $^{239,240}Pu = 8.08 \pm 5.53$(n=4) Bq kg^{-1} and ^{238}Pu=2.44± 1.25(n=3) Bq kg^{-1} fresh weight); greater black-backed gull had 5.32 Bq kg^{-1}, whereas the black-headed gull had only 0.54 ± 0.67(n=8) Bq kg^{-1} of $^{239,240}Pu$ in the liver (Lowe, 1991).

Analysing the radionuclide concentrations in birds from Ravenglass, it should be noted that birds were found to be more contaminated than fish from the Sellafield coastal area (e.g., average radiocesium concentrations in fish in 1986-1988 were about 20-30 Bq kg^{-1} (max 88 Bq kg^{-1}); $^{239,240}Pu$ concentrations in fish were 0.02-0.03 Bq kg^{-1}). Concentrations of $^{239,240}Pu$ in bird's liver can be compared with concentrations of these radionuclides in molluscs, which in 1986 were about 15 (max. 50) Bq kg^{-1}. Most probably, the relatively high contamination of birds was the result of consumption of contaminated mud along with invertebrate food items.

In the current study the conservative estimations of internal radiation exposure to seafood-eating birds, based on the maximum observed concentrations provide the following values: whole body dose rate from ^{137}Cs – about $2 \cdot 10^{-6}$ Gy day^{-1}; dose rate to liver – about $2 \cdot 10^{-5}$ Gy day^{-1} (weighted by w_r).

Woodhead (1986) has calculated conservative values of total dose equivalent to the whole body of the black-headed gull, basing his calculations on data in Allen et al. (1983). The total equivalent dose rate to the whole body of black-headed gull was estimated to be equal to $2.4 \cdot 10^{-5}$ Gy day^{-1} (including the contribution from internal organs and external exposure); the total dose equivalent rate to the gut lining was greater, being $3.42 \cdot 10^{-4}$ Gy day^{-1} (weighted by w_r).

From information available on the radiation effects to birds, the dose rates to black-headed gulls (which were not the most contaminated birds in the Sellafield area) were unlikely to produce a direct effect on the mortality of birds. The most likely cause of the desertion of gullery was an increased predation by foxes, which, in turn, was caused by a decrease in rabbit population in the area.

8.1.3 Marine mammals

The marine area in the vicinity of Sellafield (from the Clyde to the Dee Estuary) is poorly populated by seals, so there is no information on radionuclide levels in seals close to Sellafield. Most of the UK seal populations probably feed at some distance from the Sellafield discharges.

In general, information on radionuclides in seals around UK is sparce. Samples of milk and tissues of grey seals were collected in 1987 on the island North Rona (Outer Hebrides) and the Isle of May (Anderson et al., 1990). Measurements of radionuclide concentrations in milk and tissues of grey seals/pups provided the following average results:

Milk ^{137}Cs = 2.9 Bq kg^{-1}; ^{239,240}Pu = <0.3 Bq kg^{-1};
^{137}Cs in muscle and liver was ranging between 6.4 and 27.5 Bq kg^{-1}; ^{239,240}Pu = 2.25 ± 0.31 Bq kg^{-1} (muscle); ^{239,240}Pu = 3.52 ± 0.38 Bq kg^{-1} (liver).

In the present study the estimated dose rates to grey seals were $3.3 \cdot 10^{-6}$ Gy day^{-1} (weighted by w_r), with the predominant contribution from ^{239,240}Pu. In general, the dose rates to grey seals and larger fish are very similar reflecting the trophic status of grey seals as top predators feeding on fish.

Pentreath & Woodhead (1988) calculated the hypothetical radiation dose from ^{137}Cs which might be received by an average grey seal, feeding exclusively on fish in the Sellafield area. Making the assumption that seals would receive the same dose per intake as man, they estimated an annual dose of 36 mSv (10^{-4} Gy day^{-1}). This was a conservative upper estimation because in reality seals don't feed very close to the Sellafield site.

8.1.4 Uncertainties in dose assessment to marine biota

The uncertainties in the estimations of radiation exposure to organisms in natural marine ecosystems are rather large, the reasons being:

- There is a natural variability in the contamination of individual organisms within one and the same population depending on age, season, variations in metabolism, local habitat, mobility, gradients in contamination, etc.;

- Environmental monitoring programmes provide limited data on the radionuclide content in biological materials, which in some cases are not sufficient for statistical analysis of information;

- Some systematic uncertainties in the results are associated with the methods of dose calculations. Dosimetric models, used in the dose assessment, provide body-averaged dose rates to organisms. However, the actual dose distribution is likely to be non-uniform, resulting in higher exposure of some organs/tissues of organisms. The more precise results can be obtained using more complicated computer codes supplied with detailed experimental information on the radionuclide distribution within an organism. In the assessment of external dose rates from sediments the source of uncertainty is the geometric approximation of the radionuclide distribution within sediments. For example, in the northeast Irish Sea the concentration of radionuclides in sediments declined rapidly with depth, and the gamma-dose rate at the sediment surface was found to be closer to $0.25\,D_{\gamma}(\infty)$ than to $0.5\,D\gamma(\infty)$, which was estimated from a conservative formula (IAEA, 1976).

Only one type of uncertainty is estimated in this report – the uncertainty in dose rates associated with the scattering in radionuclide concentrations registered in the environmental samples.

Three sets of dose calculations can be made for each representative species of organisms:

- Average dose rates based on arithmetic annual average concentrations of each radionuclide in a given organism and its environment;

- Maximum dose rates based on maximum concentrations of each radionuclide registered during each year of observations in a given organism;

- Minimum dose rates based on lowest concentrations of each radionuclide registered during each year in a given organism.

The difference between the highest and lowest dose rate values is considered as the range of uncertainty in dose assessment for a representative organism. The typical ranges of uncertainty are shown in Figure 6 for cod at the Sellafield area.

During periods of continual quasi-equilibrium discharges of radionuclides into the marine environment, the typical range of uncertainty in dose rates to biota is about one order of magnitude. The uncertainties in doses to biota become much larger in cases of sharp changes in radionuclide discharges to the environment when the radioecological situation is strongly non-equilibrium. In this report, the uncertainty in dose assessment to marine biota is considered to be one order of magnitude.
The majority of figures in this report demonstrate the dynamics of average dose rates to biota for a number of years, the associated uncertainties are assumed to be one order of magnitude throughout these graphs.

Some uncertainties in dose estimates are associated with non-uniform radionuclide distribution within an organism. It is well known, that different radionuclides are accumulated specifically in particular organs and tissues of organisms. For instance, ^{90}Sr is deposited in the bones, plutonium isotopes are deposited in the liver and the content of guts can be contaminated with insoluble radionuclides from bottom sediments. As a result of non-uniform radionuclide distribution within a body, the dose rate to different organs can differ from the average value by one order of magnitude and more.

A radiation weighting factor of 20 has been employed as a conservative value to evaluate the biologically equivalent dose rate from the alpha component of the radiation exposure. An improved estimate of the weighting factor for alpha-particle radiation needs further investigation. To estimate the uncertainties associated with using of RBE factors, total dose rates to biota were calculated as absorbed dose rates (w_r=1) and RBE-weighted dose rates (w_r=20 for alpha-emitters), results are presented in the Appendix B. For the Sellafield area the weighted dose rates are, on average, higher than the absorbed dose rates by a factor of 1.1 for fish, 7.7 for molluscs, and 1.5 for crustaceans.

In general, uncertainties in doses to biota should be considered when the possible effects of radiation are estimated.

8.2 Cap de la Hague: dose rates to marine biota

Calculations of dose rates to marine biota in the area of the Cap de la Hague nuclear reprocessing plant were performed, using the radiological monitoring data from the Nord-Cotentin database for the period 1982-1997 (Nord-Cotentin, 1999). A general information on data, which were used for dose assessment to biota in the Cap de la Hague coastal area (France) is given in Table 10, including the monitoring sites, type of samples, and radionuclides measured by different organizations. The scheme of the Cap de la Hague area (Nord-Cotentin Peninsula) with the location of monitoring sites is presented in Figure 7.

To provide conservative estimates of dose rates to biota, the whole set of radionuclides measured at neighbouring monitoring sites was considered in dose calculations.

Due to local hydrobiological conditions, mussels do not inhabit the local area in the vicinity of the Cap de la Hague between Carteret and Barfleur. Instead of mussels, a Gastropoda mollusc Patella (limpet) is used as a bio indicator in the monitoring programmes. So, the dose assessment was made for this mollusc. Dose rates for mussels were calculated for the site Barfleur (the nearest monitoring site, where natural mussel populations exist).

Concentrations of alpha-emitters (^{239,240}Pu, ^{238}Pu, and ^{241}Am) in biological samples were reported only for molluscs Patella, but not for fish, crustaceans and mussels. Thus dose rates to fish, crabs and mussels were calculated without contribution of alpha-emitters; dose rates to limpets (Patella molluscs) were calculated including the input from ^{239,240}Pu, ^{238}Pu and ^{241}Am.

Dose rates to marine biota in the vicinity of the Cap de la Hague site for the period 1982 to 1997 are shown in Figure 8 (see also Appendix B table B2).

Molluscs and crabs were the most exposed organisms among marine biota, see Figures 9 and 10. Dose rates varied within the range $1.6 \cdot 10^{-5} – 6 \cdot 10^{-7}$ Gy day^{-1} (weighted by w_r) to molluscs Patella, and within the range $8 \cdot 10^{-6} – 1.5 \cdot 10^{-7}$ Gy day^{-1} to crabs (excluding contribution by alpha-emitters).

In general, doses to molluscs and crabs in the Cap de la Hague area were lower than those at Sellafield, also the decrease of dose rates in the period 1982-1997 was more pronounced.

The dose rates to fish at Cap de la Hague slowly decreased from $4.3 \cdot 10^{-7}$ Gy day^{-1} in 1982 to $2.1 \cdot 10^{-8}$ Gy day^{-1} in 1997, see Figure 11 (no alpha-emitters considered).

The major contributors to dose to marine biota in the Cap de la Hague area were the following radionuclides (1996 to 1997), see also see Figure 9 to 11:

- Mollusc Patella ^{241}Am – 56%; ^{106}Ru – 16%; ^{239,240}Pu – 13%; ^{248}Pu – 9%;
- Crabs ^{106}Ru – 62%; ^{110m}Ag – 17%; ^{60}Co – 11% (excluding alpha-emitters);
- Fish ^{134,137}Cs – 24%; ^{106}Ru – 23%; ^{110m}Ag – 21%; ^{60}Co – 21% (excluding alpha-emitters).

Additional calculations were made to estimate the potential contribution of alpha-emitters (Pu isotopes) to dose rates to marine biota at Cap de la Hague. For this purpose a reconstruction of ^{238}Pu, ^{239,240}Pu concentrations in marine biota was performed based on available data on Pu-isotopes in seawater and recommended values of concentration factors in marine organisms.

The reconstructed input from Pu-isotopes to dose rate was estimated to be $(1.5 - 4) \cdot 10^{-5}$ Gy day^{-1} (weighted by w_r) for mussels, and $(2\text{-}5) \cdot 10^{-7}$ Gy day^{-1} (weighted by w_r) for fish during the assessment period. Thus, the potential input to dose from Pu-isotopes can be comparable with the input from gamma/beta emitters.

8.3 Impact on marine biota from nuclear power plant (Ringhals NPP, Sweden)

An example of the impact of nuclear power plants on coastal marine biota was assessed using monitoring data from Ringhals NPP in Sweden (SSI Report 2000:04; SSI report 2000:19; Wijk & Luning, 2001).

Ringhals nuclear power plant is situated at the Swedish West Coast, approximately 50 km to the south of Gothenburg and 15 km to the north of Varberg, on the Värö peninsula. The site encompasses 4 reactors, one BWR and 3 PWRs. The installed electrical capacity is 0.75 GW for the BWR and 2.63 GW for the three PWRs.

The plants discharge into the Kattegat. There are two adjacent discharge points immediately at the coastline, one for Units 1-2, and one for Units 3-4. Air-borne releases predominantly are through the main stack of each reactor unit, i.e. from four emission points.

The environmental samples consist of local fauna and flora (algae, fish, shellfish, mosses, game), sediment, as well as local food produce (grain, milk etc.). In dose assessment the following region-specific organisms were considered: cod (*Gadus morhua*), mussel (*Mytilus edulis*), winkle (*Littorina littorea*), lobster (*Homarus gammarus*), and crab (*Cancer pagurus*).

The assessment was performed for the recent period of Ringhals NPP operation (1997 to 2000), available monitoring information on the radionuclide content in biota include the following radionuclides: ^{54}Mn, ^{58}Co, ^{60}Co, ^{137}Cs. The number of samples varied between years from one to 6 of different species; only data from the monitoring sites close to Ringhals were considered.

Since the impact from the NPP to marine biota is known to be small compared with that from other industries, maximum dose rates were estimated, based on the highest concentrations of radionuclides in assessed species found for each year.

Dose rates to cod caught in the vicinity of the Ringhals NPP varied very little from year to year amounting on average to $(1.4 \pm 0.25) \cdot 10^{-8}$ Gy day^{-1} ; these were small values, slightly higher than the man-made background in the OSPAR region.

Dose rates to molluscs were also small with the average value amounting to $(2.9 \pm 2.6) \cdot 10^{-8}$ Gy day^{-1} with larger variability in the contamination of individual specimen.

Dose rates to crustaceans (lobsters and crabs) varied within one order of magnitude from $7 \cdot 10^{-9}$ to $7 \cdot 10^{-8}$ Gy day^{-1}. Isotopes of cobalt (^{58}Co, ^{60}Co) were the major contributors to exposure of molluscs and large crustaceans; ^{137}Cs was responsible for the man-made exposure of fish. It should be noted that the estimated values of dose rates include contributions from the regional artificial contamination of the marine environment.

From the point of view of the radiological impact to marine biota dose rates to marine organisms in the vicinity of Ringhals NPP were very low during the assessed period, contributing only a minor addition to natural background.

9 Dose rates to marine biota from non-nuclear industry

9.1 Phosphate plant at Whitehaven, UK

Surveys of concentrations of naturally occurring radioactive materials (NORM) in the coastal waters of the UK revealed (Rollo et al., 1992) that the Albright & Wilson chemical plant at Whitehaven in Cumbria, UK which manufactured phosphoric acid from imported phosphate ore was an important source of NORM radionuclides to the marine environment from 1954.

Phosphogypsum, a waste product of chemical technology, has been discharged as liquid slurry by pipeline to Saltom Bay. The discharges contain low levels of natural radioactivity (NORM) consisting mainly of thorium, uranium and their daughter products, such as ^{238}U, ^{234}U, ^{232}Th, ^{230}Th, ^{228} Th, ^{210}Pb, ^{210}Po.

Since the introduction of changes in waste treatment techniques and cessation of the use of phosphate ore in 1992, the discharges declined substantially, in particular, discharges of uranium decreased by 80%, of ^{230}Th and ^{210}Pb by 95%, and of ^{210}Po by 99% (Poole et al., 1995).

The assessment of dose rates to marine biota from NORM was performed for the site at Parton (Figure 12) situated 5 km north from the phosphate plant, where greater enhancements of NORM were observed due to the local sedimentary transport system. Dose assessment was based on data from monitoring programmes and surveys for the period 1991-1999. At Parton, concentrations of NORM were measured in mussels, winkles, crabs, lobsters, and cod. Local background levels of NORM in seawater and marine biota were measured at Ravenglass, 10 km to the south from the phosphate plant, these data were used in estimation of local background exposure of marine organisms (McCartney et al., 2000; Rollo et al.,1992). The estimated values of local background dose rates to biota are the following (Gy day^{-1}, weighted by w_r): molluscs and crabs – $(2.5 – 3)\cdot 10^{-5}$, fish – $1\cdot 10^{-6}$.

The dynamics of dose rates to marine biota from NORM (at Parton) are shown in Figure 13, see also Appendix B (table B3). During the period 1991-1999 dose rates to molluscs decreased from $3\cdot 10^{-4}$ to $4.8\cdot 10^{-5}$ Gy day^{-1} (weighted by w_r), including the natural background. These dose rates are comparable with radiation exposure of biota in the Sellafield coastal area.

The dominant contributor to molluscs' dose is ^{210}Po, which is accumulated with high concentration factors, see Figure 14. The contribution to dose of uranium and thorium isotopes is considerably lower, than that of polonium. However, there is a possibility of chemical toxicity of uranium/thorium in bottom sediments for bottom-dwelling species. The aspects of chemical toxicity of NORM are outside the scope of this assessment.

Dose rates to crustaceans (crab) varied within the range from $7\cdot 10^{-5}$ to $2.8\cdot 10^{-5}$ Gy day^{-1} (weighted by w_r) including the natural background; with ^{210}Po again being the major dose contributor.

Dose rates to highly mobile organisms, such as fish (cod) from NORM (including the natural background) were estimated to be $(2-4.8)\cdot 10^{-6}$ Gy day^{-1} (weighted by w_r) during 1991-1999. The major contributors to the exposure of cod were ^{40}K (natural background) and ^{210}Po, see Figure 14.

Summarizing the results of dose assessment, the conclusion can be made that at the beginning of the assessment period, the estimated radiological impact to marine biota from a big phosphate plant at Whitehaven was comparable with that from a large nuclear reprocessing plant at Sellafield; in recent years the additional dose rates to marine biota at Whitehaven (from NORM) were of the same order of magnitude as the natural background.

9.2 Offshore oil installations in the North Sea

The offshore oil industry in the North Sea has been faced with the problem of NORM since the early 1980s, when enhanced levels of naturally occurring radionuclides were found in the production systems of several oil fields of the North Sea.

The produced waters from oil reservoirs contain elevated levels of radioactivity, mainly ^{226}Ra, ^{228}Ra and their daughter products. The concentrations of the natural radionuclides ^{226}Ra and ^{228}Ra in produced water from individual platforms' oil and gas production wells, vary between less than 0.1 Bq L^{-1} to about 200 Bq L^{-1} (Lysebo & Strand, 1997, 1998). The average concentration of the radionuclides ^{226}Ra and ^{228}Ra in produced water discharged from all oil and gas producing platforms and over all years is estimated at 10 Bq L^{-1} each.

These concentrations are approximately three orders of magnitude higher than the natural background concentrations of radium in seawater (IAEA, 1990).

Most of radioactivity from oil reservoirs is disposed with produced water into the sea. The amount of produced waters released per platform is estimated to be approximately $(3\text{-}4)\cdot10^6$ m^3 $year^{-1}$. Solid sludge from offshore oil production also contains enhanced levels of NORM (^{226}Ra, ^{228}Ra, ^{210}Pb).

At present the experimental information on the radioactive contamination of seawater and marine biota in the vicinity of offshore oil platforms in the North Sea is not available for assessment. Calculations, using a model scenario of chronic releases, were made to predict the radium concentrations in seawater around oil platforms and estimate the potential dose loads to local marine biota.

The concentrations of Ra-isotopes in seawater in the vicinity of an oil platform were estimated using a simple hydrological model, representing the marine local zone around a platform as a single compartment of 1000x1000 m^2 size with a depth of the water mixing layer of 20 m, having a natural water exchange with the open sea of about 0.5-1 times per day. The man-made input of radioactivity into this local zone was calculated from the reference concentrations of Ra-isotopes in the produced waters and the annual amount of releases.

From model calculations, the additional radium concentrations in seawater of the local zone around an oil platform are expected to be within the range of 5-10 Bq m^{-3} for each of the radionuclides ^{226}Ra and ^{228}Ra (above local background). The uncertainties in model results depend on the discharges of radionuclides, and the local intensity of water exchange.

Average concentrations of Ra-isotopes in local marine biota living within the marine local zone around the oil platform, were calculated from these predicted concentrations in seawater using typical values of radium bioaccumulation factors in molluscs, crustaceans, and fish (IAEA, 1985). Based on these assumptions the internal dose rates from radium isotopes were estimated to be about $(3\text{-}7)\cdot10^{-5}$ Gy day^{-1} (weighted by w_r) to molluscs, $(1.7\text{-}3.4)\cdot10^{-5}$ Gy day^{-1} to fish, and $(3.4\text{-}6.8)\cdot10^{-6}$ to shrimps.

The main source of external exposure to local marine biota is solid sludge with enhanced levels of NORM, which is accumulated on the seabed in the vicinity of an oil platform; however, there is no sufficient information for estimation of doses to biota from depositions on the seabed.

Model estimations of the radiation impact on marine biota in the vicinity of offshore oil installations in the North Sea demonstrate that the radiation exposure of marine biota in immediate proximity to oil platforms may be enhanced, especially in the local zones with slow water currents. More correct evaluation of this impact is a task for further investigation.

10 Comparison of the radiation exposure of marine biota in different locations of the OSPAR region

Figure 15 presents a scheme of the estimated dose rates to marine biota from activity at the selected locations within the OSPAR region, placed along the scale of radiation effects (chronic exposure) to organisms and populations. The scheme demonstrates the large differences in the exposure of marine biota in the selected sites within the OSPAR region, as well as a general improvement of the radioecological situation in the most impacted sites for the recent period (1991 to 1999).

None of estimated dose rates exceeded the lower boundary of the zone of radiation effects (see section 2 of this report) throughout the assessment period (1980s-1990s), see Figure 15 and Table 11; therefore no impact from radiation is expected for populations of marine biota.

11 Conclusions

1. An appropriate methodology has been identified for estimation of doses and radiation impact on marine biota in the OSPAR region.

2. Dose assessment has been performed for representative organisms, inhabiting selected industry-impacted locations within the OSPAR region, including: a) areas impacted by nuclear industry (Sellafield, Cap de la Hague, NPP in Sweden); b) areas impacted by non-nuclear industries (phosphate plant in UK; offshore oil installations in the North Sea); c) relatively ‘clean’ marine areas remote from industrial activity (Barents Sea). Dose assessment to marine biota was based on monitoring data of measurements of radionuclide concentrations in representative organisms, seawater and sediments for the periods from the early 1980s until the late 1990s.

4. It was found that during the assessment period, dose rates to representative marine organisms within the OSPAR region varied within a very broad range from about 10^{-9} Gy day^{-1} in the remote areas up to 10^{-4} Gy day^{-1} in the industry - impacted zones.

5. Among the marine zones affected by the nuclear industry the highest dose rates to marine biota were estimated for the coastal area impacted by BNFL Sellafield nuclear reprocessing plant.

   During the assessment period (1986-2001), the dose rates to marine biota in the vicinity of Sellafield were below the levels, where any deterministic effects of radiation could be expected in marine organisms from natural populations. A gradual decrease in dose rates to marine biota was observed in the Sellafield area during the assessment period.

6. Dose rates to marine biota in the Cap de la Hague coastal area of France were somewhat lower than those at Sellafield, with a gradual decrease throughout the assessment period 1982-1997.

7. Among the non-nuclear industry-impacted zones, the radiation exposure of marine biota during the assessment period 1991-1999, was estimated in the vicinity of the phosphate plant at Whitehaven (UK). At the beginning of the assessment period, the estimated radiological impact to marine biota from a big phosphate plant was found to be comparable with that from a large nuclear reprocessing plant at Sellafield. In the recent years the additional dose rates to marine biota at Whitehaven (from NORM) were of the same order of magnitude as the natural background due to changes in the production process.

8. Model estimations of the radiation impact on marine biota in the vicinity of offshore oil installations in the North Sea demonstrate, that the additional radiation exposure of marine biota in the immediate proximity to oil platforms may be enhanced, due to releases of produced waters with elevated levels of radium isotopes. More correct evaluation of this impact is a task for further investigation.

9. Estimated dose rates to marine biota in the vicinity of a nuclear power plant (Ringhals NPP in Sweden) were very low during the recent years (1997 to 2000), amounting to a minor addition to natural background.

10. Dose rates from artificial radionuclides in the remote marine areas of the OSPAR region (Barents Sea) are negligible compared with the natural background.

11. According to the available information, there is no identifiable impact on populations of marine biota from radioactive discharges.

The methodology for determining the impact of radioactivity on marine biota is still under development. In the future, the methodology of dose assessment to natural biota will be improved following the development of scientific knowledge on the dose-effect relationships in wildlife, and collection of more detailed information on content and radionuclide distribution within organisms.

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Table 1 Region-specific fish in the OSPAR marine region

Type of fish	Habitat	Representative species of fish in the OSPAR region	Recommended organism for dose assessment	Typical geometric size of adult organism, cm (ellipsoid)	Weight, g
Large fish	Predatory/ mixed feeding	Cod, blue whiting, hake, salmon, saithe	'Cod'	50x10x6	1500
	Benthos-feeding	Haddock	'Haddock'	50x10x6	1500
Medium-size fish	Pelagic, planktivorous	Herring, mackerel	'Herring'	25x6x4	300
	Benthos-feeding	Plaice	'Plaice'	25x20x3	800
Small fish	Pelagic, planktivorous	sardine/ pilchard or capelin (only for the northern part of the OSPAR region),	'sardine'	15x3x1.5	30
Very small fish	Pelagic, planktivorous	Sprat or anchovy (only for the southern part of the OSPAR region)	'Sprat'	7x1.5x0.9	5
Latin names of fish species: Anchovy – *Engraulis encrasicholus*; blue whiting – *Gadus poutassou*; capelin – *Mallotus villosus*; cod – *Gadus morhua*; hake – *Merluccius merluccius*; herring – *Clupea harengus*; mackerel – *Scomber scombrus;* pilchard/sardine - *Sardina pilchardus*; plaice - *Pleuronectes platessa*; saithe – *Pollachius virens;* salmon – *Salmo salar;* sprat – *Sprattus sprattus*					

Table 2 Information on environmental behaviour of the region-specific fish

Reference organism	Percentage of time, which fish spend close to bottom	Percentage of time, which fish spend in the water column
‘Cod’	30%	70%
‘Haddock’	70%	30%
‘Herring’	0%	100%
‘Plaice’	80%	20%
‘Sardine’	0%	100%
‘Sprat’	0%	100%

Table 3 Region-specific molluscs in the OSPAR marine region

Type of mollusc	Representative species of molluscs in the OSPAR region	Recommended organism for dose assessment	Typical geometric size of adult organism, cm (ellipsoid)	Weight, g
Bivalve mollusc	Mussels, cockles, scallops	'Mussel'	6x3x2.5 (total size)	5 (without shells)
Gastropoda mollusc	Winkles, limpets, whelks	'Winkle'	4x3x2	3 (without shells)
Latin names of mollusc species: Whelk - *Buccinum undatum;* mussel – *Mytilus edulis;* winkle – *Littorina littorea*; cockles - *Cerostoderma edule;* scallop – *Pecten maximus*				

Table 4 Region-specific large crustaceans in the OSPAR marine region

Representative species of crustaceans in the OSPAR region	Recommended reference organism	Typical geometric size of adult organism, cm (ellipsoid)	Weight, g
Crab, lobster	'Crab'	10x10x5 (total size)	40 (without shell)
Shrimps	'shrimp'	7x1.5x1.5	5 (without shell)
Latin names: Crab – *Cancer pagurus*; shrimp – *Pandalus borealis*; lobster -*Homarus gammarus*			

Table 5 Details of the reference organisms used in the previous dose assessments for marine biota

(Pentreath & Woodhead, 1988; IAEA, 1988)

Reference organism	Mass, g	Lengths of the axes of the representational ellipsoid, cm.	Environmental niche
Small crustacean	1.6×10^{-3}	0.6 x 0.3 x 0.2	Pelagic and benthic
Mollusc	1.0	2.5 x 1.2 x 0.6	Benthic
Large crustacean	2.0	3.1 x 1.6 x 0.8	Pelagic and benthic
Fish	1.0×10^{3}	45.0 x 9.0 x 5.0	Pelagic and benthic

Table 6 Typical concentrations of natural radionuclides in surface sea water, and marine organisms

(Woodhead, 1973a)

Radionuclide	Sea water, Bq m^{-3}	Crustaceans Bq kg^{-1}	Molluscs Bq kg^{-1}	Fish Bq kg^{-1}
^{3}H	22-110	0.02-0.1	0.02-0.1	0.02-0.1
^{14}C	7.4	22	18.5	15
^{40}K	12000	93	107	93
^{87}Rb	107	1.5	1.9	1
^{210}Po	0.2-1.6	15-60	15-41	0.02-5 (muscles); 7.4-33 (liver); 0.7-8 (bone)
^{210}Pb	0.4-2.5	1.5-2.6	0.2-0.4	0.007-0.09 (muscles); 0.4-0.9 (liver); 0.3-4.8 (bone)
^{226}Ra	1.5-1.7			0.007-0.2 (flesh)
^{234}U	48			0.003-1.3
^{238}U	44			0.0025-1.1

Table 7 Summary of dose rates (Gy day^{-1}, weighted by w_r) to marine organisms from natural environmental radioactivity

(compiled from IAEA, 1976; Woodhead, 1984, 1998)

Source	Molluscs (5 m depth, on the sea bed)	Crustaceans (10 m depth, on the sea bed)	Fish	
			(20 m depth, remote from sea bed)	(20 m depth, on the sea bed)
NATURAL BACKGROUND				
Cosmic radiation (low LET radiation only)	$3.8 \cdot 10^{-7}$	$2.6 \cdot 10^{-7}$	$1.2 \cdot 10^{-7}$	$1.2 \cdot 10^{-7}$
External radionuclides	$(3.6\text{-}38.4) \cdot 10^{-7}$	$(3.6\text{-}38.4) \cdot 10^{-7}$	$2.4 \cdot 10^{-8}$	$(3.6\text{-}38.4) \cdot 10^{-7}$
Internal radionuclides	$(1.9\text{-}7.8) \cdot 10^{-5}$	$(1.2\text{-}34) \cdot 10^{-5}$	$(1.1\text{-}13) \cdot 10^{-6}$	$(1.1\text{-}13) \cdot 10^{-6}$
TOTAL	$(1.9\text{-}7.8) \cdot 10^{-5}$	$(1.2\text{-}34) \cdot 10^{-5}$	$(1.2\text{-}13) \cdot 10^{-6}$	$(1.6\text{-}16.8) \cdot 10^{-6}$

Table 8 Current levels of artificial radionuclides in sea water and commercial species of marine biota in the Barents Sea (1995 to 1999)

Radionuclide	Sea water, Bq m^{-3}	Fish(cod, saithe, haddock, redfish), Bq kg^{-1} fresh weight	Crustaceans (shrimps, crabs, lobsters), Bq kg^{-1}	Molluscs (sea scallops, mussels), Bq kg^{-1}
^{137}Cs	3-6	0.3 (0.2-0.5)	0.2 (0.1-0.4)	0.4(0.2-0.7)
^{90}Sr	3-4	0.02(0.004-0.03) (muscles); 0.1-0.5 (bones)	0.03 (shrimp meat); 0.05(0.03-0.06) (shell)	
$^{239,240}Pu$	$(4-10)\cdot10^{-3}$	$(0.6-2)\ 10^{-3}$	0.0003 (flesh); <0.3 (shell)	0.0008 (flesh); <0.05 (shell)
^{99}Tc	0.1-1.5	-	0.25-0.7 (crabs, shrimps); 0.2-26 (lobsters)	0.5-0.7

Table 9 Dose rates to marine biota due to artificial radionuclides in the remote zone of the OSPAR region: Barents Sea (1997 to 1999)

Organism	Dose rate from artificial radionuclides, Gy day^{-1} (weighted by w_r)
Fish (cod)	$(2\text{-}3)\cdot10^{-9}$
Mollusc (mussel)	$(3\text{-}4)\cdot10^{-9}$
Crustacean (crab)	$(8\text{-}9)\cdot10^{-9}$

Table 10 **General information on data from the Nord-Contentin database, which were used for dose assessments to biota in the Cap de la Hague coastal area (France): monitoring sites, type of samples, and radionuclides measured by different organisations**

Type of sampling materials	Monitoring site in the vicinity of Cap de la Hague area	Radionuclides measured	Organisation in France conducted radionuclide analyses
Water	Cap de la Hague	^{137}Cs, ^{134}Cs, ^{125}Sb, ^{106}Ru	GEA
Water	Flamanville	^{60}Co	GEA
Water	Goury	^{90}Sr, ^{99}Tc	GEA
Water	Moulinets	$^{239,240}Pu$, ^{238}Pu	OFRI
Sediments	Moulinets	^{137}Cs, ^{90}Sr	COGEMA
Sediments	Moulinets	$^{239,240}Pu$, ^{238}Pu	OPRI
Fish (*Gadus luscus*)	Les Huquets	^{137}Cs, ^{65}Zn, ^{110m}Ag	GEA
Fish (*Gadus luscus*)	Moulinets	^{106}Ru, ^{60}Co	OPRI
Mollusc (*Mytilus edulis)*	Barfleur	^{137}Cs, ^{106}Ru, ^{60}Co, ^{125}Sb	LEFRA
Mollusc Patella (limpet, Gastropoda)	Moulinets	^{137}Cs, ^{106}Ru, ^{60}Co, ^{125}Sb, $^{239,240}Pu$, ^{238}Pu, ^{241}Am	COGEMA
Crustacean (*Cancer pagurus*), entire	Huquets	^{137}Cs, ^{106}Ru, ^{60}Co, ^{125}Sb, ^{110m}Ag, ^{65}Zn, ^{54}Mn	GEA

Table 11 Summary of recent dose rates to marine biota at different locations within the OSPAR region, Gy day^{-1} (weighted by w_r)

Local area	Type of organism		
	Molluscs	Crustaceans	Fish
Sellafield	$4 \cdot 10^{-5}$	$4 \cdot 10^{-6}$	$3 \cdot 10^{-7}$
Cap de la Hague*	10^{-7} (mussel); $6 \cdot 10^{-7}$(mollusc Patella)	$2 \cdot 10^{-7}$	$2 \cdot 10^{-8}$
Whitehaven (phosphate plant)**	$2 \cdot 10^{-5}$	$1 \cdot 10^{-5}$	$1 \cdot 10^{-6}$
Ringhals NPP*** (Sweden)	$3 \cdot 10^{-8}$	$7 \cdot 10^{-8}$	$1.4 \cdot 10^{-8}$
Barents Sea (remote area)	$(3\text{-}4) \cdot 10^{-9}$	$(8\text{-}9) \cdot 10^{-9}$	$(2\text{-}3) \cdot 10^{-9}$
Natural radiation background (world data)	$(1.9\text{-}7.8) \cdot 10^{-5}$	$(1.2\text{-}34) \cdot 10^{-5}$	$(1.2\text{-}13) \cdot 10^{-6}$
Local radiation background (Cumbrian waters, UK)	$(2.5\text{-}3) \cdot 10^{-5}$	$(2.5\text{-}3) \cdot 10^{-5}$	10^{-6}

* Dose rates to mussels, crustaceans and fish are given without input from alpha-emitters; dose rate to Patella mollusc includes the contribution from alpha-emitters.

** Dose rates to biota at Whitehaven represent the additional exposure above the local background radiation

*** Dose rates to biota in the vicinity of the Ringhals NPP represent upper estimates based on the highest concentrations of radionuclides in assessed species found for each year.

Figure 1 **Scheme of the Sellafield coastal area in the vicinity of nuclear reprocessing plant operated by BNFL**

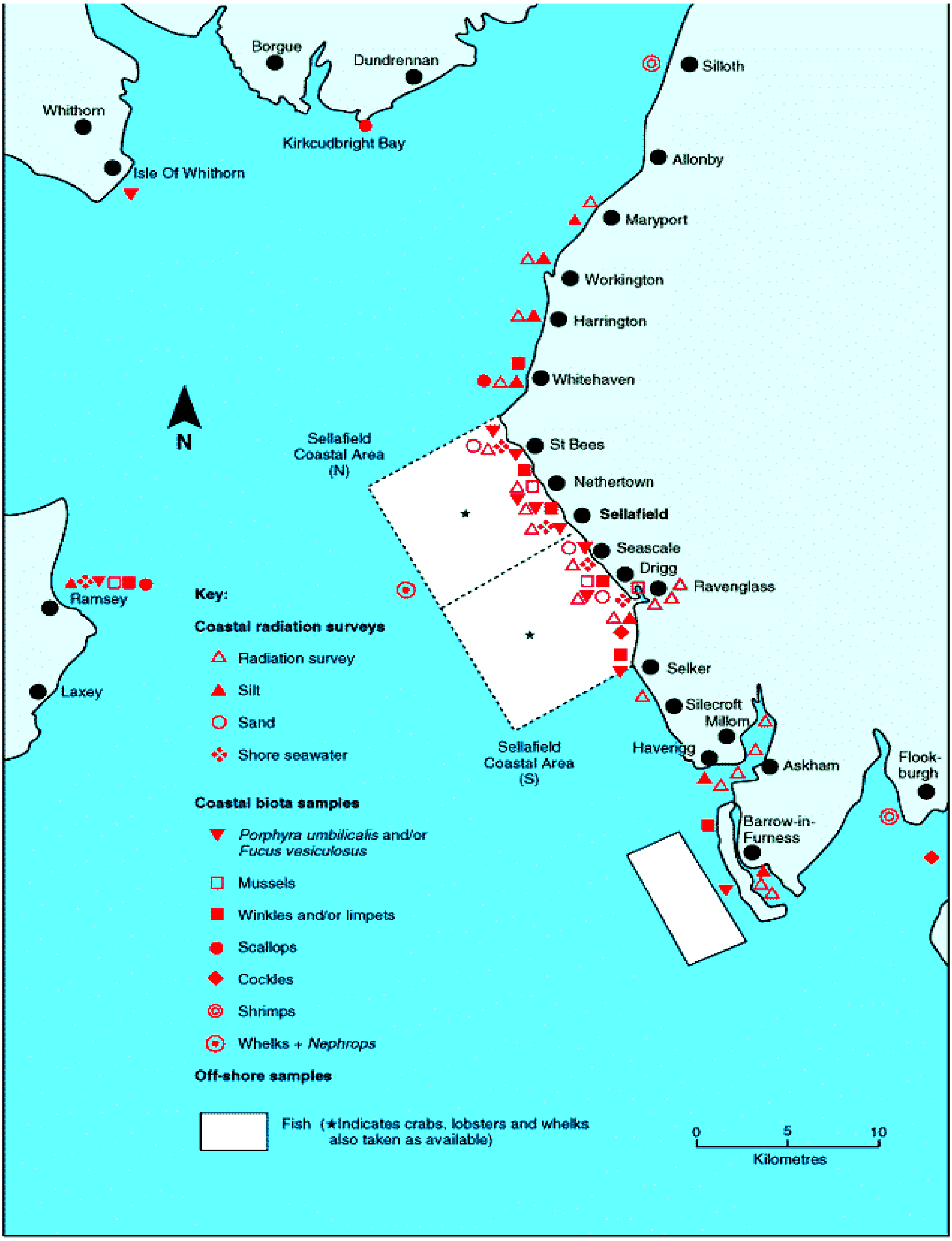


Figure 2 **Dose rates (Gy day^{-1}, weighted by w_r) to marine biota in the Sellafield coastal area (Cumbrian waters, UK) – Artificial radionuclides**

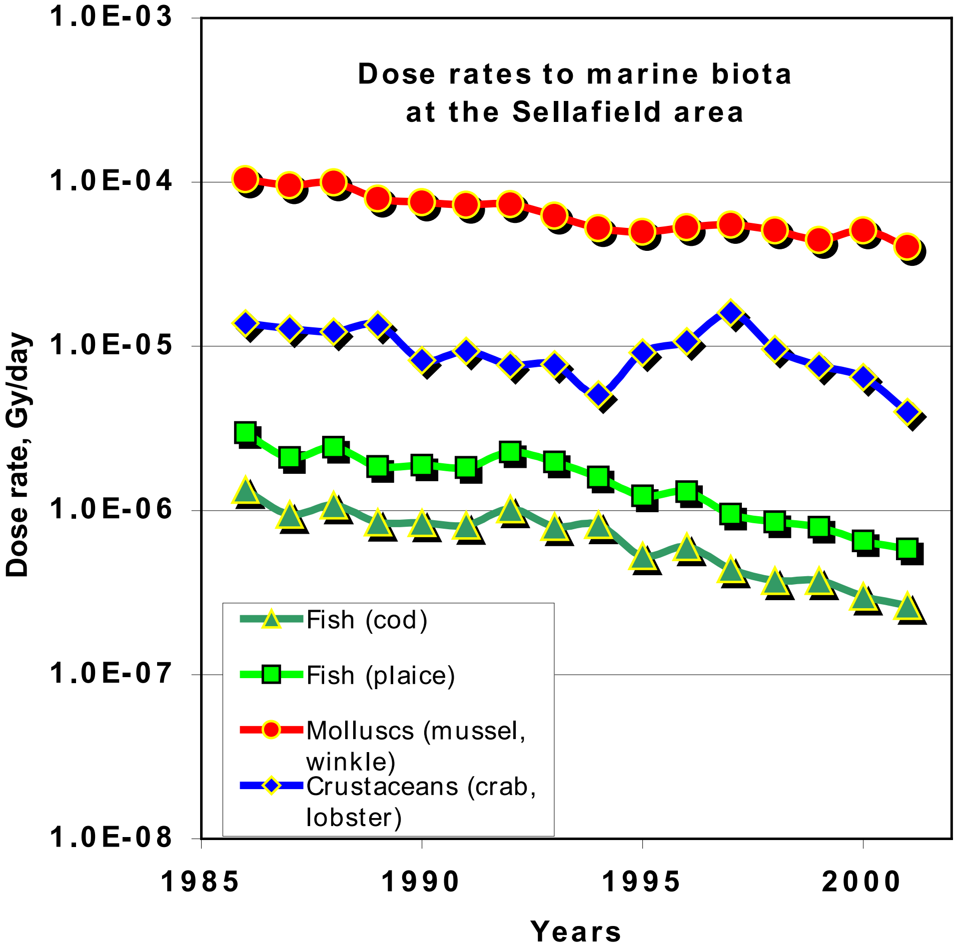
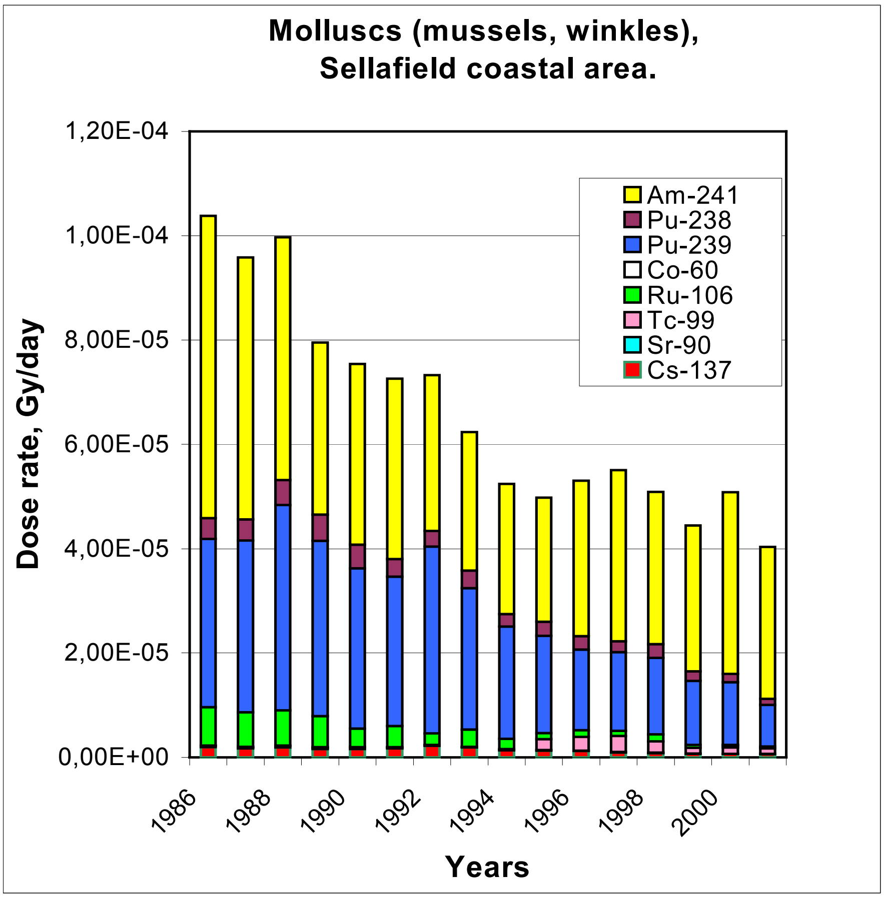


Figure 3 Dose rates (Gy day^{-1}, weighted by w_r) to molluscs, Sellafield coastal area, UK. Dynamics of the input of different radionuclides for the period 1985 to 2001, detailed figure for the year 1999



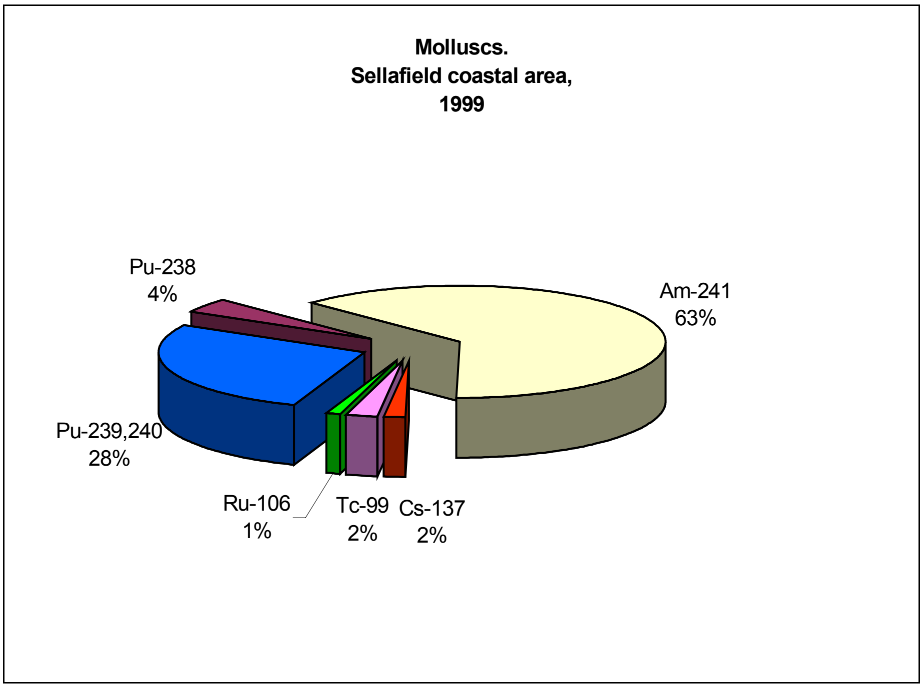
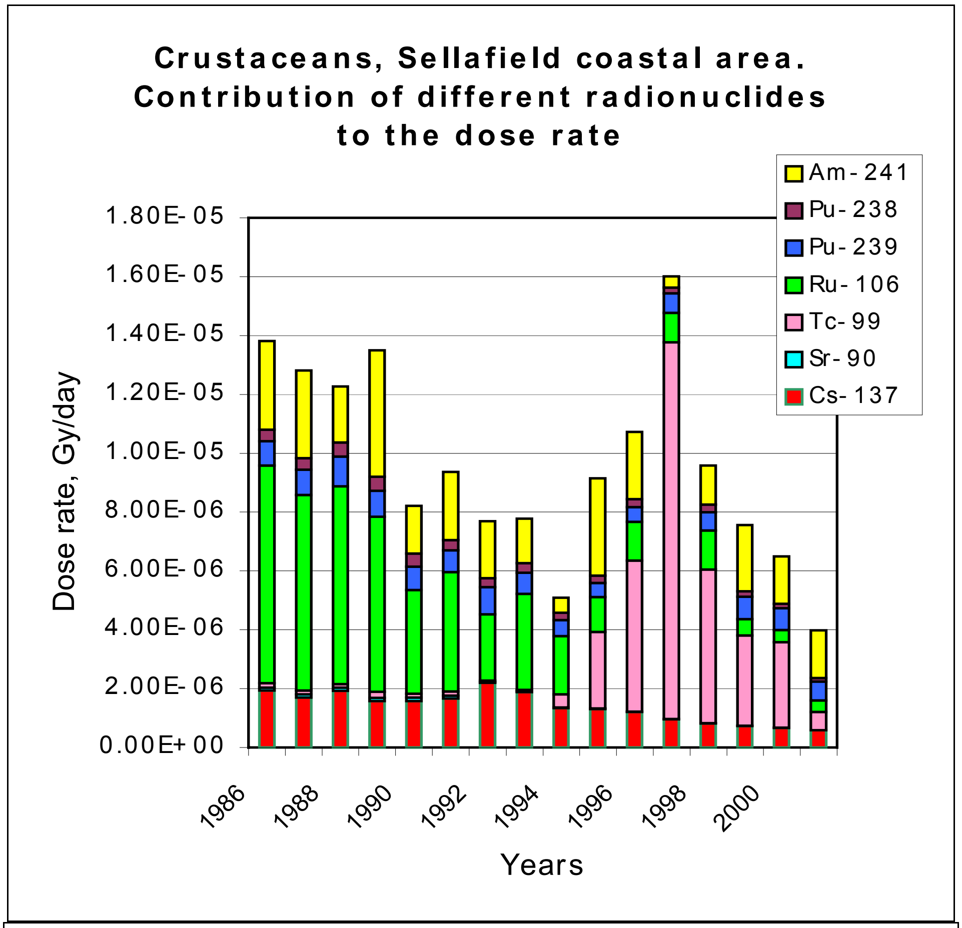


Figure 4 Dose rates (Gy day^{-1}, weighted by w_r) to large crustaceans (crabs, lobsters), Sellafield coastal area, UK. Dynamics of the input of different radionuclides for the period 1985 to 2001, detailed figure for the year 1999



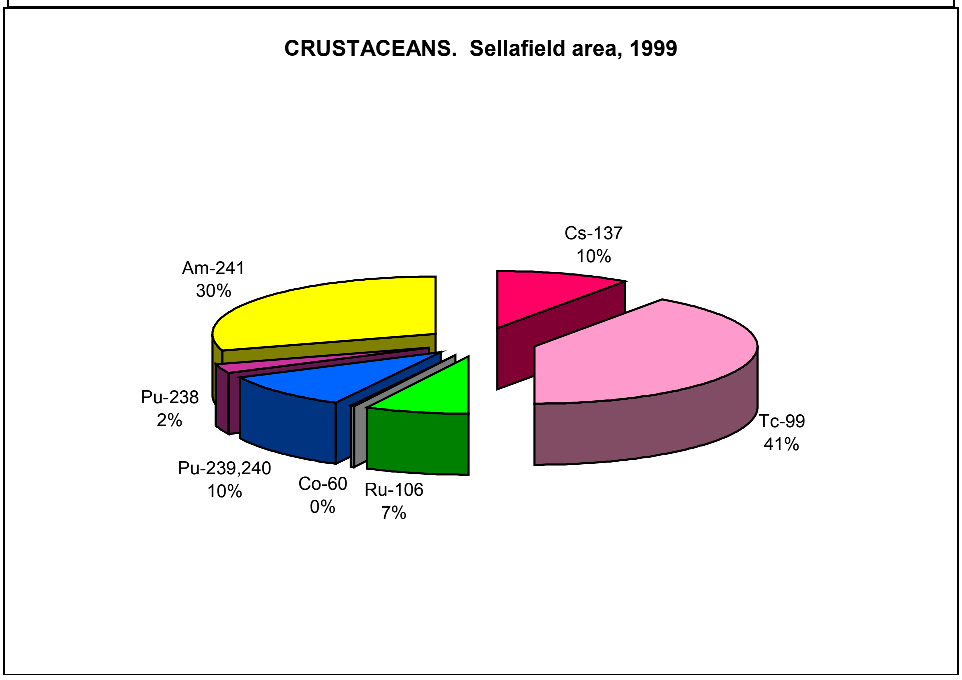
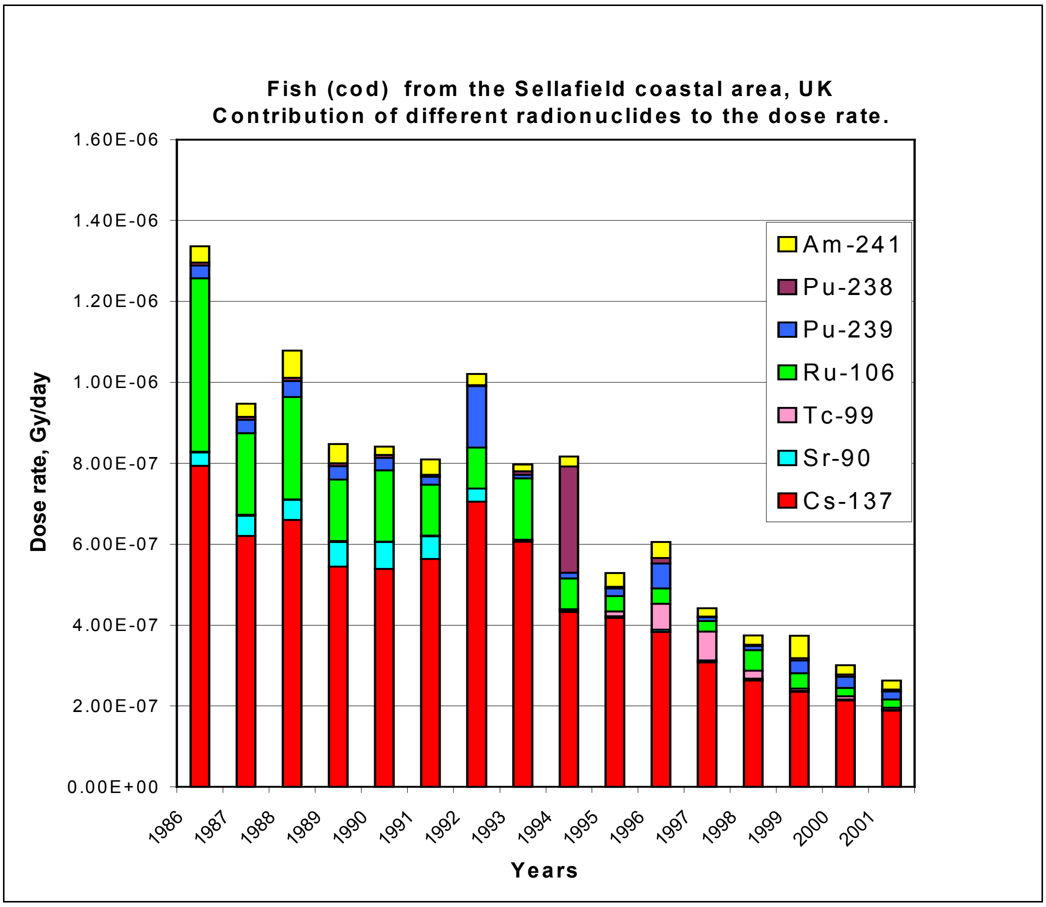


Figure 5 **Dose rates (Gy day^{-1}, weighted by w_r) to fish (cod). Sellafield coastal area, UK. Dynamics of radionuclides contribution in dose rates for the period 1985 to 2001, detailed figure for the year 1999**



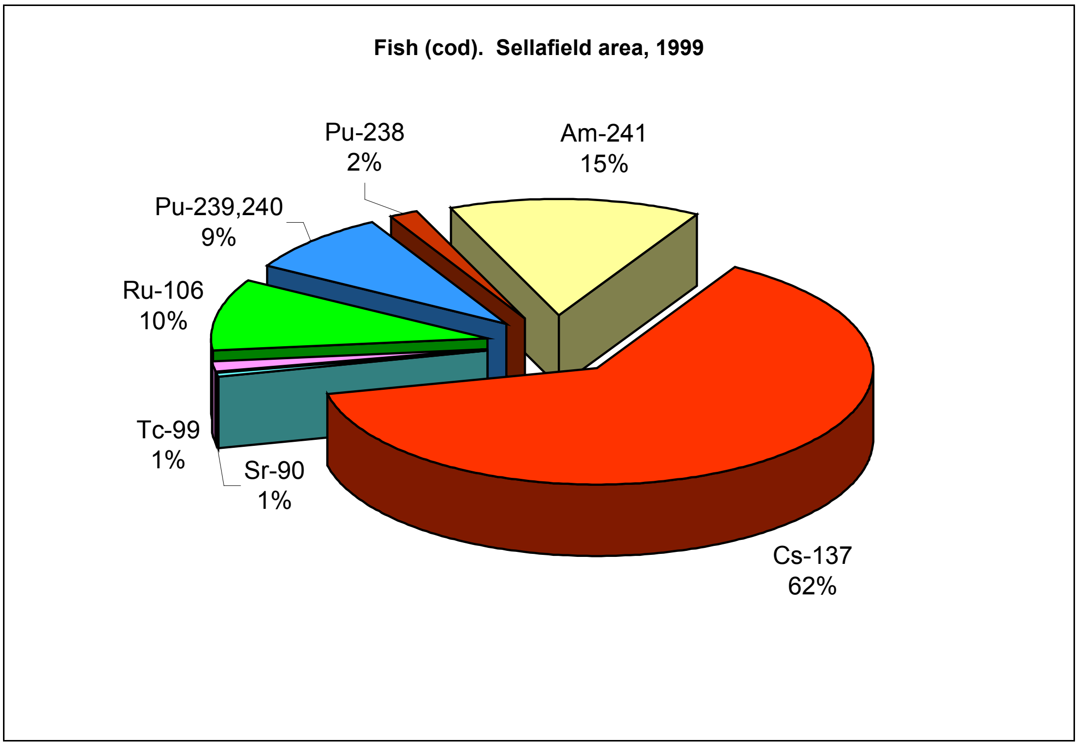


Figure 6 **Lower and upper boundaries of uncertainty in dose assessment for fish (cod). Sellafield coastal area**

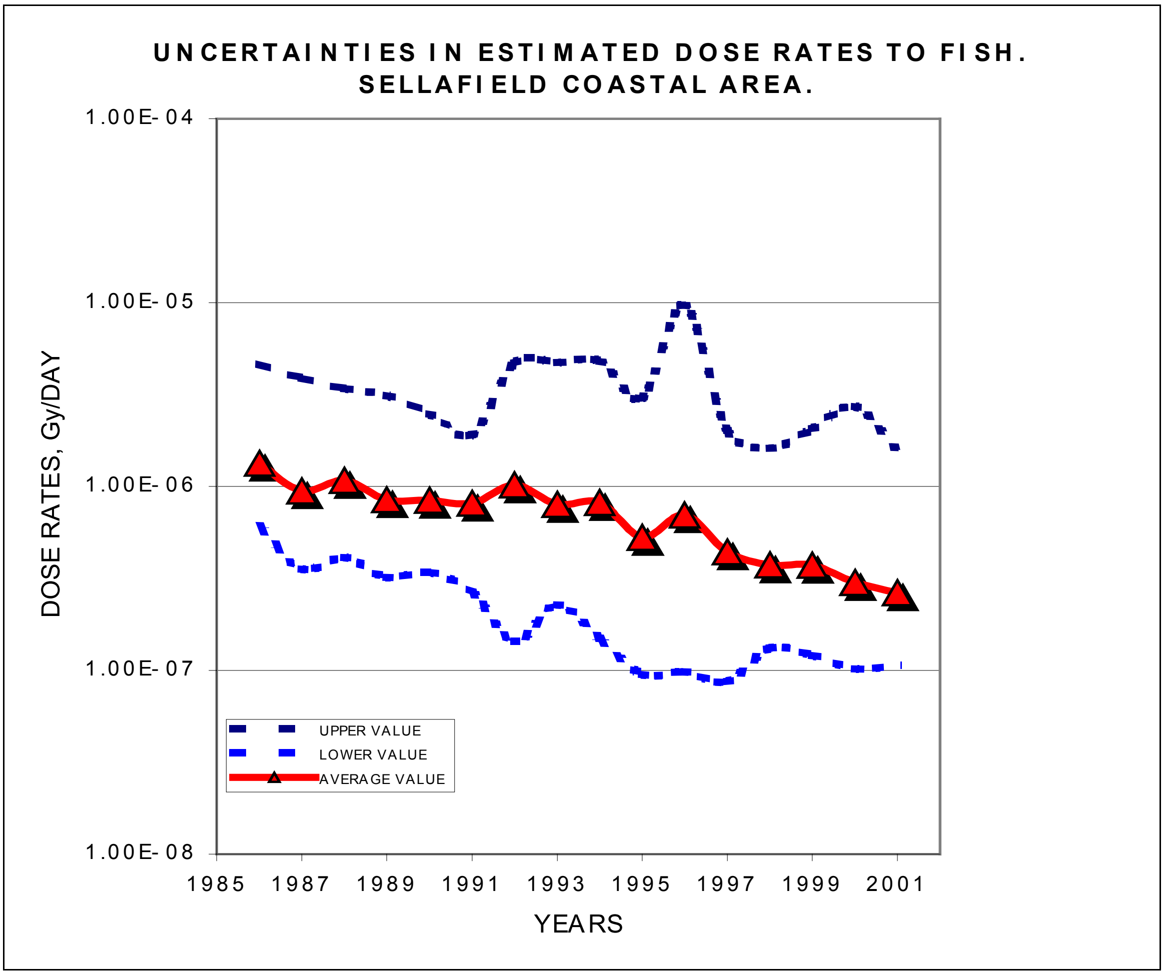


Figure 7 **Scheme of the Cap de la Hague area (France) with indication of the monitoring sites (from Nord-Cotentin database)**

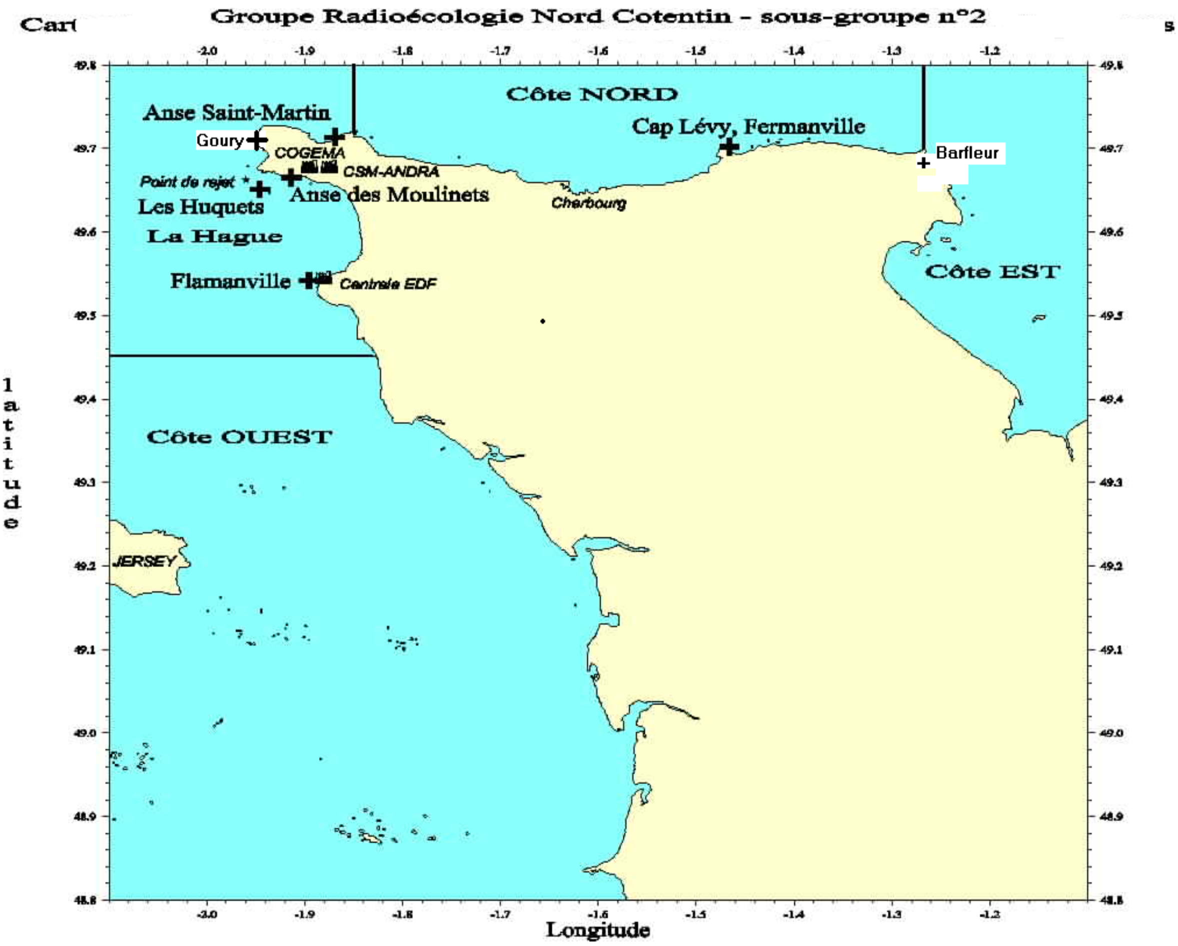


Figure 8 **Dose rates (Gy day^{-1}) to marine biota at the Cap de la Hague coastal area (France). Artificial radionuclides. *Data on alpha-emitters were available only for Patella molluscs (limpets)**

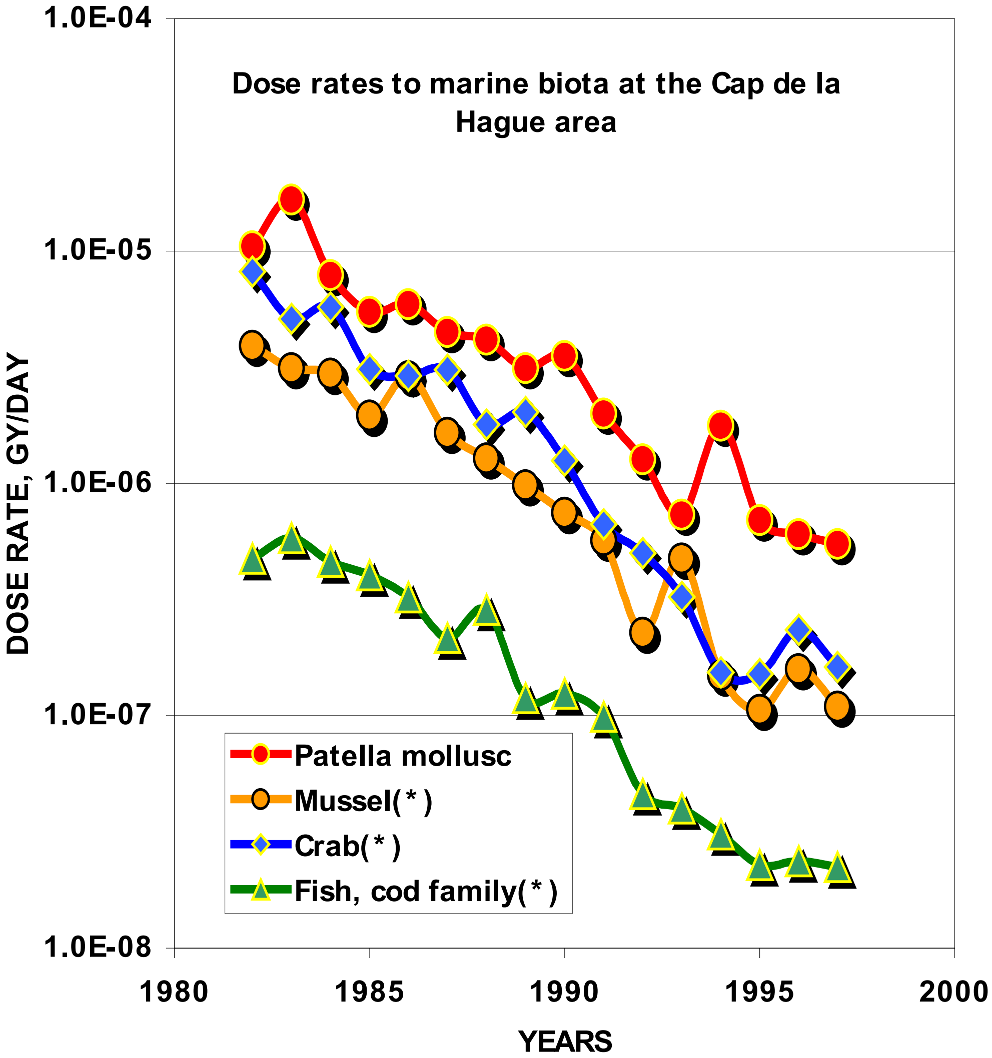
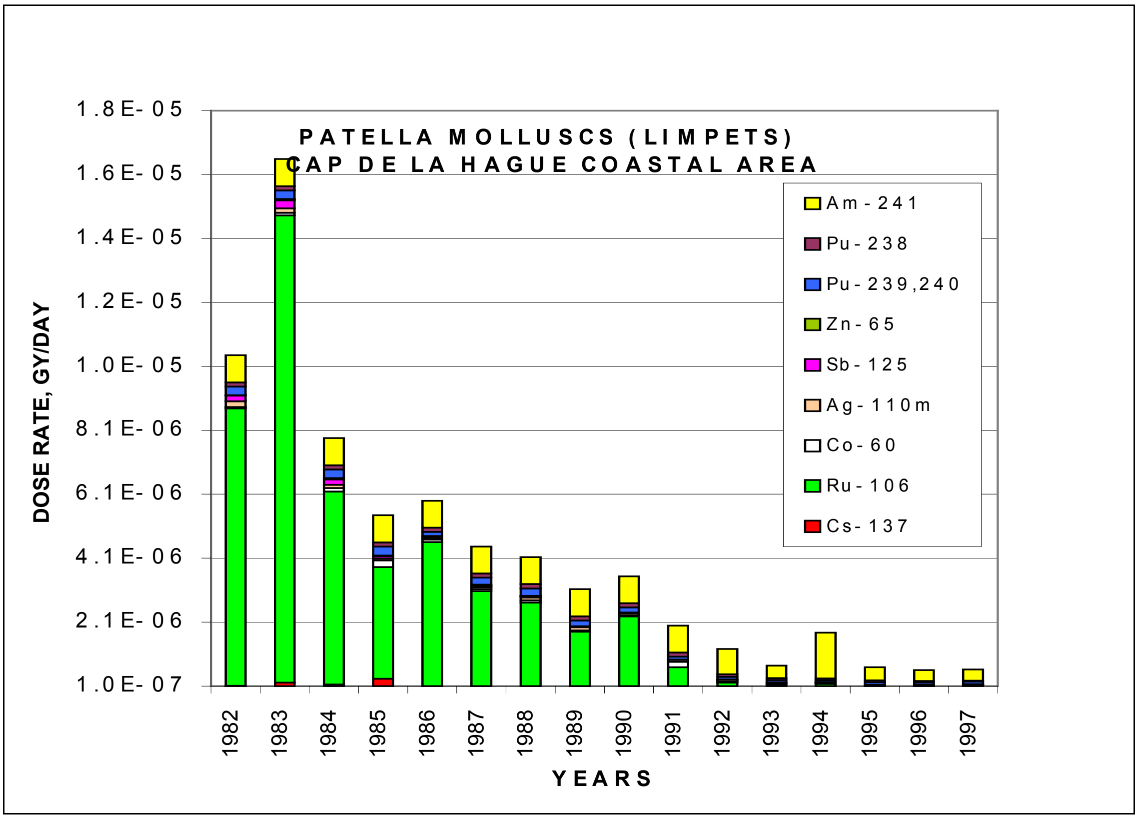


Figure 9 **Dose rates (Gy day^{-1}, weighted by w_r) to Patella molluscs (limpets), Cap de la Hague coastal area (France). Dynamics of the input of different radionuclides for the period 1982 to 1997, detailed figure for the year 1996**



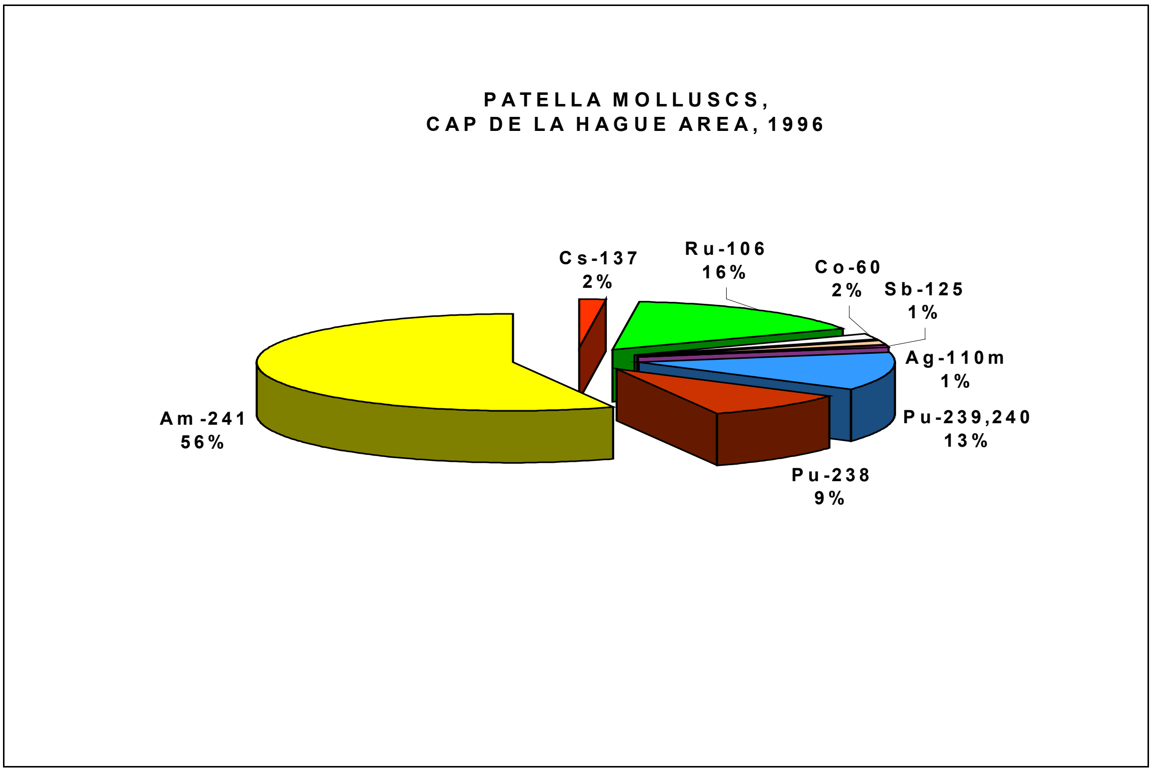
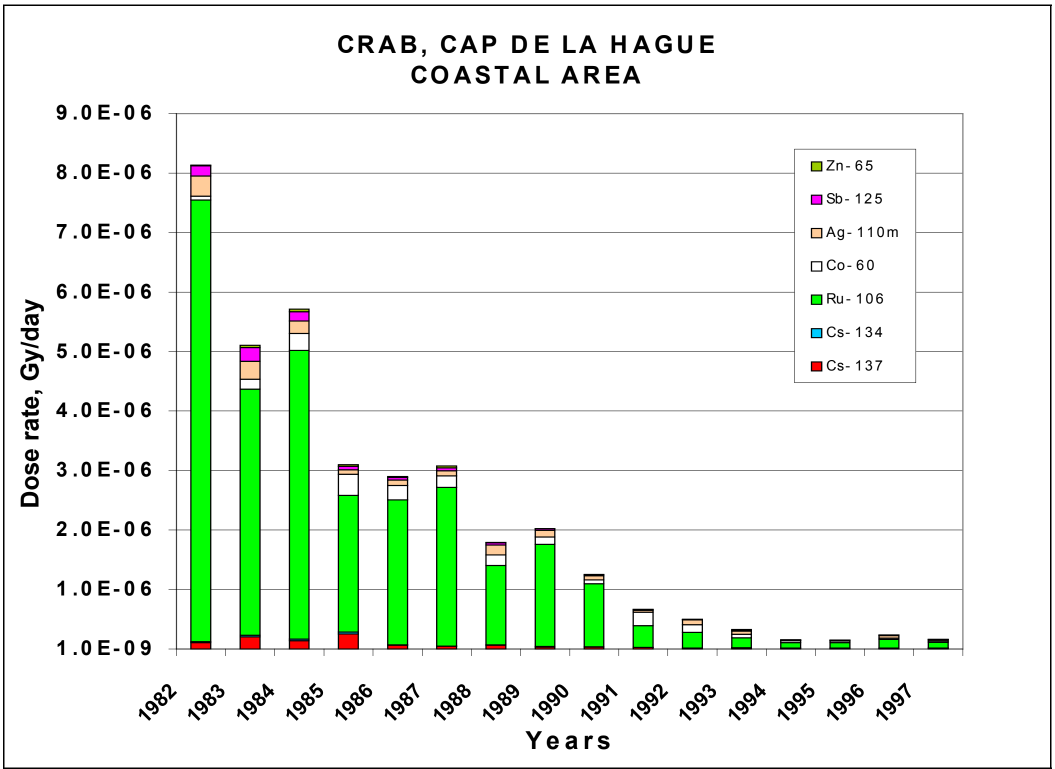


Figure 10 **Dose rates (Gy day^{-1}) to crab, Cap de la Hague coastal area (France). Dynamics of the input of different radionuclides for the period from 1982 to 1997, detailed figure for the year 1996; data on alpha emitters were not available**



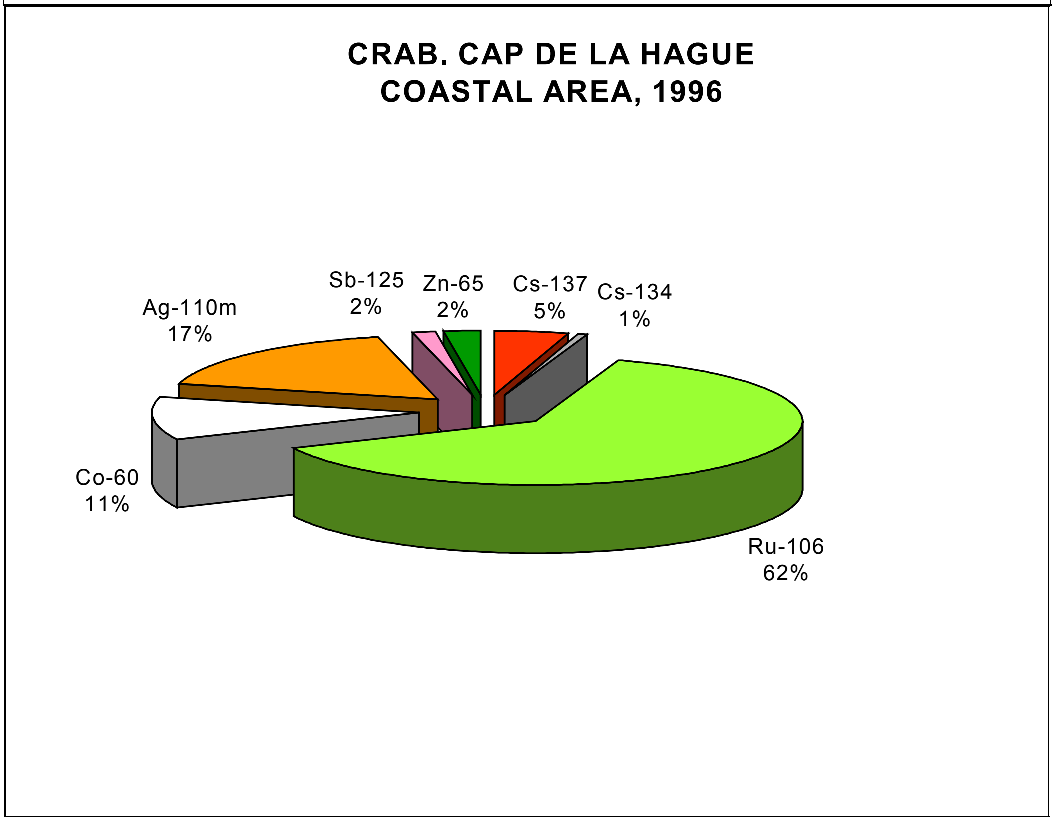
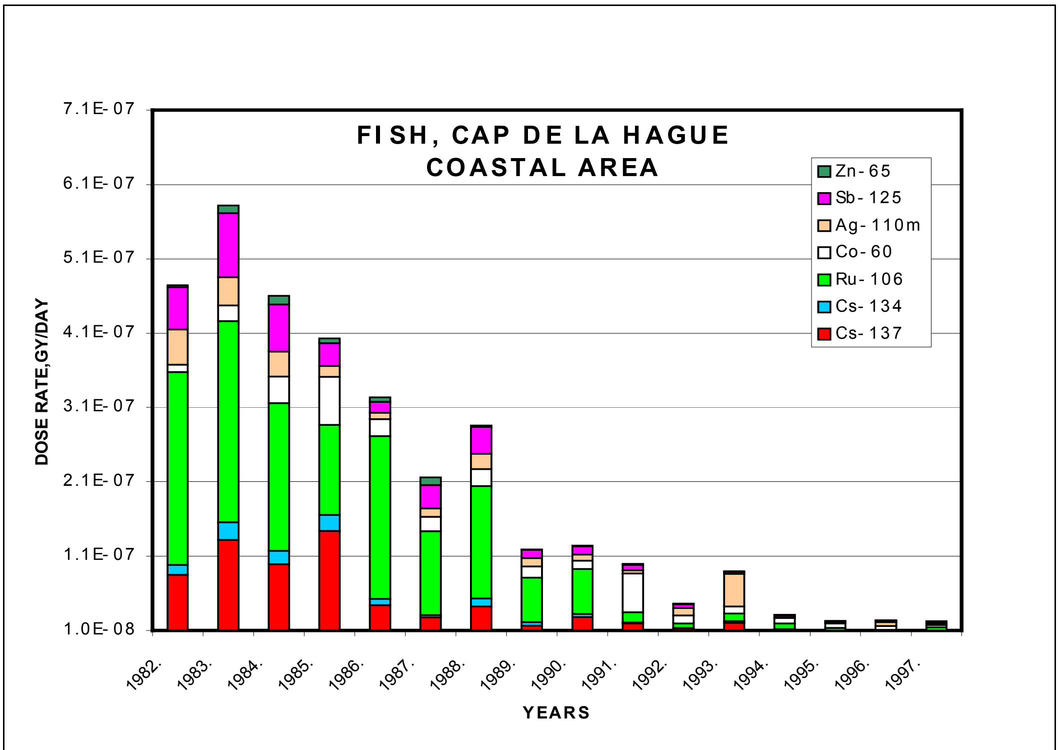


Figure 11 **Dose rate (Gy day^{-1}) to fish (*Gadus luscus*), Cap de la Hague coastal area (France). Dynamics of the input of different radionuclides for the period 1982 to 1997; detailed figure for the year 1996; data on alpha emitters in fish were not available**



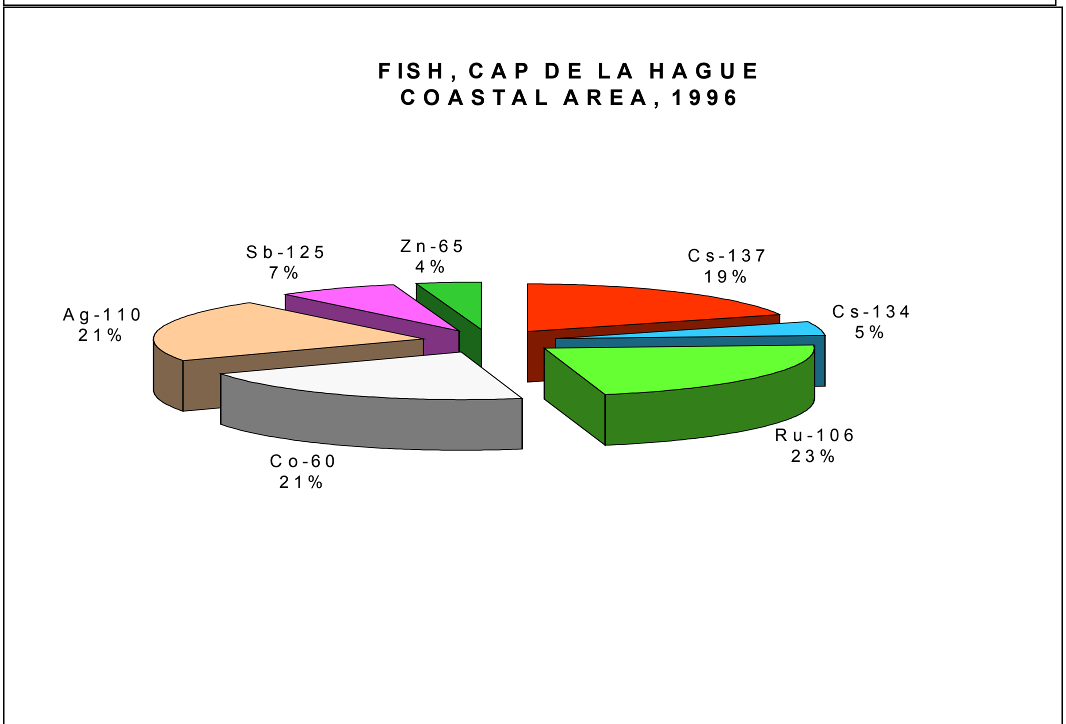


Figure 12 Scheme of the coastal area in the vicinity of phosphate plant at Whitehaven, UK

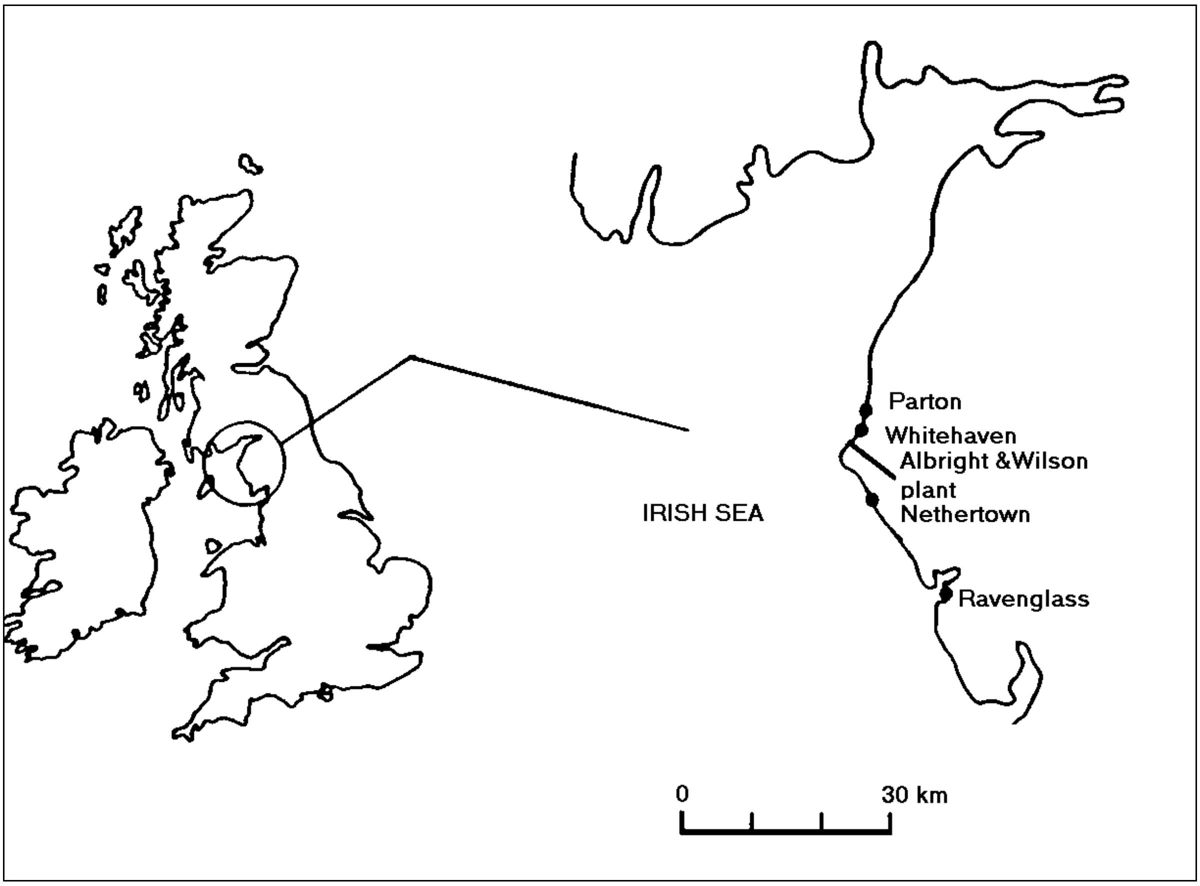


Figure 13 **Dose rates (Gy day^{-1}, weighted by w_r) to marine biota from NORM in the vicinity of phosphate plant at Whitehaven; including natural background exposure from NORM. Monitoring site Parton (5 km to the north from the plant). Cumbria waters, UK**

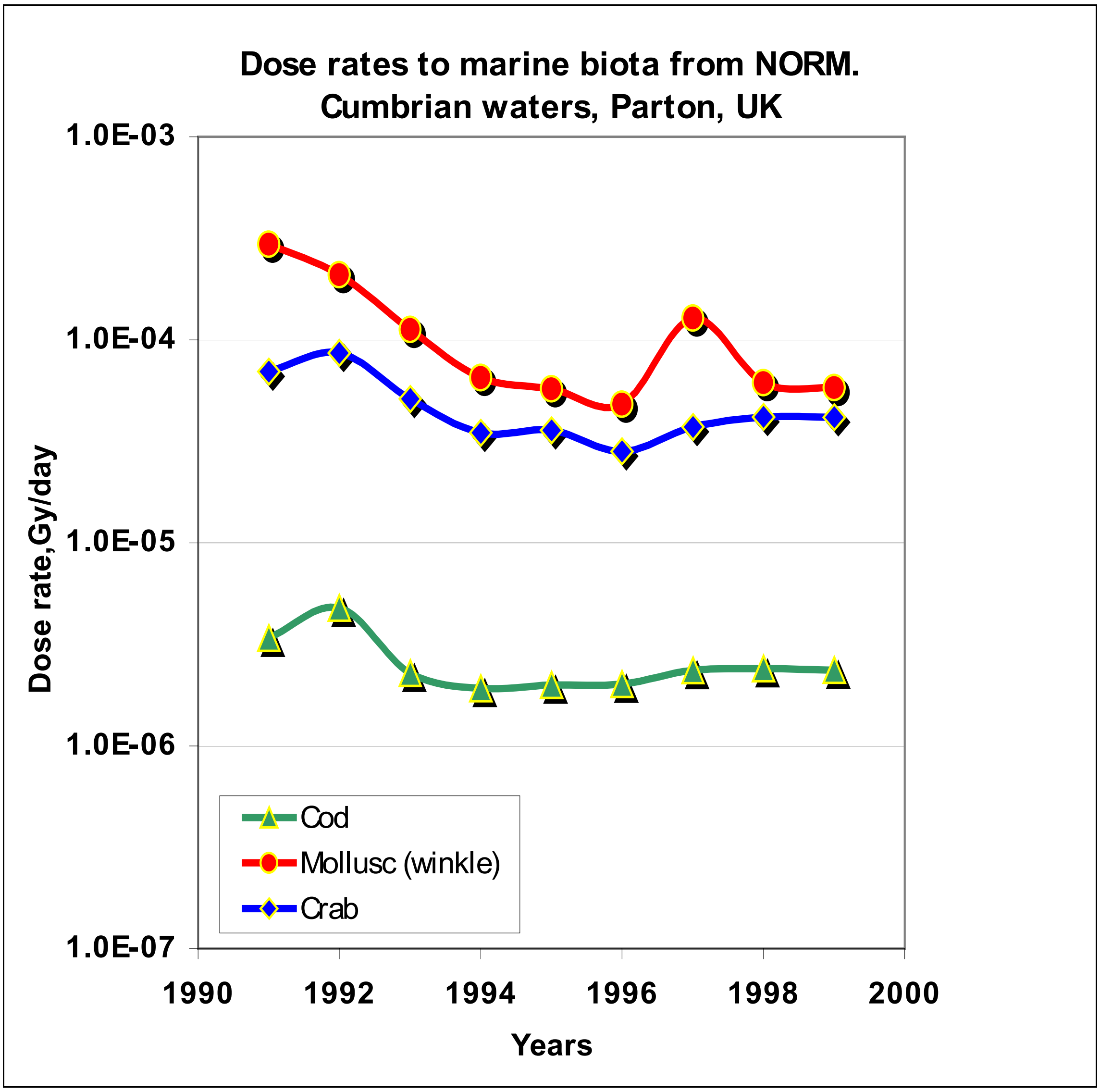
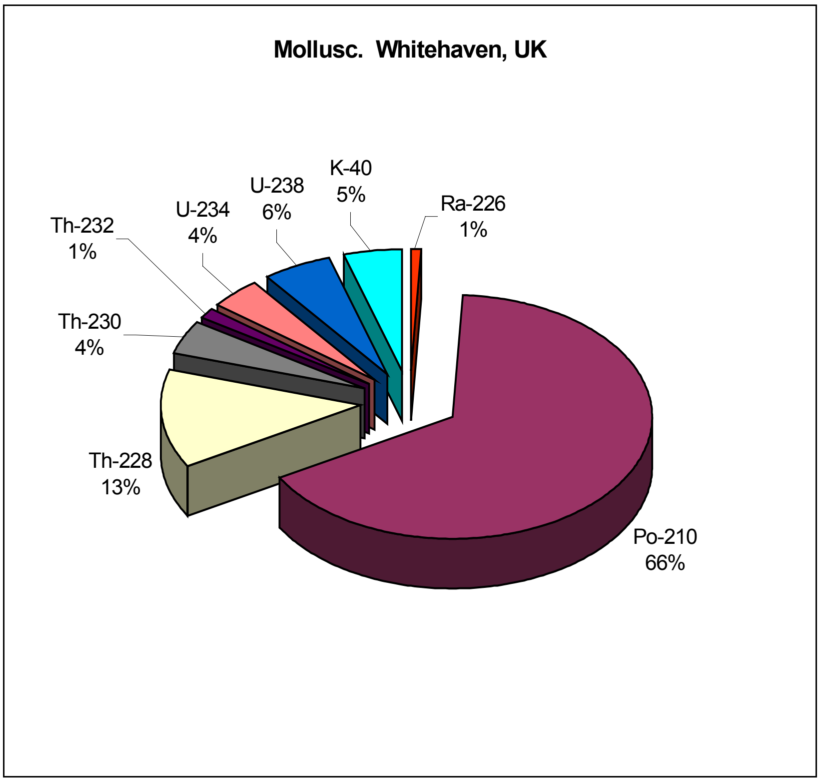
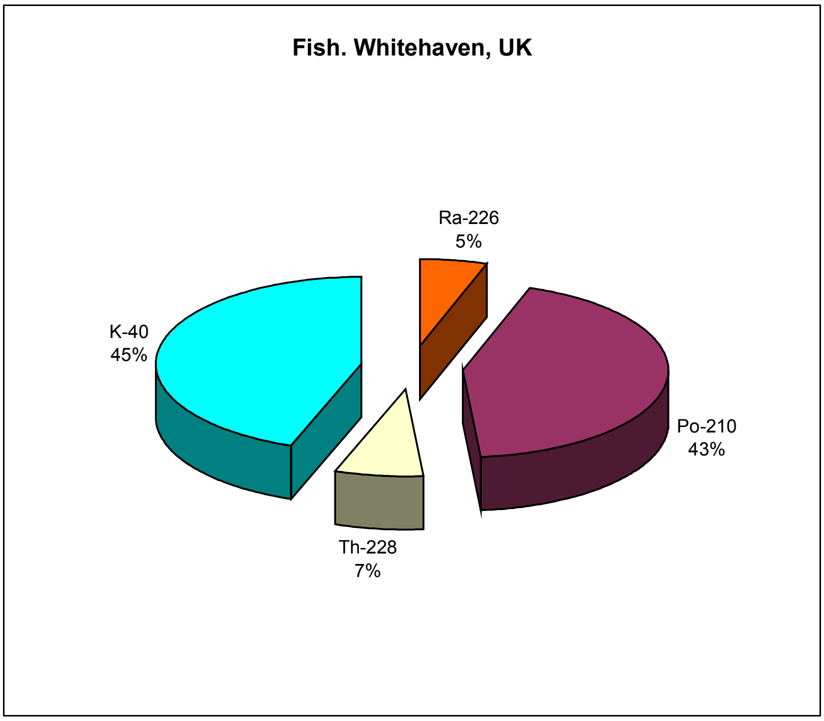


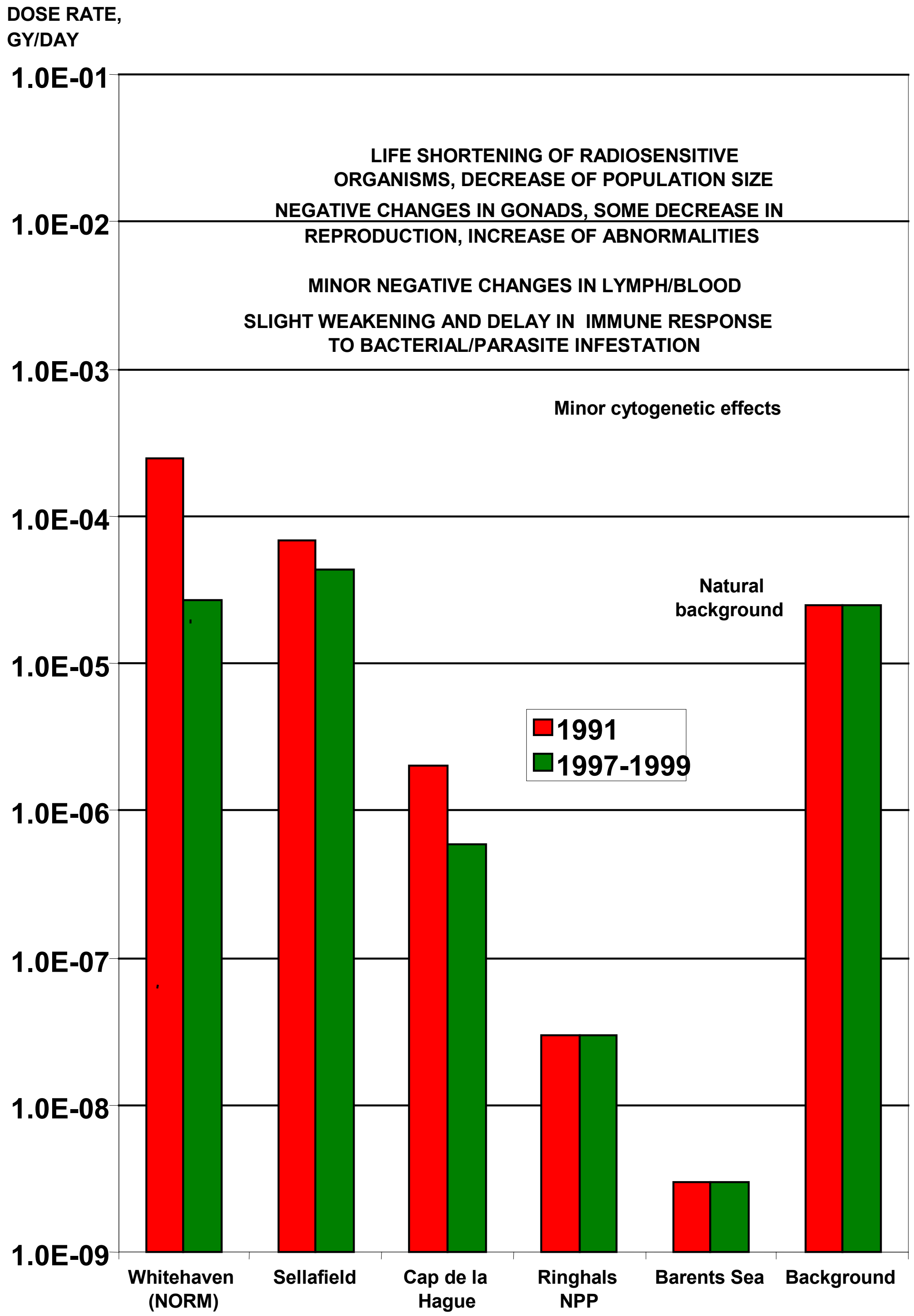
Figure 14 **Contribution of radionuclides (NORM) to the dose rate to mollusc (winkle) and fish in the vicinity of phosphate plant at Whitehaven (1998). Monitoring site Parton (5 km to the north of the plant). Cumbrian waters, UK.**





Note: Dose from K-40 is attributable to presence of this radionuclide in 'natural' sea water.

Figure 15 Dose rates (above natural background) to molluscs in the OSPAR region along the scale of radiation effects to aquatic biota.



Note: presented are annual average values of dose rates to molluscs at different locations of the OSPAR region; values for molluscs near Ringhals NPP are upper estimates of dose rates.

Appendix A - Dose conversion factors for marine biota in the North-East Atlantic

Organism	Radionuclide	Internal dose rate, (Gy day^{-1}) per Bq kg^{-1} wet weight	External dose rate from water, (Gy day^{-1}) per Bq L^{-1}	External dose rate from sediments, (Gy day^{-1}) per Bq kg^{-1} sediments, w.w.
cod	K-40	6.34E-09	1.97E-09	3.24E-10
haddock	K-40	6.34E-09	1.97E-09	7.55E-10
herring	K-40	6.27E-09	2.04E-09	0.00E+00
plaice	K-40	6.33E-09	1.99E-09	8.63E-10
sardine	K-40	6.21E-09	2.09E-09	0.00E+00
sprat	K-40	6.18E-09	2.12E-09	0.00E+00
mussel	K-40	6.16E-09	2.14E-09	1.08E-09
crab	K-40	6.29E-09	2.02E-09	1.08E-09
shrimp	K-40	6.18E-09	2.13E-09	0.00E+00
seal	K-40	6.97E-09	1.40E-09	0.00E+00
gull	K-40	6.32E-09	0.00E+00	0.00E+00
winkle	K-40	6.17E-09	2.13E-09	1.08E-09
cod	Co-60	4.64E-09	3.15E-08	5.18E-09
haddock	Co-60	4.64E-09	3.15E-08	1.21E-08
herring	Co-60	3.39E-09	3.27E-08	0.00E+00
plaice	Co-60	4.41E-09	3.17E-08	1.38E-08
sardine	Co-60	2.52E-09	3.35E-08	0.00E+00
sprat	Co-60	1.93E-09	3.40E-08	0.00E+00
mussel	Co-60	1.65E-09	3.43E-08	1.73E-08
crab	Co-60	3.84E-09	3.23E-08	1.73E-08
shrimp	Co-60	1.89E-09	3.40E-08	0.00E+00
seal	Co-60	1.51E-08	2.19E-08	0.00E+00
gull	Co-60	4.37E-09	0.00E+00	0.00E+00
winkle	Co-60	1.85E-09	3.41E-08	1.73E-08
cod	Zn-65	8.82E-10	7.27E-09	1.20E-09
haddock	Zn-65	8.82E-10	7.27E-09	2.80E-09
herring	Zn-65	5.84E-10	7.54E-09	0.00E+00
plaice	Zn-65	8.29E-10	7.32E-09	3.20E-09
sardine	Zn-65	3.79E-10	7.73E-09	0.00E+00
sprat	Zn-65	2.37E-10	7.86E-09	0.00E+00
mussel	Zn-65	1.71E-10	7.92E-09	3.99E-09
crab	Zn-65	6.92E-10	7.44E-09	3.99E-09
shrimp	Zn-65	2.28E-10	7.87E-09	0.00E+00
seal	Zn-65	3.37E-09	4.98E-09	0.00E+00
gull	Zn-65	8.17E-10	0.00E+00	0.00E+00
winkle	Zn-65	2.18E-10	7.87E-09	3.99E-09

Organism	Radionuclide	Internal dose rate, (Gy day^{-1}) per Bq kg^{-1} wet weight	External dose rate from water, (Gy day^{-1}) per Bq L^{-1}	External dose rate from sediments, (Gy day^{-1}) per Bq kg^{-1} sediments, w.w.
cod	Sr-90	1.55E-08	0.00E+00	0.00E+00
haddock	Sr-90	1.55E-08	0.00E+00	0.00E+00
herring	Sr-90	1.55E-08	0.00E+00	0.00E+00
plaice	Sr-90	1.55E-08	0.00E+00	0.00E+00
sardine	Sr-90	1.55E-08	0.00E+00	0.00E+00
sprat	Sr-90	1.55E-08	0.00E+00	0.00E+00
mussel	Sr-90	1.55E-08	0.00E+00	0.00E+00
crab	Sr-90	1.55E-08	0.00E+00	0.00E+00
shrimp	Sr-90	1.55E-08	0.00E+00	0.00E+00
seal	Sr-90	1.55E-08	0.00E+00	0.00E+00
gull	Sr-90	1.55E-08	0.00E+00	0.00E+00
winkle	Sr-90	1.55E-08	0.00E+00	0.00E+00
cod	Tc-99	1.40E-09	0.00E+00	0.00E+00
haddock	Tc-99	1.40E-09	0.00E+00	0.00E+00
herring	Tc-99	1.40E-09	0.00E+00	0.00E+00
plaice	Tc-99	1.40E-09	0.00E+00	0.00E+00
sardine	Tc-99	1.40E-09	0.00E+00	0.00E+00
sprat	Tc-99	1.40E-09	0.00E+00	0.00E+00
mussel	Tc-99	1.40E-09	0.00E+00	0.00E+00
crab	Tc-99	1.40E-09	0.00E+00	0.00E+00
shrimp	Tc-99	1.40E-09	0.00E+00	0.00E+00
seal	Tc-99	1.40E-09	0.00E+00	0.00E+00
gull	Tc-99	1.40E-09	0.00E+00	0.00E+00
winkle	Tc-99	1.40E-09	0.00E+00	0.00E+00
cod	Ru-103	1.73E-09	6.11E-09	1.02E-09
haddock	Ru-103	1.73E-09	6.11E-09	2.37E-09
herring	Ru-103	1.45E-09	6.36E-09	0.00E+00
plaice	Ru-103	1.68E-09	6.15E-09	2.71E-09
sardine	Ru-103	1.26E-09	6.53E-09	0.00E+00
sprat	Ru-103	1.13E-09	6.65E-09	0.00E+00
mussel	Ru-103	1.07E-09	6.71E-09	3.39E-09
crab	Ru-103	1.55E-09	6.27E-09	3.39E-09
shrimp	Ru-103	1.12E-09	6.66E-09	0.00E+00
seal	Ru-103	4.03E-09	3.99E-09	0.00E+00
gull	Ru-103	1.67E-09	0.00E+00	0.00E+00
winkle	Ru-103	1.11E-09	6.67E-09	3.39E-09

Organism	Radionuclide	Internal dose rate, (Gy day^{-1}) per Bq kg^{-1} wet weight	External dose rate from water, (Gy day^{-1}) per Bq L^{-1}	External dose rate from sediments, (Gy day^{-1}) per Bq kg^{-1} sediments, w.w.
cod	Ru-106	2.00E-08	2.54E-09	4.21E-10
haddock	Ru-106	2.00E-08	2.54E-09	9.82E-10
herring	Ru-106	1.99E-08	2.64E-09	0.00E+00
plaice	Ru-106	2.00E-08	2.55E-09	1.12E-09
sardine	Ru-106	1.98E-08	2.71E-09	0.00E+00
sprat	Ru-106	1.98E-08	2.76E-09	0.00E+00
mussel	Ru-106	1.97E-08	2.78E-09	1.40E-09
crab	Ru-106	1.99E-08	2.60E-09	1.40E-09
shrimp	Ru-106	1.97E-08	2.76E-09	0.00E+00
seal	Ru-106	2.09E-08	1.68E-09	0.00E+00
gull	Ru-106	2.00E-08	0.00E+00	0.00E+00
winkle	Ru-106	1.97E-08	2.76E-09	1.40E-09
cod	Ag-110m	2.11E-08	3.56E-08	5.88E-09
haddock	Ag-110m	2.11E-08	3.56E-08	1.37E-08
herring	Ag-110m	1.96E-08	3.69E-08	0.00E+00
plaice	Ag-110m	2.09E-08	3.58E-08	1.57E-08
sardine	Ag-110m	1.86E-08	3.79E-08	0.00E+00
sprat	Ag-110m	1.79E-08	3.85E-08	0.00E+00
mussel	Ag-110m	1.76E-08	3.88E-08	1.96E-08
crab	Ag-110m	2.02E-08	3.64E-08	1.96E-08
shrimp	Ag-110m	1.79E-08	3.86E-08	0.00E+00
seal	Ag-110m	3.37E-08	2.40E-08	0.00E+00
gull	Ag-110m	2.08E-08	0.00E+00	0.00E+00
winkle	Ag-110m	1.78E-08	3.86E-08	1.96E-08
cod	Sb-125	2.36E-09	5.45E-09	8.17E-10
haddock	Sb-125	2.36E-09	5.45E-09	1.91E-09
herring	Sb-125	2.12E-09	5.68E-09	0.00E+00
plaice	Sb-125	2.32E-09	5.49E-09	2.20E-09
sardine	Sb-125	1.95E-09	5.83E-09	0.00E+00
sprat	Sb-125	1.83E-09	5.94E-09	0.00E+00
mussel	Sb-125	1.78E-09	5.99E-09	2.99E-09
crab	Sb-125	2.21E-09	5.59E-09	2.80E-09
shrimp	Sb-125	1.82E-09	5.95E-09	0.00E+00
seal	Sb-125	4.42E-09	3.56E-09	0.00E+00
gull	Sb-125	2.31E-09	0.00E+00	0.00E+00
winkle	Sb-125	1.82E-09	5.95E-09	2.98E-09

Organism	Radionuclide	Internal dose rate, (Gy day^{-1}) per Bq kg^{-1} wet weight	External dose rate from water, (Gy day^{-1}) per Bq L^{-1}	External dose rate from sediments, (Gy day^{-1}) per Bq kg^{-1} sediments, w.w.
cod	Cs-134	4.41E-09	1.94E-08	3.22E-09
haddock	Cs-134	4.41E-09	1.94E-08	7.51E-09
herring	Cs-134	3.56E-09	2.02E-08	0.00E+00
plaice	Cs-134	4.26E-09	1.95E-08	8.58E-09
sardine	Cs-134	2.97E-09	2.07E-08	0.00E+00
sprat	Cs-134	2.57E-09	2.11E-08	0.00E+00
mussel	Cs-134	2.38E-09	2.13E-08	1.07E-08
crab	Cs-134	3.87E-09	1.99E-08	1.07E-08
shrimp	Cs-134	2.54E-09	2.11E-08	0.00E+00
seal	Cs-134	1.15E-08	1.29E-08	0.00E+00
gull	Cs-134	4.22E-09	0.00E+00	0.00E+00
winkle	Cs-134	2.51E-09	2.11E-08	1.07E-08
cod	Cs-137	4.26E-09	7.04E-09	1.06E-09
haddock	Cs-137	4.26E-09	7.04E-09	2.46E-09
herring	Cs-137	3.95E-09	7.33E-09	0.00E+00
plaice	Cs-137	4.21E-09	7.09E-09	2.84E-09
sardine	Cs-137	3.73E-09	7.53E-09	0.00E+00
sprat	Cs-137	3.58E-09	7.66E-09	0.00E+00
mussel	Cs-137	3.51E-09	7.73E-09	3.86E-09
crab	Cs-137	4.06E-09	7.22E-09	3.61E-09
shrimp	Cs-137	3.57E-09	7.67E-09	0.00E+00
seal	Cs-137	6.91E-09	4.61E-09	0.00E+00
gull	Cs-137	4.20E-09	0.00E+00	0.00E+00
winkle	Cs-137	3.56E-09	7.68E-09	3.84E-09

Organism	Radionuclide	Internal dose rate, (Gy day^{-1}) per Bq kg^{-1} wet weight	External dose rate from water, (Gy day^{-1}) per Bq L^{-1}	External dose rate from sediments, (Gy day^{-1}) per Bq kg^{-1} sediments, w.w.
cod	Pb-210	5.89E-09	0.00E+00	0.00E+00
haddock	Pb-210	5.89E-09	0.00E+00	0.00E+00
herring	Pb-210	5.89E-09	0.00E+00	0.00E+00
plaice	Pb-210	5.89E-09	0.00E+00	0.00E+00
sardine	Pb-210	5.89E-09	0.00E+00	0.00E+00
sprat	Pb-210	5.89E-09	0.00E+00	0.00E+00
mussel	Pb-210	5.89E-09	0.00E+00	0.00E+00
winkle	Pb-210	5.89E-09	0.00E+00	0.00E+00
crab	Pb-210	5.89E-09	0.00E+00	0.00E+00
shrimp	Pb-210	5.89E-09	0.00E+00	0.00E+00
seal	Pb-210	5.89E-09	0.00E+00	0.00E+00
gull	Pb-210	5.89E-09	0.00E+00	0.00E+00
cod	Po-210	7.45E-08	0.00E+00	0.00E+00
haddock	Po-210	7.45E-08	0.00E+00	0.00E+00
herring	Po-210	7.45E-08	0.00E+00	0.00E+00
plaice	Po-210	7.45E-08	0.00E+00	0.00E+00
sardine	Po-210	7.45E-08	0.00E+00	0.00E+00
sprat	Po-210	7.45E-08	0.00E+00	0.00E+00
mussel	Po-210	7.45E-08	0.00E+00	0.00E+00
crab	Po-210	7.45E-08	0.00E+00	0.00E+00
shrimp	Po-210	7.45E-08	0.00E+00	0.00E+00
seal	Po-210	7.45E-08	0.00E+00	0.00E+00
gull	Po-210	7.45E-08	0.00E+00	0.00E+00
winkle	Po-210	7.45E-08	0.00E+00	0.00E+00
cod	Ra-228	7.88E-09	1.16E-08	1.93E-09
haddock	Ra-228	7.88E-09	1.16E-08	4.49E-09
herring	Ra-228	7.39E-09	1.21E-08	0.00E+00
plaice	Ra-228	7.79E-09	1.17E-08	5.13E-09
sardine	Ra-228	7.05E-09	1.24E-08	0.00E+00
sprat	Ra-228	6.82E-09	1.26E-08	0.00E+00
mussel	Ra-228	6.71E-09	1.27E-08	6.42E-09
crab	Ra-228	7.57E-09	1.19E-08	6.42E-09
shrimp	Ra-228	6.80E-09	1.26E-08	0.00E+00
seal	Ra-228	1.20E-08	7.87E-09	0.00E+00
gull	Ra-228	7.77E-09	0.00E+00	0.00E+00
winkle	Ra-228	6.79E-09	1.27E-08	6.42E-09

Organism	Radionuclide	Internal dose rate, (Gy day^{-1}) per Bq kg^{-1} wet weight	External dose rate from water, (Gy day^{-1}) per Bq L^{-1}	External dose rate from sediments, (Gy day^{-1}) per Bq kg^{-1} sediments, w.w.
cod	Ra-226* low LET high LET	3.52E-07 1.49E-08 3.37E-07	2.22E-08 2.22E-08 0.00E+00	3.33E-09 3.33E-09 0.00E+00
haddock	Ra-226* low LET high LET	3.52E-07 1.49E-08 3.37E-07	2.22E-08 2.22E-08 0.00E+00	7.76E-09 7.76E-09 0.00E+00
herring	Ra-226* low LET high LET	3.51E-07 1.40E-08 3.37E-07	2.30E-08 2.30E-08 0.00E+00	0.00E+00 0.00E+00 0.00E+00
plaice	Ra-226* low LET high LET	3.52E-07 1.48E-08 3.37E-07	2.23E-08 2.23E-08 0.00E+00	8.93E-09 8.93E-08 0.00E+00
sardine	Ra-226* low LET high LET	3.50E-07 1.34E-08 3.37E-07	2.36E-08 2.36E-08 0.00E+00	0.00E+00 0.00E+00 0.00E+00
sprat	Ra-226* low LET high LET	3.50E-07 1.30E-08 3.37E-07	2.39E-08 2.39E-08 0.00E+00	0.00E+00 0.00E+00 0.00E+00
mussel	Ra-226* low LET high LET	3.50E-07 1.28E-08 3.37E-07	2.41E-08 2.41E-08 0.00E+00	1.21E-08 1.21E-08 0.00E+00
crab	Ra-226* low LET high LET	3.51E-07 1.44E-08 3.37E-07	2.27E-08 2.27E-08 0.00E+00	1.14E-08 1.14E-08 0.00E+00
shrimp	Ra-226* low LET high LET	3.50E-07 1.30E-08 3.37E-07	2.40E-08 2.40E-08 0.00E+00	0.00E+00 0.00E+00 0.00E+00
seal	Ra-226* low LET high LET	3.59E-07 2.23E-08 3.37E-07	1.54E-08 1.54E-08 0.00E+00	0.00E+00 0.00E+00 0.00E+00
gull	Ra-226* low LET high LET	3.52E-07 1.47E-08 3.37E-07	0.00E+00 0.00E+00 0.00E+00	0.00E+00 0.00E+00 0.00E+00
winkle	Ra-226* low LET high LET	3.50E-07 1.30E-07 3.37E-07	2.40E-08 2.40E-08 0.00E+00	1.20E-08 1.20E-08 0.00E+00

Organism	Radionuclide	Internal dose rate, (Gy day^{-1}) per Bq kg^{-1} wet weight	External dose rate from water, (Gy day^{-1}) per Bq L^{-1}	External dose rate from sediments, (Gy day^{-1}) per Bq kg^{-1} sediments, w.w.
cod	Th-228*	4.28E-07	1.94E-08	2.91E-09
	low LET	1.03E-08	1.94E-08	2.91E-09
	high LET	4.18E-07	0.00E+00	0.00E+00
haddock	Th-228*	4.28E-07	1.94E-08	6.80E-09
	low LET	1.03E-08	1.94E-08	6.80E-09
	high LET	4.18E-07	0.00E+00	0.00E+00
herring	Th-228*	4.28E-07	2.01E-08	0.00E+00
	low LET	9.50E-09	2.01E-08	0.00E+00
	high LET	4.18E-07	0.00E+00	0.00E+00
plaice	Th-228*	4.28E-07	1.96E-08	7.82E-09
	low LET	1.02E-08	1.96E-08	7.82E-09
	high LET	4.18E-07	0.00E+00	0.00E+00
sardine	Th-228*	4.27E-07	2.06E-08	0.00E+00
	low LET	9.00E-09	2.06E-08	0.00E+00
	high LET	4.18E-07	0.00E+00	0.00E+00
sprat	Th-228*	4.27E-07	2.10E-08	0.00E+00
	low LET	8.60E-09	2.10E-08	0.00E+00
	high LET	4.18E-07	0.00E+00	0.00E+00
mussel	Th-228*	4.27E-07	2.11E-08	1.06E-08
	low LET	8.50E-09	2.11E-08	1.06E-08
	high LET	4.18E-07	0.00E+00	0.00E+00
crab	Th-228*	4.28E-07	1.99E-08	9.94E-09
	low LET	9.80E-09	1.99E-08	9.94E-09
	high LET	4.18E-07	0.00E+00	0.00E+00
shrimp	Th-228*	4.27E-07	2.10E-08	0.00E+00
	low LET	8.60E-09	2.10E-08	0.00E+00
	high LET	4.18E-07	0.00E+00	0.00E+00
seal	Th-228*	4.35E-07	1.35E-08	0.00E+00
	low LET	1.68E-08	1.35E-08	0.00E+00
	high LET	4.18E-07	0.00E+00	0.00E+00
gull	Th-228*	4.28E-07	0.00E+00	0.00E+00
	low LET	1.01E-08	0.00E+00	0.00E+00
	high LET	4.18E-07	0.00E+00	0.00E+00
winkle	Th-228*	4.27E-07	2.10E-08	1.05E-08
	low LET	8.60E-09	2.10E-08	1.05E-08
	high LET	4.18E-07	0.00E+00	0.00E+00

Organism	Radionuclide	Internal dose rate, (Gy day^{-1}) per Bq kg^{-1} wet weight	External dose rate from water, (Gy day^{-1}) per Bq L^{-1}	External dose rate from sediments, (Gy day^{-1}) per Bq kg^{-1} sediments, w.w.
cod	Th-230	6.54E-08	0.00E+00	0.00E+00
haddock	Th-230	6.54E-08	0.00E+00	0.00E+00
herring	Th-230	6.54E-08	0.00E+00	0.00E+00
plaice	Th-230	6.54E-08	0.00E+00	0.00E+00
sardine	Th-230	6.54E-08	0.00E+00	0.00E+00
sprat	Th-230	6.54E-08	0.00E+00	0.00E+00
mussel	Th-230	6.54E-08	0.00E+00	0.00E+00
crab	Th-230	6.54E-08	0.00E+00	0.00E+00
shrimp	Th-230	6.54E-08	0.00E+00	0.00E+00
seal	Th-230	6.54E-08	0.00E+00	0.00E+00
gull	Th-230	6.54E-08	0.00E+00	0.00E+00
winkle	Th-230	6.54E-08	0.00E+00	0.00E+00
cod	U-234	6.73E-08	0.00E+00	0.00E+00
haddock	U-234	6.73E-08	0.00E+00	0.00E+00
herring	U-234	6.73E-08	0.00E+00	0.00E+00
plaice	U-234	6.73E-08	0.00E+00	0.00E+00
sardine	U-234	6.73E-08	0.00E+00	0.00E+00
sprat	U-234	6.73E-08	0.00E+00	0.00E+00
mussel	U-234	6.73E-08	0.00E+00	0.00E+00
winkle	U-234	6.73E-08	0.00E+00	0.00E+00
crab	U-234	6.73E-08	0.00E+00	0.00E+00
shrimp	U-234	6.73E-08	0.00E+00	0.00E+00
seal	U-234	6.73E-08	0.00E+00	0.00E+00
gull	U-234	6.73E-08	0.00E+00	0.00E+00
cod	U-238	7.11E-08	0.00E+00	0.00E+00
haddock	U-238	7.11E-08	0.00E+00	0.00E+00
herring	U-238	7.11E-08	0.00E+00	0.00E+00
plaice	U-238	7.11E-08	0.00E+00	0.00E+00
sardine	U-238	7.11E-08	0.00E+00	0.00E+00
sprat	U-238	7.11E-08	0.00E+00	0.00E+00
mussel	U-238	7.11E-08	0.00E+00	0.00E+00
crab	U-238	7.11E-08	0.00E+00	0.00E+00
shrimp	U-238	7.11E-08	0.00E+00	0.00E+00
seal	U-238	7.12E-08	0.00E+00	0.00E+00
gull	U-238	7.11E-08	0.00E+00	0.00E+00
winkle	U-238	7.11E-08	0.00E+00	0.00E+00

Organism	Radionuclide	Internal dose rate, (Gy day^{-1}) per Bq kg^{-1} wet weight	External dose rate from water, (Gy day^{-1}) per Bq L^{-1}	External dose rate from sediments, (Gy day^{-1}) per Bq kg^{-1} sediments, w.w.
cod	Pu-238	7.73E-08	0.00E+00	0.00E+00
haddock	Pu-238	7.73E-08	0.00E+00	0.00E+00
herring	Pu-238	7.73E-08	0.00E+00	0.00E+00
plaice	Pu-238	7.73E-08	0.00E+00	0.00E+00
sardine	Pu-238	7.73E-08	0.00E+00	0.00E+00
sprat	Pu-238	7.73E-08	0.00E+00	0.00E+00
mussel	Pu-238	7.73E-08	0.00E+00	0.00E+00
winkle	Pu-238	7.73E-08	0.00E+00	0.00E+00
crab	Pu-238	7.73E-08	0.00E+00	0.00E+00
shrimp	Pu-238	7.73E-08	0.00E+00	0.00E+00
seal	Pu-238	7.73E-08	0.00E+00	0.00E+00
gull	Pu-238	7.73E-08	0.00E+00	0.00E+00
cod	Pu-239	7.22E-08	0.00E+00	0.00E+00
haddock	Pu-239	7.22E-08	0.00E+00	0.00E+00
herring	Pu-239	7.22E-08	0.00E+00	0.00E+00
plaice	Pu-239	7.22E-08	0.00E+00	0.00E+00
sardine	Pu-239	7.22E-08	0.00E+00	0.00E+00
sprat	Pu-239	7.22E-08	0.00E+00	0.00E+00
mussel	Pu-239	7.22E-08	0.00E+00	0.00E+00
crab	Pu-239	7.22E-08	0.00E+00	0.00E+00
shrimp	Pu-239	7.22E-08	0.00E+00	0.00E+00
seal	Pu-239	7.22E-08	0.00E+00	0.00E+00
gull	Pu-239	7.22E-08	0.00E+00	0.00E+00
winkle	Pu-239	7.22E-08	0.00E+00	0.00E+00
cod	Pu-240	7.23E-08	0.00E+00	0.00E+00
haddock	Pu-240	7.23E-08	0.00E+00	0.00E+00
herring	Pu-240	7.23E-08	0.00E+00	0.00E+00
plaice	Pu-240	7.23E-08	0.00E+00	0.00E+00
sardine	Pu-240	7.23E-08	0.00E+00	0.00E+00
sprat	Pu-240	7.23E-08	0.00E+00	0.00E+00
mussel	Pu-240	7.23E-08	0.00E+00	0.00E+00
crab	Pu-240	7.23E-08	0.00E+00	0.00E+00
shrimp	Pu-240	7.23E-08	0.00E+00	0.00E+00
seal	Pu-240	7.23E-08	0.00E+00	0.00E+00
gull	Pu-240	7.23E-08	0.00E+00	0.00E+00
winkle	Pu-240	7.23E-08	0.00E+00	0.00E+00

Organism	Radionuclide	Internal dose rate, (Gy day^{-1}) per Bq kg^{-1} wet weight	External dose rate from water, (Gy day^{-1}) per Bq L^{-1}	External dose rate from sediments, (Gy day^{-1}) per Bq kg^{-1} sediments, w.w.
cod	Am-241	7.69E-08	0.00E+00	0.00E+00
haddock	Am-241	7.69E-08	0.00E+00	0.00E+00
herring	Am-241	7.69E-08	0.00E+00	0.00E+00
plaice	Am-241	7.69E-08	0.00E+00	0.00E+00
sardine	Am-241	7.69E-08	0.00E+00	0.00E+00
sprat	Am-241	7.69E-08	0.00E+00	0.00E+00
mussel	Am-241	7.69E-08	0.00E+00	0.00E+00
crab	Am-241	7.69E-08	0.00E+00	0.00E+00
shrimp	Am-241	7.69E-08	0.00E+00	0.00E+00
seal	Am-241	7.69E-08	0.00E+00	0.00E+00
gull	Am-241	7.69E-08	0.00E+00	0.00E+00
winkle	Am-241	7.69E-08	0.00E+00	0.00E+00
* The dose conversion factors for Ra-226 and Th-228 include contribution of short-lived daughter nuclides assumed in equilibrium with the parent.				

Appendix B - Dose rates to marine biota in the OSPAR region

Table B1. Dose rates to marine biota in the Sellafield coastal area

Fish (cod)				
Years	Low-LET	High-LET	Absorbed dose rate, (Gy day^{-1})	Weighted dose rate (radiation weighting factor for high-LET w_r=20), Gy day^{-1}
1986	1.26E-06	3.95E-09	1.26E-06	1.34E-06
1987	8.74E-07	3.64E-09	8.78E-07	9.47E-07
1988	9.64E-07	5.69E-09	9.70E-07	1.08E-06
1989	7.59E-07	4.41E-09	7.63E-07	8.47E-07
1990	7.83E-07	2.88E-09	7.86E-07	8.41E-07
1991	7.47E-07	3.15E-09	7.50E-07	8.10E-07
1992	8.38E-07	9.11E-09	8.47E-07	1.02E-06
1993	7.63E-07	1.71E-09	7.65E-07	7.97E-07
1994	5.15E-07	1.51E-08	5.30E-07	8.17E-07
1995	4.71E-07	2.85E-09	4.74E-07	5.28E-07
1996	4.90E-07	3.00E-09	4.93E-07	6.00E-07
1997	4.09E-07	1.58E-09	4.11E-07	4.41E-07
1998	3.38E-07	1.80E-09	3.40E-07	3.74E-07
1999	2.80E-07	4.65E-09	2.85E-07	3.73E-07
2000	2.44E-07	2.81E-09	2.47E-07	3.00E-07
2001	2.16E-07	2.38E-09	2.18E-07	2.64E-07
Fish (plaice)				
Years	Low-LET	High-LET	Absorbed dose rate, (Gy day^{-1})	Weighted dose rate (radiation weighting factor for high-LET w_r=20), Gy day^{-1}
1986	2.89E-06	3.95E-09	2.89E-06	2.97E-06
1987	2.02E-06	3.64E-09	2.02E-06	2.10E-06
1988	2.31E-06	5.69E-09	2.32E-06	2.42E-06
1989	1.76E-06	4.41E-09	1.76E-06	1.85E-06
1990	1.83E-06	2.88E-09	1.83E-06	1.89E-06
1991	1.76E-06	3.15E-09	1.76E-06	1.83E-06
1992	2.08E-06	9.11E-09	2.09E-06	2.27E-06
1993	1.94E-06	1.71E-09	1.94E-06	1.97E-06
1994	1.29E-06	1.51E-08	1.31E-06	1.60E-06
1995	1.17E-06	2.85E-09	1.17E-06	1.23E-06
1996	1.14E-06	3.74E-08	1.18E-06	1.30E-06
1997	9.17E-07	1.58E-09	9.19E-07	9.48E-07
1998	8.16E-07	1.80E-09	8.18E-07	8.52E-07
1999	6.96E-07	4.65E-09	7.01E-07	7.89E-07
2000	5.97E-07	2.81E-09	6.00E-07	6.53E-07
2001	5.34E-07	2.38E-09	5.36E-07	5.81E-07

Dose rates to marine biota in the Sellafield coastal area (Continued)

Molluscs (mussel, winkle)				
Years	Low-LET	High-LET	Absorbed dose rate, (Gy day^{-1})	Weighted dose rate (radiation weighting factor for high-LET w_r=20), Gy day^{-1}
1986	9.65E-06	4.71E-06	1.44E-05	1.04E-04
1987	8.65E-06	4.36E-06	1.30E-05	9.58E-05
1988	8.98E-06	4.54E-06	1.35E-05	9.97E-05
1989	7.88E-06	3.58E-06	1.15E-05	7.95E-05
1990	5.49E-06	3.50E-06	8.99E-06	7.54E-05
1991	5.99E-06	3.33E-06	9.32E-06	7.26E-05
1992	4.60E-06	3.43E-06	8.03E-06	7.33E-05
1993	5.30E-06	2.85E-06	8.15E-06	6.23E-05
1994	3.55E-06	2.44E-06	5.99E-06	5.24E-05
1995	4.66E-06	2.26E-06	6.92E-06	4.98E-05
1996	5.21E-06	2.39E-06	7.60E-06	5.30E-05
1997	5.08E-06	2.50E-06	7.58E-06	5.50E-05
1998	4.43E-06	2.32E-06	6.75E-06	5.09E-05
1999	2.38E-06	2.10E-06	4.48E-06	4.45E-05
2000	2.38E-06	2.42E-06	4.80E-06	5.08E-05
2001	2.12E-06	1.91E-06	4.03E-06	4.03E-05
Crustaceans (crab, lobster)				
Years	Low-LET	High-LET	Absorbed dose rate. (Gy day^{-1})	Weighted dose rate (radiation weighting factor for high-LET w_r=20). Gy day^{-1}
1986	9.59E-06	2.12E-07	9.80E-06	1.38E-05
1987	8.59E-06	2.12E-07	8.80E-06	1.28E-05
1988	8.88E-06	1.70E-07	9.05E-06	1.23E-05
1989	7.87E-06	2.82E-07	8.15E-06	1.35E-05
1990	5.37E-06	1.43E-07	5.51E-06	8.23E-06
1991	5.98E-06	1.70E-07	6.15E-06	9.38E-06
1992	4.52E-06	1.58E-07	4.68E-06	7.69E-06
1993	5.23E-06	1.27E-07	5.36E-06	7.78E-06
1994	3.79E-06	6.50E-08	3.86E-06	5.09E-06
1995	5.12E-06	2.02E-07	5.32E-06	9.16E-06
1996	7.68E-06	1.53E-07	7.83E-06	1.07E-05
1997	1.48E-05	6.14E-08	1.49E-05	1.60E-05
1998	7.39E-06	1.10E-07	7.50E-06	9.60E-06
1999	4.38E-06	1.60E-07	4.54E-06	7.59E-06
2000	4.01E-06	1.24E-07	4.13E-06	6.49E-06
2001	1.61E-06	1.19E-07	1.73E-06	3.98E-06

Table B2. Dose rates to marine biota in the Cap de la Hague coastal area

Fish (*Gadus luscus*)				
Years	Low-LET	High-LET	Absorbed dose rate, (Gy day^{-1})	Total weighted dose rate (radiation weighting factor for high-LET w_r=20), Gy day^{-1}
1982	4.30E-07	nd	4.30E-07	
1983	5.16E-07	nd	5.16E-07	
1984	4.12E-07	nd	4.12E-07	
1985	3.80E-07	nd	3.80E-07	
1986	3.12E-07	nd	3.12E-07	
1987	1.93E-07	nd	1.93E-07	
1988	2.60E-07	nd	2.60E-07	
1989	1.11E-07	nd	1.11E-07	
1990	1.16E-07	nd	1.16E-07	
1991	9.38E-08	nd	9.38E-08	
1992	4.24E-08	nd	4.24E-08	
1993	2.18E-07	nd	2.18E-07	
1994	2.92E-08	nd	2.92E-08	
1995	2.16E-08	nd	2.16E-08	
1996	2.24E-08	nd	2.24E-08	
1997	2.10E-08	nd	2.10E-08	
Note: nd – data were not available				
Mollusk (Patella)				
Years	Low-LET	High-LET	Absorbed dose rate, (Gy day^{-1})	Total weighted dose rate (radiation weighting factor for high-LET w_r=20), Gy day^{-1}
1982	9.08E-06	6.25E-08	9.14E-06	1.03E-05
1983	1.52E-05	6.25E-08	1.52E-05	1.64E-05
1984	6.50E-06	6.25E-08	6.56E-06	7.75E-06
1985	4.15E-06	6.31E-08	4.22E-06	5.41E-06
1986	4.77E-06	5.50E-08	4.83E-06	5.87E-06
1987	3.24E-06	5.98E-08	3.30E-06	4.44E-06
1988	2.90E-06	6.07E-08	2.96E-06	4.11E-06
1989	1.96E-06	5.78E-08	2.02E-06	3.12E-06
1990	2.40E-06	5.65E-08	2.45E-06	3.53E-06
1991	9.23E-07	5.31E-08	9.76E-07	1.98E-06
1992	3.03E-07	4.79E-08	3.51E-07	1.26E-06
1993	2.11E-07	2.60E-08	2.36E-07	7.30E-07
1994	2.15E-07	7.75E-08	2.92E-07	1.76E-06
1995	1.36E-07	2.77E-08	1.64E-07	6.89E-07
1996	1.32E-07	2.35E-08	1.55E-07	6.01E-07
1997	1.54E-07	2.34E-08	1.78E-07	6.22E-07

Table B3. Dose rates to marine biota in the area impacted by Whitehaven phosphate plant

Whitehaven phosphate plant, monitoring site at Parton				
Fish (cod)				
Year	Low-LET	High-LET	Absorbed dose rate, (Gy day^{-1})	Total weighted dose rate (radiation weighting factor for high-LET w_r=20), Gy day^{-1}
1991	6.88E-07	1.36E-07	8.23E-07	3.40E-06
1992	6.88E-07	2.04E-07	8.92E-07	4.77E-06
1993	6.88E-07	7.97E-08	7.67E-07	2.28E-06
1994	6.88E-07	6.16E-08	7.49E-07	1.92E-06
1995	6.87E-07	2.32E-08	7.11E-07	1.15E-06
1996	6.87E-07	6.64E-08	7.54E-07	2.02E-06
1997	6.87E-07	8.32E-08	7.71E-07	2.35E-06
1998	6.88E-07	8.56E-08	7.73E-07	2.40E-06
1999	6.87E-07	8.35E-08	7.71E-07	2.36E-06
Mollusc (winkle)				
Year	Low-LET	High-LET	Absorbed dose rate, (Gy day^{-1})	Total weighted dose rate (radiation weighting factor for high-LET w_r=20), Gy day^{-1}
1991	1.24E-06	1.47E-05	1.59E-05	2.95E-04
1992	8.82E-07	1.04E-05	1.13E-05	2.09E-04
1993	8.38E-07	5.58E-06	6.42E-06	1.12E-04
1994	8.47E-07	3.21E-06	4.05E-06	6.50E-05
1995	1.01E-06	2.82E-06	3.82E-06	5.73E-05
1996	9.07E-07	2.36E-06	3.27E-06	4.81E-05
1997	2.02E-06	6.28E-06	8.30E-06	1.28E-04
1998	7.86E-07	3.03E-06	3.81E-06	6.14E-05
1999	7.78E-07	2.86E-06	3.64E-06	5.80E-05
Crustacean (crab)				
Year	Low-LET	High-LET	Absorbed dose rate, (Gy day^{-1})	Total weighted dose rate (radiation weighting factor for high-LET w_r=20), Gy day^{-1}
1991	7.73E-07	3.44E-06	4.21E-06	6.96E-05
1992	7.71E-07	4.27E-06	5.04E-06	8.61E-05
1993	7.92E-07	2.52E-06	3.31E-06	5.11E-05
1994	7.63E-07	1.71E-06	2.47E-06	3.49E-05
1995	7.55E-07	1.75E-06	2.51E-06	3.58E-05
1996	7.54E-07	1.37E-06	2.13E-06	2.82E-05
1997	7.54E-07	1.82E-06	2.58E-06	3.72E-05
1998	7.54E-07	2.04E-06	2.80E-06	4.16E-05
1999	7.54E-07	2.04E-06	2.80E-06	4.16E-05

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