OSPAR COMMISSION

Towards the Radioactive Substances Strategy objectives

Third Periodic Evaluation

Radioactive Substances Series

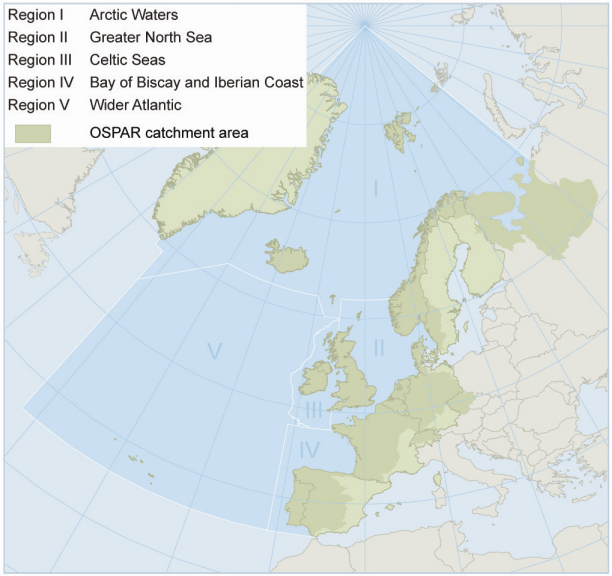
2009

OSPAR Convention

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the “OSPAR Convention”) was opened for signature at the Ministerial Meeting of the former Oslo and Paris Commissions in Paris on 22 September 1992. The Convention entered into force on 25 March 1998. It has been ratified by Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Sweden, Switzerland and the United Kingdom and approved by the European Community and Spain.

Convention OSPAR

La Convention pour la protection du milieu marin de l'Atlantique du Nord-Est, dite Convention OSPAR, a été ouverte à la signature à la réunion ministérielle des anciennes Commissions d'Oslo et de Paris, à Paris le 22 septembre 1992. La Convention est entrée en vigueur le 25 mars 1998. La Convention a été ratifiée par l'Allemagne, la Belgique, le Danemark, la Finlande, la France, l’Irlande, l’Islande, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaume-Uni de Grande Bretagne et d’Irlande du Nord, la Suède et la Suisse et approuvée par la Communauté européenne et l’Espagne.



The OSPAR maritime area and its five Regions

Acknowledgement

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Executive Summary

This report analyses the progress that Contracting Parties to the OSPAR Convention have made in reducing discharges of radioactive substances to the North-East Atlantic, in order to meet the objective of the OSPAR Radioactive Substances Strategy.[1]

Overall conclusions

There is evidence to suggest that progress is being made towards this objective. This includes:

- a reduction in total beta discharges from the nuclear sector, including Tc-99 discharges;
- reductions in marine concentrations of radioactive substances in most cases;
- estimated doses to humans well within international and EU limits;
- an indication that the calculated dose rates to marine biota from the selected radionuclides from the nuclear sector are low and are below the lowest levels at which any effects are likely to occur.

This Third Periodic Evaluation forms part of an integrated series of thematic assessments that together contribute to a wider assessment of the quality status of the marine environment of the OSPAR maritime area. On the basis of this evaluation, there is some evidence to suggest that the effect of discharges and concentrations of radioactive substances on the overall quality status of the OSPAR maritime area is low.

Although the OSPAR Radioactive Substances Committee (RSC) has made considerable progress in evaluating the extent to which the objective of the Radioactive Substances Strategy is being met, there are limitations which demonstrate that further work is needed before a future evaluation of progress can be expected to deliver robust overall conclusions. RSC recommends that its future work programme should include consideration of ways in which:

- the quantity of data reported by all Contracting Parties on discharges of radioactive substances from the non-nuclear sector could be increased; in particular, reporting from all Contracting Parties on discharges from the medical sub-sector could be improved;
- the presentation of data on discharges from the nuclear sector could be improved, to identify the contributions of exceptional discharges from decommissioning and clean-up and the effects of variability in the level of operation of installations;
- data on concentrations in the marine environment could be improved in terms of availability and of consistency in the use of limits of detection and other measurement protocols;

[1] The OSPAR Radioactive Substances Strategy provides that:

"In accordance with the general objective [of the OSPAR Convention], the objective of the Commission with regard to radioactive substances, including waste, is to prevent pollution of the maritime area from ionising radiation through progressive and substantial reductions of discharges, emissions and losses of radioactive substances, with the ultimate aim of concentrations in the environment near background values for naturally occurring radioactive substances and close to zero for artificial radioactive substances. In achieving this objective, the following issues should, inter alia, be taken into account:

a. legitimate uses of the sea;
b. technical feasibility;
c. radiological impacts on man and biota."

- the quantity of data reported by the Contracting Parties on concentrations of naturally-occurring radioactive substances could be improved; and
- more comprehensive estimation of impacts on non-human biota can be achieved.

The pressure on the marine environment from radioactive substances is decreasing

Radioactive materials have many applications from the generation of electricity to diagnostic tools in medicine. In the course of their use small quantities of radioactive substances may be released into the environment as discharges, emissions and losses, both from nuclear licensed sites and from non-nuclear operators such as medical establishments and the offshore oil and gas industry. These discharges can lead to increased radiation exposures to both humans and other biota.

The main sources discharging radioactive substances into the OSPAR maritime area can be attributed to either the nuclear sector (nuclear power stations, fuel reprocessing plants, fuel fabrication and uranium enrichment plants and research and development facilities) or the non-nuclear sector (primarily the offshore oil and gas sector and the medical sector).

The number of operational nuclear installations in Contracting Parties discharging directly or indirectly to the maritime area has decreased from 92 in 1998 to 84 in 2006.

The nuclear fuel reprocessing plants at Cap de la Hague, discharging into the English Channel, and Sellafield, discharging into the Irish Sea, are the main sources of discharges of radioactive substances to the maritime area from the nuclear sector.

The nuclear fuel fabrication and uranium enrichment site discharging the most total-beta activity into the maritime area has been Springfields in the United Kingdom. The processing of uranium ore concentrate at Springfields ended in 2006 and the production of Magnox fuel ceased in 2007, with consequent reductions in discharges.

Discharges of radioactive substances from nuclear research and development facilities are low and declining, as such facilities are closing down and being decommissioned.

Currently, the most significant non-nuclear input of radioactive substances to the sea is from the offshore oil and gas sector and arises almost entirely from de-scaling operations and produced water (‘produced water’ is extracted from oil and gas wells together with the oil and gas).

Contracting Parties are committed to applying BAT and demonstrating progress towards the OSPAR Strategy objective

Since the OSPAR Radioactive Substances Strategy was agreed in 1998, the Radioactive Substances Committee has taken important steps to promote and monitor progress towards the objective of the Strategy. These have included:

- regular reporting on the application by Contracting Parties of Best Available Techniques (BAT) to minimise and, as appropriate, eliminate pollution of the marine environment caused by radioactive discharges from nuclear industries;
- the production by each Contracting Party of a national report setting out how it intends to meet the Strategy objective;

- agreeing how progress towards the objective of the Strategy will be measured, against a baseline for discharges of radioactive substances from the nuclear industry, their concentrations in the marine environment and the resulting doses to members of the public;
- the development of a reporting template for data on discharges from the non-nuclear sector from 2005;
- a monitoring agreement identifying 15 monitoring areas and the radionuclides and environmental compartments for which data are to be collected, as a basis for the reporting and evaluation of concentrations of radioactive substances in the OSPAR maritime area;
- the development of appropriate statistical techniques for the evaluation of data relating to radioactive substances, including cases where a relatively large number of values are below the detection limit.

Statistical tests indicate reductions in discharges of some radionuclides

Evidence of the progress that has been made to date in meeting the objective of reducing radioactive discharges to the North-East Atlantic is limited to data that have been collected and reported for the five year assessment period (2002 – 2006), following the end of the baseline period (1995 – 2001).

RSC has been collecting data for discharges of radioactive substances from the non-nuclear sector only since 2005 and hence the amount of data available for this sector is limited, and is particularly lacking for the medical sub-sector. As a result, there is no agreed baseline component for the non-nuclear sector and this evaluation is, therefore, restricted in scope and applies mainly to discharges from the nuclear sector.

Nuclear sector

In the nuclear sector, discharge data are collected for four sub-sectors: nuclear fuel production and enrichment, nuclear power plants, nuclear fuel reprocessing and nuclear research. In both the baseline period and the assessment period, the major contributors to discharges were the reprocessing and fuel production and enrichment sub-sectors, with discharges from nuclear power plants and research facilities being relatively small.

Applying the appropriate statistical measures to the data (see **Annex 1**) shows that for the entire nuclear sector:

- For total-β (excluding H-3) discharges, there has been a reduction of 38% in average levels since the baseline period; this is a statistically significant change (*i.e.* both the Student's t Welch Aspin and Mann-Whitney test probabilities are below 0.05).
- For total-α, there has been an increase of 15% in the average discharge in 2002 – 2006 over the average for the baseline period. However, this change is not statistically significant (*i.e.* both the Student's t Welch Aspin and Mann-Whitney test probabilities are above 0.05).

For the individual sub-sectors:

- In the nuclear fuel production and enrichment sub-sector, there has been a 26% reduction in total-β (excluding H-3) discharges and an 18% increase in the average discharges of total-α since the baseline period, but neither change is statistically significant (*i.e.* both the Student's t Welch Aspin and Mann-Whitney test probabilities are above 0.05 in each case).

- In the nuclear power-plant sub-sector, there has been a 37% reduction in total-β (excluding H-3) discharges compared with the baseline period average, but the difference is not statistically significant. The discharges of α-emitting radionuclides from nuclear power-plants are low and of little radiological importance or environmental impact. They have therefore not been evaluated, either overall or for individual Contracting Parties.
- In the nuclear-fuel reprocessing sub-sector there has been a 47% reduction in the average discharge levels of total-β (excluding H-3) for the assessment period when compared to the baseline period and the statistical tests indicate that this change is statistically significant. There has been an increase of 26% in the average discharge levels of total-α, but this is not a statistically significant change.
- The nuclear research and development sub-sector makes a very small contribution to the level of discharges. Average discharge levels in 2002 – 2006 for total-α and total-β (excluding H-3) reduced by 93% and 87% respectively compared with the baseline period averages, but these differences were not statistically significant.

Non-nuclear sector

Because OSPAR only began to collate discharge data from the non-nuclear sector in 2005 and it is not yet comprehensive for all Contracting Parties, no baseline component for this sector has been derived. Without such a baseline component, it is not yet possible to provide firm evidence of whether the Radioactive Substances Strategy is being delivered effectively.

Two non-nuclear sub-sectors are considered in this evaluation – the offshore oil and gas industry and the medical sub-sector. The phosphate fertiliser industry, which in 1997 was identified as the predominant source of radioactive discharges from the non-nuclear sector, ceased all such discharges prior to 2005, representing a notable reduction in discharges of radioactive substances to the marine environment. However, past discharges from this industry continue to contribute to concentrations of radioactive substances in the marine environment.

In the offshore oil and gas sub-sector, the main discharge streams that need to be considered are produced water and the disposal of waste from descaling operations.

Actions taken to reduce discharges of produced water, in order to prevent pollution from hydrocarbons, have resulted in stabilisation of the amount of produced water discharged. Concentrations resulting from Ireland's radioactive discharges from this sub-sector have remained below the limits of detection.

Mineral scale containing naturally occurring radioactive material builds up gradually during the life of an installation and periodic descaling operations may be carried out, resulting in discharges to the marine environment. The decommissioning of disused offshore installations that are not being entirely removed to land may also result in discharges of radioactive scale to sea. At present, no conclusions can be reached in relation to changes in the amounts of radioactivity in scale being discharged to the OSPAR maritime area.

In the medical sub-sector, the main source of discharges is from the use of I-131 in the treatment of thyroid complaints. Due to the limited data available and the large uncertainties associated with them, data for the medical sector is not included in this report.

General conclusions for discharges to the marine environment

- For the nuclear sector overall, there has been a 38% reduction in total-β (excluding H-3) discharges since the baseline period (statistically significant) and a 15% increase in total-α discharges (not statistically significant).

- Since 2002, reductions have been achieved in discharges of Tc-99, a radionuclide to which both the 1998 and 2003 OSPAR Ministerial Meetings drew special attention. Discharges of Tc- 99 are expected to reduce further and be maintained at low levels.
- As the evaluation for the nuclear sector is based on data for only five years (2002 – 2006) and discharge data for the non-nuclear sector have only been reported since 2005, at present it is not possible to draw any general conclusions on whether the aims of the OSPAR Radioactive Substances Strategy are being delivered. However, there is evidence to suggest that progress is being made towards this objective for the nuclear sector, in particular through significant reductions in discharges of total-β (excluding H-3) and Tc-99.
- Discharges from the nuclear sector have decreased in OSPAR Regions II (The Greater North Sea), Region III (The Celtic Seas) and Region IV (The Bay of Biscay/Iberian Coast). There are no nuclear facilities belonging to Contracting Parties discharging into Region I (Arctic Waters) and no nuclear facilities discharging into Region V (The Wider Atlantic).[2]

There is an indication of reductions in marine concentrations

OSPAR has assessed progress towards achieving the Radioactive Substances Strategy objective for concentrations in the environment, by comparing average levels of radionuclides in seawater, seaweed, molluscs and fish during the assessment period 2002 to 2006 with baseline values for the period 1995 to 2001.

For this purpose, the OSPAR maritime area is subdivided into 15 monitoring areas, taking into account prevailing ocean currents. Within these, areas have been identified where sufficient data are available to provide an agreed baseline element against which subsequent changes in marine concentrations (in both seawater and marine biota) have been assessed. The available data have allowed baseline components to be calculated for some aspects of concentrations of radioactive substances, both in seawater and in biota (fish, shellfish, and seaweed), although baseline values could not be derived for all monitoring areas, radionuclides and selected biota.

The 15 monitoring areas selected by OSPAR generally represent subdivisions of the five regions of the OSPAR maritime area as set out in the 2000 and 2010 Quality Status Reports, although some of the boundaries do not coincide exactly (see Table 3.1).

Limitations to be noted in respect of marine concentrations

At present, caution must be exercised when interpreting the monitoring data, due to the limited number of data points, differences in sampling and analytical methodologies between Contracting Parties and the relatively high number of values below limits of detection. Consequently, it has not been possible to carry out statistical assessments in all cases. OSPAR has developed a technically appropriate solution to these problems, which is summarised at **Annex 1** of this document. Longer time series of data may allow more accurate and comprehensive conclusions to be reached in future.

For naturally-occurring radionuclides discharged by the non-nuclear sector, OSPAR could only collate limited concentration data and so no baseline component for these radionuclides has been derived. Without such a baseline component, it is not yet possible to determine whether the Radioactive Substances Strategy is being delivered effectively in respect of concentrations of these radionuclides.

[2] Note: These conclusions for OSPAR Regions are based on judgement of the data as presented in Annex 4 and the information on location of nuclear installations in figure 1.1.

In addition, when interpreting the analysis of monitoring data, the following points should be considered:

- the transport of radionuclides by sea currents may involve a time lag between their discharge and their measurement as environmental concentrations. This will differ between OSPAR regions and could, for example, amount to several years. Furthermore, chemical reactions in the marine environment could affect concentration data;
- concentrations may also be influenced by global nuclear fall-out from atmospheric weapons tests, the Chernobyl accident, etc.
- some of the measured concentrations may be influenced by the remobilization of radionuclides in sediments from discharges made in the past (Hunt and Kershaw, 1990).

General conclusions for marine concentrations

For seawater concentrations, in 6 out of 27 datasets there has been a statistically significant change (*i.e.* both the Student's t Welch Aspin and Mann-Whitney test probabilities are below 0.05), with the average concentrations in the assessment period being lower than the baseline values. For a further 7 datasets there is some evidence indicating change (*i.e.* either the Student's t Welch Aspin or Mann-Whitney test probability is below 0.05), with 4 instances where the assessment period average is lower than the baseline value and 3 instances where it is higher.

For concentrations in marine biota, there are 18 instances of statistically significant changes in marine biota concentrations. In 17 of these cases the average concentrations in the assessment period were lower than the baseline and for one instance, it was higher (Cs-137 in fish in monitoring area 12). There is also some evidence of change for 4 datasets, with 2 instances where the assessment period average is above the baseline value and 2 instances where it is above). Some OSPAR regions are still experiencing elevated concentrations due to outflowing Baltic water that has been contaminated with fallout from the Chernobyl accident or due to remobilisation of radionuclides from Irish Sea sediments as a result of past discharges.

Due to the limited availability of reported data, in particular for the nuclides discharged by the non-nuclear sector, it is not possible to come to firm conclusions as to whether the aims of the OSPAR Radioactive Substances Strategy are being delivered. However, there is an indication of a reduction in average marine concentrations for the nuclides discharged by the nuclear sector; where the statistical tests indicated a difference between the baseline period and the assessment period, the change was a reduction in every case but one.

The environmental monitoring data collected by OSPAR indicate a downward trend in concentrations of the assessment radionuclides associated with the nuclear sector in seawater and biota for Region III (The Celtic Seas), while in the other OSPAR Regions, no substantial change could be observed.[3]

Doses to members of the public from the nuclear sector are well below international standards

Doses to members of the public have been estimated using two different approaches derived from the MARINA II model (MARINA II, 2003). One uses data on concentrations of

[3] Note: These conclusions for OSPAR Regions are based on judgement of the information in Section 3.3 showing statistical results for changes per monitoring area. The judgement is an aggregation of assessment results per OSPAR Region to determine the dominant direction of change.

radionuclides in seawater and the other uses concentrations in biota (fish or molluscs). Both methods follow a conservative approach by only including values above the detection limits.

As the doses have been derived from concentration data, the changes for each of the radionuclides will be identical with the changes identified for concentrations.

Comparison of baseline dose values with the assessment period

Detailed statistical analysis has not been undertaken for doses directly derived from environmental concentration data. Calculated doses to humans from radioactivity linked to the North-East Atlantic are well within (and in the large majority of cases, a small fraction of) the limits recommended by the International Commission on Radiological Protection (ICRP) and, where appropriate, comply with the Basic Safety Standards for those OSPAR Contracting Parties within the European Union.

Doses based on concentrations of radionuclides in seawater

Doses derived from concentrations in seawater cover a wide range of values. The highest doses identified are from Po-210. Doses from Ra-226, Ra-228 and Pb-210 are lower, with doses from Cs-137 being even smaller. The concentrations of Po-210, Ra-226, Ra-228 and Pb-210 from which doses are derived are total environmental concentrations *i.e.* these values reflect natural background concentrations as well as contributions from discharges of these radionuclides from the oil and gas sub-sector.

The magnitude of doses from Tc-99 and Pu-239,240 lies in the middle range of estimated values. The standard deviation associated with the highest value of the dose from Tc-99 is large (the dose and the standard deviation are nearly equal), which indicates that the fluctuations of Tc-99 concentrations have been large. Nevertheless, the observed Tc-99 dose, like Cs-137, declines with distance from the highest value in monitoring area 6 (Irish Sea – Sellafield). The highest dose from Pu-239,240 concentrations in seawater is much less; limited concentration data and hence dose data are available, making it difficult to derive any substantial conclusion for this element.

The contribution from H-3 to the overall dose is low in all monitoring areas (less than 0.025 µSv/y); this is about three orders of magnitude lower than the 10 µSv/y dose considered by the Council of the European Union as a criterion for the exemption of a practice (Directive 96/29/EURATOM of 13 May 1996).

Doses based on concentrations of radionuclides in biota

There are currently insufficient data to derive baseline values for concentrations in biota of Po-210, Ra-226, Ra-228 and Pb-210. Consequently, no assessment could be made of progress towards the OSPAR Radioactive Substances Strategy objective in respect of doses arising from these radionuclides. However, the data do allow a comparison to be made in terms of orders of magnitude between doses resulting from discharges, emissions and losses from the nuclear and non-nuclear sectors.

For radionuclides from the nuclear sector, Pu-239,240 and Cs-137 concentration data in fish or molluscs are available for a number of monitoring areas. Doses from Pu-239,240 cover a very large range of values, with five orders of magnitude between the highest and the lowest doses. Pu-239,240 in molluscs gives rise to the highest dose assessed in the OSPAR baseline. The highest dose from Pu-239,240 in seafood is substantially higher than the highest dose from Cs-137 in seafood. This situation only occurs in monitoring area 6 (Irish Sea (Sellafield)), with doses from Pu-239,240 in other monitoring areas up to two orders of magnitude lower than equivalent doses from Cs-137.

Concentrations of Tc-99 have only been reported here in seaweed, which is not a significant exposure pathway to humans. H-3 is not considered relevant for biota as there is no evidence for any bioaccumulation of H-3 by marine biota (with the exception of organic H-3 compounds). Therefore no doses have been assessed for these radionuclides from concentrations in biota.

General conclusions for doses to members of the public

Sufficient data have been collected to allow a baseline to be established for doses to members of the public from radionuclides discharged from the nuclear sector. All doses calculated to date from concentrations of nuclear sector radionuclides are well below accepted international standards. Doses to man during the assessment period have not been assessed separately against the baseline values but are a scalar function of the respective environmental concentrations from seawater and biota; where an environmental concentration has increased or decreased, this has resulted in an increase or decrease in dose.

However, because data on environmental concentrations of radionuclides from the non-nuclear sector have not been collected by OSPAR, it is not possible to come to firm conclusions regarding doses to members of the public.

Calculated doses to marine biota from the nuclear sector are below the lowest levels at which any effects are likely to occur

The impact assessment of anthropogenic sources of radioactive substances on marine biota uses the Environmental Risk Assessment (ERA) methodology proposed by the European project ERICA (ERICA, 2007), the only European reference project that allows a fully integrated assessment of doses to biota.

The impact on biota of environmental concentrations of H-3, Tc-99, Cs-137, Pu-239,240, Po-210, Ra-226, Ra-228, and Pb-210 has been assessed. However, data on concentrations of all these radionuclides were not available for every monitoring area. The calculated total dose rates were compared to the screening dose rate recommended by ERICA. This value, 10 µGy/h for a generic ecosystem, has been selected as it is highly conservative and the lowest of any recommended screening values.

For biota representative of the marine ecosystems within the OSPAR area, the method adopted applies modelling of the absorbed radiological dose rates to measured or estimated environmental activity concentrations of the selected radionuclides.

For the baseline period 1995 – 2001, and each individual year of the assessment period between 2002 and 2006, radionuclide-specific dose rates have been calculated for each type of biota and the highest dose rates estimated. These total dose rates have taken into account data from previous evaluations, and also included those calculated on the basis of detection limit values (which are high in some cases). Where several sums are possible, only the highest is reported. Although the baseline period has been determined, insufficient data are available to allow a thorough statistical analysis and to establish robust conclusions. Therefore a partial assessment has been possible using the limited data.

For radionuclides from the nuclear sector, the highest estimated dose rate was generally found in invertebrates. Cs-137 and Tc-99 were the most important contributors to the dose rate in this case, with Cs-137 dose rates generally being higher. For radionuclides from the non-nuclear sector (Po-210, Ra-226, Ra-228, Pb-210), very few data were available and it was not possible to distinguish the contribution of the non-nuclear sector from the background dose to biota. Nevertheless, the overall doses due to these radionuclides (background included) were calculated. The results show that the highest estimated dose rate was generally found in

invertebrates, Po-210 being the most important contributor with a dose rate 10 times higher than the highest dose rate from Cs-137 or Tc-99.

The highest dose rates were estimated for monitoring area 6 (including dose rate estimates for the baseline period) and to a lesser extent for monitoring areas 4 and 7 (except in 2004 for monitoring area 7). These values are from one to three orders of magnitude higher than the dose rates summed for the same radionuclides for other monitoring areas. For monitoring areas 4, 6 and 13, Tc-99 is the most important contributor to the "total" dose rates for macroalgae and invertebrates, delivering a dose rate one order of magnitude higher than that delivered by Cs-137. For fish from the same monitoring areas, Cs-137 delivers a higher dose rate than Tc-99.

General conclusions for impacts on biota

The radionuclides of highest radiotoxicity, and hence greatest significance, have been selected in estimating impacts on biota. This makes it possible to characterise the potential risk to the structure and function of the marine ecosystems in each RSC monitoring area, even though this does not represent the total biological effect of ionising radiation in the OSPAR maritime area. The dose rates summed for the selected radionuclides can be expressed as a percentage of the ERICA screening value of 10 µGy/h. On this basis, the calculated dose rates to marine biota from the selected radionuclides from the nuclear sector are low and are below the lowest levels at which any effects are likely to occur according to current scientific understanding.

To sum up

Steps have been taken by OSPAR Contracting Parties towards the implementation of the Radioactive Substances Strategy. These have led to reductions in discharges of some radionuclides from the nuclear sector and corresponding reductions in some environmental concentrations. However, further work is needed, particularly in respect of radioactive discharges from the non-nuclear sector, to determine whether the objective of the Radioactive Substances Strategy is being achieved.

Récapitulatif

Le présent rapport analyse les progrès réalisés par les Parties contractantes à la Convention OSPAR quant à la réduction des rejets de substances radioactives dans l'Atlantique du Nord-est, dans le sens de l'objectif de la Stratégie OSPAR substances radioactives.[4]

Conclusions générales

Les preuves disponibles suggèrent que des progrès ont été réalisés dans le sens de cet objectif. Il s'agit notamment:

- d'un réduction des rejets de β-total provenant du secteur nucléaire, notamment des rejets de Tc-99;
- des réductions des teneurs de substances radioactives dans la mer dans la plupart des cas;
- des doses estimées pour l'homme se situant facilement dans les limites internationales et de l'UE;
- une indication que les taux calculés des doses dans le milieu vivant marin de radionucléides sélectionnés provenant du secteur nucléaire sont faibles et inférieurs aux niveaux les plus bas risquant d'entraîner des effets.

Cette troisième évaluation périodique fait partie d'une série intégrée d'évaluations thématiques qui, ensemble, contribuent à une évaluation plus large de l'état de santé du milieu marin de la zone maritime OSPAR. Cette évaluation comporte des preuves suggérant que l'effet des rejets et teneurs de substances radioactives sur l'état de santé général de la zone maritime OSPAR est faible.

Bien que le Comité OSPAR substances radioactives (RSC) ait fait des progrès considérables dans l'évaluation de la mesure dans laquelle l'objectif de la Stratégie substances radioactives est atteint, des limites démontrent que des travaux supplémentaires sont nécessaires avant de pouvoir réaliser une future évaluation tirant des conclusions robustes. Le RSC recommande que son futur programme de travail comporte une étude de la manière:

- d'améliorer la quantité des données notifiées par toutes les Parties contractantes sur les rejets de substances radioactives provenant du secteur non nucléaire et en particulier la notification de toutes les Parties contractantes sur les rejets provenant du sous-secteur médical;

[4] La Stratégie OSPAR substances radioactives stipule que:

«Conformément à l'objectif général [de la Convention OSPAR], l'objectif de la Commission, en ce qui concerne les substances radioactives, y compris les déchets radioactifs, consiste à prévenir la pollution de la zone maritime par les radiations ionisantes, ceci par des réductions progressives et substantielles des rejets, émissions et pertes de substances radioactives, le but étant en dernier ressort de parvenir à des concentrations, dans l'environnement, qui soient proches des valeurs ambiantes dans le cas des substances radioactives présentes à l'état naturel et proches de zéro dans celui des substances radioactives de synthèse. Dans la réalisation de cet objectif, il convient qu'entre autres, les points ci-après soient pris en compte :

a. les utilisations légitimes de la mer ;
b. la faisabilité technique ;
c. les impacts radiologiques sur l'homme et sur le milieu vivant.»

- d'améliorer la présentation des données sur les rejets provenant du secteur nucléaire, afin de déterminer les contributions aux rejets exceptionnels provenant de la mise hors service et du nettoyage et des effets de la variabilité du niveau opérationnel des installations;
- d'améliorer les données sur les teneurs dans le milieu marin, du point de vue de leur disponibilité et de leur cohérence pour l'utilisation des limites de détection et d'autres protocoles de mesure;
- d'améliorer la quantité des données, notifiées par les Parties contractantes, sur les teneurs des substances radioactives présentes à l'état naturel; et
- de parvenir à une estimation plus exhaustive des impacts sur le milieu vivant non humain.

La pression exercée sur le milieu marin par les substances radioactive est en baisse

Les matériaux radioactifs ont de nombreuses applications, allant de la production d'électricité aux outils diagnostiques en médecine. Lors de leur utilisation, de petites quantités de substances radioactives risquent d'être déchargées dans l'environnement sous forme de rejets, d'émissions ou de pertes, aussi bien à partir de sites nucléaires autorisés que d'exploitants non nucléaires tels que des établissements médicaux et l'industrie pétrolière et gazière d'offshore. Ces rejets peuvent entraîner une exposition accrue aux radiations aussi bien pour l'homme que pour les autres milieux vivants.

Les principales sources rejetant des substances radioactives dans la zone maritime OSPAR peuvent être attribuées soit au secteur nucléaire (centrales nucléaires, usines de retraitement de combustible, production de combustible et usines d'enrichissement de l'uranium et les installations de recherche et de développement) soit au secteur non nucléaire (essentiellement le secteur pétrolier et gazier d'offshore et le secteur médical).

Le nombre d'installations nucléaires opérationnelles chez les Parties contractantes rejetant directement ou indirectement dans la zone maritime est passé de 92 en 1998 à 84 en 2006.

Les usines de retraitement de combustible nucléaire du Cap de la Hague, rejetant dans la Manche et Sellafield, rejetant dans la mer d'Irlande, sont les principales sources de rejets de substances radioactives dans la zone maritime provenant du secteur nucléaire.

Springfields, au Royaume-Uni était le site de production de combustible nucléaire et d'enrichissement de l'uranium rejetant le plus de β-total dans la zone maritime. Le traitement du concentré de minerai d'uranium à Springfields s'est terminé en 2006 et la production de combustible Magnox a cessé en 2007, les rejets accusant dont des réductions.

Les rejets de substances radioactives provenant des installations nucléaires de recherche et de développement sont faibles et en déclin car ces installations sont en cours de fermeture ou de mise hors service.

L'apport le plus important de substances radioactives à la mer provient actuellement du secteur pétrolier et gazier d'offshore et découle presque totalement des opérations de décapage et de l'eau de production ("l'eau de production" est extraite des puits pétroliers et gaziers en même temps que le pétrole et le gaz).

Les Parties contractantes se sont engagées à appliquer les BAT et à progresser dans le sens de l'objectif de la Stratégie OSPAR

Depuis que la Stratégie OSPAR substances radioactives à été convenue en 1998, le Comité substances radioactives a pris des mesures importantes pour promouvoir et surveiller les progrès réalisés dans le sens de l'objectif de la Stratégie. Il s'agit notamment:

- de la notification régulière de l'application par les Parties contractantes des meilleures techniques disponibles (BAT) afin de minimiser et, le cas échéant, d'éliminer la pollution du milieu marin causée par les rejets radioactifs provenant de l'industrie nucléaire;
- de la production, par chaque Partie contractante, d'un rapport national déterminant comment elle prévoit de parvenir à l'objectif de la Stratégie;
- de convenir comment évaluer les progrès réalisés dans le sens de l'objectif de la Stratégie par rapport à une ligne de base pour les rejets de substances radioactives provenant de l'industrie nucléaire, leurs teneurs dans le milieu marin et les doses qui en résultent pour la population;
- du développement d'un formulaire de notification pour les données sur les rejets provenant du secteur non nucléaire à partir de 2005;
- d'un accord sur la surveillance déterminant 15 zones de surveillance et les radionucléides et les compartiments de l'environnement pour lesquels les données seront recueillies, servant de base à la notification et à l'évaluation des teneurs de substances radioactives dans la zone maritime OSPAR;
- du développement de techniques statistiques appropriées pour l'évaluation des données relatives aux substances radioactives, notamment pour les cas où un nombre relativement important de valeurs se situent en dessous de la limite de détection.

Les tests statistiques indiquent une réduction des rejets de certains radionucléides

Les preuves des progrès réalisés à ce jour dans le sens de l'objectif de réduction des rejets radioactifs dans l'Atlantique du Nord-est se limitent aux données recueillies et notifiées pour la période d'évaluation (2002 – 2006), à la fin de la période ligne de base (1995 – 2001).

Le RSC ne recueille les données sur les rejets de substances radioactives provenant du non nucléaire que depuis 2005 et la quantité de données disponibles pour ce secteur est donc limitée et pratiquement non existante pour le sous-secteur médical. Il n'existe donc aucune composante de ligne de base convenue pour le secteur non nucléaire et cette évaluation a donc une portée restreinte et s'applique principalement aux rejets provenant du secteur nucléaire.

Secteur nucléaire

Les données sur les rejets provenant du secteur nucléaire sont recueillies pour quatre sous-secteurs: la production et l'enrichissement du combustible nucléaire, les centrales nucléaires, le retraitement de combustible nucléaire et la recherche nucléaire. Aussi bien pour la période ligne de base que pour la période d'évaluation, les principaux contributeurs aux rejets sont les sous secteurs de la production et du retraitement de combustible et de l'enrichissement, les rejets provenant des centrales nucléaires et des installations de recherche étant relativement faibles.

Si on applique les mesures statistiques appropriées aux données (voir **annexe 1**) on obtient pour le secteur nucléaire dans son ensemble:

- pour les rejets de β-total (à l'exception du H-3), une réduction de 38% des niveaux moyens depuis la période ligne de base; il s'agit d'un changement statistiquement significatif (*c'est-à-dire* que les probabilités des tests de Student d'Aspin Welch et de Mann-Whitney sont inférieures à 0,05).
- pour les rejets moyens d'α-total, on relève une augmentation de 15% entre 2002 et 2006 par rapport à la moyenne pour la période ligne de base. Ce changement n'est cependant pas statistiquement significatif (*c'est-à-dire que* les probabilités des tests de Student d'Aspin Welch et de Mann-Whitney sont inférieures à 0,05).

En ce qui concerne les sous-secteurs individuels:

- pour le sous-secteur de la production et de l'enrichissement de combustible nucléaire, on relève une réduction de 26% des rejets de β-total (à l'exclusion du H-3) et une augmentation de 18% des rejets moyens de α-total par rapport à la période ligne de base, Ces changements ne sont cependant pas statistiquement significatifs (*c'est-à-dire que* les probabilités des tests de Student d'Aspin Welch et de Mann-Whitney sont inférieures à 0,05).
- pour le sous-secteur des centrales nucléaires, on relève une réduction de 37% des rejets de β-total (à l'exclusion du H-3) par rapport à la période ligne de base, mais la différence n'est pas statistiquement significative. Les rejets de radionucléides émetteurs-α provenant de centrales nucléaires sont faibles et ne présentent qu'une importance radiologique et un impact environnemental moindre. Ils n'ont donc pas été évalués, que ce soit dans l'ensemble ou pour chaque Partie contractantes.
- pour le sous-secteur du retraitement du combustible nucléaire, on relève une réduction de 47% des rejets moyens de β-total (à l'exclusion du H-3) pour la période d'évaluation par rapport à la période ligne de base et les tests statistiques indiquent que ce changement est statistiquement significatif. Les rejets moyens de α-total ont augmenté de 26%, Ce changement n'est cependant pas statistiquement significatif.
- la contribution du sous-secteur de la recherche et du développement nucléaires aux rejets est très petite. Les rejets moyens, de 2002 à 2006 pour le α-total et le β-total (à l'exclusion du H-3) ont diminué de 93% et 87% respectivement par rapport aux moyennes de la période ligne de base, mais ces différences ne sont pas statistiquement significatives.

Secteur non nucléaire

Aucune composante de ligne de base n'a pu être dérivée car OSPAR a seulement commencé à recueillir des données sur les rejets provenant du secteur non nucléaire en 2005 et ces données ne sont pas exhaustives pour toutes les Parties contractantes. Il n'est pas encore possible de fournir des preuves solides montrant que l'objectif de la Stratégie substances radioactives est effectivement réalisé, sans posséder cette composante de ligne de base.

Dans cette évaluation on considère deux sous-secteurs non nucléaires – l'industrie pétrolière et gazière d'offshore et le sous-secteur médical. La production d'engrais phosphatés, qui a été déterminée en 1997 comme étant la source prédominante de rejets radioactifs provenant du secteur non nucléaire, a cessé tous ses rejets avant 2005, ce qui représente une réduction notable des rejets de substances radioactives dans le milieu marin. Les rejets, provenant de cette industrie, qui ont eu lieu dans le passé continuent cependant à contribuer aux teneurs de substances radioactives dans le milieu marin.

Les principaux rejets à considérer dans le sous-secteur pétrolier et gazier d'offshore sont l'eau de production et l'élimination des déchets provenant des opérations de décapage.

Les mesures de réduction des rejets de l'eau de production prises afin d'empêcher la pollution par les hydrocarbures ont permis de stabiliser la quantité d'eau de production rejetée. Les teneurs découlant des rejets radioactifs en Irlande provenant de ce sous-secteur demeurent inférieures aux limites de détection.

Les dépôts minéraux contenant des substances radioactives présentes à l'état naturel s'accumulent graduellement au cours de l'existence d'une installation et des opérations périodiques de détartrage peuvent être effectuées entraînant des rejets dans le milieu marin. La mise hors service des installations offshore désaffectées qui ne sont pas complètement ramenées à terre peut également donner lieu à des rejets de dépôts radioactifs à la mer. On ne peut pas tirer de conclusions, à l'heure actuelle, sur les modifications des quantités de substances radioactives dans le détartrage rejetées dans la zone maritime OSPAR.

La source principale de rejets du sous-secteur médical provient de l'utilisation de I-131 pour le traitement des troubles thyroïdiens. Les données portant sur le secteur médical ne figurent pas dans le présent rapport car elles sont limitées et présentent des incertitudes importantes.

Conclusions générales sur les rejets dans le milieu marin

- le secteur nucléaire dans son ensemble, présente une réduction de 38% des rejets de β-total (à l'exclusion du H-3) par rapport à la période ligne de base (statistiquement significative) et une augmentation de 15% des rejets de α-total (pas statistiquement significative).
- on est parvenu, depuis 2002, à des réductions des rejets de Tc-99, radionucléide sur lequel les Réunions ministérielles d'OSPAR de 1998 et de 2003 ont particulièrement attiré l'attention. On prévoit que les rejets de Tc- 99 diminueront encore plus et se maintiendront à des niveaux bas.
- il n'est pas possible, à l'heure actuelle, de tirer des conclusions générales sur la réalisation de l'objectif de la Stratégie OSPAR substances radioactives car l'évaluation relative au secteur nucléaire se fonde sur des données portant sur cinq ans seulement (2002 – 2006) et les données sur les rejets provenant du secteur non nucléaire ne sont notifiées que depuis 2005. Il semblerait cependant que des progrès aient été réalisés dans le sens de cet objectif dans le secteur nucléaire, grâce en particulier à des réductions significatives des rejets de β-total (à l'exclusion du H-3) et de Tc-99.
- les rejets provenant du secteur nucléaire ont diminué dans les Régions OSPAR II (Mer du Nord au sens large), III (Mers celtiques) et IV (Golfe de Gascogne et côtes ibériques). Il n'existe aucune installation nucléaire appartenant aux Parties contractantes qui rejette dans la Région I (Eaux arctiques) ni aucune installation nucléaire rejetant dans la Région V (Atlantique au large).

Les teneurs marines accusent une réduction

OSPAR a évalué les progrès réalisés dans le sens de l'objectif de la Stratégie OSPAR substances radioactives pour les teneurs dans l'environnement, en comparant les niveaux moyens de radionucléides dans l'eau de mer, les algues, les mollusques et le poisson pour la période d'évaluation de 2002 à 2006 avec les valeurs de ligne de base pour la période de 1995 à 2001.

A cette fin, la zone maritime OSPAR est sous-divisée en quinze zones de surveillance, en tenant compte des courants océaniques dominants. Au sein de celles-ci, on a déterminé des zones pour lesquelles on dispose de suffisamment de données pour définir un élément de ligne

de base convenu par rapport auquel on a évalué les modifications subséquentes des teneurs marines (aussi bien dans l'eau de mer que dans le milieu vivant marin). Les données disponibles ont permis de calculer des composantes de ligne de base pour certains aspects des teneurs de substances radioactives, aussi bien dans l'eau de mer que dans le milieu vivant marin (poisson, mollusques et crustacés et algues), bien qu'il ne soit pas possible de dériver des valeurs de ligne de base pour toutes les zones surveillées, les radionucléides et le milieu vivant sélectionnés.

Les quinze zones de surveillance sélectionnées par OSPAR représentent dans l'ensemble des sous-divisions des cinq Régions de la zone maritime OSPAR déterminées dans les Bilans de santé de 2000 et de 2010, bien que certaines limites ne coïncident pas exactement (voir le tableau 3.1).

Limites à noter en ce qui concerne les teneurs marines

Il faut procéder avec prudence lorsque l'on interprète les données découlant de la surveillance. En effet les points de données sont limités, les méthodologies d'échantillonnage et d'analyse varient d'une Partie contractante à l'autre et il existe un nombre relativement élevé de valeurs inférieures aux limites de détection. Il n'a donc pas été possible de réaliser des évaluations statistiques dans tous les cas. OSPAR a développé une solution qui convient techniquement à ces problèmes et qui est résumée dans l'**annexe 1** au présent document. Des séries temporelles de données plus longues pourraient permettre de tirer des conclusions plus précises et plus exhaustives à l'avenir.

En ce qui concerne les radionucléides présents à l'état naturel rejetés par le secteur non nucléaire, OSPAR n'a pu recueillir qu'un nombre limité de données sur les teneurs et il n'a donc pas été possible de dériver de composante de ligne de base pour ces radionucléides. Il n'est pas encore possible de déterminer si l'objectif de la Stratégie substances radioactives et atteint efficacement en ce qui concerne les teneurs de ces radionucléides, sans cette composante de ligne de base.

De plus, il faut tenir compte des points suivants lors de l'interprétation de l'analyse des données découlant de la surveillance:

- le transport des radionucléides par les courants marins peut causer un décalage dans le temps entre leurs rejets et leur analyse au titre de leur teneur dans l'environnement. Ceci varie d'une Région OSPAR à l'autre et pourrait, par exemple représenter plusieurs années. De plus, les réactions chimiques dans le milieu marin pourraient affecter les données sur les teneurs;
- les teneurs peuvent être également influencées par les retombées nucléaires globales provenant des essais d'armes nucléaires, l'accident de Chernobyl, etc.
- certaines teneurs mesurées risquent d'être influencées par la remobilisation des radionucléides dans les sédiments provenant des rejets réalisés dans le passé (Hunt et Kershaw, 1990).

Conclusions générales sur les teneurs marines

Six des 27 séries de données sur les teneurs dans l'eau de mer révèlent un changement statistiquement significative (*c'est-à-dire* que les probabilités des tests de Student d'Aspin Welch et de Mann-Whitney sont inférieures à 0,05), les teneurs moyennes pour la période d'évaluation étant inférieures aux valeurs de ligne de base. Sept autres séries de données révèlent un changement (*c'est-à-dire* que les probabilités des tests de Student d'Aspin Welch

et de Mann-Whitney sont inférieures à 0,05), la moyenne pour la période d'évaluation étant inférieure à la ligne de base pour quatre d'entre elles et supérieure pour les trois autres.

On relève dix-huit cas de changements statistiquement significatifs des teneurs dans le milieu marin, la moyenne pour la période d'évaluation étant inférieure à la ligne de base pour dix-sept d'entre elles et supérieure pour l'autre (Cs-137 dans le poisson dans la zone de surveillance 12). Il semble également que quatre séries de données révèlent des changements, la moyenne pour la période d'évaluation étant inférieure à la ligne de base pour deux d'entre elles et supérieure pour les deux autres. Certaines Régions OSPAR présentent encore des teneurs élevées du fait de l'écoulement des eaux baltiques contaminées par les retombées de l'accident de Chernobyl ou de la remobilisation des radionucléides provenant des sédiments de la mer d'Irlande et découlant de rejets antérieurs.

Il n'est pas possible, à l'heure actuelle, de tirer des conclusions définitives sur la réalisation de l'objectif de la Stratégie OSPAR substances radioactives car les données notifiées disponibles sont limitées. Il semblerait cependant qu'il y ait une réduction des teneurs moyennes marines rejetées par le secteur nucléaire, les tests statistiques indiquant une différence entre la période ligne de base et la période d'évaluation, correspondant à une réduction dans tous les cas sauf un.

Les données découlant de la surveillance de l'environnement recueillies par OSPAR révèlent une tendance à la baisse des teneurs des radionuclides évalués et associés avec le secteur nucléaire dans l'eau de mer et le milieu vivant pour la Région III (Mers celtiques), alors que l'on ne relève aucune modification significative dans les autres Régions OSPAR.

Les doses pour la population, provenant du secteur nucléaire, sont inférieures aux normes internationales

On a estimé les doses pour la population, en utilisant deux approches différentes dérivées du modèle MARINA II (MARINA II, 2003). L'une utilise des données sur les teneurs des radionucléides dans l'eau de mer et l'autre sur les teneurs dans le milieu vivant (poisson ou mollusques). Ces deux méthodes suivent une approche conservative en ne tenant compte que des valeurs supérieures aux limites de détection.

Les changements pour chaque radionucléide seront identiques à ceux déterminés pour les teneurs car les doses ont été dérivées des données sur les teneurs.

Comparaison des valeurs de dose de la ligne de base avec la période d'évaluation

On n'a pas entrepris d'analyse détaillée pour les doses dérivées directement des données sur les teneurs environnementales. Les doses calculées pour la population et provenant de la radioactivité liée à l'Atlantique du Nord-est se situent tout à fait (et dans la majorité des cas, dans une petite portion) des limites recommandées par la Commission internationale de protection radiologique (CIPR) et, le cas échéant, sont conformes aux normes de base dans le cas des Parties contractantes OSPAR faisant partie de l'Union européenne.

Doses basées sur les teneurs des radionucléides dans l'eau de mer

Les doses dérivées des teneurs dans l'eau de mer couvrent un éventail étendu de valeurs. Les doses les plus élevées déterminées proviennent du Po-210. Les doses de Ra-226, Ra-228 et Pb-210 sont plus faibles, celles du Cs-137 étant encore plus basses. Les teneurs de Po-210, Ra-226, Ra-228 et Pb-210 à partir desquelles on dérive les doses représentent des teneurs environnementales totales, c'est-à-dire que ces valeurs reflètent les teneurs ambiantes naturelles ainsi que les contributions provenant des rejets de ces radionucléides par le sous-secteur pétrolier et gazier.

La magnitude des doses de Tc-99 et de Pu-239,240 se situe dans la gamme moyenne des valeurs estimées. La déviation standard associée à la valeur la plus élevée de la dose de Tc-99 est importante (la dose et la déviation standard sont presque égales). Ceci indique que les fluctuations des teneurs de Tc-99 sont importantes. La dose observée de Tc-99, tel que le Cs-137, diminue cependant avec la distance à partir de la valeur la plus élevée dans la zone de surveillance 6 (Mer d'Irlande – Sellafield). La dose la plus élevée des teneurs de Pu-239,240 dans l'eau de mer est bien moindre; on ne dispose que de données limitées sur les teneurs et donc sur les doses ce qui rend difficile la dérivation de toute conclusion substantielle pour cet élément.

La contribution du H-3 à la dose totale est faible dans toutes les zones de surveillance (< 0,025 µSv/y); ce qui correspond à une valeur inférieure d'environ trois ordres de grandeur à la dose de 10 µSv/y considérée par le Conseil de l'Union européenne comme critère pour l'exemption d'une pratique (Directive 96/29/EURATOM du 13 mai 1996).

Doses basées sur les teneurs des radionucléides dans le milieu vivant

On dispose actuellement d'une quantité insuffisante de données pour pouvoir dériver des valeurs de ligne de base pour les teneurs, dans le milieu vivant, de Po-210, Ra-226, Ra-228 et Pb-210. On n'a donc pas été en mesure d'effectuer une évaluation des progrès réalisés dans le sens de l'objectif de la Stratégie OSPAR substances radioactives en ce qui concerne les doses provenant de ces radionucléides. Les données permettent cependant d'établir une comparaison, en termes d'ordre de grandeur, entre les doses provenant des rejets, émissions et pertes des secteurs nucléaires et non nucléaires.

On dispose de données sur les teneurs des radionucléides provenant du secteur nucléaire, Pu-239,240 et Cs-137 dans le poisson et les mollusques pour un certain nombre de zones de surveillance. Les doses de Pu-239,240 couvrent un éventail très étendu de valeurs, la différence entre les doses les plus élevées et les plus faibles étant de trois ordres de grandeur. Le Pu-239,240 dans les mollusques correspond à la dose la plus élevée évaluée dans la ligne de base OSPAR. La dose la plus élevée de Pu-239,240 dans les fruits de mer est substantiellement plus élevée que la dose la plus élevée de Cs-137 dans les fruits de mer. Cette situation ne se présente que dans la zone de surveillance 6 (Mer d'Irlande (Sellafield)), les doses de Pu-239,240 dans les autres zones de surveillance étant inférieures de deux ordres de grandeur aux doses équivalentes de Cs-137.

Les teneurs de Tc-99 n'ont été notifiées ici que dans les algues, ce qui ne représente pas une voie de pénétration significative pour l'homme. On ne considère pas que le H-3 soit pertinent pour le milieu vivant car il ne semble pas que le milieu vivant marin soit capable de le bioaccumuler (à l'exception des composés de H-3 organique). On n'a donc pas évalué de doses pour ces radionucléides provenant des teneurs dans le milieu vivant.

Conclusions générales sur les doses pour la population

On ne dispose pas d'une quantité suffisante de données pour pouvoir déterminer une ligne de base pour les doses, pour la population, de radionucléides rejetés par le secteur nucléaire. Toutes les doses calculées, à ce jour, des teneurs de radionucléides provenant du secteur nucléaire se situent bien en dessous des normes internationales acceptées. Les doses pour l'homme pendant la période d'évaluation n'ont pas été évaluées séparément par rapport aux valeurs de ligne de base mais elles représentent une fonction scalaire des teneurs dans l'environnement respectives dans l'eau de mer et le milieu vivant, lorsque une teneur environnementale a augmenté ou diminué la dose a augmenté ou diminué.

OSPAR n'a cependant pas recueilli de données sur les teneurs dans l'environnement de radionucléides provenant du secteur non nucléaire, il n'a donc pas été possible de tirer des conclusions définitives sur les doses pour la population.

Les doses calculées pour le milieu vivant marin provenant du nucléaire sont inférieures aux niveaux les plus bas risquant d'entraîner des effets

L'évaluation de l'impact des sources anthropiques de substances radioactives sur le milieu vivant marin applique la méthodologie d'évaluation du risque environnemental (ERA) proposée par le projet européen ERICA (ERICA, 2007), seul projet de référence européen permettant une évaluation totalement intégrée des doses dans le milieu vivant.

L'impact, sur le milieu vivant, des teneurs environnementales de H-3, Tc-99, Cs-137, Pu-239,240, Po-210, Ra-226, Ra-228, et Pb-210 a été évalué. Cependant on ne dispose pas de données sur les teneurs de tous ces radionucléides pour chaque zone de surveillance. Les taux de dose totale calculés ont été comparés au taux de dose de filtrage recommandé par ERICA. Cette valeur, 10 µGy/h pour un écosystème générique, a été sélectionnée car elle est très conservative et la plus faible des valeurs de filtrage recommandées.

La méthode adoptée pour la partie des écosystèmes marins représentant le milieu vivant dans la zone OSPAR, applique la modélisation des taux de dose radiologique absorbée aux teneurs de l'activité environnementale des radionucléides sélectionnés mesurées ou estimées.

Les taux de dose propre aux radionucléides ont été calculés pour chaque type de milieu vivant et les taux de dose les plus élevés ont été estimés, pour la période ligne de base de 1995 à 2001, et chaque année individuelle de la période d'évaluation entre 2002 et 2006. Ces taux de dose totale tiennent compte des données provenant d'évaluations précédentes et comportent également celles calculées sur la base des valeurs de limite de détection (qui sont élevées dans certains cas). Lorsque plusieurs sommes sont possibles, seule la plus élevée est notifiée. Bien que la période ligne de base ait été déterminée, la quantité de données est insuffisante pour permettre une analyse statistique approfondie et tirer des conclusions solides. Une évaluation partielle a donc été possible en utilisant les données limitées.

Le taux le plus élevé de dose estimé, pour les radionucléides provenant du secteur nucléaire, se trouve généralement dans les invertébrés. Le Cs-137 et le Tc-99 sont les plus importants contributeurs au taux de dose dans ce cas, les taux de dose du Cs-137 étant généralement plus élevés. Très peu de données sont disponibles pour les radionucléides provenant du secteur non nucléaire (Po-210, Ra-226, Ra-228, Pb-210), et il n'a pas été possible de distinguer la contribution du secteur non nucléaire de la dose ambiante dans le milieu vivant. On a néanmoins calculé les doses d'ensemble de ces radionucléides (y compris les doses ambiantes). Les résultats montrent que le taux de dose estimé le plus élevé se trouve généralement dans les invertébrés, le Po-210 étant le plus important contributeur avec un taux de dose dix fois supérieur au taux de dose le plus élevé pour le Cs-137 ou le Tc-99.

On a estimé les taux de dose les plus élevés pour la zone de surveillance 6 (notamment les taux de dose estimés pour la période ligne de base) et dans une moindre mesure pour les zones de surveillance 4 et 7 (à l'exception de la zone de surveillance 7 en 2004). Ces valeurs sont supérieures, de trois ordres de grandeur, aux taux de dose additionnés pour les mêmes radionucléides dans les autres zones de surveillance. Le Tc-99 est le plus important contributeur aux taux de dose "totale" pour les macroalgues et les invertébrés, dans les zones de surveillance 4, 6 et 13, ayant un taux de dose supérieur d'un ordre de grandeur à celui du

Cs-137. Le Cs-137 a un taux de dose supérieur à celui du Tc-99 pour le poisson dans les mêmes zones de surveillance.

Conclusions générales sur les impacts sur le milieu vivant

On a sélectionné les radionucléides possédant la radiotoxicité la plus élevée, et étant donc les plus importants, pour l'estimation des impacts sur le milieu vivant. Il est donc possible de caractériser le risque potentiel pour la structure et le fonctionnement des écosystèmes marins dans chaque zone de surveillance RSC, même si ceci ne représente pas les effets biologiques totaux de la radiation ionisante dans la zone maritime OSPAR. Les taux de dose additionnés pour les radionucléides sélectionnés peuvent être exprimés en pourcentage de la valeur de filtrage ERICA de 10 µGy/h. Sur cette base, les taux de dose calculés pour le milieu vivant marin provenant des radionucléides du secteur nucléaire sont faibles et inférieurs aux niveaux les plus bas risquant entraîner des effets, selon le raisonnement scientifique actuel.

En résumé

Les Parties contractantes OSPAR ont pris des mesures dans le sens de la mise en oeuvre de la Stratégie substances radioactives. Elles ont conduit à des réductions des rejets de certains radionucléides provenant du secteur nucléaire et des réductions correspondantes de certaines teneurs environnementales. Des travaux supplémentaires sont cependant nécessaires, en particulier en ce qui concerne les rejets radioactifs provenant du secteur non nucléaire, afin de déterminer si on parvient à l'objectif de la Stratégie substances radioactives.

1 Introduction

Radioactive materials are in daily use. They have many applications from the generation of electricity to diagnostic tools in medicine. In the course of their use small quantities of radioactive substances may be discharged into the environment, both from nuclear licensed sites and from non-nuclear operators such as medical establishments and the oil and gas industry. Discharges are in the form of gases, mists, dusts, particles or liquids. These discharges can lead to additional radiation exposures to both humans and other biota; these are usually small in comparison with radiation exposures expected from background radiation from naturally-occurring radioactive materials in the ground and from cosmic rays irradiating the earth from outer space.

1.1 Background

International action to protect the marine environment from all forms of pollution was first agreed in 1972 through the Oslo Convention (OSPAR, 1972). This Convention acknowledged that radioactive substances were one of the forms of pollution to be addressed, and committed the Contracting Parties to working through the appropriate United Nations (UN) specialised agencies and other international bodies to promote measures to protect the marine environment against the impacts of these wastes. When the Paris Convention (OSPAR, 1974) was adopted in 1974 to provide for international action on land-based sources of marine pollution, the Contracting Parties undertook “to adopt measures to forestall and, as appropriate, eliminate pollution of the maritime area from land-based sources by radioactive substances” (EURATOM, 2000).

The two Conventions were updated and unified in 1992 and the OSPAR Convention for the Protection of the Marine Environment of the North East Atlantic was agreed (OSPAR, 1992). Stringent restrictions were included not merely on the dumping of any radioactive waste or matter (which was then temporarily halted under an international moratorium) but also on any possibility of resuming such dumping. In addition, radioactivity was included as one of the factors against which the need for control measures on discharges from land-based sources would be judged.

When the first Ministerial meeting under the 1992 Convention of the OSPAR Commission was held in 1998 at Sintra, Portugal, agreement was reached on both:

- a complete and permanent ban on all dumping of radioactive waste and other matter; and
- a strategy to guide the future work of the OSPAR Commission on protecting the marine environment of the North-East Atlantic against radioactive substances arising from human activities (OSPAR, 2003a).

OSPAR is preparing a major holistic assessment of the state of the North-East Atlantic, the Quality Status Report (QSR) 2010. It will inform the 2010 OSPAR Ministerial Meeting about the environmental condition of the North-East Atlantic and will propose future actions for its protection and conservation. The QSR 2010 will also demonstrate the extent to which the aims of the thematic strategies of the OSPAR Commission have been delivered. The OSPAR Radioactive Substances Strategy is one of these thematic documents.

This report analyses the progress that Contracting Parties to the OSPAR Convention have made in reducing anthropogenic[5] inputs of radioactive substances to the North-East Atlantic, in order to meet the objective of the OSPAR Radioactive Substances Strategy.

The OSPAR Radioactive Substances Strategy provides that

"In accordance with the general objective [of the OSPAR Convention], the objective of the Commission with regard to radioactive substances, including waste, is to prevent pollution of the maritime area from ionising radiation through progressive and substantial reductions of discharges, emissions and losses of radioactive substances, with the ultimate aim of concentrations in the environment near background values for naturally occurring radioactive substances and close to zero for artificial radioactive substances. In achieving this objective, the following issues should, *inter alia*, be taken into account:

a. legitimate uses of the sea;

b. technical feasibility;

c. radiological impacts on man and biota."

The Strategy further provides that:

"This Strategy will be implemented in accordance with the Programme for More Detailed Implementation of the Strategy with regard to Radioactive Substances (the "RSS Implementation Programme") (OSPAR, 2001a). In order to achieve [its objective] by the year 2020, the Commission will ensure that discharges, emissions and losses of radioactive substances are reduced to levels where the additional concentrations in the marine environment above historic levels, resulting from such discharges, emissions and losses, are close to zero."

The RSS Implementation Programme and the agreements made at the second OSPAR Ministerial meeting provide that:

- the Contracting Parties will each prepare a national plan for achieving the objective of the Strategy;
- they will monitor and report on progress in implementing those plans; and
- the OSPAR Commission will periodically evaluate progress against an agreed baseline.

This report is an evaluation of type (c) above and is the third such periodic evaluation to be produced by the OSPAR Commission. It compares data for the assessment period (2002 – 2006) with data for the baseline period (1995 – 2001).

Under Annex IV to the OSPAR Convention, OSPAR is required to produce periodic assessments of the quality status of the maritime area covered by the Convention. A general assessment of the whole of the North-East Atlantic was produced in 2000, supported by five sub-regional reports. The next Quality Status Report (QSR) 2010 will concentrate on the extent to which the aims of the thematic strategies of the OSPAR Commission have been delivered. The present assessment is an important contribution to QSR 2010 and is in turn based on the data and conclusions of the first and second periodic evaluation and complementary documentation in relation to the OSPAR Radioactive Substances Strategy (Box 1).

5 Radioactive substances arising as a consequence of human activity, including Naturally Occurring Radioactive Material (NORM) that has been processed and is therefore not in its natural form.

Box 1

Electronic navigator to complementary QSR assessments and documentation

QSR assessments

- Progressive and substantial reductions in discharges of radioactive substances (first periodic evaluation) (OSPAR, 2006)
- Concentrations of radioactive substances in the marine environment (second periodic evaluation) (OSPAR, 2007)
- Impact of radioactive substances from anthropogenic sources on marine biota (OSPAR, 2008a)

Complementary documentation

- Implementation of BAT to minimise radioactive discharges (OSPAR, 2008c)
- Liquid discharges from nuclear installations in 2007 (OSPAR, 2009c)
- Discharges of radioactive substances from the non-nuclear sector (OSPAR, 2009b)

1.2 Approach

The implementation of this strategy requires attention to **discharges** (reductions in which are the main means of action), **concentrations** (the measure of the ultimate aim) and **doses** to the public and biota (consequence of the two preceding factors, and essential as quality status indicators).

This report is structured in a logical sequence to answer the questions:

- what are the discharges of radioactive substances to the marine environment?
- what are the consequences of these discharges in terms of environmental concentrations of radionuclides?
- what are the radiological consequences (doses) to the human population of these marine concentrations?
- what are the radiological consequences (doses) to non-human species of these marine concentrations?

The Second Ministerial Meeting of the OSPAR Commission in 2003 agreed on the period 1995 – 2001 as the reference period for the baseline against which progress in implementing the strategy could be evaluated. It also referred consideration of the following issues to the Radioactive Substances Committee (RSC):

- an appropriate method for applying the baseline to the radionuclides I-129, C-14 and H-3;
- an appropriate method of dealing with exceptional discharges arising either from the decommissioning of nuclear installations or from operations to recover old waste;
- how to take account of variability in the level of operation of installations.

RSC 2008 established a working group to further examine the issues referred to RSC by the 2003 OSPAR Ministerial Meeting. Annex 3 contains further details of the current position with regards to the evaluation of data on C-14, I-129 and H-3.

1.2.1 Measurement techniques

In reporting to OSPAR on radioactive discharges and concentrations, Contracting Parties have adopted two alternative approaches to estimate alpha (α) and beta (β) activity. These are:

- the activity concentrations of a number of α and β emitting radionuclides are separately determined and reported, and these results are summed to provide 'total-α' or 'total-β'. The discharges for total-β always exclude H-3;
- a sample is analysed for gross-α or gross-β.

In the first case, a limited number of radionuclides are analysed. In the second case, the gross activity can include a contribution from radionuclides which can not be individually analysed, including some naturally-occurring radionuclides. However, the gross activity as measured depends on the mix of radionuclides in the sample, the detection efficiencies for these radionuclides and the energy measurement range of the detector. Hence a figure for 'total-α' or 'total-β (excluding H-3)' obtained by summing the results of determinations of individual radionuclides is not directly comparable to the gross-α and gross-β results.

The measurement techniques used by Contracting Parties to quantify total and gross activity values are summarised in Table 1.1.

Table 1.1: *Summary of measurement techniques*

Normal	Measurement technique
Gross-α	Low background gas flow proportional counters Zinc sulphide (ZnS) solid scintillation counter Liquid scintillation counting Passivated implanted planar silicon (PIPS) alpha detectors
Gross-β	Low background gas flow proportional counters Liquid scintillation counting Geiger Muller detector
Total-α	Passivated implanted planar silicon (PIPS) alpha detectors
Total-β	Gamma spectrometry Liquid scintillation counting Cerenkov counting

There are uncertainties associated with all the techniques used; where the assessment of radioactivity is carried out by radiochemical means, the degree of uncertainty is typically around 15%, where gamma spectroscopy is used, the degree of uncertainty can reach as much as 30 – 40%.

There is little consistency in the total-α/β measurement/reporting by individual Contracting Parties between the different nuclear sub-sectors. For example, some Contracting Parties report the gross activity value for one sub-sector and the sum of the individual activity results for another sector. In general, however, each Contracting Party is consistent in the approaches taken within each sub-sector.

1.2.2 Statistical methods and the baseline element

A baseline has been established against which progress in achieving the Strategy can be evaluated. Where sufficient information is available, the four questions set at 1.2 have been

addressed in terms of changes (*i.e.* increases or reductions) over time, when compared to this baseline.

The overall **baseline** consists of three **baseline elements**:

- the baseline element for discharges,
- the baseline element for concentrations, and
- the baseline element for doses.

The baseline element for discharges only includes liquid discharges and currently does not incorporate non-nuclear sector discharges as OSPAR has only been collecting this data since 2005 and it is not yet comprehensive, especially for the medical sub-sector. The baseline element is therefore based on data provided by the Contracting Parties for the annual OSPAR reports on liquid discharges from nuclear installations. For concentrations and doses, the baseline element only covers anthropogenic radionuclides.

In support of the work already undertaken to meet the objective of the Radioactive Substances Strategy, a report was commissioned by OSPAR to assess the statistical techniques applicable to the OSPAR Radioactive Substances Strategy (OSPAR, 2009a). That report serves to strengthen the statistical analysis of data relating to radioactive substances. It considers the applicable statistical techniques, the relevance of trend analysis and the treatment of results where a relatively large number of values are below the detection limit. Such analyses provide important tools for evaluating the progress the Contracting Parties are making in achieving the objective of the Radioactive Substances Strategy. A summary of statistical methods employed appears at **Annex 1**.

Case Study 1

Data on radionuclide concentrations in the marine environment may include indeterminate values when the concentrations are below the measurement detection limits (DL). Such data are reported as "<DL value", which means that the actual radionuclide concentration value is somewhere between zero and the DL value. These data are referred to as "non-detect values". This case study provides an illustration of how such values should be considered. See Annex 2 for more information.

OSPAR has agreed that the baseline element is to be the mean (average) of the observed values for the years 1995 to 2001, with an interval centred on this mean of 1.96 times the standard deviation, giving a “bracket”. This “bracket” would contain 95% of the observed discharge and concentration values if they were normally distributed – an assumption made for the data analysis. In comparing the baseline period to the assessment period (2002 to 2006), simple comparisons have been made initially to determine if there is a change between the baseline period and the assessment period, *i.e.* the mean for the assessment period lies outside the brackets for the baseline period. This applies to discharges, marine concentrations and radiation doses to humans.

However, simple comparisons are not adequate to determine if there is a statistically significant change. More sophisticated statistical tests (‘parametric’ and ‘non-parametric’) are needed and have been employed in the Periodic Evaluations. These methods are set out in **Annex 1** to this document. When both the parametric and non-parametric statistical tests agree that the basic hypothesis can be rejected and that there has been a change in data since the baseline period,

this is deemed to be ‘statistically significant’. Where the tests disagree, and only one test indicates that there has been a change since the baseline period, this indicates that there is ‘some evidence’ of an increase or reduction since the baseline period.

In order to maintain linkages with the other OSPAR strategies (particularly those on eutrophication and hazardous substances), the data may also be examined using trend-detection techniques of the kind used in other fields by OSPAR. This has not yet been applied to radioactive substances due to the limited availability of data.

1.3 Context

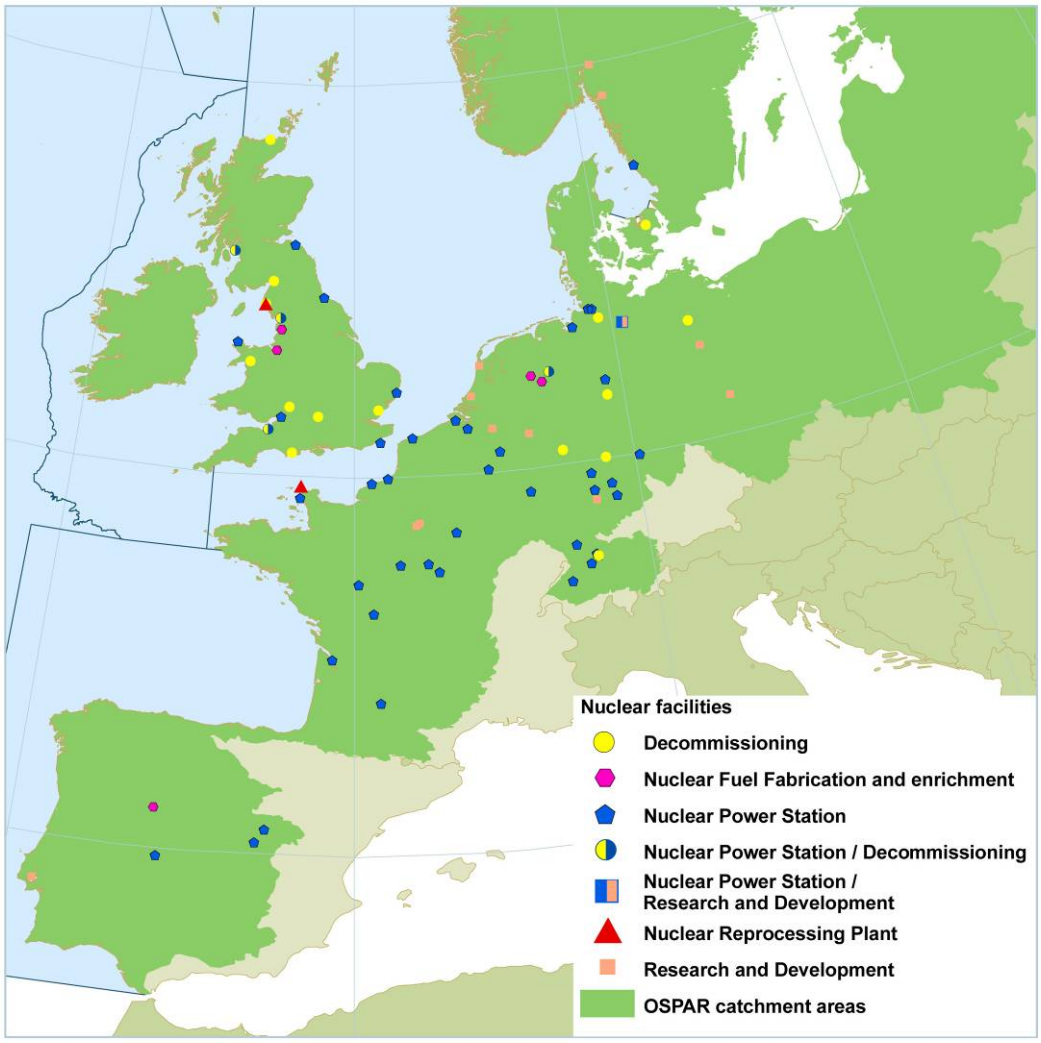


Figure 1.1: *Nuclear sites (within Contracting Parties) impacting upon the North-East Atlantic maritime area.*

2 Discharges to the marine environment

2.1 Introduction

This section assesses the progress that has been made so far in reducing discharges of radioactive substances in line with the objective of the OSPAR Radioactive Substances Strategy. The available evidence is limited to data that has been collected and reported for the five year assessment period (2002 – 2006), following the end of the baseline period. Although some data have been collected for discharges of radioactive substances from the non-nuclear sectors, the evaluation is still limited as OSPAR has only gathered such data since 2005 and it is not yet fully reported by all Contracting Parties, particularly for the medical sector. This evaluation is, therefore, restricted in scope and applies mainly to discharges from the nuclear sector.

2.1.1 Discharges from the nuclear sector

The discharge data used has been taken from the Annual OSPAR Reports on Liquid Discharges from Nuclear Installations from 1995 to 2006. It must be recognised that all data on levels of radioactivity have an inevitable degree of uncertainty attached to them, some of which is due to uncertainties in the measurement techniques used by the Contracting Parties.

The data considered for the nuclear sector as a whole are for discharges of total-α and total-β (excluding H-3). Individual radionuclides cannot be aggregated for the nuclear sector as a whole, since they only appear in some sub-sectors.

Four sub-sectors are considered within the nuclear sector; nuclear fuel production and enrichment, nuclear power plants, nuclear fuel reprocessing, and research and development.

Nuclear fuel production and enrichment

U-235 (which forms approximately 0.7% of natural uranium) is the isotope which is needed to achieve fission in a light-water nuclear reactor for the release of thermal energy for electricity generation. For this purpose, the concentration of the U-235 needs to be increased to between 3% and 5%, by a process known as uranium enrichment. Two main technologies are available: centrifuges and gaseous diffusion, in both cases employing the chemical intermediate uranium hexafluoride. Gaseous diffusion technology is no longer used in the OSPAR area.

Subsequently, there is a need to convert the enriched uranium hexafluoride into a different solid form of uranium and to assemble the resulting pelleted material into fuel rods; in the OSPAR catchment areas, there are (or have been) seven installations undertaking this work. (One of the installations, in addition, was responsible for producing natural uranium fuel rods; that is, using uranium which had not been enriched in U-235. This process has now ceased).

Nuclear power plants

Nuclear power plants are of various types, often classified according to their coolant systems and moderators, but the common feature is that they drive electricity-generating turbines by thermal power produced by nuclear reactors. Radioactive substances in a nuclear power-plant reactor are of three kinds:

- uranium and transuranic elements – the fuel;
- fission products resulting from fission of the fuel;
- radionuclides resulting from irradiation of non-radioactive substances – activation products.

Nuclear fuel reprocessing

Spent nuclear fuel contains up to 97% of reusable energy materials (up to 96% uranium, up to 1% plutonium). Reprocessing involves the recovery of these reusable materials, the conditioning of the remaining waste (mainly fission products) into a safe final form for disposal, and results in some discharges to the environment.

Among Contracting Parties, both France and the United Kingdom operate spent nuclear fuel reprocessing plants. On the initiative of other Contracting Parties, however, the Paris Commission recommended that new authorisations for nuclear reprocessing plants should only be given after special consideration of other options for spent fuel management, a full environmental impact assessment and consultation of the OSPAR Commission (PARCOM Recommendation 1993/5). The OSPAR Commission decided that current authorisations for discharges or releases of radioactive substances from nuclear reprocessing facilities must be reviewed as a matter of priority, with a view to, *inter alia*, implementing the non-reprocessing option (OSPAR Decision 2000/1)[6].

There are currently two sites in the OSPAR area where reprocessing is carried out. These are:

- Sellafield site (UK), with two reprocessing facilities: the Magnox reprocessing plant for Magnox reactor fuels; and the Thorp facility, which deals with advanced gas cooled reactor (AGR) and light water reactor (LWR) oxide fuels.
- La Hague site (France), with two facilities (UP2-800 and UP3) which deal mainly with pressurised water reactor (PWR) oxide fuels.

Other OSPAR countries with nuclear power plants use, or have in the past used, one or other of these plants for their reprocessing needs. Germany has now stopped doing so, and Switzerland has a moratorium for 10 years, which started in the middle of 2006. Both Sellafield and La Hague have a number of other international customers for reprocessing.

Research and development

Many of the nuclear installations considered in this report under other sectors of the nuclear industry carry out research and development. These activities are aggregated with the other activities carried on at those sites, and any discharges relating to nuclear research and development are reported along with those from the principal activities at those sites. This section is concerned only with those sites that are exclusively devoted to nuclear research and development.

2.1.2 Discharges from the non-nuclear sector

When OSPAR prepared a report in 1997 (OSPAR, 1997) on discharges of radioactive substances by non-nuclear industries, it was considered that discharges of radioactive substances arose mainly from:

- mining and ore processing;
- burning of coal, oil or natural gas in thermal power stations;
- the production of phosphate fertilisers;
- miscellaneous industries (for example, concrete and ceramics production).

The 1997 report concentrated principally on the phosphate fertiliser industry; at this time it was responsible for the predominant discharge of radioactive substances from the non-nuclear

6 The recommendation and the decision were not accepted by and do not apply to France and the United Kingdom.

sector. By 2005, all radioactive discharges from the phosphate fertiliser industry in the OSPAR states had ceased, resulting in a major reduction in discharges of radioactive substances to the marine environment. However, historic discharges from this industry continue to contribute to concentrations of radioactive substances in the marine environment and their resulting doses.

Following the publication of the OSPAR report in 1997, OSPAR agreed that further work was required to identify and quantify discharges of radioactive substances from other non-nuclear industries into the marine environment. The report on non-nuclear discharges (OSPAR, 2002a) indicated broadly the sectors of industry that have been important sources of radioactive discharges in recent years. The report also drew on information from the MARINA II study, carried out for the European Commission (MARINA II 2003).

The OSPAR 2002 report concluded that the estimates for non-nuclear sectors are subject to considerable uncertainty due to the variability of data submitted. OSPAR therefore decided to institute a system for collecting data on these discharges, in order to ensure the application of the Radioactive Substances Strategy to the non-nuclear sectors.

The context for the 2 main sub-sectors is given below.

Offshore oil & gas

Seven Contracting Parties have an offshore oil and gas industry (Denmark, Germany, Ireland, the Netherlands, Norway, Spain and the United Kingdom[7]). The Dutch (predominantly) and Irish (entirely)[8] offshore industries are only for gas production. In Norway, the offshore oil and gas industry is extremely important, being responsible for more than one quarter of the State's revenues.

The longer-lived radionuclides are those of natural origin such as Ra-226 and Ra-228, Pb-210 and Po-210. The premises discharging these are in the extractive (or related) sector, in particular the offshore oil and gas exploration and production facilities. The MARINA II study provided *inter alia* an estimate of discharges of alpha-emitting radionuclides in produced water from offshore oil and gas installations[9].

Medical sector

Following publication of the OSPAR 2002 report, further work was commissioned to investigate the overall activity from artificial radionuclides discharged by the medical sector into the marine environment, primarily focusing on discharges of Tc-99m and I-131, which in most cases are made to public sewers.

Technetium has no stable isotopes. The isotope most often employed is Tc-99m, with a half-life of 6.01 hours. This is used in many medical radioisotope tests because of its short physical and biological half-lives, the energy of the gamma ray it emits and the ability of technetium to be chemically bound to many biologically active molecules. It allows medical practitioners to image internal body organs without causing radiation damage. Approximately 85 percent of diagnostic imaging procedures in nuclear medicine currently use this isotope. Tc-99m decays to Tc-99, which has a half-life of 213 000 years.

Radioactive iodine is used for both diagnostic and therapeutic purposes, primarily for conditions of the thyroid gland. In small amounts, I-131 (which has a half-life of 8 days) is used to

7 In addition, France had one exploratory well operational during part of 1995 and another during part of 2004.

8 Discharges from the Irish gas industry are negligible, remaining below detection limits.

9 The MARINA II study showed that levels of discharges from the non-nuclear sector needed monitoring. The estimated values in this study were, however, higher than the values derived directly through monitoring in some sectors.

determine whether or not the thyroid gland is functioning normally, through imaging. When administered in larger doses, it can lower the activity of an overactive thyroid gland and cause it to function normally. In even higher doses, it is used to treat thyroid carcinoma.

2.2 Baseline element for discharges

Each year, OSPAR receives data on radioactive discharges from nuclear installations, particularly discharges of total-α, total-β (excluding H-3) and H-3. An Expert Assessment Panel evaluates this information and prepares an overview for the Radioactive Substances Committee and the OSPAR Commission.

OSPAR has been collecting discharge data only since 2005 for the non-nuclear sector. There is therefore less information, of comparable quality to that for the nuclear sector, on discharges from the non-nuclear sector. This particularly applies to the baseline period during which there was no reporting to the OSPAR Commission, resulting in no baseline component for the non-nuclear sector. However, information presented in the 2002 report on discharges from the non-nuclear industries clearly indicated that such discharges make a contribution to the total input of radioactivity into the maritime area.

It is therefore not possible at present to compile an overall and accurate baseline element for discharges that reflects all the components of the baseline. As a consequence, for the time being, the evaluation of progress towards the objective for discharges from the non-nuclear sector can only be qualitative.

For a future stage of the evaluation of progress, it will be necessary to develop quantitative starting points and/or agreed baseline values for non-nuclear discharges.

2.2.1 Changes in annual radioactive discharges

There are some significant issues to be addressed in making inter-year comparisons using data on discharges of radioactive substances. Differences between years in the levels of annual discharges of installations may be caused by random and systematic factors. For random factors, the mean value of the discharges remains fairly constant over a particular period. Systematic causes can fundamentally change the level of radioactive discharges thereby giving rise to a temporal trend to higher or lower values.

Random changes in the discharges of an installation can result, for example, from:

- fluctuations in the technical performance of liquid discharge treatment plants (variation of the decontamination factor);
- variations in the daily volume of liquid discharges;
- variations in the radionuclide composition in liquid discharges;
- fuel failures in nuclear power plants;
- plant outages for maintenance and engineering modifications or safety inspections;
- random uncertainties in activity measurements as a result of:
    i. fluctuations in the physical-chemical properties of liquid discharges;
    ii. deviations of the measuring sample from the calibration samples;
    iii. changes in the chemical yield in the radiochemical measuring method;
    iv. calibration uncertainties of equipment for activity measurements;

v. variations in the counting statistics of activity measurements.

Systematic changes in annual discharges can be caused, for example, by:

- changes in the output of nuclear reactors;
- changes in the annual throughput and degree of burn-up of spent fuel elements in reprocessing plants;
- technological improvements in existing plants for liquid discharge treatment;
- use of new plants with higher decontamination factors for liquid discharge treatment;
- other measures to reduce discharges of radioactive substances;
- decommissioning and closure of nuclear installations;
- possible future development of new nuclear power plants;
- (for the non-nuclear sectors) changes in the quantity of produced water in ageing oil and gas fields, and the development of new nuclear medicine techniques.

2.2.2 Defining the baseline element for discharges

A major difficulty in establishing the baseline element has been the variability of discharges of radioactive substances that arises from the above factors. Consideration needed to be given to a means of allowing for this variability (for example, by taking averages over a period of years or by applying statistical techniques such as linear regression) and to the years to be taken into account in such calculations.

The absence of data before 2005 for discharges from industries other than the nuclear industry, the potential scale of such discharges and the fact that the Strategy applies equally to all anthropogenic discharges, were further factors that needed to be taken into account. To reflect the full implications of the Strategy, the baseline element needed to cover all discharges of radioactive substances from all sectors. However, as mentioned above, for this periodic evaluation, it has not been possible to construct a baseline component for the non-nuclear industry.

The baseline element for discharges contains two parts, based on the run of annual figures for discharges for the years 1995 – 2001:

- the first part is the average of the range of these years (arithmetic mean);
- the second part allows for the inherent variability of the processes giving rise to the discharges;
- both these parts relate to total-α, total-β (excluding H-3) and H-3 discharges from all sources in the nuclear sector to the OSPAR maritime area as a whole.

The variability component is the standard deviation calculated at the 95% probability level of an assumed random normal distribution. This variability component thus allows for the facts that:

- the figures for these years have been influenced by the factors mentioned above; and
- the figures for any particular year will deviate to an unknown extent from the underlying progress that is being made towards the objective.

In the light of what is known about discharges of radioactive substances, and in particular the significance for radiation dose of the various radionuclides studied, OSPAR has selected certain

radionuclides and groups of radionuclides as the most significant for the purpose of evaluating progress towards the objective of the OSPAR Radioactive Substances Strategy.

The selected radionuclides and groups of radionuclides are as follows:

Nuclear sector: Tc-99; Cs-137; Pu-239,240; total-α; total-β (excluding H-3)

RSC has considered the role of H-3, C-14 and I-129 in evaluating progress in implementing the OSPAR Radioactive Substances Strategy (see **Annex 3**). These additional radionuclides are not, however, considered in this evaluation, except in so far as C-14 and I-129 form part of the statistics on total-β (excluding H-3) activity in discharges. H-3 is excluded from the statistics on total-β activity used in this evaluation[10].

Further consideration is, in addition, being given to appropriate methods to take into account in the implementation of the Strategy:

- changes in the level of operation of installations (for example, the different levels of energy generated by a power station in different years);
- exceptional discharges arising either from the decommissioning of nuclear installations or from operations to recover old waste.

Non-nuclear sector:

Offshore oil and gas industry: Pb-210; Ra-226; Ra-228; Th-228;

Medical sub-sector: Tc-99 (as a decay product of Tc-99m); I-131;

After further study of the possibility of including Po-210 as a selected radionuclide, RSC agreed that reporting from the offshore industry should be confined to Pb-210, since Po-210 is derived from Pb-210, even though Po-210 is important as a long-term source of radiation dose. When more is known about the pattern of discharges from other non-nuclear sectors, consideration will be given to the radionuclides to be chosen for them. Thorium is included as an indicator of discharges from de-scaling operations offshore, but no data on this was reported in 2005 and 2006.

2.2.3 Baseline-element values

Table 2.1 shows the baseline element values for the total liquid α and β (excluding H-3) discharges from the nuclear industry reported to OSPAR. This also provides an explanation and clarification of the statistical techniques used. The discharge data are assumed to be normally distributed around the mean of the reported values. The “bracket” is therefore calculated as the interval which should contain 95% of the measurements taken. Given the normal distribution, and assuming a sufficiently large sample, 95% of the measurements should therefore lie within 1.96 times the standard deviation. For all summary tables of data, where the lower baseline bracket would have a negative value, this has been shown as zero and treated as such for statistical purposes. In these instances, the simple comparison can only be used to compare the assessment period average against the baseline upper bracket.

10 The current intention is that data on tritium discharges should be collected and reported separately from discharges of other β emitting substances.

Table 2.1: *Baseline element components for total-α and total-β (excluding H-3) from the nuclear industry*

	Total-α TBq/ year		Total-β (excluding H-3) TBq/ year	
Time period	**Baseline average**	**Bracket**	**Baseline average**	**Bracket**
1995 – 2001	4.52E-01	2.27E-01 – 6.76E-01	2.80E+02	1.51E+02 – 4.10E+02

Comparisons made between these baseline-element values and discharge data for periods after 2001 only give an approximate and partial view of the progress made against a fixed starting point. Further, more detailed comparisons with discharge figures for periods after 2001 are made through the use of the formalised statistical tests, as described in **Annex 1**. Table 2.2 shows the OSPAR statistics for total discharges from nuclear installations upon which Table 2.1 is based.

In Table 2.2 (and subsequent tables), where the simple comparison indicates that the average for the assessment period is outside the baseline brackets, the values are shown in red type. This notation is also used to indicate "some evidence of change", when either one of the two statistical tests gives a P-value of less than 0.05. Where both of the statistical tests give P-values less than 0.05, the values are shown in **bold red type**. This is considered to be a "statistically significant change" between the baseline period and the evaluation period. The way in which the results of these tests and the conclusions that can be drawn from them are presented in the subsequent data tables is presented below:

Test	Criterion	Presentation in table	Conclusion
Simple comparison	Assessment period average is greater/lower than upper/lower bracket respectively.	Assessment period average is presented in red type	There is a possible increase/decrease.
Statistical tests (Student's t Welch Aspin and Mann-Whitney[11] tests)	One test probability <0.05	Either Student's t Welch Aspin or Mann-Whitney test probability presented in red type	There is some evidence of change.
	Both test probabilities <0.05	Both Student's t Welch Aspin and Mann-Whitney test probabilities presented in **bold red type**	There is a statistically significant change.

11 Mann-Whitney probabilities are approximate values when there are ties (equal values) in the data. This does not change the result of the assessment.

Table 2.2: *Summary table of data for the nuclear sector. (Explanatory note on use of red bold type is given above.)*

	Baseline average (TBq)	Baseline lower bracket (TBq)	Baseline upper bracket (TBq)	Assessment average (TBq)	Student's t Welch-Aspin probability	Mann-Whitney probability
Overall						
Total-α	0.451	0.227	0.676	0.519	0.365	0.343
Total-β (excluding H-3)	280	151	410	174	**0.028**	**0.030**

The data in Table 2.2 show that, for the nuclear sector as a whole, there has been a 38% reduction in the overall average discharge of total-β (excluding H-3) since the baseline period and that this is a statistically significant difference. There was a 15% increase in total-α discharges since the baseline period, but this change was not statistically significant.

2.3 Nuclear fuel production and enrichment plants

2.3.1 Overall situation

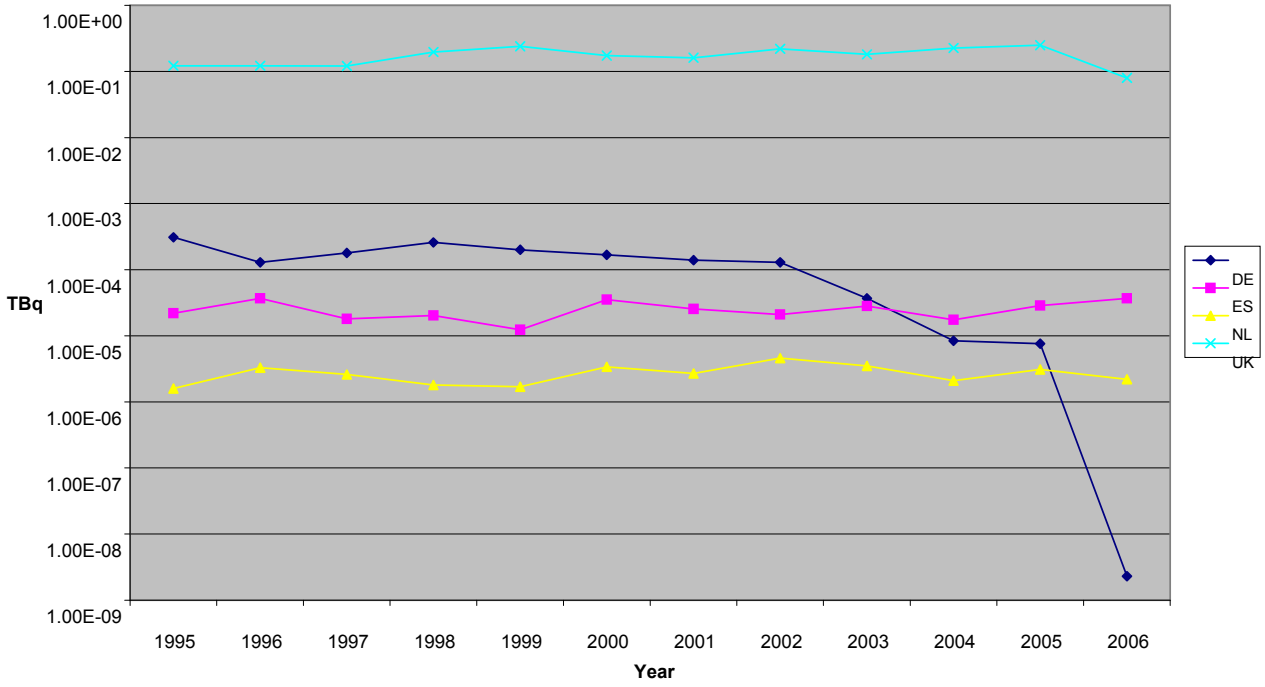
To include the most significant radionuclides for evaluating progress, whilst keeping the number of comparisons to a manageable level, OSPAR has chosen discharges of total-α, total-β (excluding H-3) and Tc-99 as the appropriate datasets for this sub-sector.

2.3.2 Discharges

The overall levels of discharges of total-α and total-β (excluding H-3) from the nuclear-fuel sub-sector are given in Table 2.3. The line graphs at Figures 2.1, 2.2 and 2.3 show the total-α, total-β (excluding H-3) and Tc-99 discharges for this sub-sector from 1995 to 2006 per country. Table A4.1 in **Annex 4** shows the individual Contracting Party discharges from nuclear fuel production and enrichment plants.

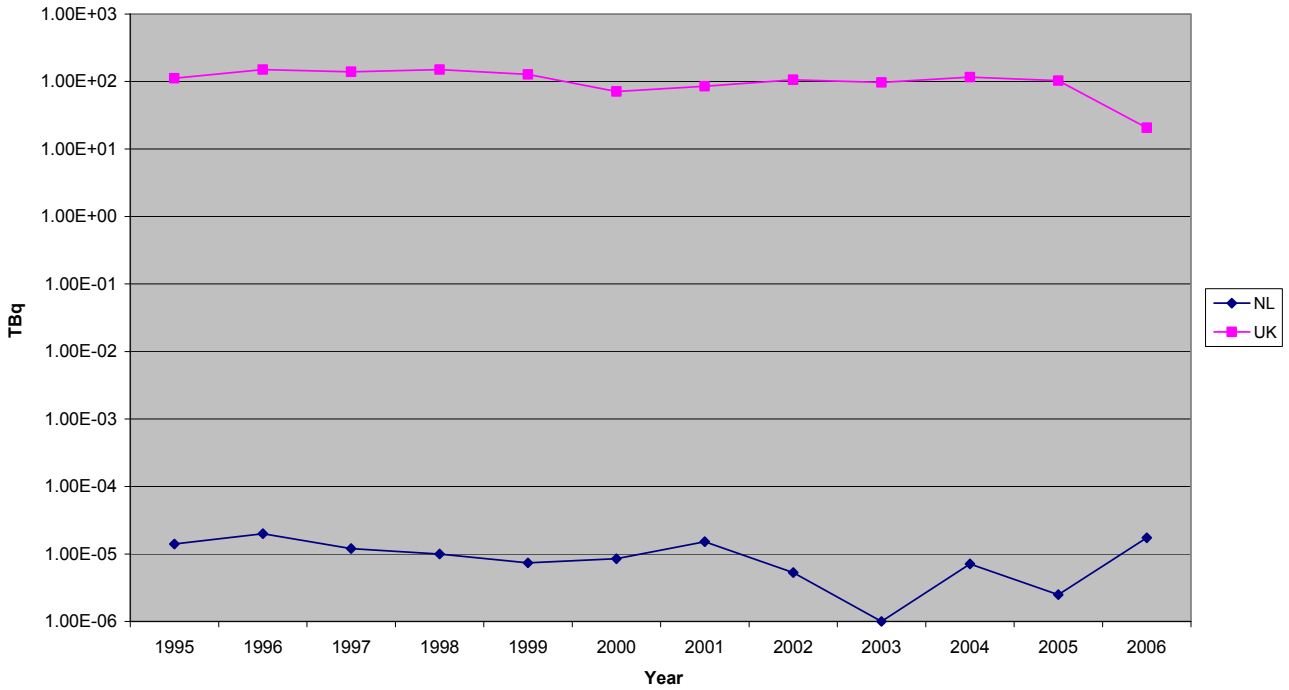
Table 2.3: Discharges from the nuclear fuel production and enrichment plant sub-sector

Year	Total-α (TBq)	Total-β (excluding H-3) (TBq)
1995	0.122	112
1996	0.122	150
1997	0.121	140
1998	0.196	150
1999	0.240	128
2000	0.174	71.3
2001	0.162	85.1
2002	0.220	106
2003	0.181	97.0
2004	0.227	116
2005	0.250	103
2006	0.080	20.7



A logarithmic scale has been used for the graph.

Figure 2.1: *Total-α discharges from nuclear fuel production and enrichment plants per country*



A logarithmic scale has been used for the graph.

Figure 2.2: *Total-β (excluding H-3) discharges from nuclear fuel production and enrichment plants per country*

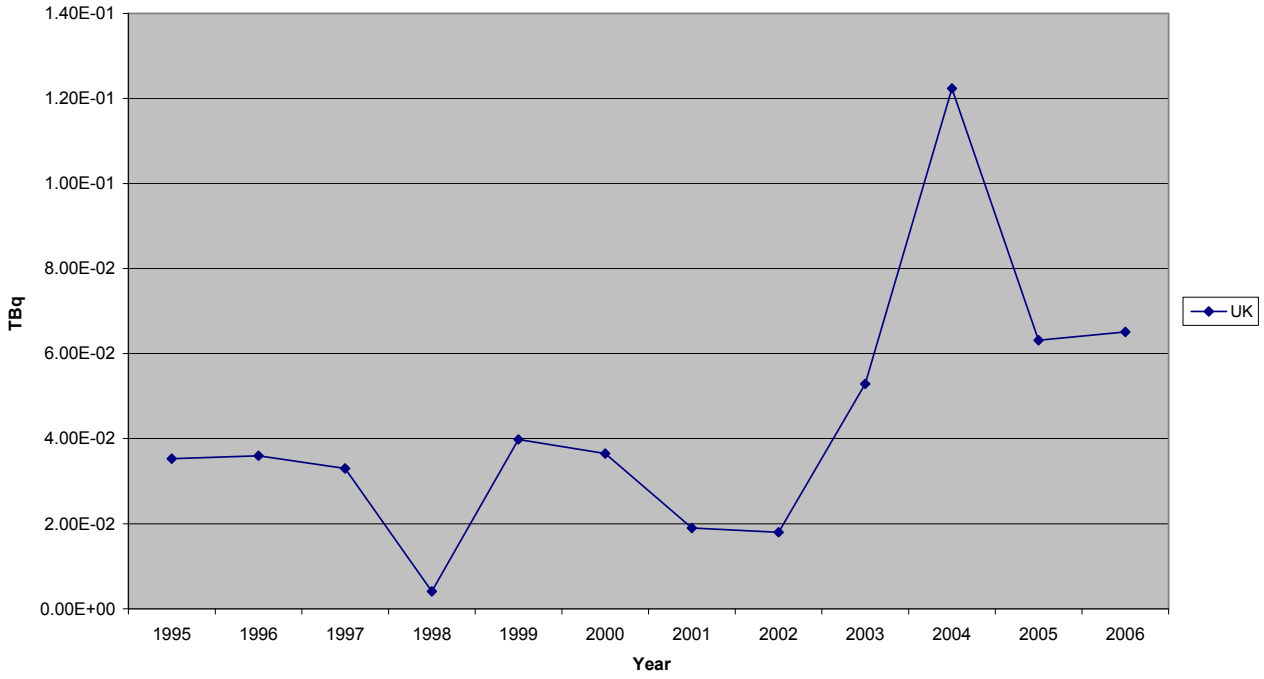


Figure 2.3: *Tc-99 discharges from nuclear fuel production and enrichment plants per country*

Table 2.4 shows that for the nuclear fuel production and enrichment sub-sector, there has been an 18% increase in the overall average discharges of total-α since the baseline period, and a 26% decrease in total-β (excluding H-3) discharges. Neither of these changes is statistically significant.

With regard to the individual Contracting Parties, the largest contribution to the discharges from this sub-sector is from the United Kingdom. There is some evidence of change in the average level of Tc-99 discharges from the United Kingdom, but this increase is not statistically significant.

The only statistically significant change in total-α discharges occurred in Germany and this was a reduction.

Table 2.4: *Summary table of data for nuclear fuel production and enrichment plants (Explanatory note on use of red type and red bold type is on page 27.)*

	Baseline average (TBq)	Baseline lower bracket (TBq)	Baseline upper bracket (TBq)	Assessment average (TBq)	Student's t Welch-Aspin probability	Mann-Whitney probability
Overall						
Total-α	0.163	0.074	0.251	0.192	0.428	0.343
Total-β (excluding H-3)	119	57.9	195	88.5	0.180	0.202
Germany						
Total-α	1.98E-04	7.03E-05	3.26E-04	3.66E-05	**0.001**	**0.003**
Spain						
Total-α	2.44E-05	6.69E-06	4.21E-05	2.65E-05	0.665	0.639
Netherlands						
Total-α	2.44E-06	9.64E-07	3.92E-06	3.10E-06	0.264	0.268
Total-β (excluding H-3)	1.24E-05	3.89E-06	2.10E-05	6.66E-06	0.128	0.073
United Kingdom						
Total-α	1.62E-01	7.31E-02	2.52E-01	1.92E-01	0.426	0.343
Total-β (excluding H-3)	1.19E+02	5.79E+01	1.81E+02	8.85E+01	0.180	0.202
Tc-99	2.91E-02	3.81E-03	5.44E-02	6.43E-02	0.104	0.073

2.4 Nuclear power plants

2.4.1 Overall situation

In order to keep the number of comparisons required to a manageable level while at the same time ensuring that the evaluation adequately covers the most significant radionuclides, OSPAR has agreed that the measurements to be considered in relation to nuclear power plants should be those of discharges of total-α, total-β (excluding H-3) and Cs-137.

The overall liquid discharges of α-emitting radionuclides have not been evaluated, since they are of little radiological importance or environmental impact. The total-α activity in liquid discharges from nuclear power plants is so low that in most cases it falls below the detection limit associated with the measuring devices. It is not possible to conduct a meaningful statistical analysis on the basis of these values. Total-α discharges from nuclear power-plants are also so low that they have not been evaluated for individual Contracting Parties.

It should be noted that the UK has reported separately to OSPAR (under the category of decommissioning discharges) data relating to the decommissioning of facilities in this sub-sector since 2005. For the purposes of this evaluation, however, such data have been incorporated back into this sub-sector, to allow valid comparisons to be made against the baseline.

2.4.2 Discharges

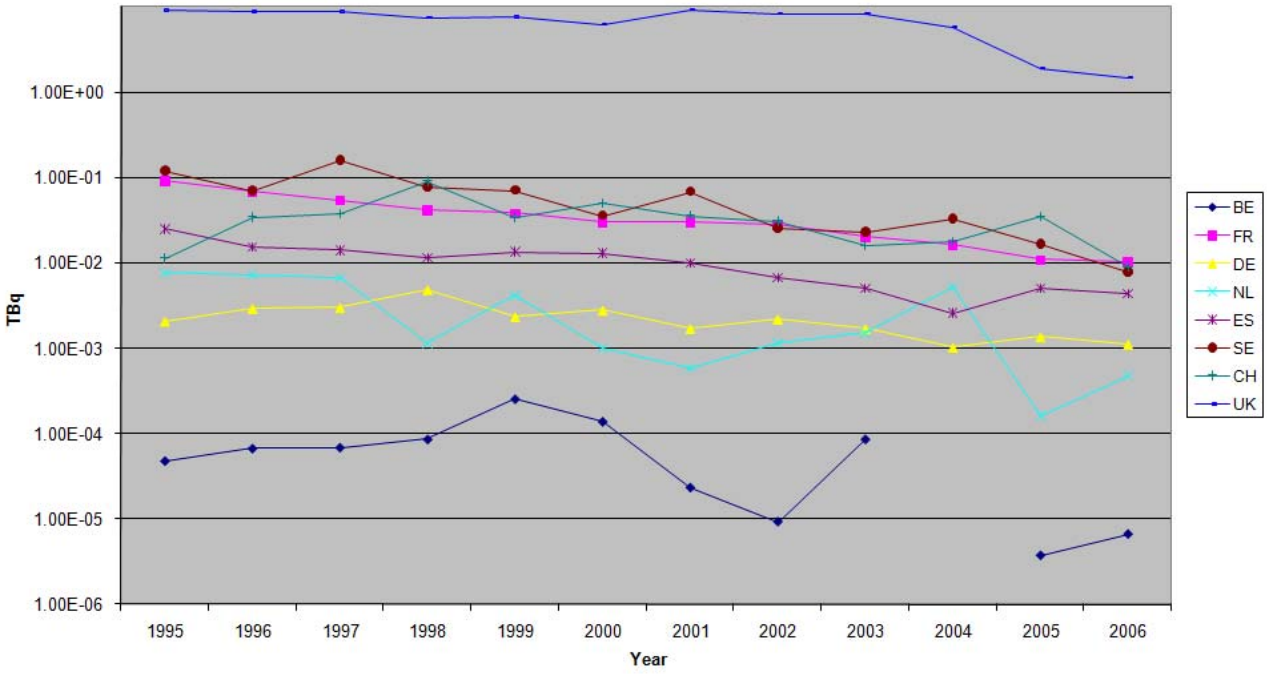
The overall levels of discharges of total-β (excluding H-3) from the nuclear power sub-sector are shown in Table 2.5. Figures 2.4 and 2.5 show the total-β (excluding H-3) and Cs-137 discharges for this sub-sector, by Contracting Party.

Case Study 2

The substantial reduction of discharges from the Ringhals site in Sweden during the last decade illustrates how Contracting Parties are working in order to reduce anthropogenic discharges of radioactive substances to the North-East Atlantic, in line with the commitments in the OSPAR Radioactive Substances Strategy. It also provides an example of how the reduction of discharges as a result of OSPAR measures can benefit adjacent marine areas, in this case the Baltic Sea. See Annex 2 for more information.

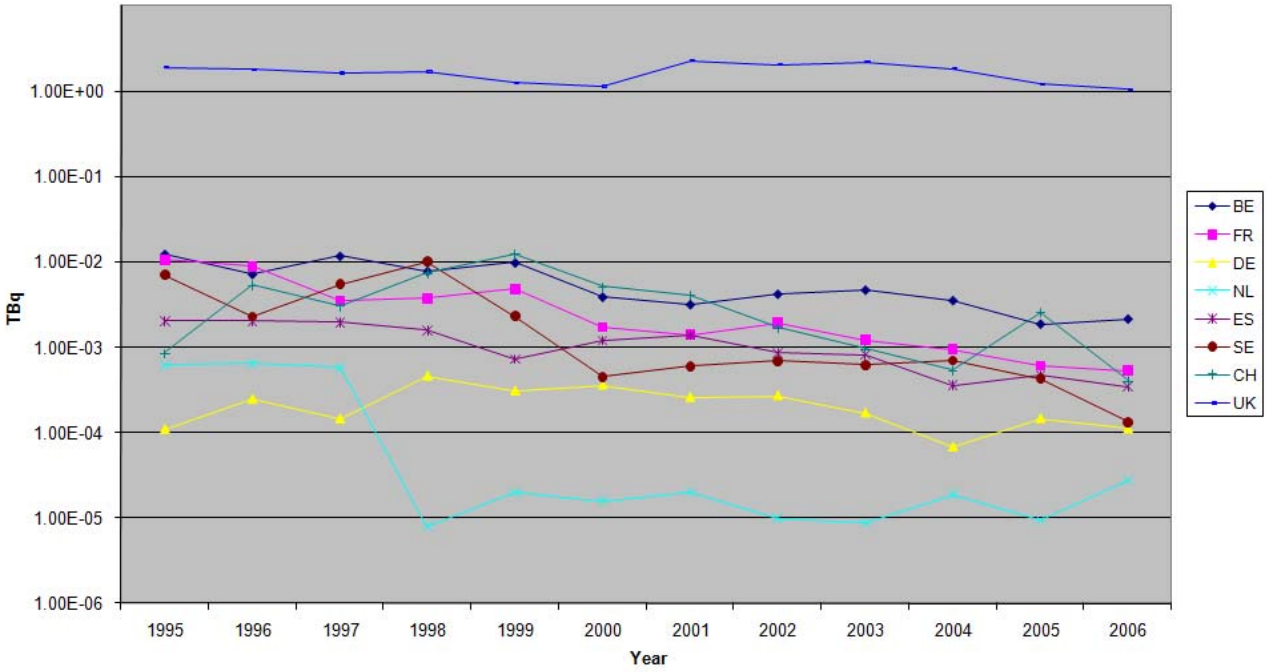
Table 2.5: *Discharges from the nuclear power plant sub-sector*

Year	Total-β (excluding H-3) (TBq)
1995	9.25
1996	8.91
1997	9.00
1998	7.57
1999	7.70
2000	6.32
2001	9.29
2002	8.39
2003	8.33
2004	5.88
2005	1.96
2006	1.52



A logarithmic scale has been used for the graph.

Figure 2.4: *Total-β (excluding H-3) discharges from the nuclear power plant sub-sector per country*



A logarithmic scale has been used for the graph.

Figure 2.5: *Cs-137 discharges from the nuclear power plant sub-sector per country*

Table 2.6 summarises data for overall discharges into the OSPAR maritime area, from nuclear power plants in OSPAR Contracting Parties, as well as data for individual Contracting Parties.

Table 2.6: *Summary table of data for nuclear power plants (Explanatory note on use of red type and red bold type is on page 27.)*

Note: Where the lower baseline bracket has a negative value, it is shown as zero for statistical purposes.

	Baseline average (TBq)	Baseline lower bracket (TBq)	Baseline upper bracket (TBq)	Assessment average (TBq)	Student's t Welch-Aspin probability	Mann-Whitney probability
Overall						
Total-β (excluding H-3)	8.29E+00	6.09E+00	1.05E+01	5.21E+00	0.108	0.073
Cs-137	1.68E+00	9.46E-01	2.42E+00	1.66E+00	0.943	1.000
Belgium						
Total-β (excluding H-3)	9.69E-05	0	2.48E-04	2.09E-05	**0.048**	**0.048**
Cs-137	7.90E-03	9.64E-04	1.48E-02	3.25E-03	**0.013**	**0.048**
France						
Total-β (excluding H-3)	5.07E-02	6.07E-03	9.53E-02	1.71E-02	**0.007**	**0.003**
Cs-137	4.92E-03	0	1.18E-02	1.04E-03	**0.026**	**0.010**
Germany						
Total-β (excluding H-3)	2.82E-03	8.20E-04	4.81E-03	1.48E-03	**0.014**	**0.010**
Cs-137	2.69E-04	3.38E-05	5.05E-04	1.53E-04	0.067	0.202
The Netherlands						
Total-β (excluding H-3)	4.12E-03	0	1.04E-02	1.72E-03	0.147	0.268
Cs-137	2.71E-04	0	8.95E-04	1.50E-05	0.078	0.202
Spain						
Total-β (excluding H-3)	1.47E-02	4.94E-03	2.45E-02	4.74E-03	**0.001**	**0.003**
Cs-137	1.56E-03	5.85E-04	2.53E-03	5.64E-04	**0.001**	**0.010**
Sweden						
Total-β (excluding H-3)	8.65E-02	6.38E-03	1.67E-01	2.13E-02	**0.005**	**0.003**
Cs-137	4.04E-03	0	1.11E-02	5.14E-04	0.042	0.073
Switzerland						
Total-β (excluding H-3)	4.20E-02	0	8.95E-02	2.17E-02	0.083	0.073
Cs-137	5.43E-03	0	1.26E-02	1.23E-03	**0.022**	**0.018**
United Kingdom						
Total-β (excluding H-3)	8.09E+00	5.93E+00	1.02E+01	5.14E+00	0.119	0.073
Cs-137	1.66E+00	9.19E-01	2.40E+00	1.65E+00	0.991	1

Table A4.2 in **Annex 4** shows the individual Contracting Party discharges from nuclear power plants.

Table 2.6 shows that, for the nuclear power plant sub-sector, there has been a 37% reduction in the overall average discharges of total-β (excluding H-3) since the baseline period.

There were statistically significant changes in total-β (excluding H-3) discharges from Belgium, France, Germany, Spain and Sweden, and Cs-137 discharges from Belgium, France, Germany, Spain, Sweden and Switzerland. In every case, these represent reductions in the average discharge during the assessment period, compared with the baseline value.

2.5 Nuclear fuel reprocessing

2.5.1 Overall situation

Detailed reports on all the radionuclides detected in the liquid discharges from the reprocessing plants at La Hague and Sellafield have been made to OSPAR since reporting started on liquid discharges from nuclear installations. OSPAR has, however, agreed that for the purpose of this evaluation, the reported levels of discharges of total-α, total-β (excluding H-3), Tc-99, Cs-137 and Pu-239,240 should be considered.

Technetium 99 (Tc-99)

Tc-99 is a long-lived (half-life of 213,000 years), β-emitting artificial radionuclide. Its presence in the marine environment results principally from discharges from reprocessing plants and to a minor extent from atmospheric nuclear-weapon tests.

Since 1990, this radionuclide has been subject to a specific removal process (chemical extraction) and conditioning process (vitrification) at La Hague. Discharges of this radionuclide to the sea have been reduced by a factor of 100 between 1989 and 2004. This radionuclide is thus an indicator of the improvement of the process achieved at La Hague, with less than 0.06% of the input of this radionuclide to the processing plant now being released.

At Sellafield, Tc-99 has been directed to the vitrification process since 1994 for oxide fuels, and since 2003 for Magnox fuels. Discharge of this radionuclide to sea (primarily from treatment of stored Magnox wastes) has thus been reduced by a factor of 34 between 1995 and 2006.

Tc-99 is a radionuclide on which previous OSPAR assessments for the reprocessing sector have focussed. As a result of the reductions in discharges that have taken place in recent years, this radionuclide is now of reducing importance in terms of the selection criteria for radionuclides discharged into the marine environment.

Caesium 137 (Cs-137)

Cs-137 is a medium-lived (half-life of 30.1 years), artificial radionuclide. Its presence in the marine environment results from three main sources: atmospheric nuclear-weapon tests, fallout from the Chernobyl accident and authorised discharges from reprocessing plants. With its short-lived daughter (Ba-137m), it is a beta/gamma emitter fission product of high radiotoxicity.

At Sellafield, this radionuclide has been the subject of particular attention. The discharge reduction process began in the late 1970s with the introduction of local fuel-pond water-treatment, followed by the completion in 1986 of a large-scale ion-exchange plant. Cs-137 releases have been reduced by a factor of 450 between the late 1970s and 2004.

At La Hague, discharges of this radionuclide have been drastically reduced since the middle of the 1990s, due to the setting up of new effluent management arrangements. This management approach is mainly based on an increased use of evaporation to maximise concentration and

the extraction of radionuclides intended for vitrification (solid waste). This optimised liquid effluent management strategy has resulted in more than a 10-fold of reduction in discharges of Cs-137 since 2000.

Cs-137 remains a significant radionuclide in the context of OSPAR strategy assessments for the reprocessing sector, due principally to the historic (*i.e.* pre-1998) discharges.

Polonium 239, Polonium 240 (Pu-239,240)

Pu-239 and Pu-240 are highly radiotoxic and long-lived artificial radionuclides (half-lives of 24 100 years and 6563 years respectively). Their presence in the OSPAR marine environment results mainly from reprocessing plants. At La Hague, Pu-239,240 releases have been reduced by a factor of 10 between 1989 and 1999, primarily due to the optimisation of abatement processes. Since 2002 – 2003, a new facility which allows the almost total recycling of the effluent produced in the process of vitrification, has led to a further twofold reduction in Pu-239,240 discharges.

At Sellafield, the reduction process began in the late 1970s with the storage of effluent, prior to the introduction in the early 1980s of evaporators to reduce the volume of the effluent. The concentrated effluents were then stored until the completion of a large-scale actinide-removal plant. This commenced operation in 1994. Pu-239,240 discharges have been reduced by a factor of 360 between 1976 and 2006.

Despite the success in reducing discharges, these radionuclides remain among the main contributors to doses to the critical group and as such are significant radionuclides in the context of OSPAR strategy assessments for the reprocessing sector. Due to their high particle reactivity, pre-1998 discharges of Pu-239,240 have become associated with sediment close to the Sellafield discharge pipeline. Remobilisation from these deposits is now the predominant source of these isotopes in seawater (Leonard *et al.*, 1999) and it is estimated that historic discharges currently account for around 90% of the dose from these radionuclides.

2.5.2 Discharges

The overall levels of discharges of total-α and total-β (excluding H-3) from nuclear fuel reprocessing are shown in Table 2.7, with Figures 2.6, 2.7, 2.8, 2.9 and 2.10 showing the total-α, total-β (excluding H-3), Tc-99, Cs-137 and Pu-239,240 discharges respectively, for France and the UK. Note that Figures 2.8 and 2.10 have a logarithmic scale (because reductions in Tc-99 and Pu 239,240 discharges have been so large) while the others have arithmetic scales.

Table 2.7: *Discharges from the nuclear fuel reprocessing sub-sector*

Year	Total-α (TBq)	Total-β (excluding H-3) (TBq)
1995	0.470	243
1996	0.316	169
1997	0.228	167
1998	0.221	112
1999	0.173	126
2000	0.157	98.0
2001	0.251	138
2002	0.389	125
2003	0.430	96.9
2004	0.310	86.4
2005	0.270	54.4
2006	0.230	36.6

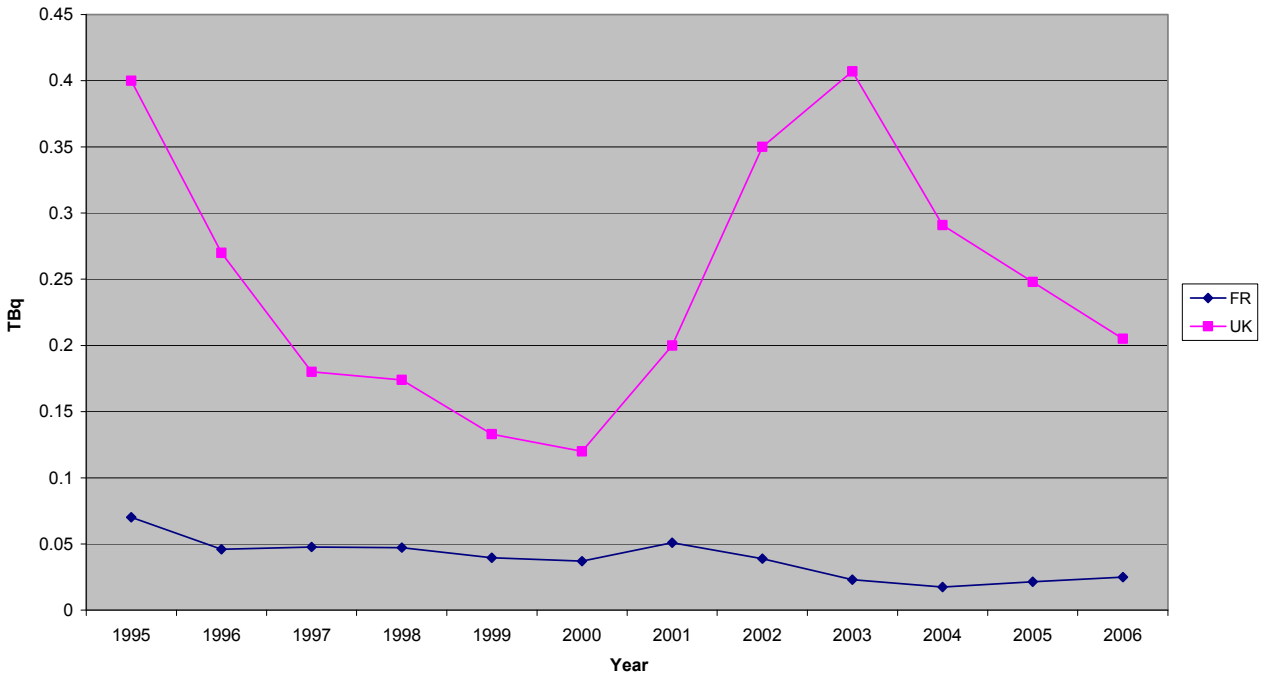


Figure 2.6: *Total-α discharges from the nuclear fuel reprocessing sub-sector per country*

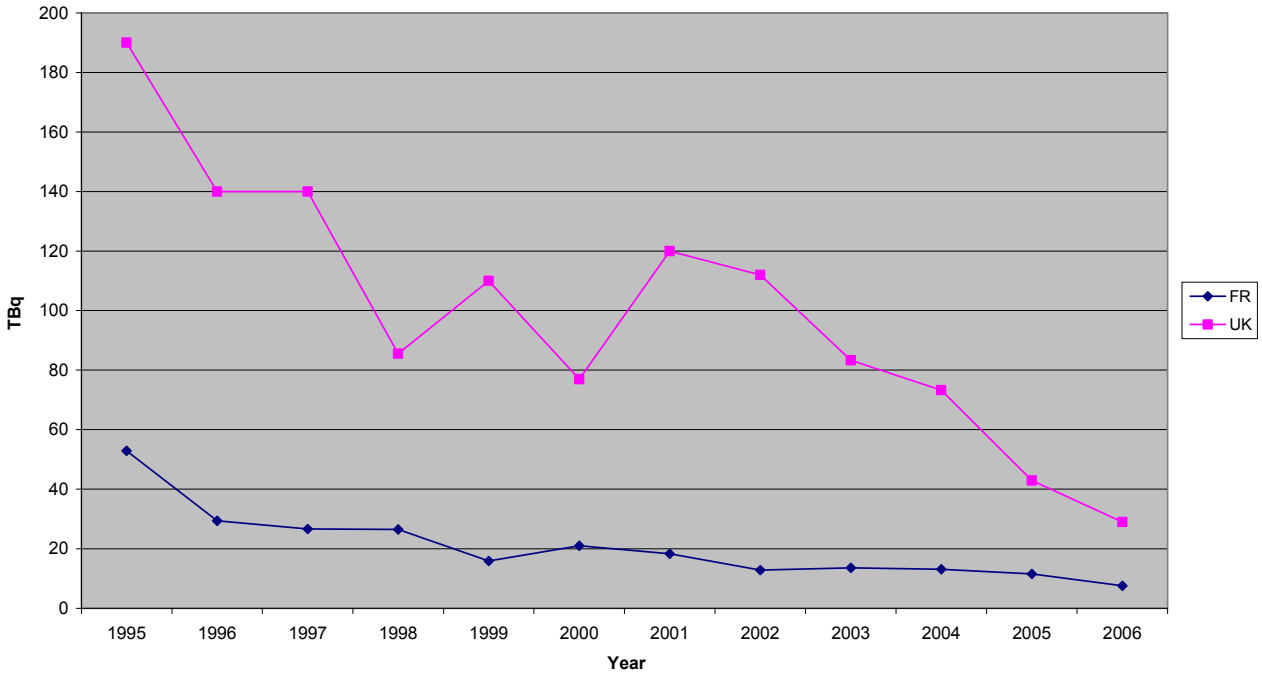


Figure 2.7: *Total-β (excluding H-3) discharges from the nuclear fuel reprocessing sub-sector per country*

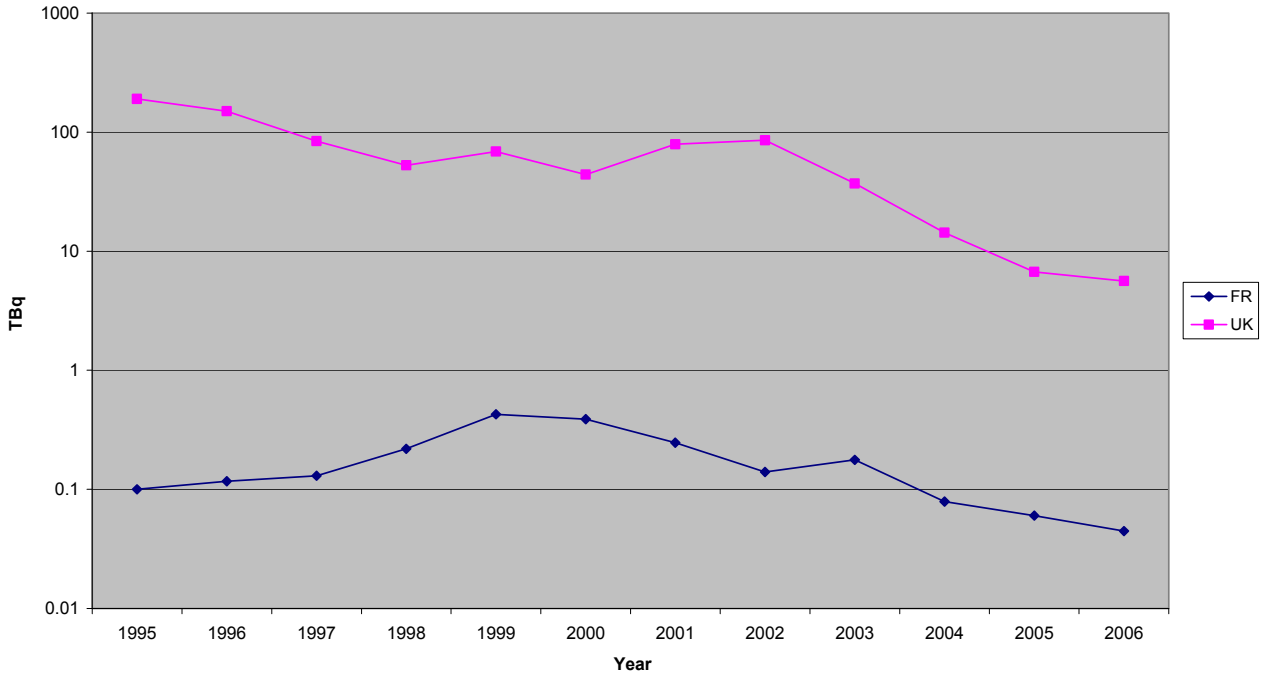
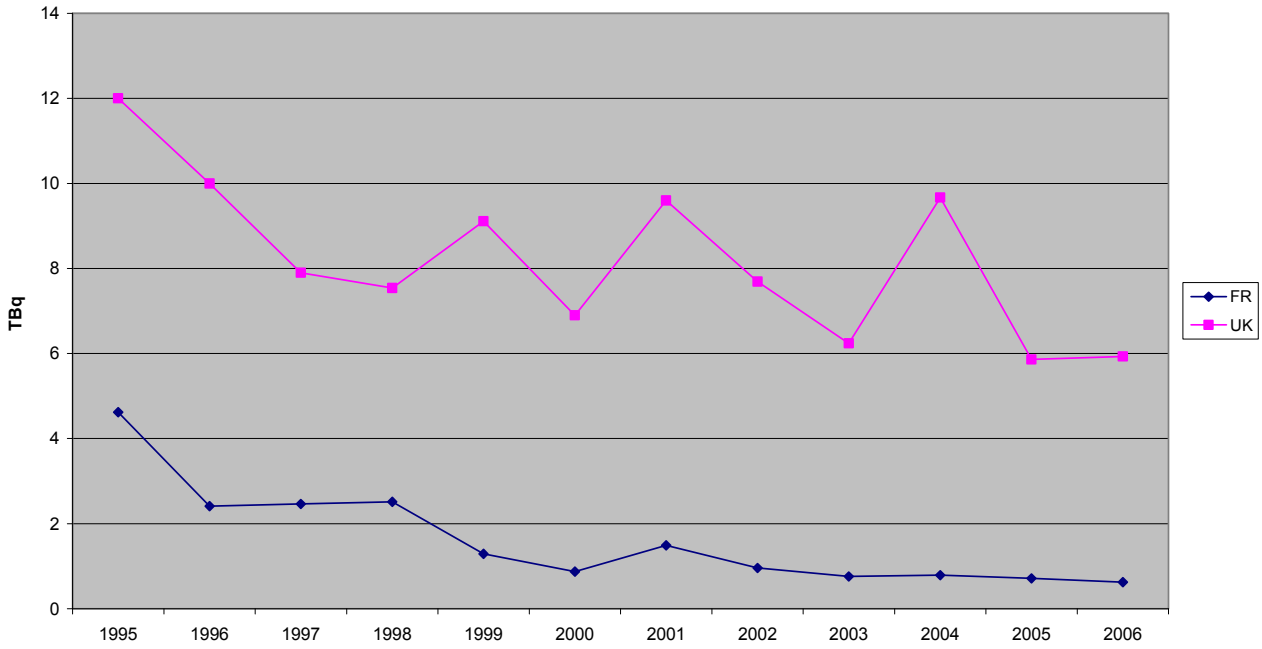
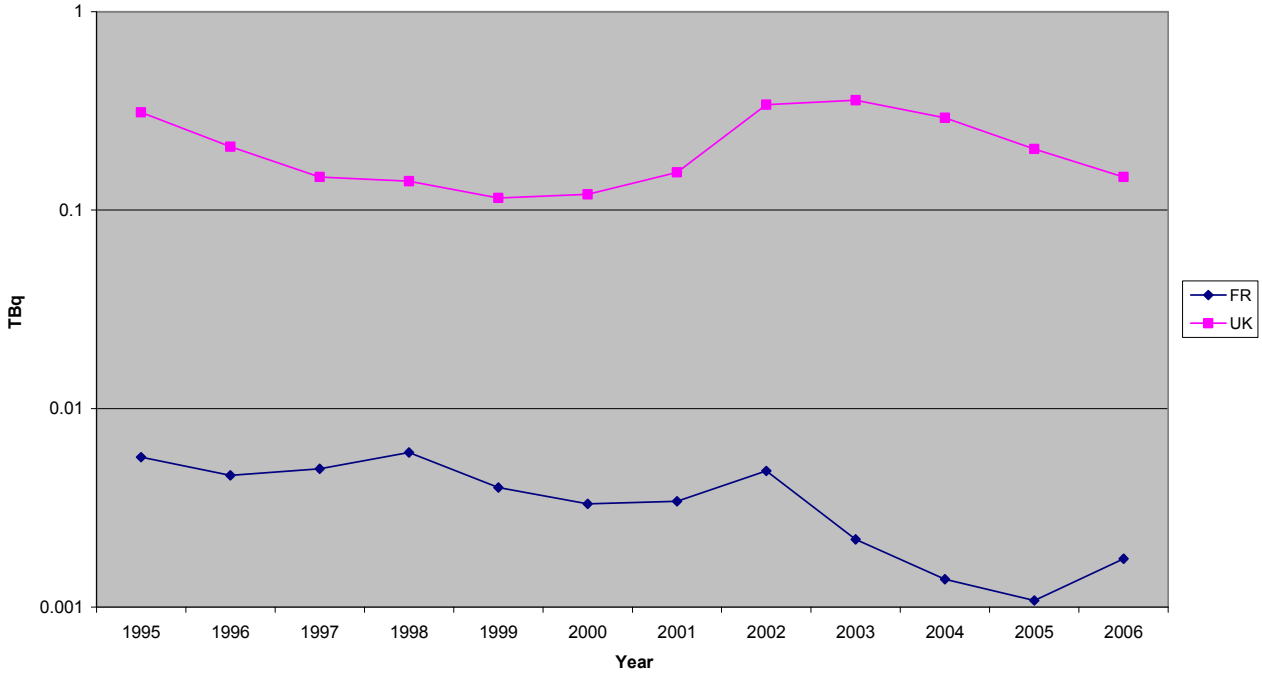


Figure 2.8: *Tc-99 discharges from the nuclear fuel reprocessing sub-sector per country*



A logarithmic scale has been used for the graph.

Figure 2.9: *Cs-137 discharges from the nuclear fuel reprocessing sub-sector per country*



A logarithmic scale has been used for the graph.

***Figure 2.10**: Pu-239,240 discharges from the nuclear fuel reprocessing sub-sector per country*

Table 2.8 summarises data for discharges into the OSPAR maritime area from nuclear fuel reprocessing plants in OSPAR Contracting Parties.

Table A4.3 in **Annex 4** shows the individual Contracting Party discharges from nuclear fuel reprocessing plants.

Table 2.8 shows that, for the nuclear fuel reprocessing sub-sector overall, there has been a 47% reduction in average discharge levels of total-β (excluding H-3) since the baseline period and this represents a statistically significant change. There have also been statistically significant changes (with the comparison of averages indicating reductions) in discharges of Cs-137 and Tc-99. There has also been an increase of 25% in average discharge levels of total-α since the baseline period, but this was not statistically significant.

For France, there have been statistically significant changes (representing discharge reductions) for all categories apart from Tc-99, for which there is some evidence of change. For the United Kingdom, there have been statistically significant changes in total-β (excluding H-3) and Tc-99 (representing discharge reductions in both cases). There is also some evidence of an increase in the average Pu-239,240 discharge during the assessment period, but this is not statistically significant and the data indicate that there has been a continual reduction in discharges since 2004.

Table 2.8: *Summary table of data for nuclear fuel reprocessing plants (Explanatory note on use of red type and **red bold type** is on page 27.)*

	Baseline average (TBq)	Baseline lower bracket (TBq)	Baseline upper bracket (TBq)	Assessment average (TBq)	Student's t Welch-Aspin probability	Mann-Whitney probability
Overall						
Total-α	2.59E-01	5.04E-02	3.66E-01	3.25E-01	0.256	0.202
Total-β (excluding H-3)	1.50E+02	5.53E+01	1.99E+02	7.98E+01	**0.015**	**0.010**
Tc-99	9.57E+01	0	2.01E+02	2.99E+01	**0.027**	**0.048**
Cs-137	1.12E+01	5.86E+00	1.66E+01	7.85E+00	**0.025**	**0.048**
Pu-239,240	1.76E-01	3.93E-02	3.12E-01	2.70E-01	0.091	0.106
FR						
Total-α	4.84E-02	2.73E-02	5.91E-02	2.52E-02	**0.002**	**0.005**
Total-β (excluding H-3)	2.72E+01	3.07E+00	3.96E+01	1.17E+01	**0.015**	**0.002**
Tc-99	2.33E-01	0	3.64E-01	1.00E-01	0.043	0.073
Cs-137	2.24E+00	0	3.47E+00	7.68E-01	**0.020**	**0.005**
Pu-239,240	4.57E-03	2.50E-03	5.63E-03	2.25E-03	**0.022**	**0.030**
UK						
Total-α	2.11E-01	2.16E-02	3.08E-01	3.00E-01	0.113	0.073
Total-β (excluding H-3)	1.23E+02	4.83E+01	1.61E+02	6.81E+01	**0.024**	**0.030**
Tc-99	9.55E+01	0	1.50E+02	2.98E+01	**0.027**	**0.048**
Cs-137	9.01E+00	5.60E+00	1.07E+01	7.08E+00	0.080	0.106
Pu-239,240	1.71E-01	3.57E-02	2.40E-01	2.68E-01	0.083	0.073

Case Study 3

As early as 1992, the French Authorities required licensees to optimise radioactive substance discharges. Licensees implemented technical and organisational programmes which resulted in a large decrease in discharges of radioactive substances in the marine environment. See Annex 2 for more information.

Case Study 4

The reduction of Tc-99 discharges from the Sellafield reprocessing facility provides an example of regulatory and management decisions being taken to reduce a site-specific source of discharges, as a result of OSPAR measures and associated consideration by Contracting Parties. See Annex 2 for more information.

2.6 Nuclear research and development facilities

2.6.1 Overall situation

These specific research and development sites cover a wide range of activities. Some sites are still operational, while others are in the process of being decommissioned. There is therefore no consistent overall picture. This sub-sector makes only a small contribution to overall discharges from the nuclear sector.

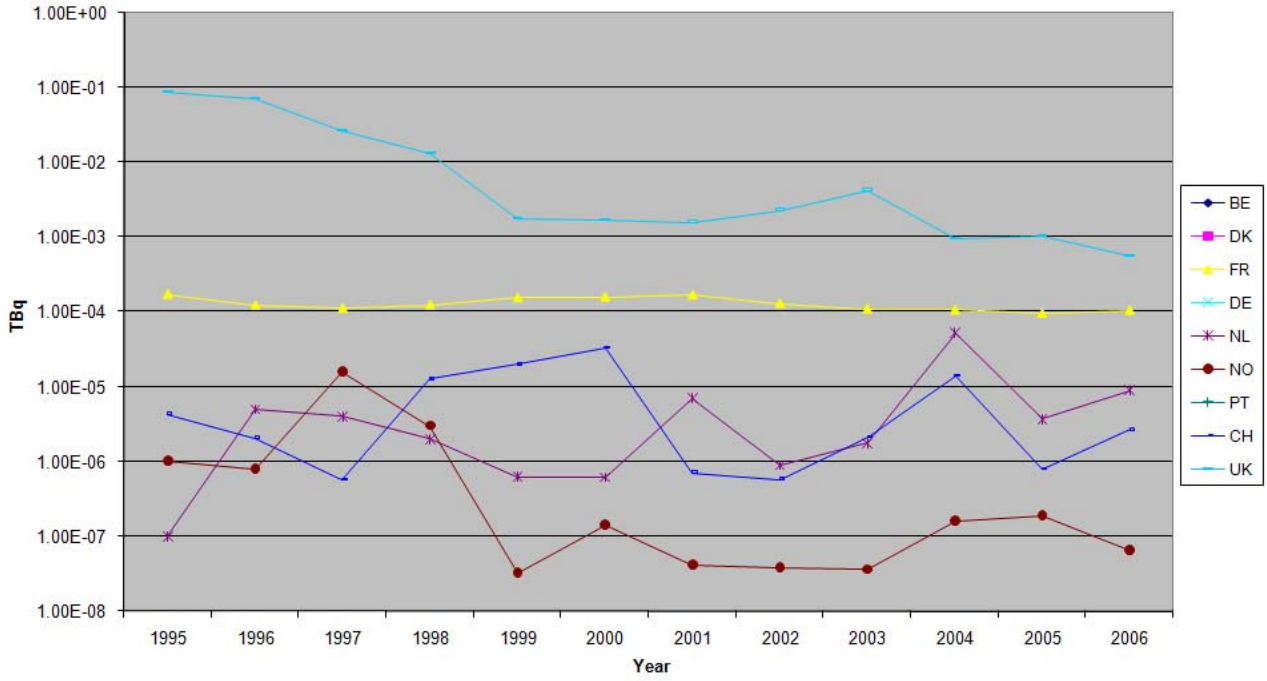
Although both UK and Switzerland have been reporting separate decommissioning data (with all UK discharges for this sub-sector solely being decommissioning discharges) since 2005, for the purposes of this evaluation, the relevant discharges have been incorporated back into this sub-sector to allow valid comparisons to be made against the baseline. Switzerland's decommissioning data also includes some data for nuclear power stations, industry and the medical sub-sector. France's discharges for research and development also include discharges from the medical sub-sector as it is difficult to separate the discharges for these two sub-sectors.

2.6.2 Discharges

The overall levels of discharges of total-α and total-β (excluding H-3) reported to OSPAR for the years in question are shown in Table 2.9. Figures 2.11 and 2.12 show the total-α and total-β (excluding H-3) discharges respectively, for this sub-sector.

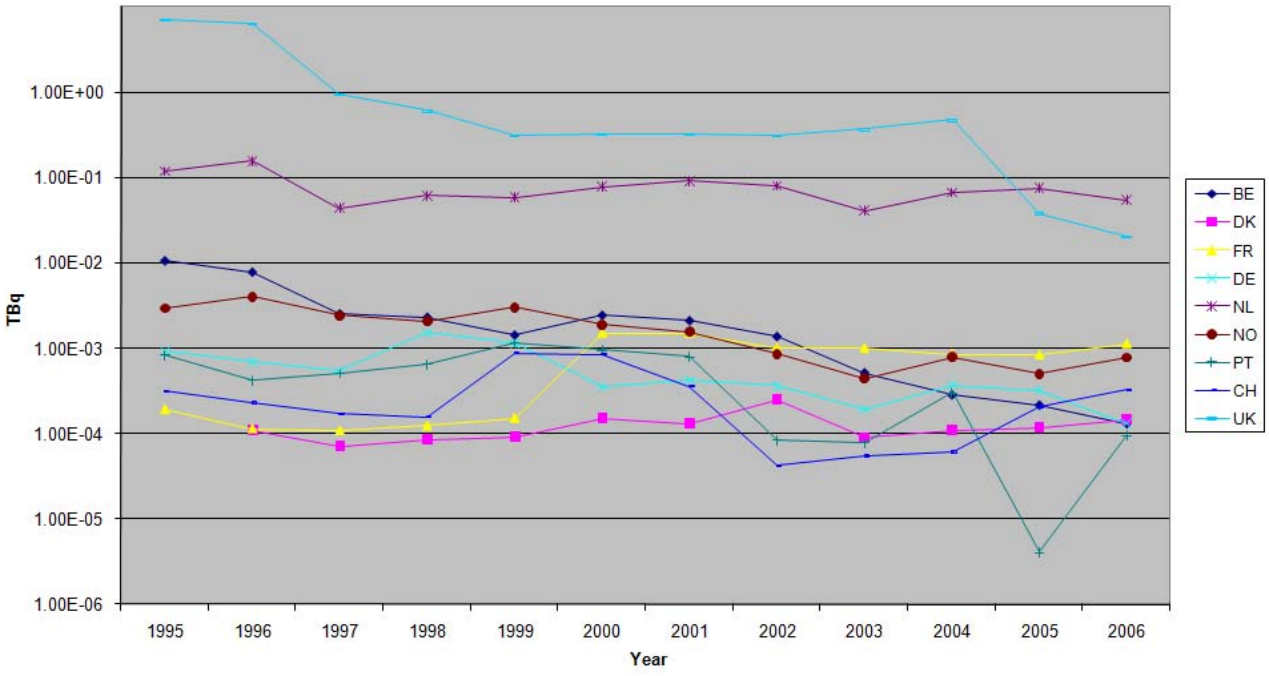
Table 2.9: *Discharges from the nuclear research sub-sector*

Year	Total-α (TBq)	Total-β (excluding H-3) (TBq)
1995	8.82E-02	7.17E+00
1996	7.31E-02	6.47E+00
1997	2.70E-02	1.00E+00
1998	1.36E-02	6.75E-01
1999	1.94E-03	3.81E-01
2000	1.89E-03	4.06E-01
2001	1.78E-03	4.21E-01
2002	2.45E-03	3.94E-01
2003	4.39E-03	4.12E-01
2004	1.13E-03	5.44E-01
2005	1.13E-03	1.16E-01
2006	6.83E-04	7.81E-02



A logarithmic scale has been used for the graph.

Figure 2.11: *Total-α discharges from the nuclear research sub-sector per country*



A logarithmic scale has been used for the graph.

Figure 2.12: *Total-β (excluding H-3) discharges from the nuclear research sub-sector per country*

***Table 2.10**: Summary table of data for nuclear research (Explanatory note on use of red type and **red bold type** is on page 27.)*

	Baseline average (TBq)	Baseline lower bracket (TBq)	Baseline upper bracket (TBq)	Assessment average (TBq)	Student's t Welch-Aspin probability	Mann-Whitney probability
Overall						
Total-α	2.97E-02	0	1.01E-01	1.96E-03	0.090	0.073
Total-β (excluding H-3)	2.36E+00	0	8.36E+00	3.09E-01	0.127	0.073
Belgium						
Total-β (excluding H-3)	4.20E-03	0	1.12E-02	5.03E-04	**0.034**	**0.003**
Denmark						
Total-β (excluding H-3)	1.06E-04	4.78E-05	1.64E-04	1.43E-04	0.285	0.329
France						
Total-α	1.65E-04	1.51E-04	1.79E-04	1.10E-04	**0.003**	**0.018**
Total-β (excluding H-3)	1.50E-03	1.50E-03	1.50E-03	9.64E-04	0.001	0.268
Germany						
Total-β (excluding H-3)	8.00E-04	0	1.64E-03	2.74E-04	**0.017**	**0.010**
The Netherlands						
Total-α	2.76E-06	0	7.91E-06	1.35E-05	0.335	0.343
Total-β (excluding H-3)	8.76E-02	9.07E-03	1.66E-01	6.37E-02	0.191	0.343
Norway						
Total-α	2.98E-06	0	1.43E-05	9.72E-08	0.235	0.268
Total-β (excluding H-3)	2.56E-03	9.15E-04	4.21E-03	6.76E-04	**0.001**	**0.003**
Portugal						
Total-β (excluding H-3)	7.67E-04	2.67E-04	1.27E-03	1.14E-04	**0.000**	**0.003**
Switzerland						
Total-α	1.06E-05	0	3.49E-05	4.05E-06	0.251	0.639
Total-β (excluding H-3)	4.21E-04	0	1.02E-03	1.38E-04	0.058	0.073
United Kingdom						
Total-α	2.95E-02	0	1.01E-01	1.83E-03	0.090	0.073
Total-β (excluding H-3)	2.26E+00	0	8.19E+00	2.42E-01	0.128	0.073

Table A4.4 in **Annex 4** shows the individual Contracting Party discharges from nuclear research facilities.

Table 2.10 shows that, for the nuclear research and development sub-sector, there have been reductions of 93% and 87% respectively in average discharge levels of total-α and total-β (excluding H-3) since the baseline period. However, since the lower baseline brackets are zero in both cases, no conclusions can be drawn from a simple comparison about the relevance of these reductions. Nor do the statistical tests suggest that the changes are significant.

There have been statistically significant changes (indicating reductions) in total-β (excluding H-3) discharges for Belgium, Germany, Norway and Portugal, and in total-α discharges for France.

2.7 The offshore oil and gas industry

2.7.1 Overall situation

Inputs of radioactive substances to the sea from the offshore oil and gas industry arise almost entirely from:

- produced water;
- descaling operations.

“Produced water” is the water that is extracted from oil and gas wells along with the oil and gas. Radioactivity in produced water arises from naturally occurring radionuclides in the U-238 and Th-232 decay chains – particularly the longer-lived radionuclides Pb-210, Po-210, Ra-226 and Ra-228. These radionuclides can occur in produced water either in solution or as fine mineral suspended solids.

“Scale” is deposited on the insides of pipes and tanks through which the oil or gas and produced water passes, as a result of the chemical reaction of barium with sulphate ions in sea water. Because of its chemical similarity to barium, radium is co-deposited in this scale. Periodic descaling is often necessary to prevent pipes and tanks becoming obstructed by the scale.

The level of radioactivity in both produced water and scale varies greatly between fields (both for oil and gas), due to the different geological histories of the reservoirs. There is also evidence of substantial variation over time in the levels of radioactivity (see the data given below for Norway). In addition, there are also variations as a result of operating practices:

- variation in the specific wells within a field that are on-stream at the time when samples are taken may produce variations in the level of radioactivity, since the pattern of “breakthrough” (that is, the extent to which seawater has penetrated into the reservoir) often varies between wells;
- changes in the use of scale inhibitors or dissolvers at the facility (including the use of scale removal chemicals injected into the well and in the treatment of oil after it has come up from the well), which can cause more or less radioactivity to pass into the produced water stream.

In both produced water and scale, the concentrations of radionuclides are very low. However, the volumes of produced water can be very large, resulting in substantial annual discharges. The volumes of produced water that are discharged also tend to increase substantially in the course of the productive life of an oil or gas well. Since many oil and gas fields in the North Sea are well advanced in their productive life, this is an important factor in determining radioactive discharges.

The number of oil and gas installations in the OSPAR maritime area capable of generating radioactive discharges has grown steadily since the beginning of the baseline period (see

Table A4.5 in **Annex 4**, which contains the number of offshore installations capable of discharging or emitting radionuclides to the OSPAR maritime area). However, some of this growth is only apparent, since there were changes in the definition of what constitutes a separate installation, leading to reclassifications and consequent increases in numbers, particularly between 1999 and 2000.

2.7.2 Discharges

OSPAR has begun collecting data for this sub-sector since 2005. Although it is not yet possible to develop a baseline, fairly comprehensive data have been reported for 2005 and 2006.

Measurements are made of the quantity of water discharged. From 1996 (the second year of the baseline period), OSPAR has collected and published data on the estimated average daily quantities of these discharges. From 1996 to 2001, the statistics covered only the totals of produced water and displacement water together[12]. Since 2002, figures for the annual totals of produced water discharges have also been collected separately, and so it has been possible to look specifically at the figures most relevant to the discharge of radioactive substances. Table A4.6 in **Annex 4** shows the daily water discharge rates of produced and displaced water for each Contracting Party from 1996 to 2006.

The differences between countries are caused mainly by the differences between oil and gas fields: gas fields result in very much less produced water than oil fields. However, different regulatory approaches also account for some of the differences.

Produced water

Produced water and displacement water have been of interest to OSPAR since the beginning of the Paris Commission in the 1970s, primarily because of the potential polluting effects of the hydrocarbon content. As the quantities of produced water and displacement water increased, these concerns over the hydrocarbon content also grew. In 2001, OSPAR therefore adopted Recommendation 2001/1 (OSPAR, 2001b), which committed Contracting Parties to achieve a 15% reduction in total discharges of oil in produced water between 2001 and 2006.

One of the methods of achieving this target has been to reduce the amount of the discharges into the sea, principally by re-injecting the water into the oil or gas reservoirs in the seabed, resulting in stabilisation of the amount of produced water and displacement water discharged. Table A4.7 shows the annual discharges of produced water.

Displacement water is not significant in the context of radioactive discharges, since it consists mainly of seawater used in storage installations.

Scale

Scale builds up gradually during the life of an installation and periodic descaling operations are often needed. However, the main impacts on radioactive discharges to the marine environment are likely to arise at the end of the life of offshore installations.

No OSPAR measures have been developed for dealing with descaling while installations are in service. However, OSPAR Decision 98/3 on the Disposal of Disused Offshore Installations requires an environmental assessment of the disposal options for a disused offshore installation which is not being entirely removed to land. This assessment must cover the substances within the installation, including radioactive scale.

12 Offshore oil and gas installations also discharge “displacement water”. This is sea-water which has been used as ballast in offshore storage tanks and similar installations. Since it has not been in sustained contact with oil and underground rock formations, it is not significant from the point of view of discharges of radioactive substances. However, it is significant for the discharge of hydrocarbons.

Except for Denmark and Norway, no substantial national regulatory measures have been adopted specifically for descaling operations and the disposal of scale during the life of an offshore installation.

No conclusions can therefore be reached on any changes in the amounts of radioactivity in scale being discharged to the OSPAR maritime area.

As mentioned above, no baseline component for the offshore oil and gas sub-sector can be constructed, since the relevant data have only been collated since 2005. Table 2.12 shows the discharge data (OSPAR, 2009b):

Table 2.12: *Discharges from the Oil and Gas sector*

Year	Total-α (TBq)	Total-β (excluding H-3) (TBq)
2005	6.4	4.25
2006	6.9	4.67

2.8 The medical sub-sector

2.8.1 Overall situation

RSC has gathered data on discharges from the medical sector since 2005. Contracting Parties have reported discharges of 1-131 and Tc-99 (calculated as a decay product of Tc-99m). However, RSC 2009 took the decision to cease reporting on Tc-99 from the medical sector, since its contribution is very small and is estimated to amount to approximately 1 MBq per year, in comparison with several TBq (*i.e.* several million times more) from nuclear fuel reprocessing.

Due to the limited amount of data available and the large uncertainties associated with it, as yet, the RSC is not publishing any data for the medical sector and is not able to make any assessment of discharges from this sub-sector.

2.9 General conclusions for discharges to the marine environment

For the nuclear sector:

- there has been a 38% reduction in total-β (excluding H-3) discharges since the baseline period and the statistical tests indicate that this is statistically significant;
- there has been a 15% increase in total-α discharges since the baseline period, but this is not statistically significant;
- since 2002, reductions have been achieved in discharges of Tc-99, a radionuclide to which both the 1998 and 2003 OSPAR Ministerial Meetings drew special attention; discharges of Tc-99 are expected to reduce further and be maintained at low levels.

For the non-nuclear sector:

- due to the limited data available, it was not possible to identify the contribution of discharges from non-nuclear industries, nor to run any statistical test to compare the concentrations in the assessment period to the baseline.

Overall:

- As the evaluation for the nuclear sector is based on data for only five years (2002 – 2006) and discharge data for the non-nuclear sector have only been reported since 2005, at present it is not possible to draw any general conclusions on whether the aims of the OSPAR Radioactive Substances Strategy are being delivered. However, there is evidence to suggest that progress is being made towards this objective for the nuclear sector, in particular through significant reductions in discharges of total-β (excluding H-3) and Tc-99.

In due course, the data on discharges may be examined using trend-detection techniques of the kind used in other fields by OSPAR. These evaluations will, where appropriate:

- consider levels for discharges, or groups of discharges, in specific areas or of specific types, thus enabling a view of the progress that is being made in the OSPAR maritime area as a whole;
- consider radionuclides, or groups of radionuclides, in addition to total-α, total-β (excluding H-3) and H-3 (and also be subject, in the case of H-3, to the further consideration to be given to the evaluation of this radionuclide);
- consider data on non-nuclear anthropogenic discharges of radioactive substances (to which the objective of the Strategy equally applies).

3 Marine concentrations

3.1 Introduction

This chapter examines progress made towards the objective of the Radioactive Substances Strategy concerning concentrations in the environment. It presents the approach used for establishing the baseline element for concentrations in the marine environment. It explains the environmental monitoring and data collection methods for both the baseline period and assessment period, and compares the data for the assessment period with the baseline values. It builds on existing information from monitoring data published by several Contracting Parties and includes further data on marine environmental concentrations submitted by several Contracting Parties. In addition, the results of the MARINA II study have been made available by the European Commission. It needs to be noted, however, that although discharges can, to some extent, be controlled, marine concentrations can not. Furthermore, the link between recent discharges and current marine concentrations is not straightforward.

3.2 Baseline element for seawater and biota concentrations

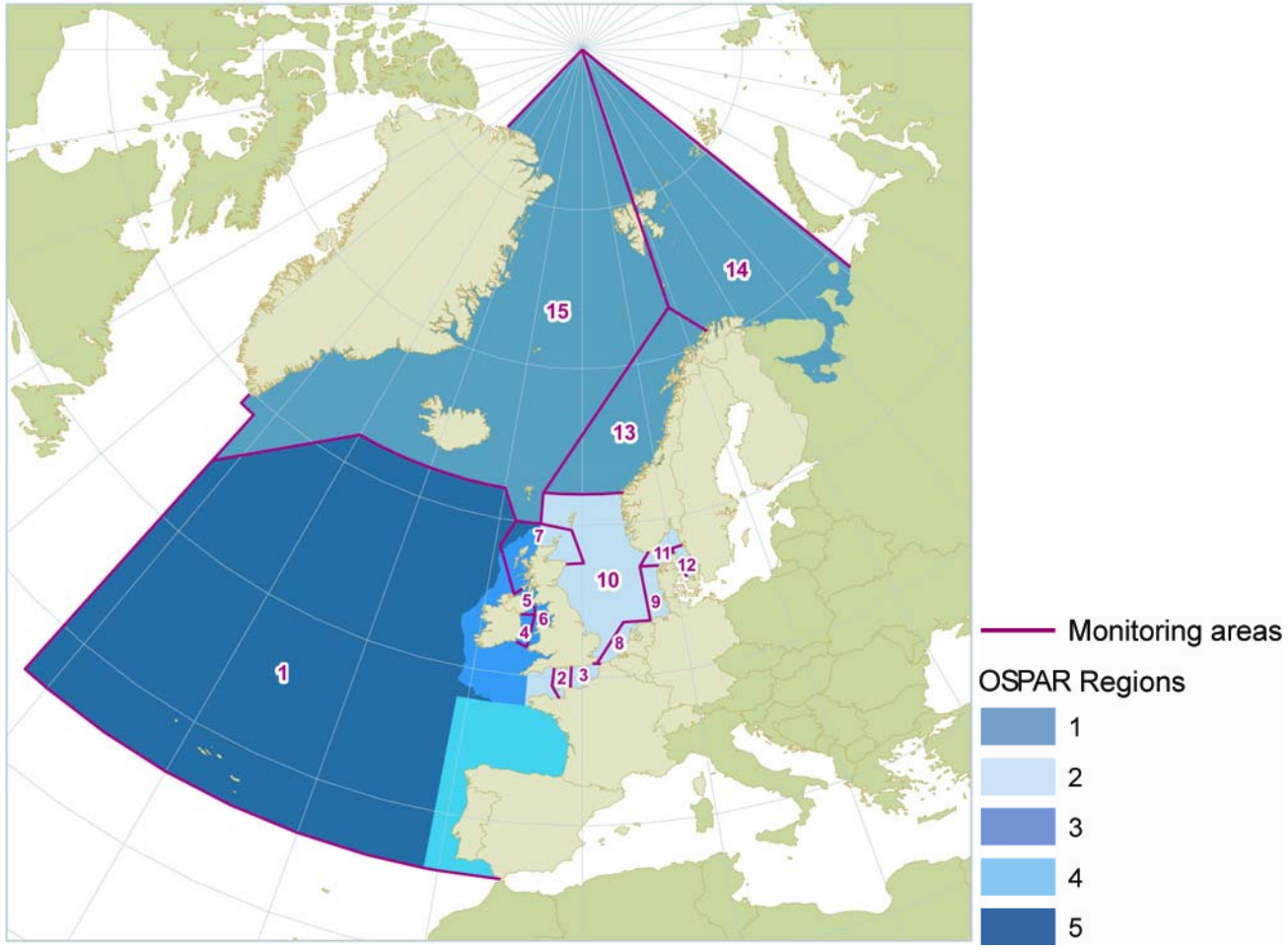
The 2003 Progress Report on the More Detailed Implementation of the OSPAR Strategy with regard to Radioactive Substances sets out the principles on which the baseline for the evaluation of concentrations of radioactive substances has been derived. It was essential that the baseline element for concentrations should mirror the arrangements made for monitoring concentrations in the marine environment. Arrangements were agreed by the OSPAR Commission in 2004 on appropriate monitoring areas, radionuclides and environmental compartments, which are embodied in OSPAR Agreement 2005/8.

The baseline period chosen is the same as for the baseline element for discharges (1995 – 2001). To establish the baseline element for concentrations, three aspects of the available information needed to be resolved.

The first step was to divide the OSPAR maritime area into 15 monitoring areas, taking into account prevailing currents and the areas used in the MARINA II study. Within these, areas have been identified where sufficient data are available to provide an agreed baseline element against which subsequent changes in marine concentrations (in both seawater and marine biota) have been assessed. The 15 monitoring areas generally represent subdivisions of the five regions of the OSPAR maritime area as set out in the 2000 and 2010 Quality Status Reports, although some of the boundaries do not coincide exactly (see Table 3.1).

Table 3.1: *Monitoring areas identified for the establishment of baseline values for concentrations of radioactive substances*

OSPAR Region	RSC monitoring area	Related MARINA II area
Regions III, IV, V	1. Wider Atlantic, Iberian Coast and Biscay and Channel West	8 – 10: (Atlantic North SE) 38 – 44: (Celtic Sea, Bristol Channel, Bay of Biscay, French Continental shelf, Cantabrian Sea, Portuguese Continental shelf, Gulf of Cadiz) 46: English Channel West; part of 47:, Channel Islands
Region II	2. Channel (Cap de la Hague)	48: Cap de la Hague; 49: Lyme Bay
Region II	3. Channel East	50 – 54: Baie de la Sein, Sam's Beach, Central Channel SE, Central Channel N.E., Isle of Wight, part of 47
Region III	4. Irish Sea (Rep. of Ireland)	33: Irish Sea West; 36 Irish Sea South
Region III	5. Irish Sea (Northern Ireland)	30: Irish Sea NW
Region III	6. Irish Sea (Sellafield)	31, 32, 33, 35, 37: Irish Sea N, Irish Sea NE, Irish Sea SE, Cumbrian Waters, Liverpool and Morecambe Bays
Regions II, III, V	7. Scottish waters (Dounreay)	28 – 29: Scottish Waters West and East
Region II	8. North Sea South (Belgian and Dutch Coast)	56: North Sea SE
Region II	9. German Bight	58: North Sea East
Regions I, II	10. North Sea (Northwest, Southeast and Central)	55, 57, 59: North Sea SW, North Sea Central, North Sea North
Region II	11. North Sea (Skagerrak)	60: Skagerrak
Region II	12. Kattegat	61/62: Kattegat
Region I	13. Norwegian Coastal Current	27: Norwegian Waters
Region I	14. Barents Sea	23 – 26: Barents Sea
Region I	15. Norwegian, Greenland Seas and Icelandic Waters	2 – 4: Atlantic North NE 16 – 19: Arctic Ocean and Spitsbergen



1. Wider Atlantic
2. Cap de la Hague Channel
3. Channel East
4. Irish Sea (Rep. of Ireland)
5. Irish Sea (Northern Ireland)
6. Irish Sea (Sellafield)
7. Scottish waters (Dounreay)
8. North Sea South (Belgian and Dutch coast)
9. German Bight
10. North Sea (NW, SE and Central)
11. North Sea (Skagerrak)
12. Kattegat
13. Norwegian Coastal Current
14. Barents Sea
15. Norwegian, Greenland Seas and Icelandic waters

Figure 3.1: *RSC monitoring areas identified for the establishment of baselines on concentrations of radioactive substances*

The second step was to identify in each RSC monitoring area the radionuclides for which information was available and to select those on which it was appropriate to concentrate. These radionuclides have been selected as H-3, Tc-99, Cs-137 and Pu-239,240. The third step was to identify the environmental compartments which should be monitored. Although the need was identified for establishing baseline values for, as far as possible, seawater, sediment and biota, sediments were not generally considered useful for this purpose. The concentration data depend heavily on the nature and properties of the sediment, so it is difficult and unreasonable to draw conclusions about sediment sampled at different locations. It is therefore sufficient to derive baseline values for each radionuclide in seawater and in one type of biota.

For biota, data generally relate to coastal measurements with the exception of certain monitoring results in fish. H-3 is not considered relevant for biota because there is no evidence for any bioaccumulation of H-3 by marine biota (with the exception of organic H-3 compounds). Where biota (seaweed, fish and molluscs) concentration data has been reported as dry weight, a conversion factor of 5 has been used to calculate concentration data as wet weight.

Baseline values were calculated as mean values of available annual mean concentrations from the baseline period and presented with their respective standard deviations; the raw data for each of the monitoring areas can be found in Tables A4.8 and A4.9 in **Annex 4**. A comparison of the assessment period (2002 to 2006) was made against the baseline using the methods indicated in **Annex 1**. It is worth noting that the 'Baseline Average' and 'Assessment Average' values have been calculated by substituting values below the detection limit with the detection limit values. Probability data from the two statistical tests have, however, been obtained from datasets processed with Helsel (2005) methods (see **Annex 1**) to estimate the annual means.

The available data have allowed baseline components to be calculated for some aspects of concentrations of radioactive substances, both in seawater and in biota (fish, shellfish, and seaweed), although baseline values could not be derived for all monitoring areas, radionuclides and selected biota. The resulting baseline-element values are provided in Tables 3.2 and 3.3.

3.3 Regional conclusions

Identical methods for environmental monitoring were used during the assessment period as were employed during the baseline period. The conclusions in this section are based on those datasets where sufficient data are available for both the baseline and assessment periods. Tables 3.2 and 3.3 show the statistical analysis of the concentration data in seawater and biota during the assessment period, as compared with the baseline period. Figures 3.3 and 3.4 illustrate graphically each incidence of a statistically significant change, in seawater and biota data respectively.

In interpreting these results, the following comments and limitations should be borne in mind:

- **representativeness of data:** in dividing the OSPAR maritime area geographically, compromises had to be made between the number of RSC monitoring areas and the monitoring data which were available to use. Too few monitoring areas could have meant large ranges on the baseline-element values. Too many monitoring areas could have meant that a lot of them did not have any monitoring data. The baseline-element values were sometimes based on coastal monitoring results from within a small area, and at other times from much larger marine areas, depending on the available data. In applying the baseline element in future, this will need to be taken into account;
- **differences in the size of data sets***:* some calculated values were based on long-term regular monitoring programmes, while other values have been derived from short-term, or

single, monitoring-campaigns. Some values were based on individual results within a year, whereas others were based on average annual values which may have been derived from several samples in a year;

- **monitoring results below detection limits:** some values were calculated from samples where the value was less than the limit of detection by the analytical methods available. In such cases, the assumption had to be made that the value was equal to the limit of detection. In these cases, the "true" values for the baseline-element values may well be less than the values given, but there is no way of knowing this, based on the information available. If average values have been computed with detection limits, in the cases where most or all raw data is below detection limits, no statistical tools have been displayed, and those values are clearly identified in the tables. Where up to 80% of the values have been below the detection limits, the Helsel method has been applied (see **Annex 1** for more information).

3.3.1 Summary of data for concentrations from seawater

Table 3.2: *Data measures for concentrations from seawater*

Key to the table:

- Baseline seawater value in '<' + *italic* denotes that all measurements on which the value has been based were below the detection limit.
- Baseline seawater value in '<' + ***bold italic*** denotes that some/most measurements on which the value has been based were below detection limit.
- Dash: Standard deviation not calculated because baseline seawater value has been based on all or some/most measurements below detection limit.

Explanatory note on use of red type and **red bold type** is on page 27.

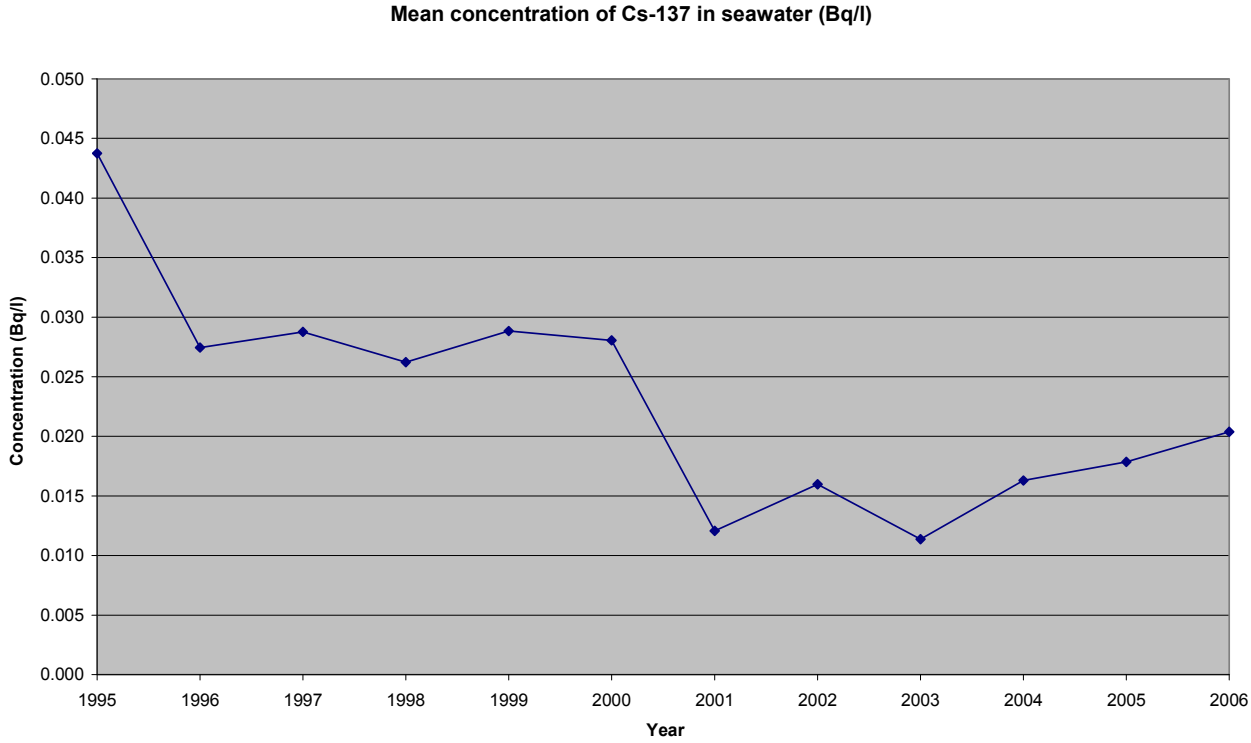
RSC monitoring area	Radionuclide	Baseline average (Bq/l)	Baseline lower bracket (Bq/l)	Baseline upper bracket (Bq/l)	Assessment average (Bq/l)	Student's t Welch-Aspin probability	Mann-Whitney probability
1	H-3	***<2.83E+00***	-	-	***<2.60E+00***	0.155	0.030
	Cs-137	*<1.54E-01*	-	-	***<7.54E-02***	-	-
	Tc-99	-	-	-	*<8.67E-04*	-	-
2	H-3	***<1.36E+01***	-	-	***<1.18E+01***	0.055	0.036
	Cs-137	***<3.03E-02***	-	-	***<2.49E-02***	-	-
3	H-3	*<1.03E+01*	-	-	***<1.03E+01***	-	-
	Cs-137	*<3.44E-02*	-	-	*<2.65E-02*	-	-
4	Cs-137	2.79E-02	9.87E-03	4.59E-02	1.64E-02	**0.016**	**0.030**
	Tc-99	2.32E-02	5.34E-03	4.10E-02	1.58E-02	0.092	0.030
5	Cs-137	2.81E-02	9.78E-03	4.64E-02	1.75E-02	**0.024**	**0.048**

RSC monitoring area	Radionuclide	Baseline average (Bq/l)	Baseline lower bracket (Bq/l)	Baseline upper bracket (Bq/l)	Assessment average (Bq/l)	Student's t Welch-Aspin probability	Mann-Whitney probability
6	H-3	***<1.50E+01***	-	-	***<1.46E+01***	0.894	0.876
	Cs-137	1.75E-01	9.78E-02	2.52E-01	1.02E-01	**0.005**	**0.010**
	Tc-99	3.57E-01	0	1.02E+00	1.42E-01	0.154	0.073
7	H-3	***<1.65E+00***	-	-	***<1.31E+00***	-	-
	Cs-137	***<5.35E-02***	-	-	***<8.72E-02***	-	-
8	H-3	4.07E+00	2.65E+00	5.48E+00	4.65E+00	0.278	0.255
	Cs-137	4.32E-03	2.27E-03	6.36E-03	***9.73E-02***	-	-
	Pu-239,240	1.31E-05	7.49E-06	1.88E-05	***3.51E-04***	-	-
9	H-3	2.93E+00	1.21E+00	4.64E+00	***4.17E+00***	0.052	0.044
	Cs-137	5.38E-03	1.42E-03	9.34E-03	2.94E-03	**0.018**	**0.010**
	Tc-99	1.67E-03	0	4.03E-03	-	-	-
	Pu-239,240	1.14E-05	2.15E-06	2.07E-05	8.10E-06	0.247	0.286
10	H-3	***<8.45E-01***	-	-	***<1.73E+00***	0.038	0.063
	Cs-137	7.29E-03	8.68E-04	1.37E-02	4.29E-03	0.164	0.063
	Tc-99	2.78E-03	1.34E-03	4.22E-03	-	-	-
	Pu-239,240	1.62E-05	0	5.18E-05	1.45E-05	0.922	1

RSC monitoring area	Radionuclide	Baseline average (Bq/l)	Baseline lower bracket (Bq/l)	Baseline upper bracket (Bq/l)	Assessment average (Bq/l)	Student's t Welch-Aspin probability	Mann-Whitney probability
11	Cs 137	1.46E-02	0	3.09E-02	6.50E-03	0.145	0.114
	Tc-99	2.24E-03	0	6.33E-03	1.37E-03	0.409	0.691
	Pu-239,240	3.83E-06	1.47E-06	6.18E-06	5.72E-06	0.247	0.400
12	H-3	-	-	-	***<2.62E+00***	-	-
	Cs-137	3.03E-02	9.56E-03	5.10E-02	***<4.64E-02***	0.064	0.048
	Tc-99	1.33E-03	4.33E-04	2.22E-03	5.13E-04	**0.036**	**0.016**
13	Cs-137	4.82E-03	4.51E-03	5.13E-03	3.03E-03	0.009	0.095
	Tc-99	1.10E-03	4.31E-04	1.77E-03	8.28E-04	0.156	0.222
	Pu-239,240	6.55E-06	2.25E-06	1.08E-05	5.62E-06	0.663	0.533
14	Cs-137	3.51E-03	-	-	2.65E-03	-	-
	Tc-99	6.96E-04	0	1.72E-03	3.23E-04	0.343	0.571
	Pu-239,240	7.23E-06	4.20E-06	1.03E-05	6.08E-06	0.473	0.533
15	Cs-137	4.49E-03	2.61E-03	6.37E-03	2.73E-03	**0.002**	**0.005**
	Tc-99	-	-	-	1.08E-04	-	-
	Pu-239,240	6.56E-06	4.40E-06	8.72E-06	5.79E-06	0.742	0.700

Table 3.2 shows that, for seawater concentrations, in 6 out of 27 datasets there has been a statistically significant change (*i.e.* both the Student's t Welch Aspin and Mann-Whitney test probabilities are below 0.05), with the average concentrations in the assessment period being lower than the baseline values. For a further 7 datasets, there is some evidence indicating change (*i.e.* either the Student's t Welch Aspin or Mann-Whitney test probability is below 0.05), with 4 instances where the assessment period average is lower than the baseline value and 3 instances where it is higher. In these latter cases, the apparent increases in concentrations may be artefacts resulting from changes in the limits of detection used, since the relevant datasets all contain some values for the assessment period average which are derived from values below limits of detection.

Monitoring area 4



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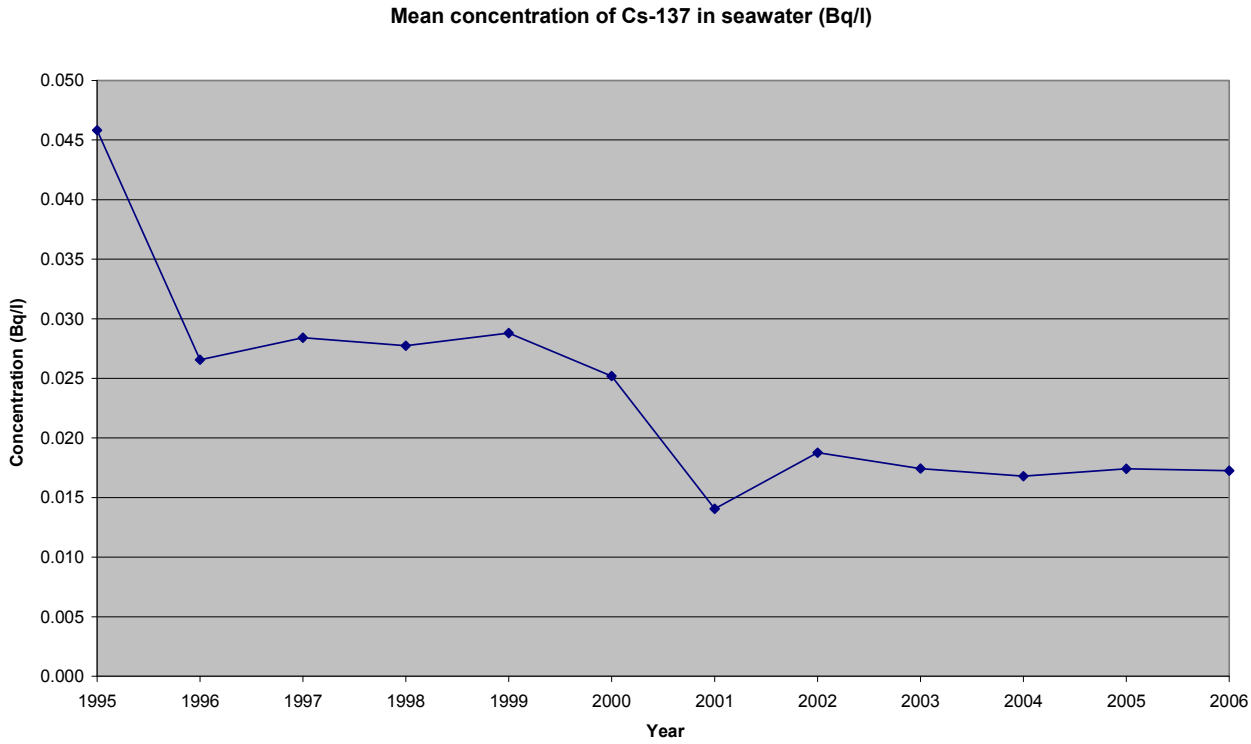

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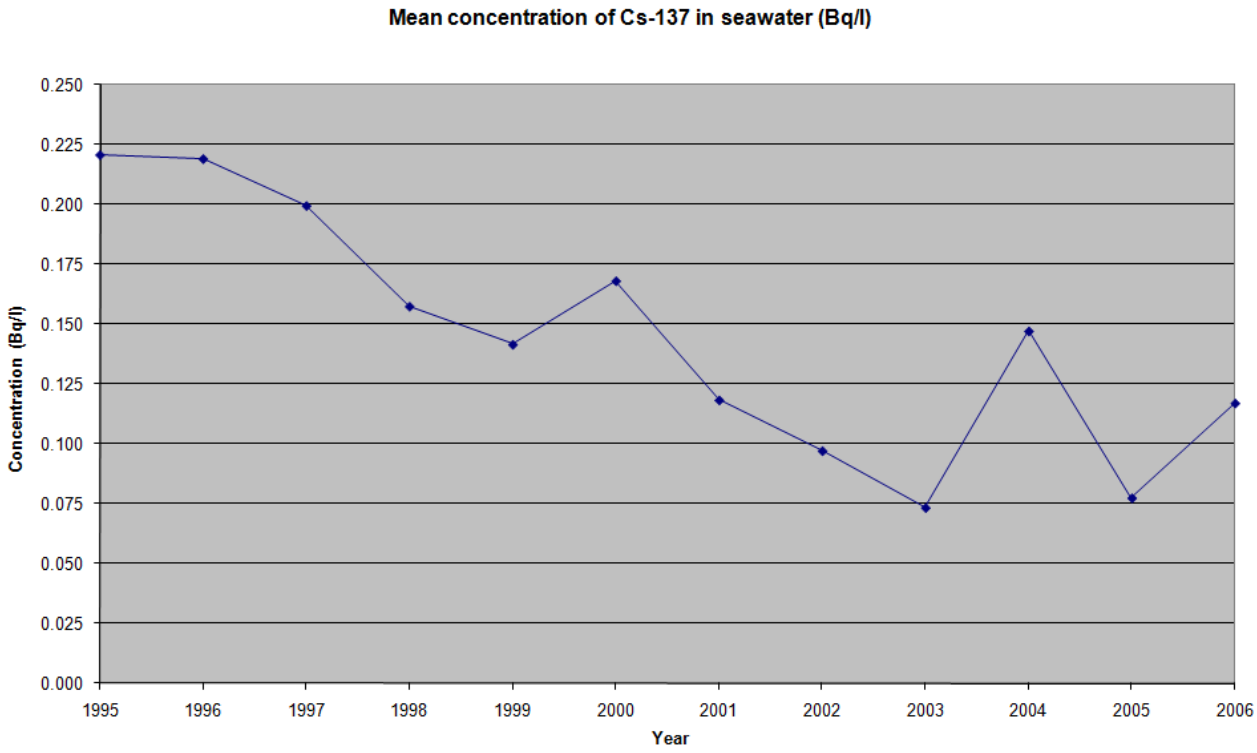

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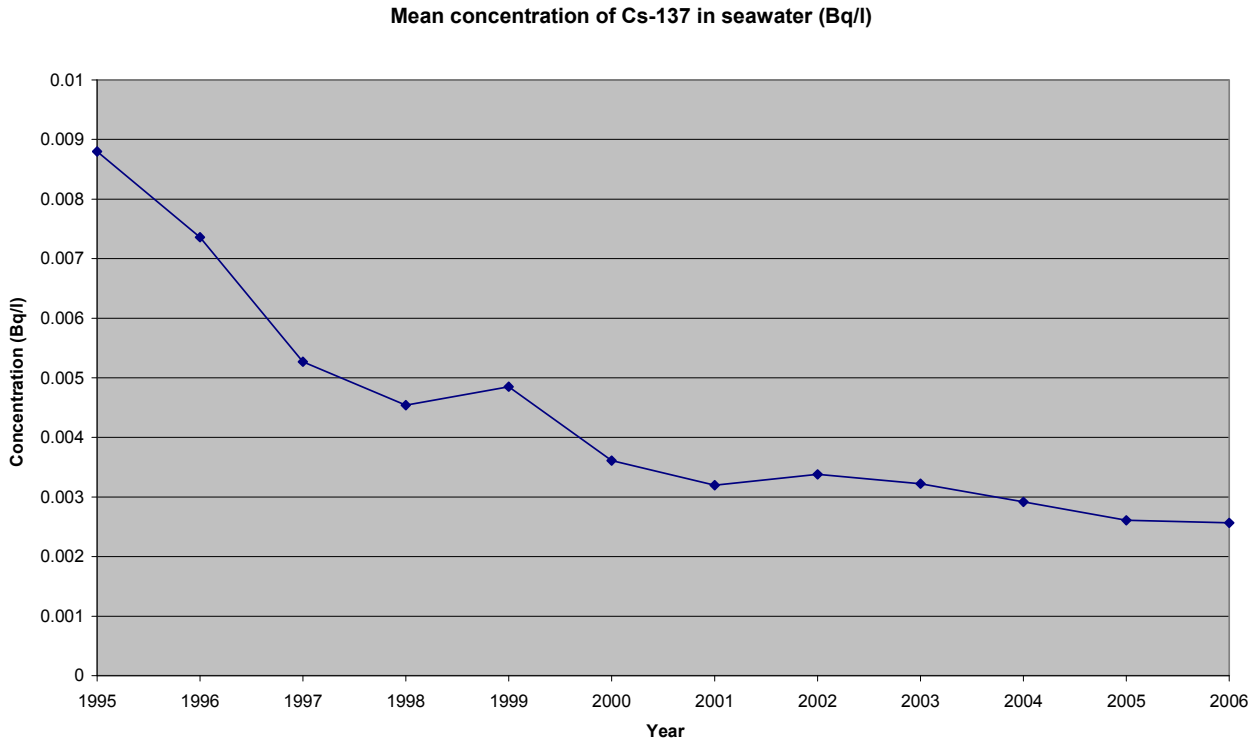
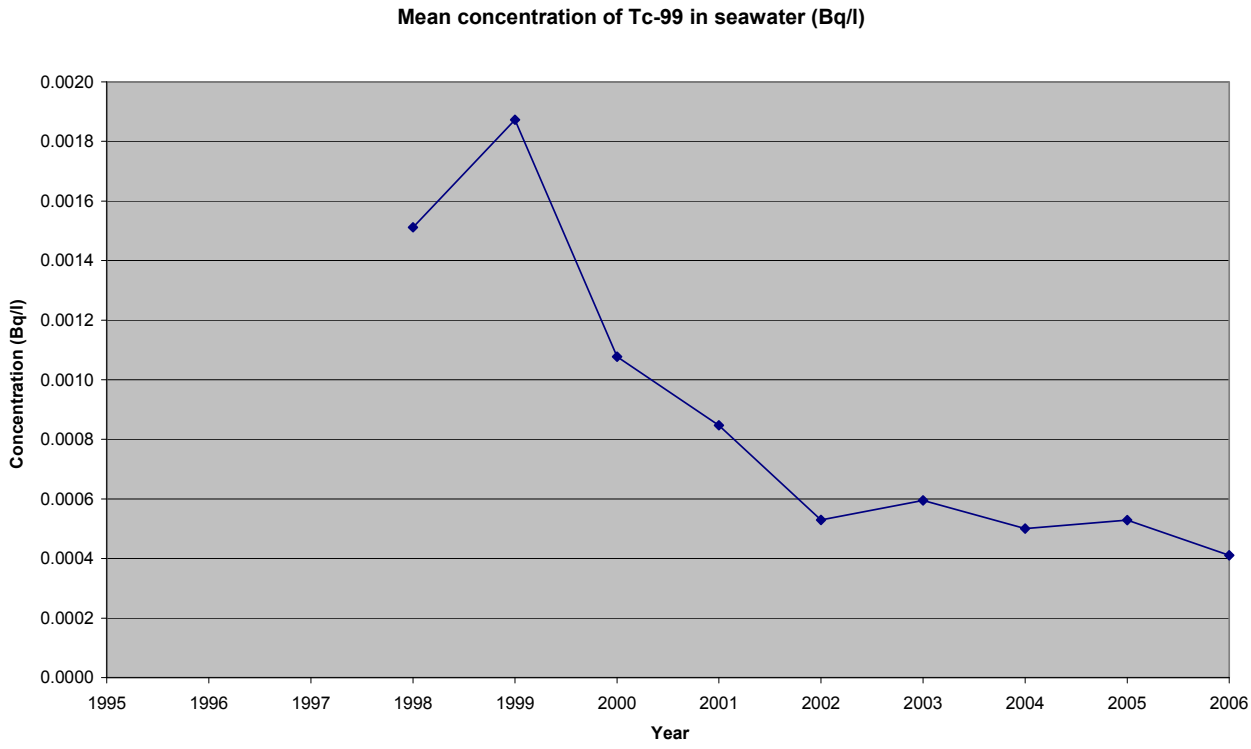


Monitoring area 12



Monitoring area 15

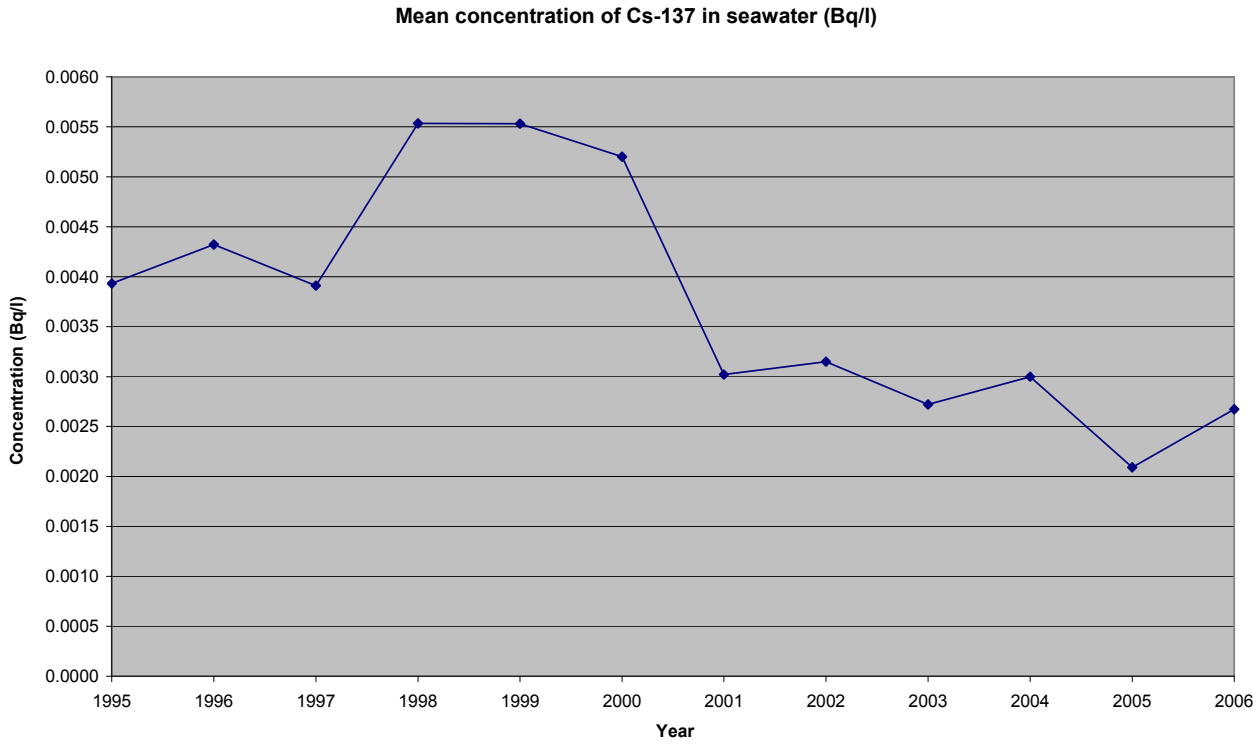


Figure 3.3: *Graphs showing statistically significant changes in concentrations of radionuclides in seawater*

3.3.2 Summary table of data for concentrations from biota

***Table 3.3**: Data measures for concentrations from biota*

Key to the table:

Baseline biota value in '<' + *italic* denotes that all measurements on which the value has been based were below the detection limit.

Baseline biota value in '<' + ***bold italic*** denotes that some/most measurements on which the value has been based were below detection limit.

Dash: Standard deviation not calculated because baseline biota value has been based on all or some/most measurements below detection limit.

*(Explanatory note on use of red type and **red bold type** is on page 27.)*

Monitoring area	Biota	Radionuclide	Baseline Average (Bq/kg w.w.)	Baseline Lower Bracket (Bq/kg w.w.)	Baseline Upper Bracket (Bq/kg w.w.)	Assessment Average (Bq/kg w.w.)	Student's t Welch-Aspin Probability	Mann-Whitney Probability
1	Fish	Cs-137	-	-	-	2.77E-01	-	-
	Seaweed	Cs-137	***<9.00E-02***	-	-	***<6.00E-02***	0.100	0.048
	Seaweed	Tc-99	-	-	-	1.86E+00	-	-
2	Molluscs	Pu-239,240	1.69E-02	1.12E-02	2.26E-02	***<1.10E-02***	**0.001**	**0.01**
	Seaweed	Cs-137	***<2.00E-01***	-	-	***<1.23E-01***	**0.023**	**0.01**
	Seaweed	Tc-99	9.11E+00	4.08E+00	1.41E+01	3.48E+00	**0.001**	**0.003**
3	Fish	Pu-239,240	***<4.59E-05***	-	-	-	-	-
	Seaweed	Cs-137	***<1.40E-01***	-	-	***<1.77E-01***	0.089	0.03
	Seaweed	Tc-99	7.29E+00	5.32E+00	9.26E+00	***<4.81E+00***	**0.011**	**0.003**

Monitoring area	Biota	Radionuclide	Baseline Average (Bq/kg w.w.)	Baseline Lower Bracket (Bq/kg w.w.)	Baseline Upper Bracket (Bq/kg w.w.)	Assessment Average (Bq/kg w.w.)	Student's t Welch-Aspin Probability	Mann-Whitney Probability
4	Molluscs	Pu-239,240	1.89E-01	5.73E-02	3.20E-01	3.63E-02	**0.001**	**0.006**
	Seaweed	Cs-137	9.40E-01	5.97E-01	1.28E+00	6.53E-01	**0.005**	**0.01**
	Seaweed	Tc-99	6.66E+02	2.43E+02	1.09E+03	3.91E+02	**0.022**	**0.018**
5	Fish	Cs-137	2.66E+00	1.75E+00	3.58E+00	***<1.87E+00***	**0.036**	**0.048**
	Molluscs	Pu-239,240	1.73E-01	1.23E-01	2.22E-01	1.96E-01	0.649	0.432
	Seaweed	Tc-99	2.87E+02	8.57E+01	4.89E+02	3.07E+02	0.787	1
6	Molluscs	Cs-137	6.11E+00	3.02E+00	9.20E+00	3.76E+00	**0.007**	**0.003**
		Pu-239,240	1.04E+01	7.52E+00	1.32E+01	9.20E+00	0.167	0.432
	Seaweed	Tc-99	9.26E+03	0	1.97E+04	3.73E+03	0.041	0.149
7	Molluscs	Pu-239,240	2.31E-01	0	5.13E-01	8.78E-02	**0.04**	**0.018**
	Seaweed	Cs-137	6.40E-01	0	1.39E+00	***<2.07E-01***	**0.027**	**0.003**
	Seaweed	Tc-99	2.87E+02	1.30E+02	4.44E+02	1.71E+02	**0.013**	**0.018**
8	Fish	Cs-137	5.10E-01	2.32E-01	7.89E-01	***<1.69E-01***	**0**	**0.008**
		Pu-239,240	***<2.13E-02***	-	-	***<2.52E-02***	-	-
	Molluscs	Pu-239,240	***<4.42E-02***	-	-	***<1.72E-01***	-	-

Monitoring area	Biota	Radionuclide	Baseline Average (Bq/kg w.w.)	Baseline Lower Bracket (Bq/kg w.w.)	Baseline Upper Bracket (Bq/kg w.w.)	Assessment Average (Bq/kg w.w.)	Student's t Welch-Aspin Probability	Mann-Whitney Probability
9	Fish	Cs-137	4.25E-01	1.12E-01	7.39E-01	2.19E-01	**0.017**	**0.03**
		Pu 239/240	***<3.24E-05***	-	-	4.06E-05	-	-
10	Fish	Cs-137	6.47E-01	2.17E-01	1.08E+00	3.69E-01	**0.021**	**0.03**
	Molluscs	Pu-239,240	5.67E-02	4.30E-02	7.04E-02	7.18E-02	0.02	0.063
	Seaweed	Tc-99	3.90E+01	7.58E+00	7.04E+01	4.28E+01	0.729	0.876
11	Seaweed	Cs-137	6.40E-01	3.84E-02	1.25E+00	5.09E-01	0.46	0.556
	Seaweed	Tc-99	5.20E+01	6.05E+00	9.79E+01	3.11E+01	0.421	0.191
12	Fish	Cs-137	2.95E+00	2.07E+00	3.83E+00	5.83E+00	**0.001**	**0.003**
	Seaweed	Cs-137	1.71E+00	1.16E+00	2.26E+00	1.25E+00	**0.004**	**0.003**
	Seaweed	Tc-99	1.88E+01	0	3.90E+01	2.41E+01	0.224	0.315
13	Seaweed	Cs-137	1.20E-01	3.68E-02	1.99E-01	1.20E-01	0.953	0.548
	Seaweed	Tc-99	4.37E+01	1.94E+00	8.54E+01	3.87E+01	0.634	0.691
14	Fish	Cs-137	2.92E-01	2.18E-01	3.67E-01	2.37E-01	0.111	0.114
15	Fish	Cs-137	1.43E-01	1.15E-01	1.71E-01	1.41E-01	0.893	0.931
	Seaweed	Cs-137	4.50E-02	3.89E-02	5.20E-02	***<4.10E-02***	**0.001**	**0.005**
	Seaweed	Tc-99	7.90E-01	2.45E+00	5.55E+00	7.19E-01	0.785	0.556

Table 3.3 shows that, for concentrations in marine biota, there are eighteen instances of statistically significant changes in marine biota concentrations. In seventeen of these cases the average concentration in the assessment period was lower than the baseline and for one instance it was higher (Cs-137 in fish in monitoring area 12). The levels of Cs-137 in fish and sediments in the Kattegat region are mainly as a result of the Chernobyl accident. The levels tend to vary in the region as a result of different reasons such as the weather conditions. There does not appear to be a connection between the releases from Ringhals nuclear power plant and the concentration of Cs-137 in fish. A possible explanation is the redistribution of Cs-137 between the deposits on land and to the sea and into the seawater, sediments and fish.

In addition, there is some evidence of change in four datasets, with two instances where the assessment period average is above the baseline value and two instances where it is above (Cs-137 in seaweed in monitoring area 3 and Pu-239,240 in molluscs in monitoring area 10). For the latter, there does not appear to be a connection with discharges from nuclear installations in the vicinity of the monitoring site. A possible explanation is the remobilisation of plutonium from the Irish Sea (see case study 5).

A graphical summary of the statistically significant changes can be found in Figure 3.4.

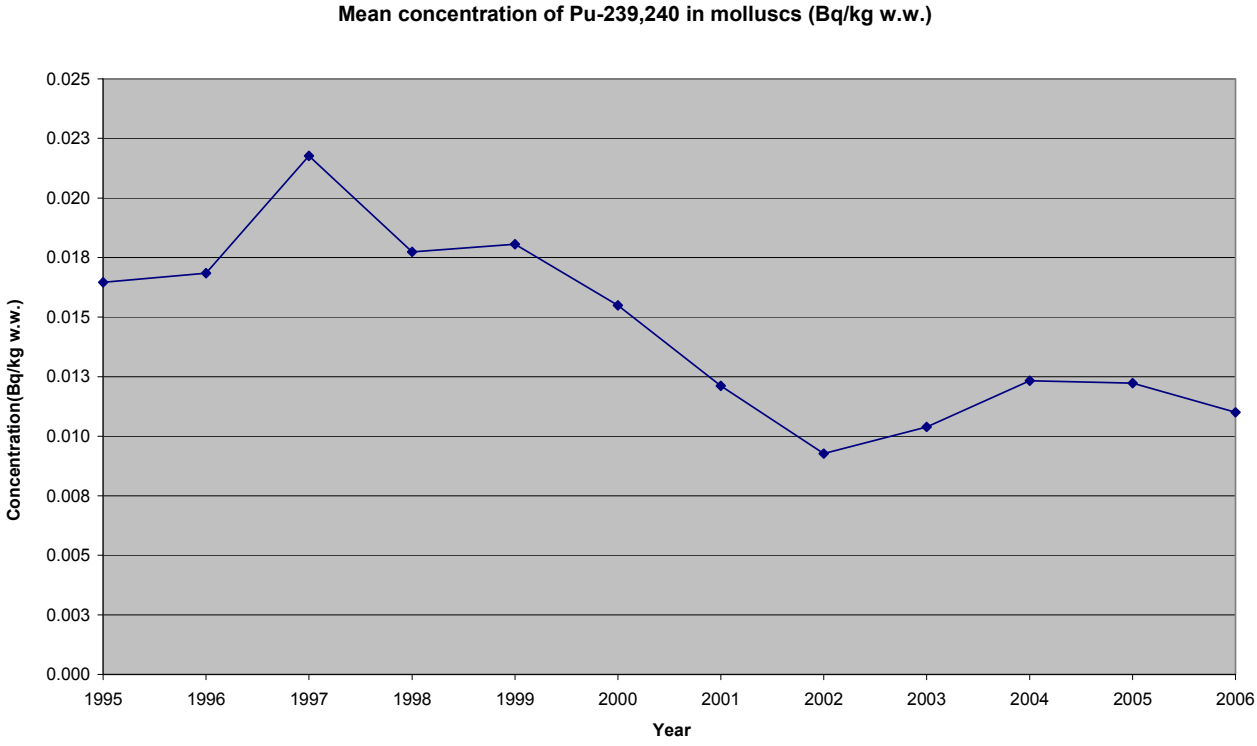
Case Study 5

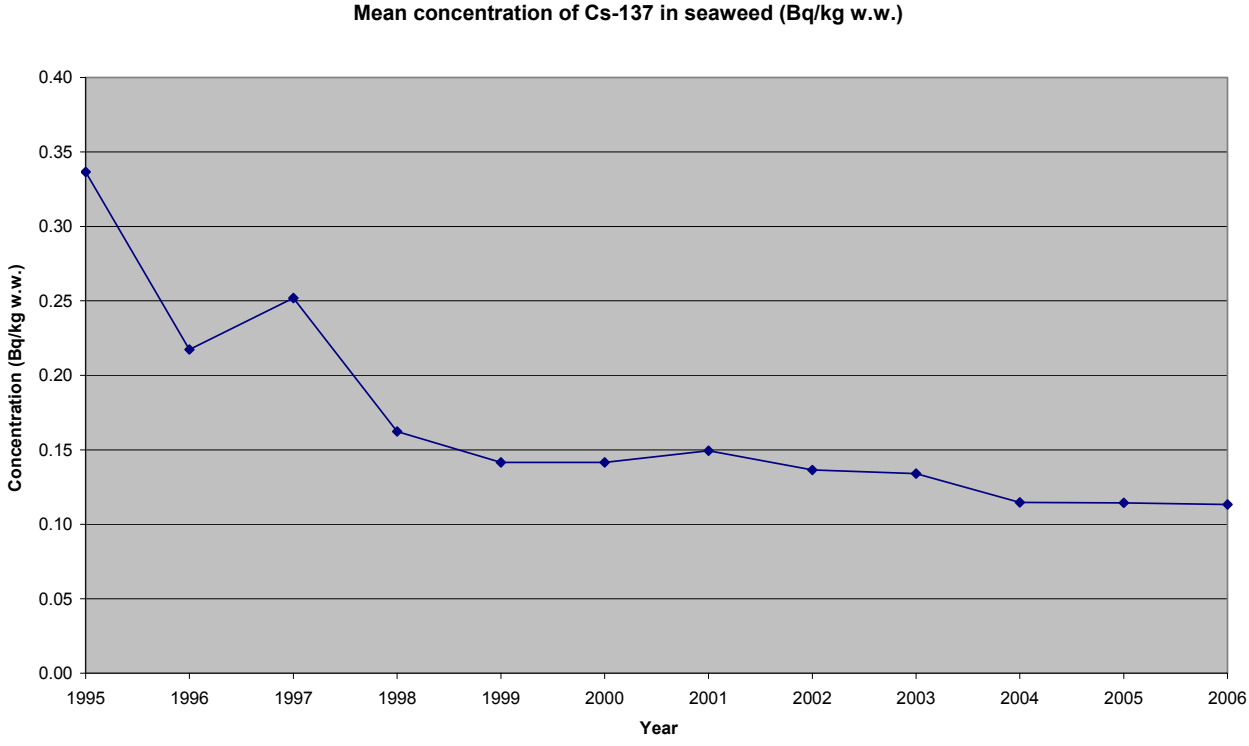
The OSPAR Radioactive Substances Strategy sets objectives in terms of discharges of radioactive substances and their resulting concentrations in the marine environment. The Second Periodic Evaluation of Progress noted some limitations in the interpretation of concentrations of H-3, Tc-99, Cs-137 and Pu-239,240 in the marine environment. Some of these limitations lead to problems when one attempts to link current authorised discharges with observed concentrations of radionuclides in the marine environment. See Annex 2 for more information.

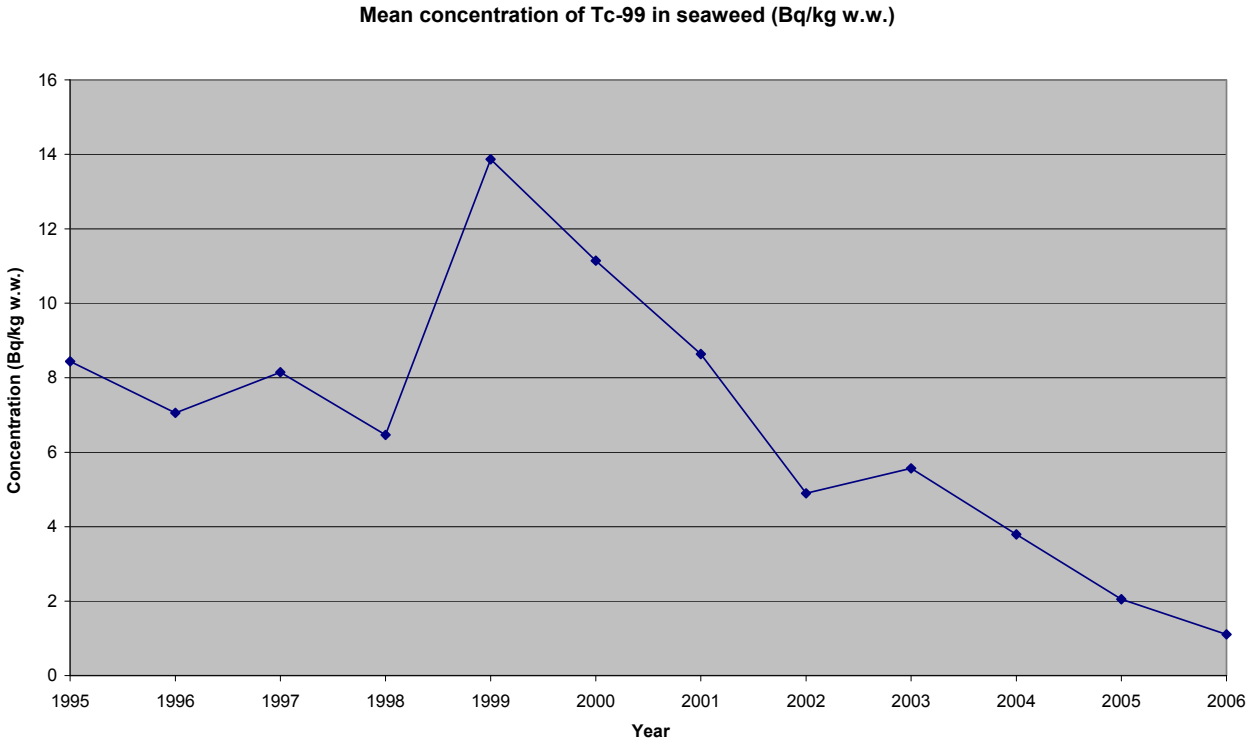
Case Study 6

The German Federal Maritime and Hydrographic Agency carried out a study between 2005 to 2009, to establish the geographical distribution of various artificial radionuclides in the North Sea and adjacent sea areas. The distributions of Sr-90, Cs-137, H-3, Tc-99 and I-129 were mapped. Iodine has only one stable isotope, I-127, which was used as a reference value for I-129 concentrations. These data supplement those reported by OSPAR Contracting Parties and demonstrate how concentrations of the measured radionuclides are distributed in the North Sea and their patterns of transport. See Annex 2 for more information.

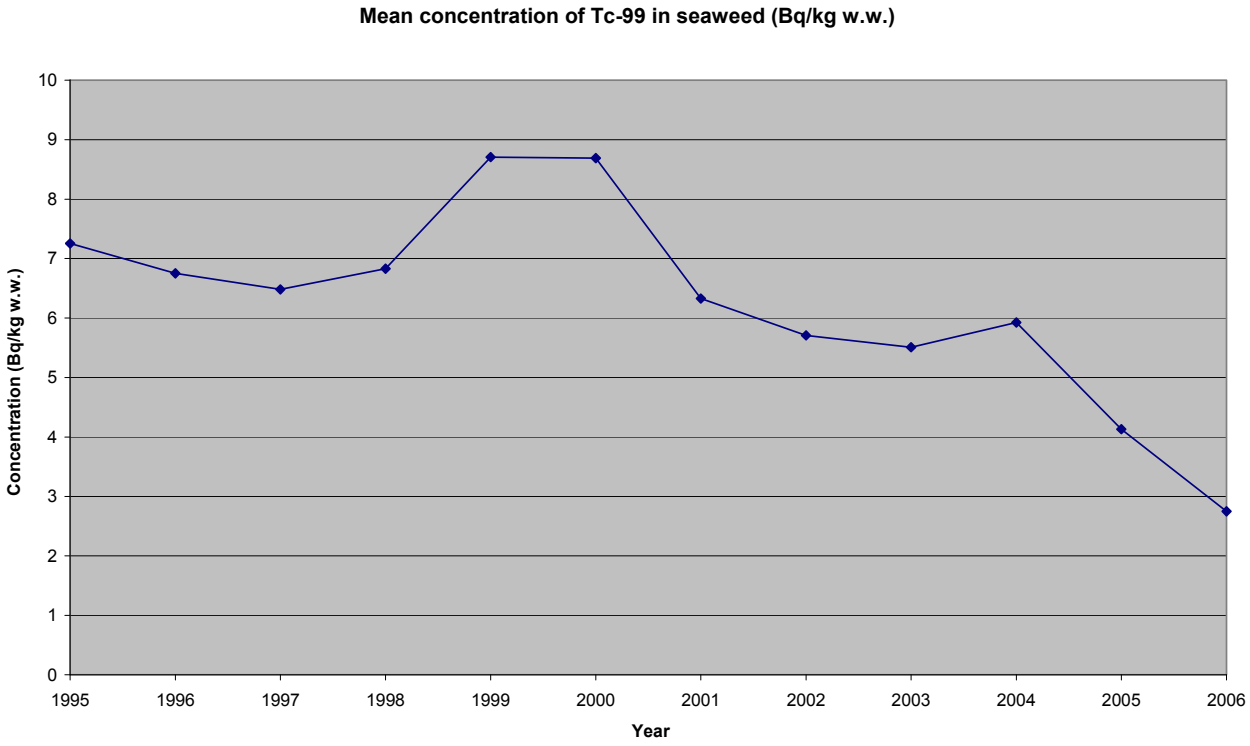
Monitoring area 2



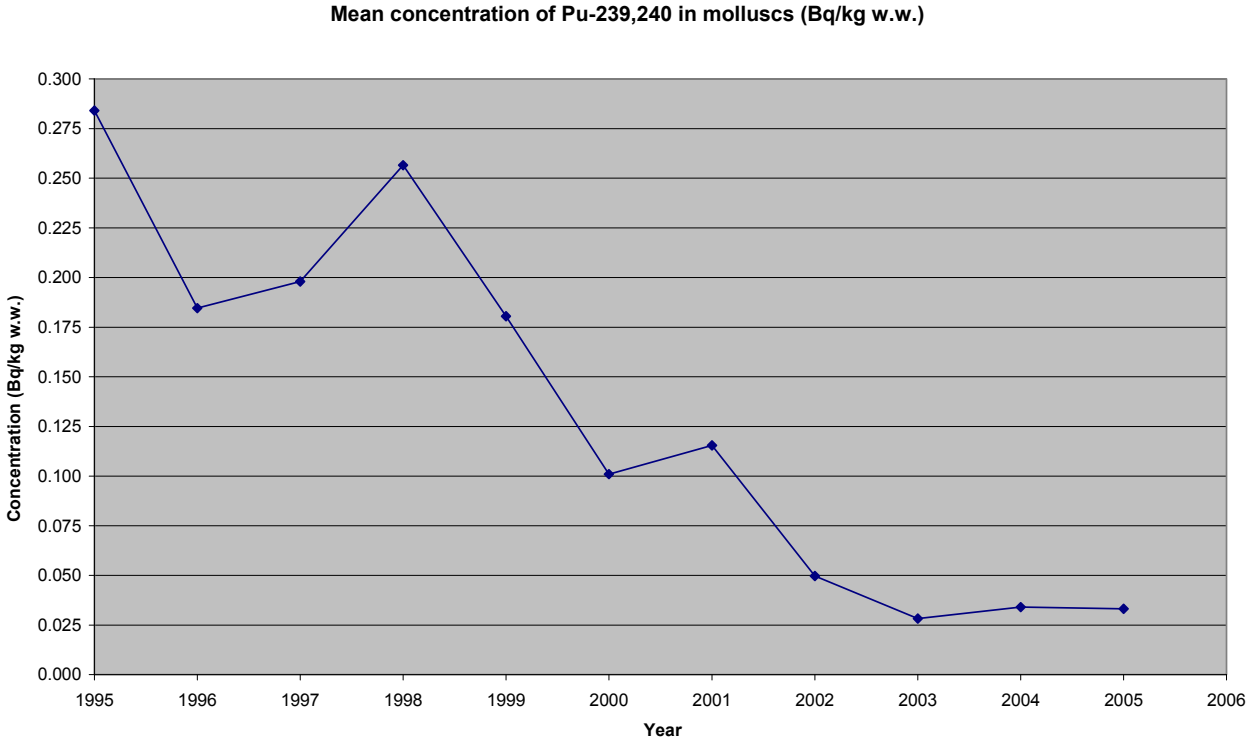


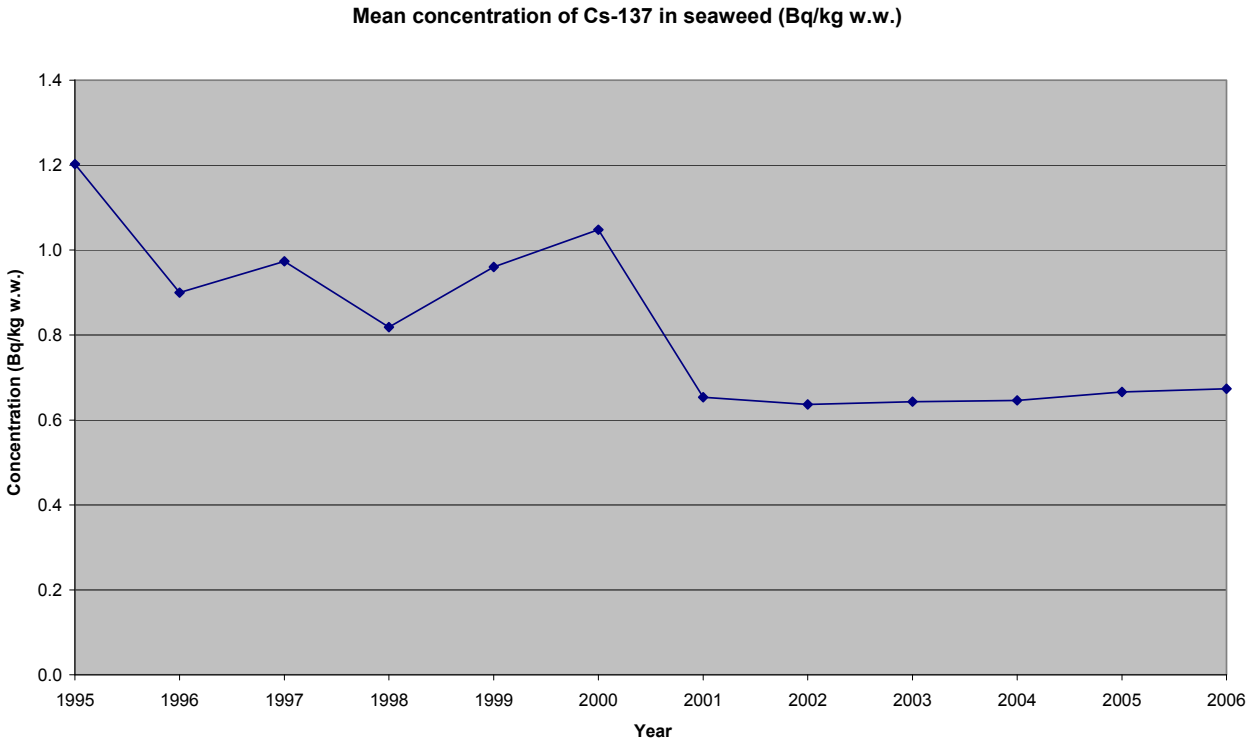


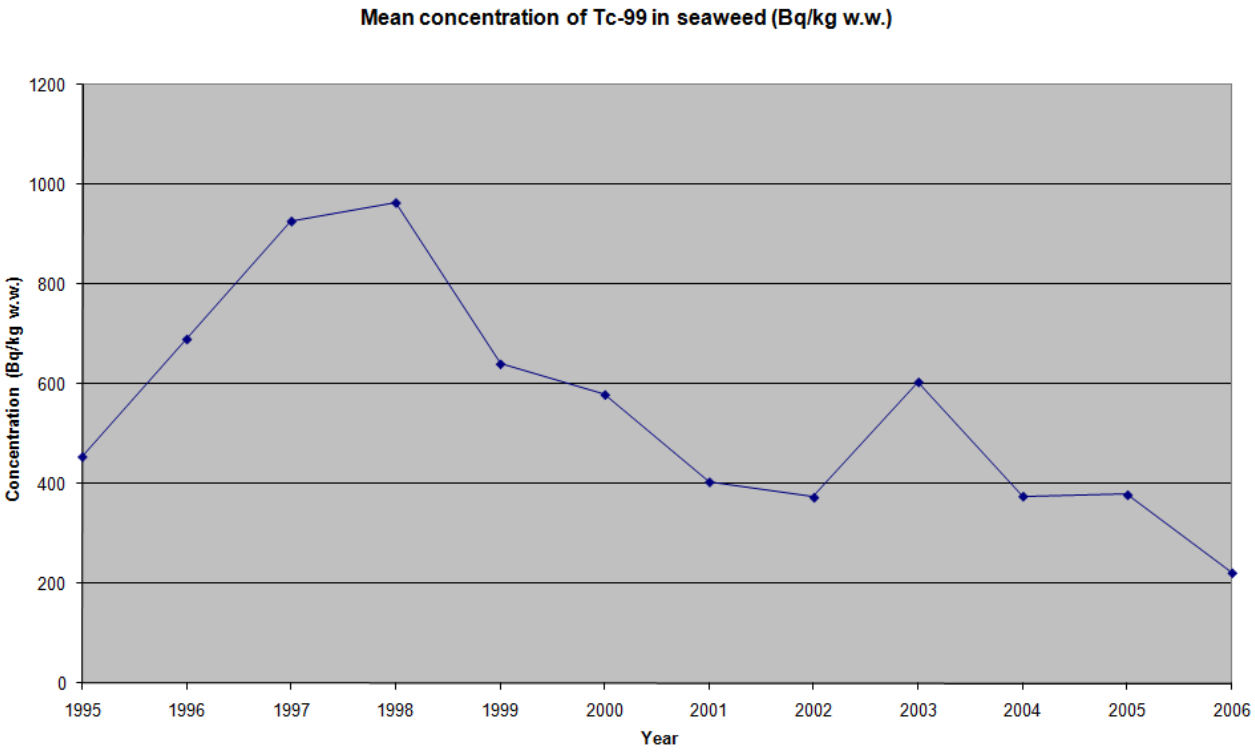
Monitoring area 3



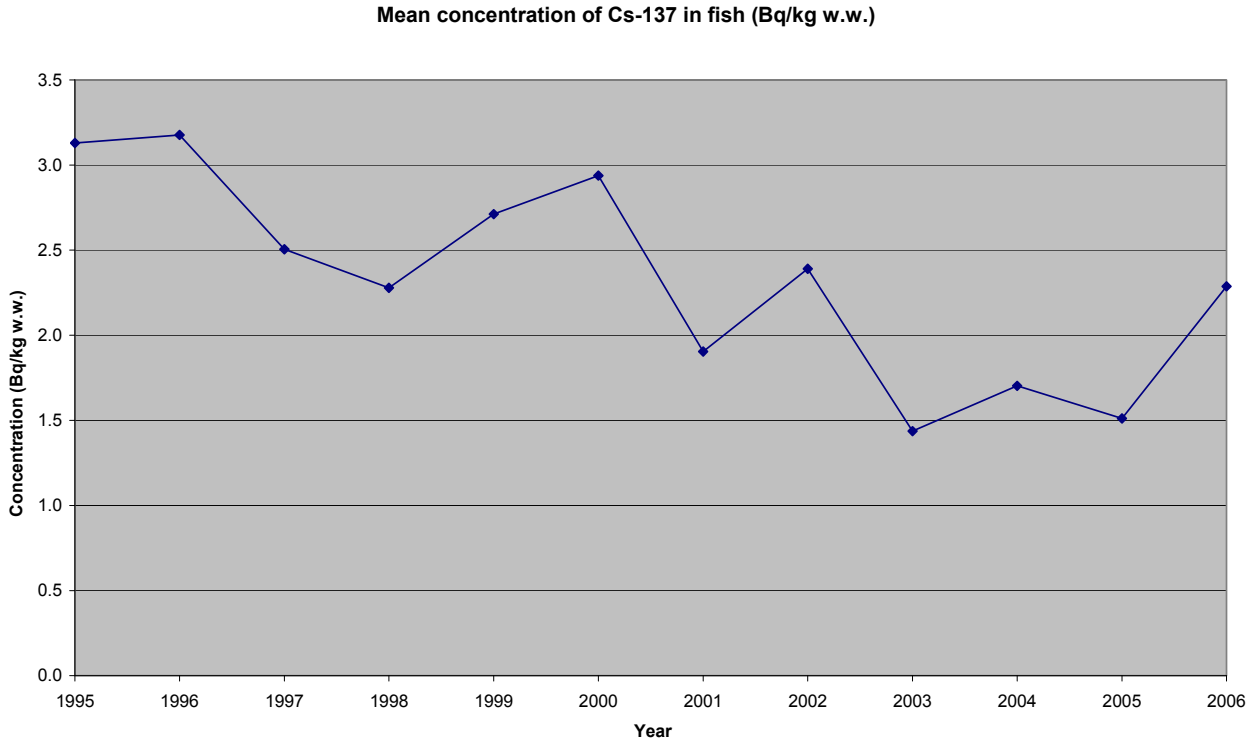
Monitoring area 4



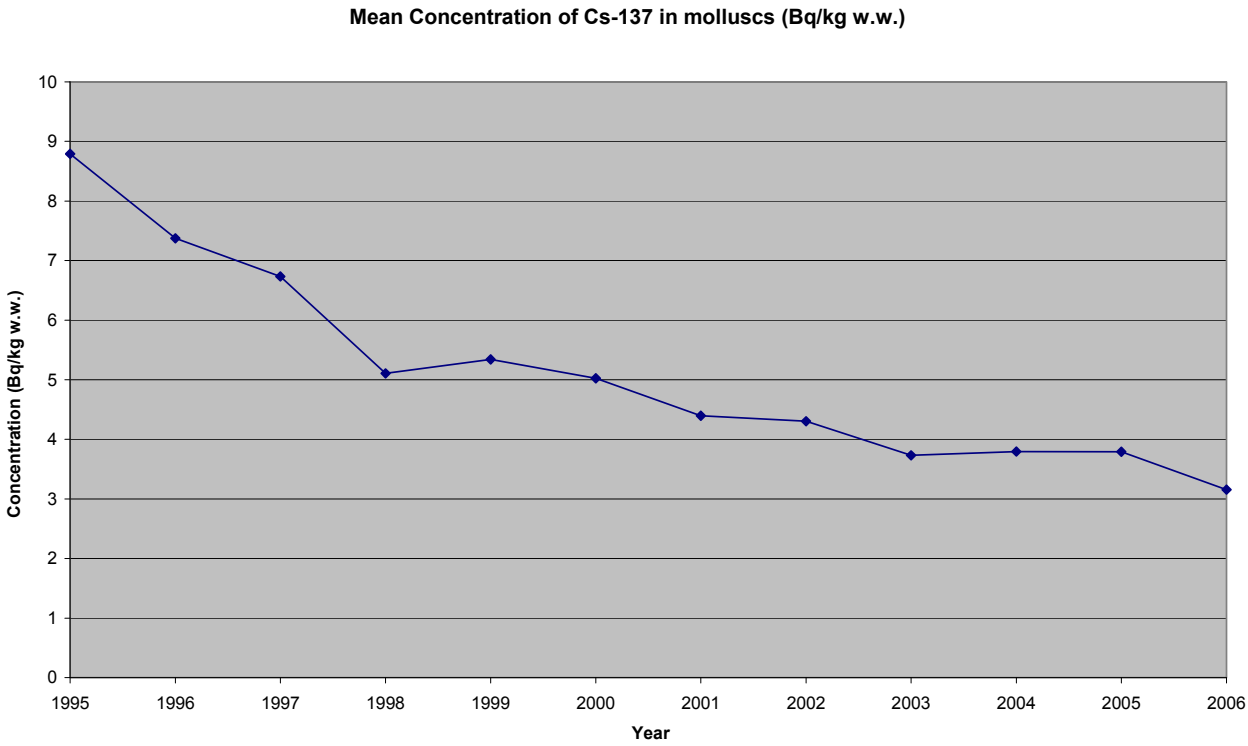




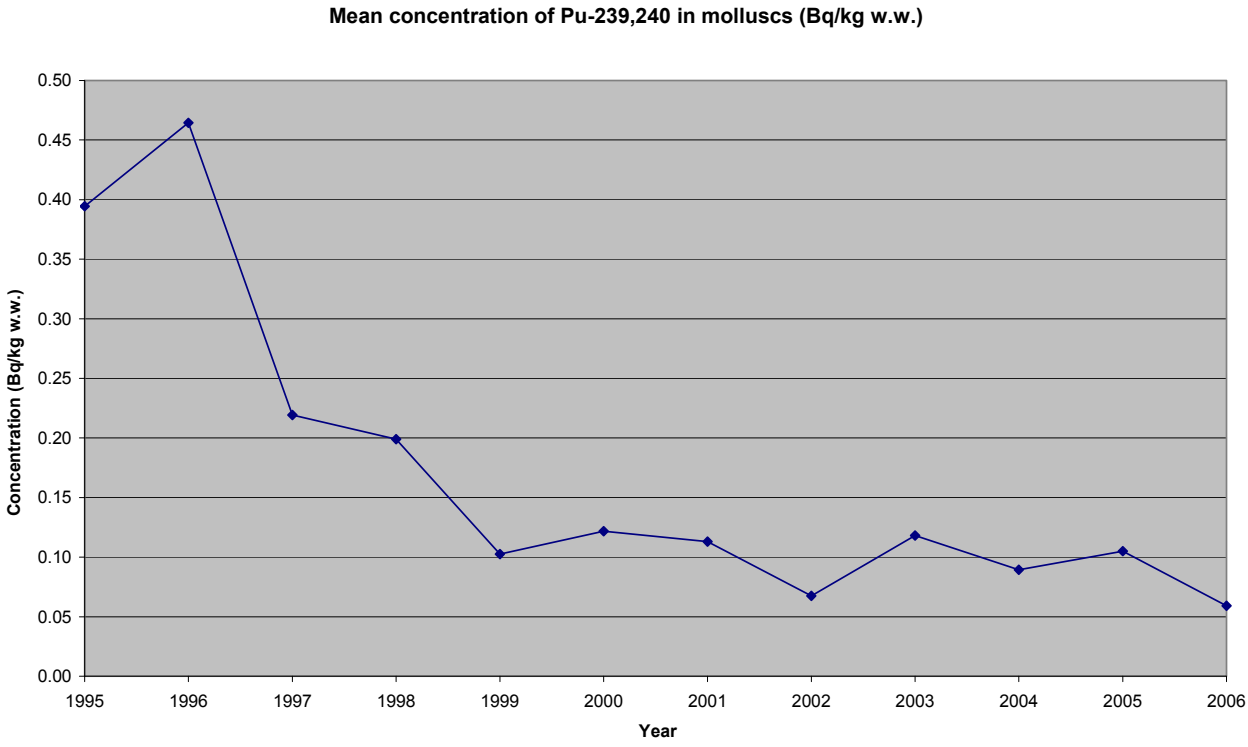
Monitoring area 5



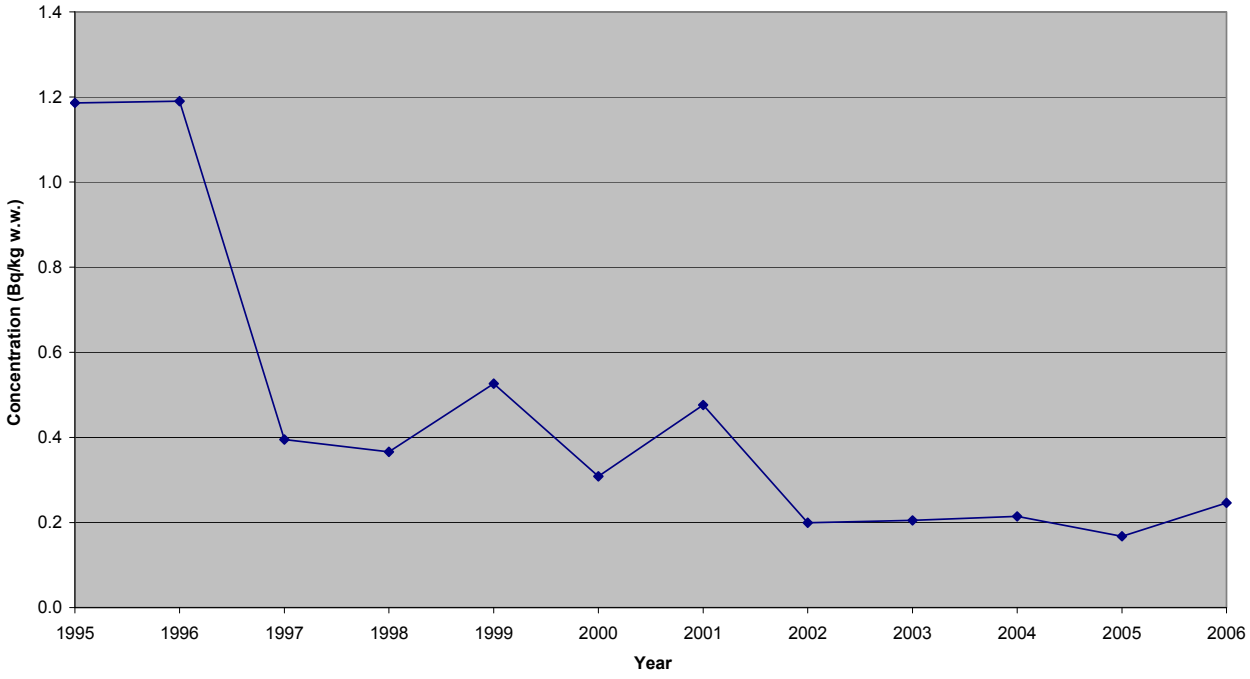
Monitoring area 6



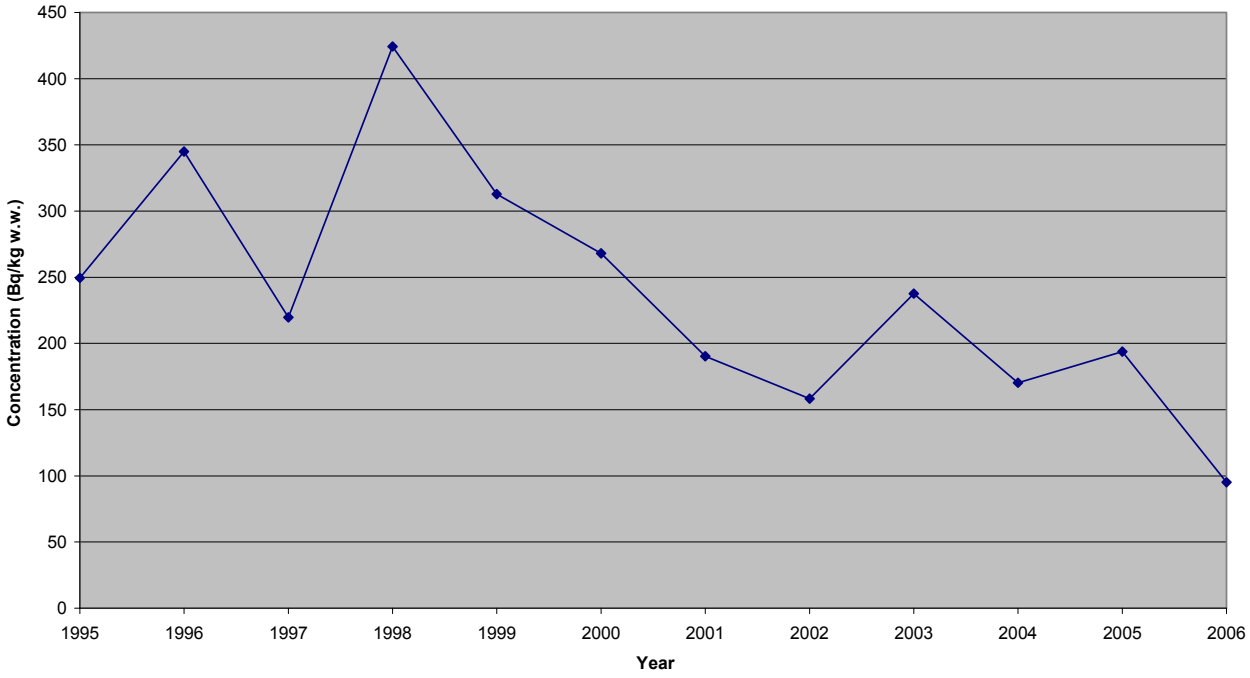
Monitoring area 7



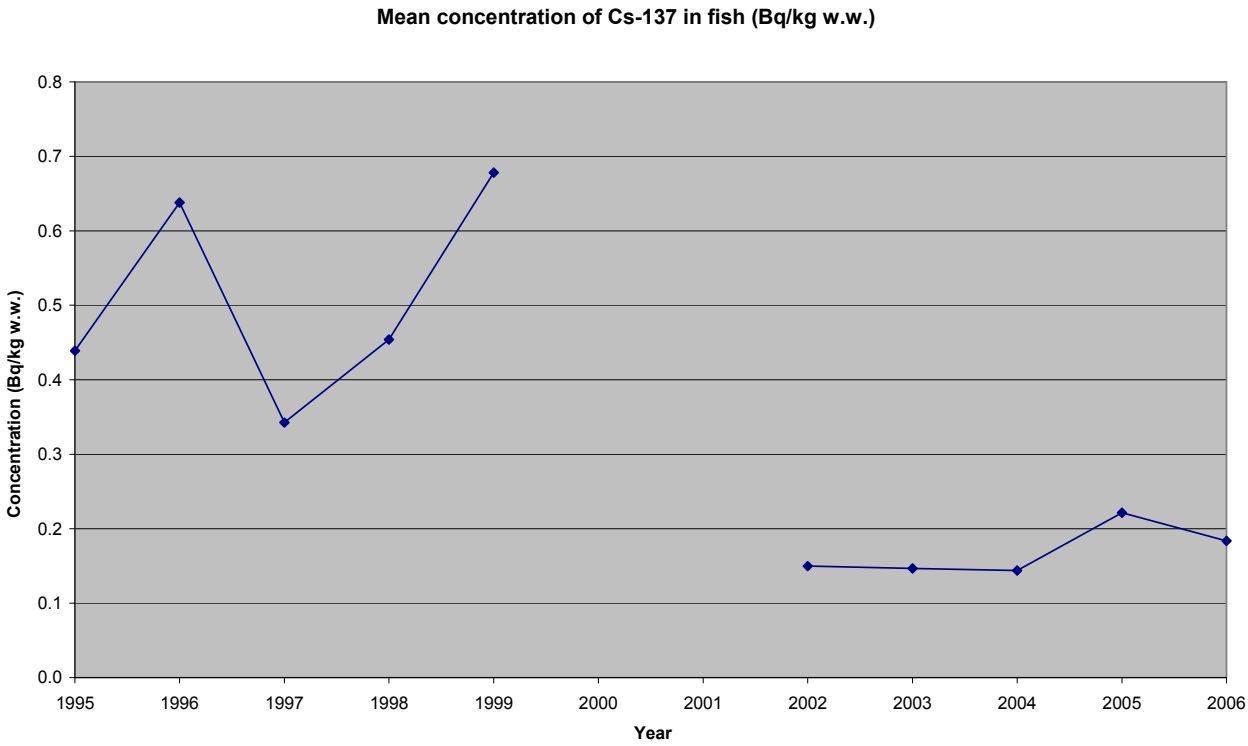
Mean concentration of Cs-137 in seaweed (Bq/kg w.w.)



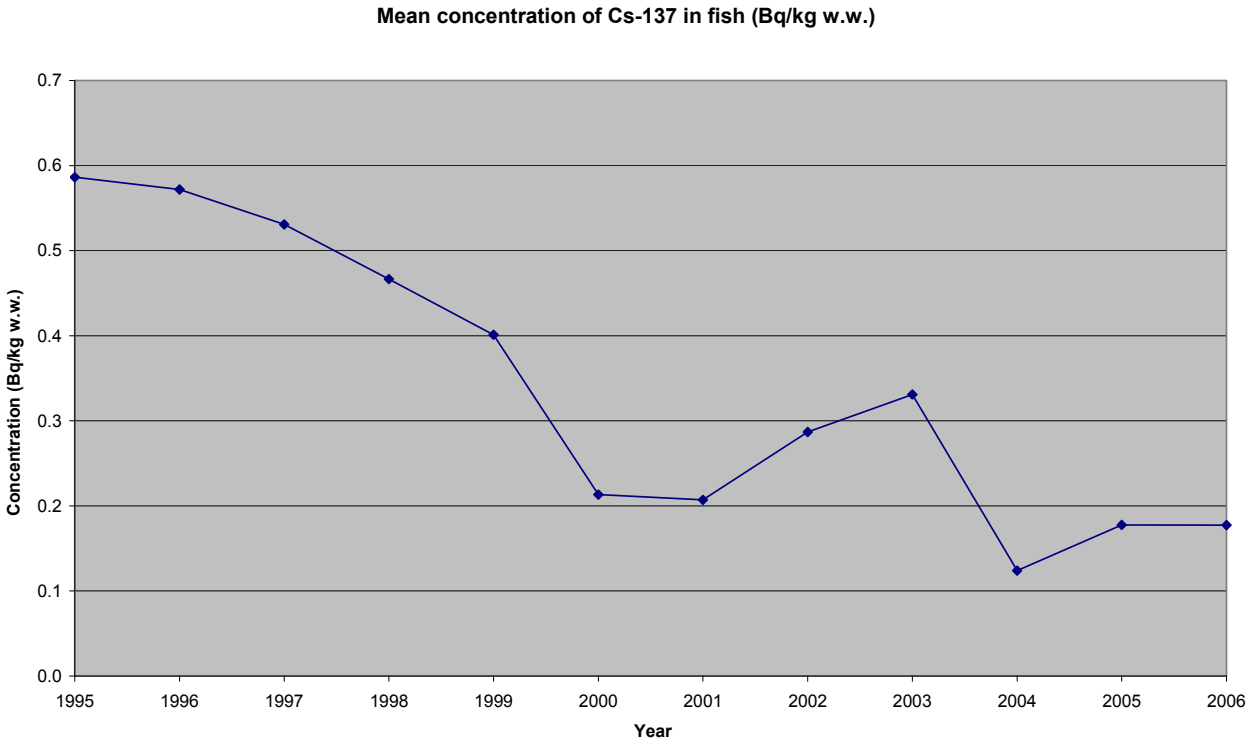
Mean concentration of Tc-99 in seaweed (Bq/kg w.w.)



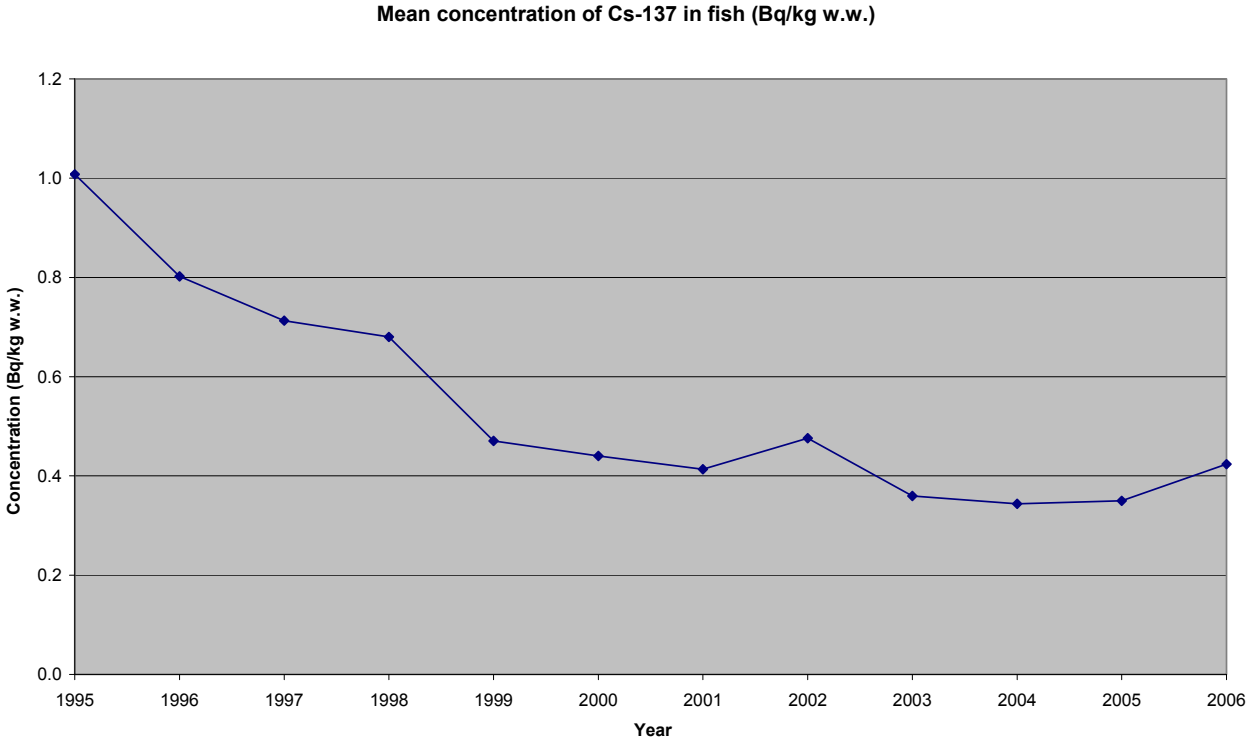
Monitoring area 8



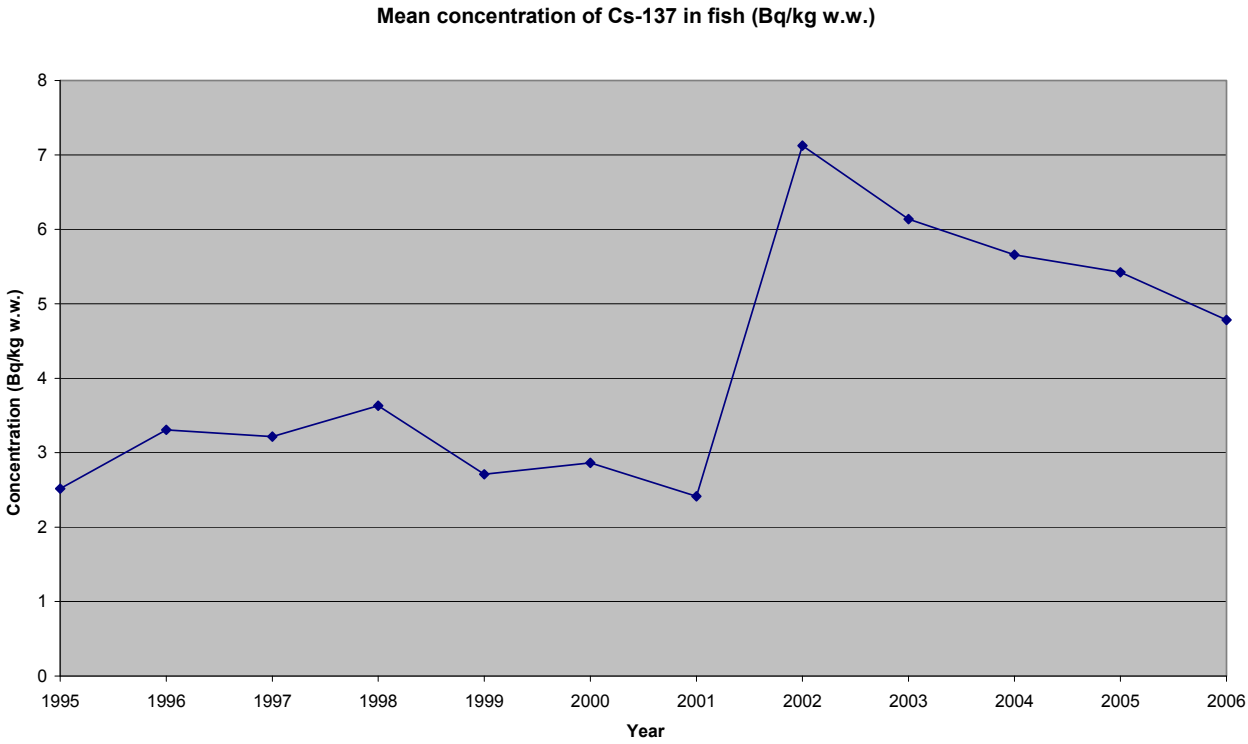
Monitoring area 9

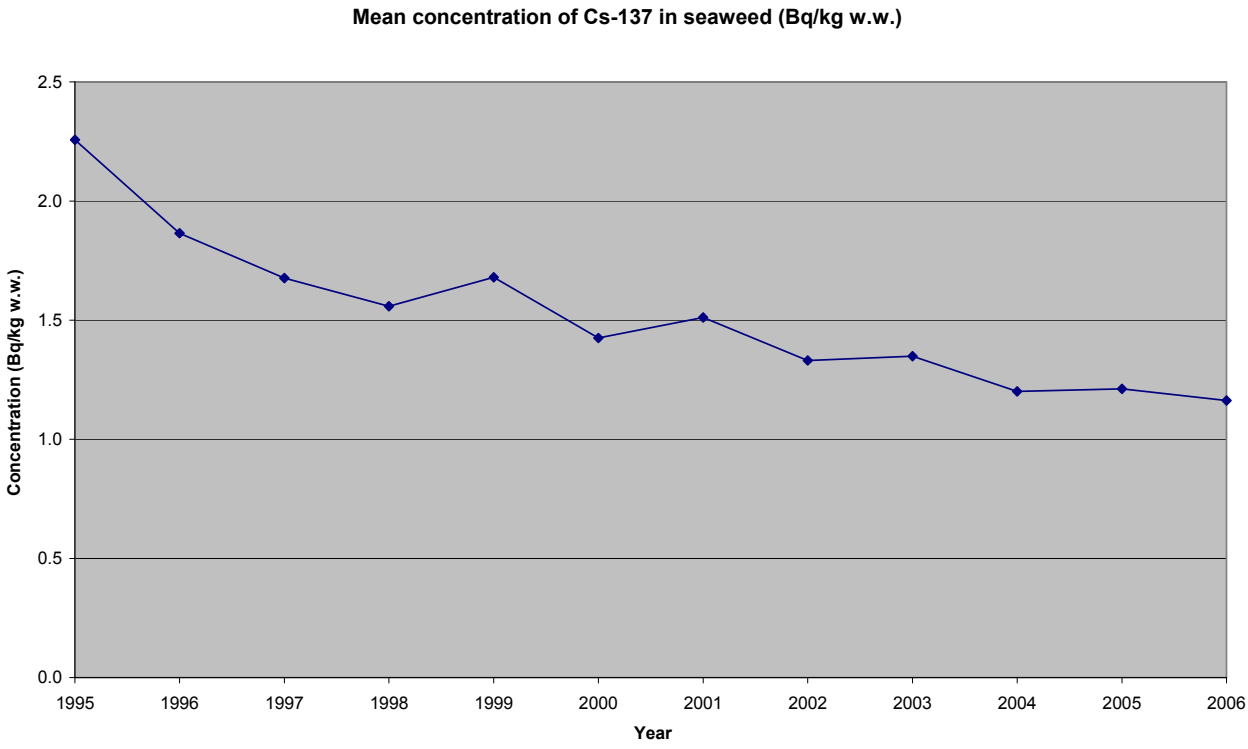


Monitoring area 10



Monitoring area 12





Monitoring area 15

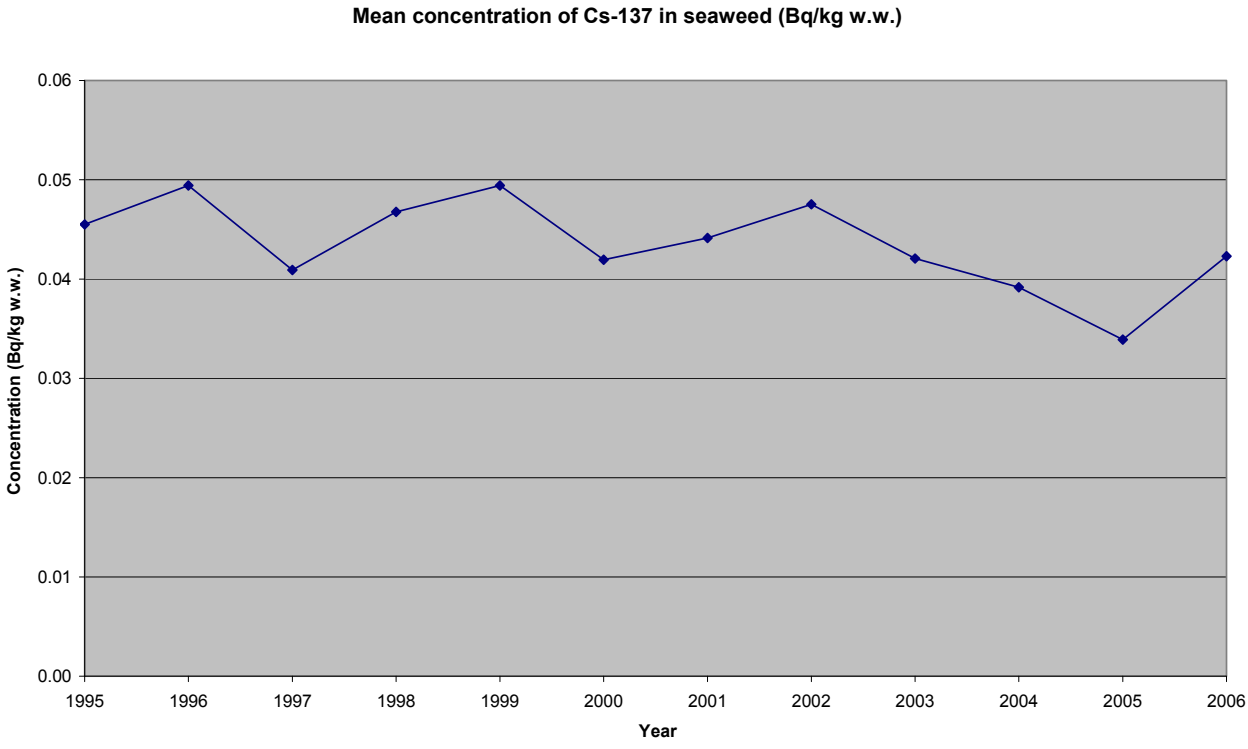


Figure 3.4: *Graphs showing statistically significant changes in concentrations of radionuclides in biota*

3.3.3 Concentrations of naturally occurring radionuclides in OSPAR Regions

Limited data are available on seawater concentrations of the naturally occurring radionuclides Ra-226, Ra-228, Pb-210 and Po-210 in the OSPAR regions for the baseline period (1995 – 2001). Published data are available from before and after this period. As the concentration of these radionuclides from natural sources varies quite considerably, it is sometimes difficult to detect the elevated levels originating from anthropogenic sources.

The tables in this section show the available monitoring data on environmental concentrations of Ra-226 and Ra-228 as averages, with standard deviations, by monitoring area (Table A4.10 in **Annex 4** shows the available and identified literature data). It should be noted that these values are total environmental concentrations *i.e.* they reflect natural background concentrations and possible contributions from discharges of these radionuclides from non-nuclear industries. The highest concentrations of radium-isotopes occur in coastal regions.

The highest concentrations of Ra-226 appear in monitoring area 8 near the Dutch coast but there is evidence that levels have been decreasing over the last 10 years. The enrichment of Ra-228 in shallow and coastal areas can be seen in several monitoring areas (The Wash Estuary, Irish Sea, Skagerrak and English Channel).

Table 3.4: *Seawater concentrations of naturally occurring radionuclides in OSPAR monitoring areas*

Key to the table:
- *n – number of observations; SD – standard deviation.*
- *Empty box: no data available.*
- *Dash: Standard deviation not calculated because n=1.*

		Seawater					
Monitoring area	**Year**	**Ra-226 (Bq/l)**			**Ra-228 (Bq/l)**		
		n	**Mean**	**SD**	**n**	**Mean**	**SD**
8. North Sea South (Belgian and Dutch Coast)	1995	23	1.27E-02	7.44E-03			
	1996	24	1.02E-02	2.54E-03			
	1997	25	9.76E-03	2.67E-03			
	1998	25	7.20E-03	2.06E-03			
	1999	35	6.77E-03	2.33E-03			
	2000	36	5.14E-03	1.50E-03			
	2001	36	3.94E-03	9.24E-04			
	2002	37	4.30E-03	1.15E-03			
	2003	37	3.81E-03	9.38E-04			
	2004	36	4.22E-03	1.33E-03			
	2005	37	3.81E-03	9.95E-04			
	2006	37	3.81E-03	1.17E-03			
9. German Bight	2005	2	1.80E-03	9.90 E-04			
10. North Sea (Northwest, Southeast and Central)	2002	24	1.39E-03	2.92E-04			
	2004	21	1.69E-03	5.07E-04	8	1.14E-03	1.14E-03
	2005	5	1.62E-03	5.17E-04			
11. North Sea (Skagerrak)	2004	4	2.06E-03	5.39E-04			
	2005	2	3.50E-03	2.26E-03			
13. Norwegian Coastal Current	2004	2	1.46E-03	4.02E-05	2	1.52E-04	3.95E-05

Table 3.5: *Biota concentrations of naturally occurring radionuclides in OSPAR regions*

Key to the table:

- *n – number of observations; SD – standard deviation*
- *Empty box: no data available.*
- *Dash: Standard deviation not calculated because n=1*
- *F = Fish*
- *M = Molluscs*

Monitoring area	Year	Ra-226 (Bq/kg w.w.)				Pb-210 (Bq/kg w.w.)				Pb-210 (Bq/kg w.w.)			
		Type	N	Mean	SD	Type	n	Mean	SD	Type	N	Mean	SD
	1995					M	1	2.49E+00	-				
	1996					M	1	2.48E+00	-				
	1997	M	1	3.00E-02	-	M	1	3.03E+00	-				
	1998	M	1	6.90E-02	-	M	1	3.98E+00	-				
	1999					M	1	2.60E+00	-				
	2000	M	1	2.00E-02	-	M	1	2.65E+00	-				
	2001	M	1	1.18E-02	-	M	1	4.93E+00	-				
6. Irish Sea (Sellafield)	2002	M	1	2.21E-02	-								
	2004					M	1	2.34E+00	-				
10. North Sea (Northwest, Southeast and Central)	2005					M	1	2.24E+00	-				
	2006					M	1	2.61E+00	-				
12. Kattegat	2004									F	3	1.22E-01	3.93E-02
	2005									F	3	7.10E-02	9.31E-03

Table 3.5 continued

Monitoring area	Year	Po-210 (Bq/kg w.w.)				Po-210 (Bq/kg w.w.)			
		Type	n	Mean	SD	Type	n	Mean	SD
4. Irish Sea (Rep. of Ireland)	1995	M	2	4.21E+01	4.24E-01				
6. Irish Sea (Sellafield)	1995	M	4	1.14E+01	1.78E+00				
	1996	M	4	1.28E+01	3.56E+00				
	1997	M	4	1.60E+01	1.91E+00				
	1998	M	4	1.90E+01	4.46E+00				
	1999	M	5	1.54E+01	3.52E+00				
	2000	M	5	1.67E+01	6.74E+00				
	2001	M	5	2.05E+01	1.00E+01				
	2002	M	5	1.71E+01	3.90E+00				
	2003	M	5	1.55E+01	3.63E+00				
	2004	M	5	1.68E+01	3.71E+00				
	2005	M	5	1.62E+01	5.60E+00				
	2006	M	5	1.56E+01	3.54E+00				
10. North Sea (Northwest, Southeast and Central)	2002					F	10	1.24E+00	7.15E-01
	2004	M	1	2.54E+01	-	F	34	3.30E+00	1.83E+00
	2005	M	2	1.38E+01	6.79E+00	F	1	1.46E+00	-
	2006	M	2	1.63E+01	8.88E+00				
12. Kattegat	2002					F	3	4.24E-01	1.42E-01
	2003					F	3	9.44E-01	9.23E-01
	2004					F	3	5.71E-01	3.39E-01
	2005					F	3	5.90E-01	5.77E-01
	2006					F	3	5.50E-01	3.46E-01
13. Norwegian Coastal Current	2004					F	7	7.33E-01	5.36E-01
	2006					F	2	3.30E-01	1.41E-01

3.4 General conclusions for marine concentrations

From the data that are available, the following conclusions can be drawn:

For seawater concentrations, in 6 out of 27 datasets there has been a statistically significant change (*i.e.* both the Student's t Welch Aspin and Mann-Whitney test probabilities are below 0.05), with the average concentrations in the assessment period being lower than the baseline values., For a further 7 datasets there is some evidence indicating change (*i.e.* either the Student's t Welch Aspin or Mann-Whitney test probability is below 0.05), with 4 instances where the assessment period average is lower than the baseline value and 3 instances where it is higher.

For concentrations in marine biota, there are eighteen instances of statistically significant changes in marine biota concentrations. In seventeen of these cases the average concentrations in the assessment period were lower than the baseline and for one instance, it was higher (Cs-137 in fish in monitoring area 12). There is also some evidence of change for 4 datasets, with 2 instances where the assessment period average is above the baseline value and 2 instances where it is above).

Some OSPAR regions are still experiencing elevated concentrations due to outflowing Baltic water that has been contaminated with fallout from the Chernobyl accident or due to remobilisation of radionuclides from Irish Sea sediments as a result of past discharges.

Overall, due to the limited availability of reported data, in particular for the radionuclides discharged by the non-nuclear sector, it is not possible to come to firm conclusions as to whether the aims of the OSPAR Radioactive Substances Strategy are being delivered. However, there is an indication of a reduction in average marine concentrations for the radionuclides discharged by the nuclear sector; where the statistical tests indicated a difference between the baseline period and the assessment period, the change was a reduction in every case but one.

Considerations for future monitoring and data collection and storage

During the establishment of baseline values for concentrations in the marine environment, it became clear that the availability of a common database could have made the work easier. Storage of data in the MaRis database (as agreed by RSC 2009) will improve data handling in future.

Limited data are available on seawater concentrations in the OSPAR maritime area for the naturally-occurring radionuclides Ra-226, Ra-228, Pb-210 and Po-210, which are discharged by the offshore oil and gas sector. More data are required to determine whether the objective of the OSPAR Radioactive Substances Strategy is being delivered in respect of concentrations of these radionuclides.

At present, there is no agreement by OSPAR Contracting Parties to report data on concentrations of naturally-occurring radionuclides. However, RSC will review the 2005 monitoring agreement.

The data used in calculating baseline values were provided by individual Contracting Parties. Generally their monitoring programmes have not been established for the purposes of the OSPAR Radioactive Substances Strategy. Furthermore, the monitoring has not been undertaken using any agreed OSPAR-wide approach, such as the Coordinated Environmental Monitoring Programme (OSPAR 2002b) or guidelines established under the Joint Assessment and Monitoring Programme (JAMP; OSPAR, 2003b). These points should be taken into consideration when further compilations of data are carried out, and when monitoring arrangements are reviewed.

4 Doses to members of the public

4.1 Introduction

The Contracting Parties agreed in Sintra in 1998 that the achievement of the OSPAR objective for radioactive substances should take into account, *inter alia*, the radiological impact on man. The Radioactive Substances Strategy includes the identification of radioactive substances which give rise to the most concern about the impact of discharges, emissions or losses of radioactive substances. This identification should be based upon an evaluation of, *inter alia*, the radiation exposure of humans. It should also take account of existing methodologies for the scientific assessment of dose.

Doses are an important factor in considering which radionuclides may give rise to concern in the framework of the application of the OSPAR strategy, allowing:

- quantification of the radiological significance of the measured concentration of each radionuclide included in the baseline element for concentrations;
- comparison, in terms of doses, of the variations in concentration of various radionuclides within the same region.

This section considers the establishment of a baseline element for doses to members of the public (based on doses from measured concentrations in seawater and biota between 1995 and 2001), and assesses recent progress against the baseline element.

4.1.1 Dose assessment methods

Doses to members of the public have been estimated using two different approaches derived from the MARINA II model. One uses data on concentrations of radionuclides in seawater and the other uses concentrations in biota (fish or molluscs). Both methods follow a conservative approach by only including concentration values above the limits of detection. These approaches are described below.

- In both cases, the standard deviation values are based on the standard deviation in the values for the background-element for concentration of radioactive substances in the marine environment.
- Under both approaches, doses are assessed only for ingestion pathways. Both include assessments for consumption of fish and molluscs, and the seawater model also includes crustaceans. Since the baseline values for concentrations do not distinguish the sources of the radionuclides, the baseline-element for doses will similarly aggregate together all sources of the relevant radionuclides, including nuclear-weapons fall-out and natural sources, in addition to nuclear installations and non-nuclear sources. For some situations, there is also a significant component from historic discharges which have long ceased.
- As and when other radionuclides are included in the baseline element for concentrations, they will need to be taken into the baseline element for doses.

The dose assessment methodologies for measured concentrations in seawater and biota can be found in **Annex 5**.

4.1.2 General comments on derived doses

Derived doses cover a very large range of values. This confirms that dose can be a powerful tool to identify those radionuclides of higher or lower concern with regard to the impact of

discharges. Doses assessed from concentrations in biota may be considered more reliable than those assessed from concentrations in seawater, because no concentration factors are required in the assessment model.

However, there are some advantages in the derivation of doses from environmental concentrations in seawater. Doses derived from seawater concentrations include H-3 and take into account three ingestion pathways (fish, molluscs and crustaceans) as opposed to just two (fish and molluscs) in the case of doses derived from biota. As there are more data available for seawater concentrations than seafood concentrations, the doses derived using concentrations in seawater cover more OSPAR regions than the corresponding analysis of doses from concentrations in biota.

One should note that, apart from monitoring area 9 for doses derived from seawater, none of the monitoring areas has a full set of baseline values for all the radionuclides considered, due to the limited environmental concentration data from which doses have been derived. For this reason, comparisons between highest and lowest baseline values should be interpreted with caution.

4.2 Baseline element for doses to members of the public

In order to establish baseline values for doses to members to the public, the following factors were considered:

- whether and, if so which, statistical techniques (consistent with those for the other baseline elements) are appropriate to establish baselines values centred on 1998 and taking into account the seven years 1995 – 2001;
- on the basis of contributions from each Contracting Party, a description of the systems used by the Contracting Parties to assess doses effectively reaching the critical groups for each nuclear installation or other significant source of radioactive discharges or each grouping of such sources;
- a standard method to assess the doses received by individuals using data on the concentrations of radionuclides in the marine environment and criteria for defining the monitoring areas for which such assessments should be made;
- whether further relevant data exist and, if so, how they should be obtained.

The baseline element for doses to members of the public is a tool to interpret the baseline element for discharges and the baseline element for the concentrations in the environment, as it indicates the relative radiological significance of the radionuclides discharged into the environment or measured in environmental compartments.

The calculation of the baseline element for doses takes into account:

- the need for consistency with the approaches for establishing the baseline element for discharges and the baseline element for concentration in the environment;
- the radionuclides and compartments defined for the baseline element for concentrations in the environment;
- the methods used by EC project MARINA II;

The approach that has been used for defining the baseline element for doses to members of the public is as follows:

- a baseline value is defined as the mean of the annual doses between 1995 and 2001; this is consistent with the baseline elements for discharges and for concentrations in the environment;
- the period for averaging a number of years is consistent with the baseline elements for discharges and for concentrations in the environment;
- any underlying trend has not been removed; this is consistent with the baseline elements for discharges and for concentrations in the environment;
- the variability is quantified as the standard deviation; this is consistent with the baseline elements for discharges and for concentrations in the environment;
- where doses have been calculated from environmental baseline values that have been derived using all or most of the results below analytical detection limits, these values are identified in the tables through use of italics (all results below detection limits) or bold italics (some/most results below detection limits). Doses calculated using all or some/most results below detection limits are reported without any standard deviation.

A limited assessment has been undertaken for human doses from radionuclide concentrations in seawater; the results are shown in Table 4.6 and are based on the human dose data in Table A4.11 in **Annex 4**. All standard deviations reported for baseline values are based on the respective standard deviations calculated for the baseline values for concentrations of radionuclides in seawater.

The values for human doses derived from concentrations in biota (*i.e.* fish and molluscs) are given in Table A4.12 in **Annex 4**, with a partial assessment undertaken in Table 4.7. The standard deviation values are based on the respective standard deviations calculated for the baseline values for concentrations of radionuclides in biota. Tables A4.11 and A4.12 in **Annex 4** enable comparisons to be made between the two approaches.

The total dose due to discharges can not be inferred from these tables. To encompass the total exposure of humans due to discharges, emissions or losses of radioactive substances from nuclear installations of the Contracting Parties, impacts of other radionuclides discharged by those installations should be taken into account.

In addition, there are other sources of H-3, Cs-137, Tc-99 and Pu-239,240 than the present discharges of nuclear installations of the Contracting Parties: nuclear installations of other countries (for example, discharges in the Baltic Sea or the Mediterranean Sea which result in inputs to the OSPAR area), past discharges, fallout from atmospheric nuclear weapon tests and from events such as the Chernobyl accident and from non-nuclear activities. These sources may increase the concentrations of H-3, Cs-137, Tc-99 and Pu-239,240 in the OSPAR regions such that the doses shown may result from more than just the present discharges of the nuclear installations of the Contracting Parties.

Furthermore, it is important to note that there are other sources of exposure to humans, such as the dose from natural radionuclides present in seawater. According to UNSCEAR (1996), the order of magnitude of natural exposure of humans is a few millisieverts (mSv) per year, *i.e.* nearly two orders of magnitude higher than the doses shown in Tables 4.6 and 4.7.

4.3 Regional conclusions

4.3.1 Doses from anthropogenic radionuclides

The simple comparison for doses has been restricted to those data where all of the results during the baseline period are above the detection limit. The results are shown in Tables 4.6 and 4.7. Values in red indicate that the average during the assessment period is outside the baseline brackets.

Table 4.6: *Assessment of doses from seawater*

Key to the table:
– Dash indicates some or all of the values are below the detection limit, hence value has not been inserted.
(Explanatory note on use of ***red bold type*** *is on page 27.)*

Monitoring area	Radionuclide	Baseline (µSv/y)	SD (µSv/y)	Lower bracket (µSv/y)	Upper bracket (µSv/y)	Assessment average (µSv/y)
4	Cs-137	**1.48E+00**	**4.89E-01**	**5.25E-01**	**2.44E+00**	**8.70E-01**
	Tc-99	**3.56E-01**	**1.40E-01**	**8.21E-02**	**6.31E-01**	**2.43E-01**
5	Cs-137	**1.49E+00**	**4.97E-01**	**5.20E-01**	**2.47E+00**	**9.32E-01**
6	Cs-137	**9.31E+00**	**2.10E+00**	**5.20E+00**	**1.34E+01**	**5.45E+00**
	Tc-99	**5.49E+00**	**5.23E+00**	**0**	**1.57E+01**	**2.18E+00**
8	H-3	**4.17E-03**	**7.39E-04**	**2.72E-03**	**5.62E-03**	**4.78E-03**
	Cs-137	**2.29E-01**	**1.98E-01**	**0**	**6.18E-01**	**-**
	Pu-239,240	**1.27E-01**	**2.79E-02**	**7.27E-02**	**1.82E-01**	**-**
9	H-3	**3.00E-03**	**8.98E-03**	**1.24E-03**	**4.76E-03**	**-**
	Cs-137	**2.86E-01**	**1.07E-01**	**7.52E-02**	**4.96E-01**	**1.56E-01**
	Tc-99	**2.56E-02**	**1.85E-02**	**0**	**6.19E-02**	**-**
	Pu-239,240	**1.11E-01**	**4.58E-02**	**2.08E-02**	**2.01E-01**	**7.86E-02**
10	Cs-137	**3.87E-01**	**1.74E-01**	**4.62E-02**	**7.29E-01**	**2.28E-01**
	Tc-99	**4.27E-02**	**1.13E-02**	**2.05E-02**	**6.48E-02**	**-**
	Pu-239,240	**1.57E-01**	**1.76E-01**	**0**	**5.03E-01**	**1.41E-01**
11	Cs-137	**7.77E-01**	**4.43E-01**	**0**	**1.65E+00**	**3.46E-01**
	Tc-99	**3.45E-02**	**3.21E-02**	**0**	**9.73E-02**	**2.10E-02**
	Pu-239,240	**3.71E-02**	**1.17E-02**	**1.42E-02**	**6.00E-02**	**5.56E-02**
12	Cs-137	**1.61E+00**	**5.62E-01**	**5.09E-01**	**2.71E+00**	**-**
	Tc-99	**2.04E-02**	**7.01E-03**	**6.66E-03**	**3.41E-02**	**7.88E-03**
13	Cs-137	**2.56E-01**	**8.47E-03**	**2.40E-01**	**2.73E-01**	**1.61E-01**
	Tc-99	**1.69 E-02**	**5.25E-03**	**6.63E-03**	**2.72E-02**	**1.27E-02**

Monitoring area	Radionuclide	Baseline (µSv/y)	SD (µSv/y)	Lower bracket (µSv/y)	Upper bracket (µSv/y)	Assessment average (µSv/y)
	Pu-239,240	6.35E-02	2.13E-0	2.19E-02	1.05E-01	5.45E-02
14	Cs-137	1.87E-01	-	-	-	1.41E-01
	Tc-99	1.07E-02	8.07E-03	0	2.65E-02	4.96E-03
	Pu-239,240	7.01E-02	1.50E-02	4.07E-02	9.94E-02	5.89E-02
15	Cs-137	2.39E-01	5.10E-02	1.39E-01	3.39E-01	1.45E-01
	Pu-239,240	6.36E-02	1.07E-02	4.26E-02	8.46E-02	5.62E-02

There is a possible reduction in dose within monitoring area 13 for Cs-137 as the assessment period average is lower than the lower bracket value.

Table 4.7: *Assessment of the doses from biota*

Dash indicates some or all of the values are below the detection limit, hence value has not been inserted. (Explanatory note on use of red type is on page 27.)

Monitoring area	Radionuclide	Biota	Baseline (µSv/y)	SD (µSv/y)	Lower bracket (µSv/y)	Upper bracket (µSv/y)	Assessment average (µSv/y)
2	Pu-239,240	M	4.65E-02	8.00E-03	3.09E-02	6.22E-02	-
4	Pu-239,240	M	5.19E-01	1.84E-01	1.58E-01	8.79E-01	1.00E-01
5	Cs-137	F	1.18E+00	2.06E-01	7.73E-01	1.58E+00	8.25E-01
	Pu-239,240	M	4.74E-01	6.99E-02	3.37E-01	6.11E-01	5.40E-01
6	Cs-137	M	8.74E-01	2.25E-01	4.32E-01	1.32E+00	5.37E-01
	Pu-239,240	M	2.85E+01	3.98E+00	2.07E+01	3.63E+01	2.53E+01
7	Pu-239,240	M	6.34E-01	3.97E-01	0	1.41E+00	2.41E-01
8	Cs-137	F	2.26E-01	6.28E-02	1.02E-01	3.49E-01	-
9	Cs-137	F	1.88E-01	7.07E-02	4.95E-02	3.27E-01	9.70E-02
10	Cs-137	F	2.86E-01	9.68E-02	9.60E-02	4.76E-01	1.73E-01
	Pu-239,240	M	1.56E-01	1.92E-02	1.18E-01	1.93E-01	2.03E-01
12	Cs-137	F	1.31E+00	1.98E-01	9.17E-01	1.69E+00	2.58E+00
14	Cs-137	F	1.29E-01	1.69E-02	9.62E-01	1.62E-01	1.05E-01
15	Cs-137	F	6.32E-02	6.24E-03	5.10E-02	7.55E-02	6.24E-02

There is a possible decrease in monitoring area 4, where the assessment period average is lower than the lower bracket value, and two possible increases in monitoring areas 10 and 12, where the assessment period average is higher than the respective upper bracket value.

Possible explanations for these apparent increases in doses are discussed in the context of the concentrations data in Table 3.3.

4.3.2 Doses from naturally occurring radionuclides

The results of dose assessments from naturally occurring radionuclides are shown in Tables 4.8 and 4.9. Those derived from the literature data can be found in Table A4.13 in **Annex 4**. These have not been used for assessment purposes and are included solely to allow a comparison with doses resulting from the radionuclides being considered for the nuclear sector.

Table 4.8: *Assessment of the doses from seawater*

Key to the table:
- *SD – standard deviation.*
- *Empty box: no data available.*
- *Dash: Standard deviation not calculated because n=1.*
- ** indicates values derived from the concentration values extracted from literature (see chapter 3)*

		Seawater			
Monitoring area	**Year**	**Ra-226**		**Ra-228**	
		Dose (µSv/y)	**SD**	**Dose (µSv/y)**	**SD**
8. North Sea South (Belgian and Dutch Coast)	1995	1.04E+02	6.08E+01		
	1996	8.35E+01	2.07E+01		
	1997	7.98E+01	2.18E+01		
	1998	5.89E+01	1.69E+01		
	1999	5.54E+01	1.90E+01		
	2000	4.20E+01	1.22E+01		
	2001	3.22E+01	7.56E+00		
	2002	3.51E+01	9.41E+00		
	2003	3.12E+01	7.67E+00		
	2004	3.45E+01	1.09E+01		
	2005	3.12E+01	8.14E+00		
	2006	3.12E+01	9.60E+00		
9. German Bight	2005	1.47E+01	8.09E+00		
10. North Sea (Northwest, Southeast and Central)	2002	1.13E+01	2.39E+00		
	2004	1.38E+01	4.15E+00	2.30E+01	2.30E+01
	2005	1.32E+01	4.22E+00		
11. North Sea (Skagerrak)	2004	1.68E+01	4.41E+00		
	2005	2.86E+01	1.85E+01		
13. Norwegian Coastal Current	2004	1.20E+01	3.29E-01	3.06E+00	7.97E-01

From the limited data available, doses occurring from measured concentrations of Ra-226 and Ra-228 in seawater in the OSPAR region are typically of the order 10 µSv/y.

Table 4.9: *Assessment of the doses from biota*

Monitoring area	Year	Ra-226			Pb-210			Pb-210		
		Type	(µSv/y)	SD	Type	(µSv/y)	SD	Type	(µSv/y)	SD
6. Irish Sea (Sellafield)	1995				M	1.89E+01				
	1996				M	1.88E+01				
	1997	M	9.24E-02		M	2.30E+01				
	1998	M	2.13E-01		M	3.02E+01				
	1999				M	1.97E+01				
	2000	M	6.16E-02		M	2.01E+01				
	2001	M	3.63E-02		M	3.74E+01				
	2002	M	6.81E-02							
	2003									
	2004									
	2005									
	2006									
10. North Sea (Northwest, Southeast and Central)	2002									
	2004				M	1.78E+01				
	2005				M	1.70E+01				
	2006				M	1.98E+01				
12. Kattegat	2002									
	2003									
	2004							F	2.99E+00	9.22E-01
	2005							F	1.67E+00	2.18E-01
	2006									

Monitoring area	Year	Po-210 Type	Po-210 (µSv/y)	Po-210 SD	Po-210 Type	Po-210 (µSv/y)	Po-210 SD
4. Irish Sea (Rep. of Ireland)	1995	M	5.56E+02	5.60E+00			
6. Irish Sea (Sellafield)	1995	M	1.51E+02	2.35E+01			
	1996	M	1.69E+02	4.70E+01			
	1997	M	2.11E+02	2.52E+01			
	1998	M	2.50E+02	5.89E+01			
	1999	M	2.04E+02	4.65E+01			
	2000	M	2.20E+02	8.90E+01			
	2001	M	2.71E+02	1.32E+02			
	2002	M	2.25E+02	5.15E+01			
	2003	M	2.05E+02	4.79E+01			
	2004	M	2.22E+02	4.89E+01			
	2005	M	2.14E+02	7.39E+01			
	2006	M	2.06E+02	4.68E+01			
10. North Sea (Northwest, Southeast and Central)	2002				F	5.06E+01	2.92E+01
	2004	M	3.36E+02		F	1.35E+02	7.48E+01
	2005	M	1.82E+02	8.96E+01	F	5.96E+01	
	2006	M	2.15E+02	1.17E+02			
12. Kattegat	2002				F	1.73E+01	5.79E+00
	2003				F	3.85E+01	3.77E+01
	2004				F	2.33E+01	1.38E+01
	2005				F	2.41E+01	2.35E+01
	2006				F	2.24E+01	1.41E+01
13. Norwegian Coastal Current	2004				F	2.99E+01	2.19E+01
	2006				F	1.35E+01	5.77E+00

From the limited data available, the highest doses occur from Pb-210 and Po-210 in molluscs.

4.4 General conclusions for doses to members of the public

Sufficient data have been collected to allow a baseline to be established for doses to members of the public from radionuclides discharged from the nuclear sector. All doses calculated to date from concentrations of nuclear sector radionuclides are well below accepted international standards. Doses to man during the assessment period have not been assessed separately against the baseline values but are a scalar function of the respective environmental concentrations from seawater and biota; where an environmental concentration has increased or decreased, this has resulted in an increase or decrease in dose.

However, because data on environmental concentrations of radionuclides from the non-nuclear sector have not been collected by OSPAR, it is not possible to come to firm conclusions regarding doses to members of the public.

5 Impacts on marine biota

5.1 Introduction

Until now, the ecological impact of radioactive substances released into ecosystems has been almost exclusively seen in terms of human radiation protection (dose) under the umbrella of the following statement of the International Commission on Radiological Protection (ICRP, 1991):

“The Commission believes that the standard of environmental control needed to protect man to the degree currently thought desirable will ensure that other species are not put at risk. Occasionally, individual members of non-human species might be harmed, but not to the extent of endangering whole species or creating imbalance between species”.

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Historically, radiological protection has been based on the protection of people and it has been assumed that if humans are adequately protected then “other living things are also likely to be sufficiently protected” (ICRP, 1977) or that “other species are not put at risk” (ICRP, 1991). Until recently, our ability to test this assumption has been limited. This study at La Hague illustrates some recent developments in the field. See Annex 2 for more information.

Although one purpose of the Euratom Treaty is to guarantee high safety standards from the effects of ionising radiation, the Treaty and its subsidiary legislation are focused on protecting the health of workers and the general public, rather than non-human species. There is however, a range of other international legislation and binding agreements that includes requirements to protect the environment more broadly (for example, in the European Union, the Habitats and Birds Directives) – including protection against the harmful effects of radioactive substances (NEA, 2007).

The ICRP has now directly addressed environmental protection as an element of its latest recommendations (ICRP, 2007). In 2005, the ICRP appointed a new Committee to make recommendations for the establishment of an environmental protection system that takes into account the current debate about environmental, as opposed to human, protection. This parallels systems developed in other areas of environmental protection (for example, for hazardous substances) that can be operated in conjunction with the system for radiological protection of humans.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) regularly publishes broad reviews of the sources and effects of ionising radiation. In 1996, UNSCEAR published its first report on the effects of ionising radiation on plants and animals in the environment as a separate Annex to the UNSCEAR 1996 Report to the General Assembly of the United Nations (UN). An updated Annex on biota will be included in the forthcoming UNSCEAR report to be released shortly (UNSCEAR, in press).

In 2004, the IAEA established a Biota Working Group under its Environmental Modelling for Radiation Safety (EMRAS) programme with the objective of comparing and validating approaches being used and developed by Member States for biota dose assessment (Beresford and Howard, 2005. Beresford *et al.*, 2005). In July 2007, the IAEA launched the Basic Safety Standards revision which will include a section devoted to the radioprotection of the environment.

OSPAR has considered the available knowledge in the field and its application to the OSPAR Maritime Area regions as shown in the assessment of impacts on biota (OSPAR, 2008a). This section summarises the conclusions of the assessment and takes into account data which has subsequently been made available for the OSPAR Maritime area. It demonstrates how the progress that Contracting Parties are making in reducing anthropogenic inputs of radioactive substances to the North-East Atlantic is being reflected in doses or dose rates to biota living in the exposed marine ecosystems.

At RSC 2009, the IAEA presented a report on progress in international forums regarding the development of environmental quality criteria, together with information and opinions on progress concerning standards for radiological protection of the environment. The rationale was that although risk assessment is generally based on human health considerations and this approach has demonstrated efficacy to also protect non-human species in most exposure scenarios, the consideration of possible impacts on non-human species would strengthen the conceptual basis of radiological protection of the environment. This could possibly influence a review on the requirements for additional standards or revisions to existing ones. IAEA reported that they considered that within this process, the following should be taken into account:

(a) radiation is one of many environmental stressors, probably relatively minor if compared to others;

(b) there is a need to understand implications of any proposed improvement on the current system of regulation and to test the practical adequacy;

(c) the process of reviewing Safety Standards does not necessarily mean major standard revisions; and

(d) there are expectations on the ICRP results regarding the definition of a system for protection of the environment.

In addition to its work on revision of the Basic Safety Standards, the IAEA is producing a new safety guide on Radiological Environmental Impact Analysis (for protection of people and environment) intended to assist the international community with more practical guidance, at the level of the definition of a framework and discussions on methods, parameters and radiological criteria.

OSPAR remains committed to developing environmental quality criteria, but it is still too early for OSPAR to take action on environmental quality criteria for radioactive substances. RSC will continue to follow international developments before deciding on what action to take.

5.2 Methodology

Although suitable assessment methodologies have existed for some years (IAEA, 1979, 1988; NCRP, 1991), the need for a system to protect the environment from ionising radiation has only recently been recognised internationally (IAEA, 2003; ICRP, 2003). There is a need to bring radiological protection approaches up to date with current environmental protection regulation, so that they are consistent with those applied for chemicals (IAEA, 2003; ICRP, 2003). There

are a number of key differences between chemical and radioactive effects on biota, for example, for radioactive substances, the effects analysis is dependent on the amount of radiation energy absorbed by the body of the living organism rather than the concentration to which it is exposed. In principle, though, there is no compelling argument for radioactive substances to be considered in a different way from that used for conventional chemicals and a similar approach could be used for both.

An Environmental Risk Assessment-type method has recently been conceived, 'Environmental Risk from Ionising Contaminants: Assessment and management (ERICA)', which takes an integrated approach to assess and manage environmental risk from radioactive substances (ERICA, 2007). This method comprises *inter alia* the traditional components of problem formulation, exposure analysis, effects analysis and risk characterisation. This method is generally applied as a tiered approach, from screening level, simplistic and conservative assessment to full, site-specific and detailed assessment. The detailed methodology can be found in **Annex 6**.

5.2.1 Natural background

Screening against background is often motivated by the low ecological risk of background concentrations and doses (Jones and Gilek, 2004) as well as the low probability of any risk management decision ever being based on levels of exposure similar to background (Suter *et al.*, 2000). Following this line of reasoning ICRP (ICRP, 2003) has proposed the development of derived consideration levels for reference flora and fauna, with explicit reference to background dose rates. The idea is to aid in the consideration of different management options by compiling information about ecological effects on various reference organisms (ROs) relative to natural background levels. This information could then be classified into bands of concern recommending various management actions. For example, dose rates in the background range would generally imply low concern with no actions considered (ERICA, 2005).

There are, however, several problems with using natural background levels as screening criteria. Basic information on natural background in the OSPAR area is limited and gives rise to uncertainties. Defining which value to use as representative of the natural background at the impacted site could be a substantial problem due to potential anomalies and inhomogeneous distributions (Suter *et al.*, 2000). Natural and enhanced substances may have different routes of exposure to resident organisms, leading to an underestimation of risk.

The use of natural background data for comparison is motivated by the assumption that levels in this range are safe for non-human biota. However, even though the empirical evidence supports this assumption, the use of screening criteria based on derived safe doses of the specific radioactive substances being assessed is more scientifically justified.

5.2.2 Assumptions and limitations

To ensure consistency with the previous evaluations of discharges and concentrations (OSPAR, 2006 and OSPAR, 2007), the dose calculations in the assessment of impacts on biota (OSPAR, 2008a) were based on seawater and biota activity concentration data for defined monitoring areas as reported and set out in the Second Periodic Evaluation, the assessment of concentrations (OSPAR, 2007). A number of limitations on the approach adopted to generate the seawater and biota concentration values and on the actual values themselves were identified in the Second Periodic Evaluation (OSPAR, 2007). These included:

- the geographical representativeness of the data;
- that calculated values are based on different sizes of data sets;

- that monitoring results may contain data below detection limits;
- that there may be a time lag involved between changes in discharges and the transport of radionuclides thereafter;
- that concentration may also be influenced by, for example, global nuclear fall-out following atmospheric weapons tests, the Chernobyl accident etc.;
- the limited number of data points, and/or differences between sampling and analytical methodologies between Contracting Parties;
- that some of the data concentrations may be influenced by the remobilisation of radionuclides in sediments from discharges made in the past.

In basing these calculations solely on concentration methods, a number of additional limitations must be considered in terms of investigating impacts on biota from H-3 and anthropogenic sources (past and present) of radioactive substances:

- Dose calculations in the assessment of the impact on marine biota of anthropogenic sources of radioactive substances (OSPAR, 2008a) (presented in Tables 4.12a to 4.14d) and subsequently for this report (for Figures 5.3 to 5.8) have been based solely on seawater data. Biota concentrations data were used for a very limited number of datasets to show that there was agreement between dose rates calculated on the basis of water concentrations data only and dose rates calculated on the basis of both water and biota data. Furthermore, in monitoring areas where concentration data were available for biota only, no dose rates were calculated; biotic compartments are usually better indicators of radioactivity levels in the environment than water.
- The limited number of radionuclides considered – this report only contains environmental concentration data for H-3 and the anthropogenic radionuclides, Tc-99, Cs-137 and Pu-239,240, and for the naturally occurring radionuclides Pb-210, Po-210, Ra-226 and Ra-228. Moreover, in many cases, data do not exist for all of these radionuclides in all of the monitoring areas. Therefore, it is important to note that the dose calculated in this demonstration for each representative species does not represent the total dose from both anthropogenic and natural sources of radionuclides.
- The limited time period considered. This evaluation only contains environmental concentration data for anthropogenic radionuclides for the years 1995 to 2006. It therefore excludes consideration of impacts on biota from anthropogenic sources of radionuclides from early time periods, for example, as a result of global fall out from atmospheric nuclear weapon testing in the 1960's, peak authorised discharges from Sellafield and Cap la Hague in the 1970's and 1980's and the Chernobyl accident in 1986.

For a particular radionuclide and a specific monitoring area, seawater and biota activity concentrations are used directly to estimate the dose rate to biota. Activity concentrations in biota are calculated on the basis of the equilibrium assumption with the water compartment, using appropriate concentration ratios.

5.3 Doses from naturally-occurring radionuclides by year and OSPAR region

Concentration data available for naturally occurring radionuclides during the baseline period (1995 – 2001) are scarce and generally relate to seawater and a limited range of radionuclides (Pb-210, Po-210, Ra-226, and Ra-228). Data series are heterogeneous from one monitoring

area to another. In addition, dose rates to biota have only been calculated on the basis of the seawater concentrations as input data.

Estimated dose rates in this evaluation are based on activity concentration measurements in the environment. This means that for naturally occurring radionuclides, the estimated dose rate for each biota is based on natural background concentrations and any potential contributions of naturally occurring radionuclides resulting from human activities. There is limited data available in and prior to the baseline period in RA-3 (see the assessment of the impact on marine biota of anthropogenic sources of radioactive substances (OSPAR, 2008a) for the limited data that is available).

This report is based on the assessment of impact and data for 2006 but for radionuclides from the non-nuclear sector, sufficient data are still not available to enable an assessment of doses to biota to be carried out.

5.4 Doses from anthropogenic radionuclides by year and OSPAR region

Annual means of seawater concentrations for each monitoring area were used to estimate the corresponding dose rates to biota, for each of the reference organisms previously described. Radionuclide-specific dose rates have been estimated for H-3, Cs-137, Tc-99 and Pu-239,240. From the whole set of results obtained, only the calculated dose rates for the reference organisms giving the maximum value per taxonomic group are reported here. In some cases, dose rates are based on concentration means calculated from data where all or some results are below analytical detection limits. Where this occurs, such values are identified in the tables through use of different formats:

a. *italics* (all concentration measurements below detection limits);
b. ***bold italics*** (some/most concentration measurements below detection limits).

When a mean includes an activity concentration value less than the limit of detection, the assumption has been made that the value is equal to the limit of detection. Values calculated using all or some/most results below detection limits are reported without any component for variability. When a standard deviation was reported in the Second Periodic Evaluation, the same calculation as for the concentration itself was processed, and the result, reported in smaller normal characters, is assumed to be the equivalent of a standard deviation of the dose rate.

Figures 5.3 to 5.8 show graphical representations of maximum total dose rates as percentages of the ERICA screening value of 10µGy/h in 2006.

In each case, a sum of incremental dose rate based on results obtained for each radionuclide (H-3, Cs-137, Tc-99 and Pu-239,240) has been calculated. Dose rate estimates based on seawater concentration detection limits have been used to obtain a maximum value of these summed dose rate estimates for each monitoring area, compartment and year or period.

Calculated dose rates for macroalgae vary considerably according to the monitoring area and the radionuclide. For the radionuclides, the lowest value observed has been for H-3 and the maximum for Tc-99, with Cs-137 a close second. Values for Pu-239,240 are too scarce to draw any conclusion about their contribution to the dose rates. From the results gathered, it can be seen that monitoring area 6 has the highest dose rates and monitoring areas 9 to 15 have the lowest dose rates. In Figures 5.3 to 5.8 radionuclides are also ranked by decreasing order of contribution to the total dose rate for each monitoring area. The use of the symbol “>“indicates the difference in dose rates, in terms of order of magnitude, between radionuclides for a particular monitoring area. For example, Cs-137 >> H-3 means that the dose rate delivered by

Cs-137 is two orders of magnitude higher than the dose rate delivered by H-3. The use of the symbol "=" indicates that dose rates from radionuclides are of a similar order of magnitude. Where two doses are stated in associated tables, the value based only on real data (excluding data at the detection limit) is used.

5.5 General conclusions for impacts on biota

Including only selected radionuclides, and solely those from the nuclear sector, in the assessment has inevitably led to an incomplete picture in terms of the total biological effect of ionising radiation in the OSPAR maritime area. However, since the radionuclides of most significance (highest radiotoxicity) have been included, it is still possible to express the dose rates summed for the selected radionuclides as a percentage of the ERICA screening value of 10 µGy/h, in order to characterise the potential risk to the structure and function of the marine ecosystems in each OSPAR monitoring area.

On this basis, the following can be seen:

Table 5.1: *Average maximum total dose rates as a percentage of the screening value of 10µGy/h for each of the biota assessed in the monitoring areas (MA1 – MA15, see Table 3.1) in the North Sea*

Percent of the screening value	Macroalgae	Invertebrates (crab)	Vertebrates (plaice)
1 to 10	MA6	MA6	-
0.1 to 1	MA1-MA4-MA7-MA8	MA1-MA4-MA7-MA8	MA1-MA7-MA8
0.01 to 0.1	MA2-MA3-MA5-MA10-MA11-MA12-MA13-MA14-MA15	MA2-MA3-MA5-MA11-MA12-MA13	MA2-MA3-MA4-MA5-MA6-MA10-MA11-MA12
< 0.01	MA9	MA9-MA10-MA14-MA15	MA9-MA13-MA14-MA15

Such an assessment indicates that the calculated dose rates to marine biota from the selected radionuclides from the nuclear sector are low and are below the lowest levels at which any effects are likely to occur according to current scientific understanding.

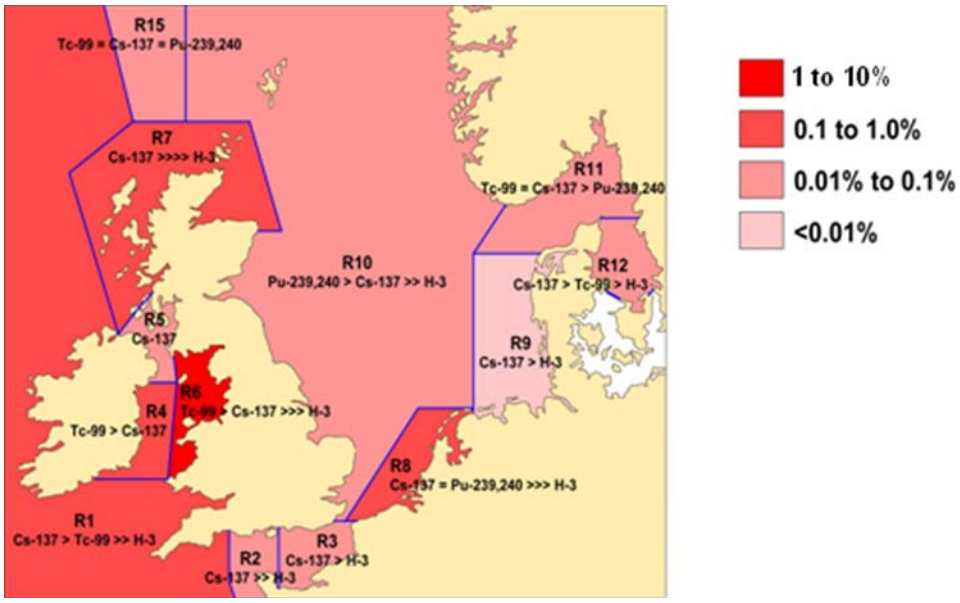


Figure 5.3: *Graphical representation (colour coded) of the average maximum total dose rates (sum on detected radionuclides) as a percentage of the screening value of 10 µGy/h for macroalgae in the North Sea and surrounding waters in 2006*

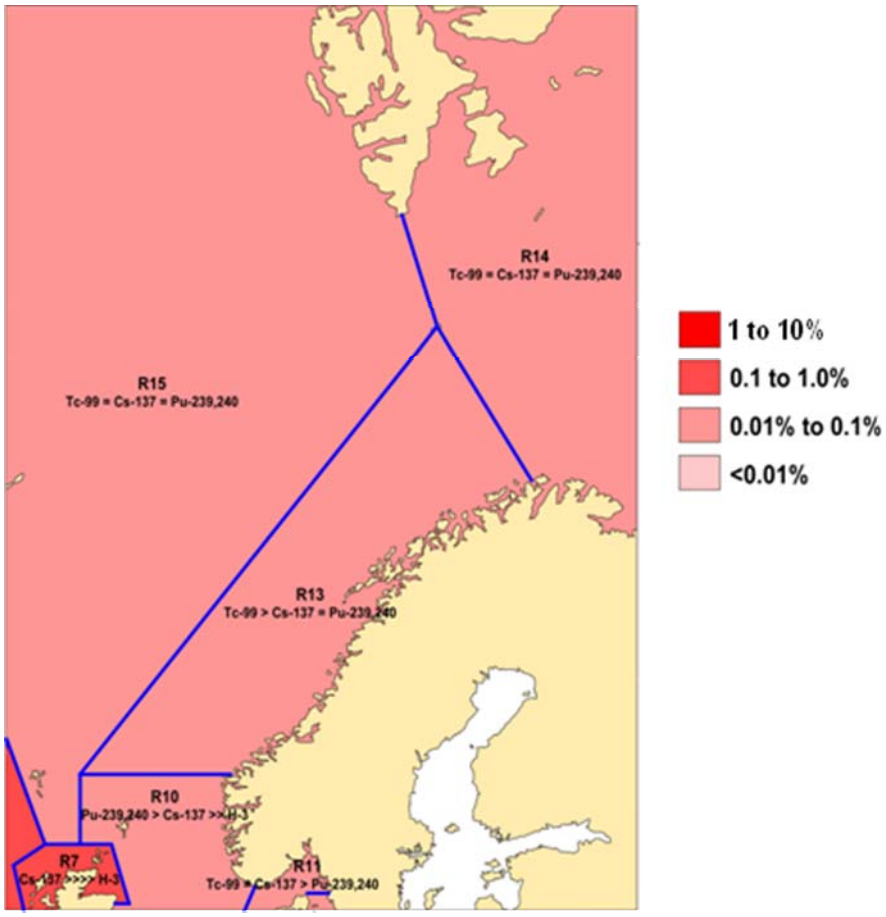


Figure 5.4: *Graphical representation (colour code) of the percentage contribution of the average maximum total dose rates (sum on detected radionuclides) to the screening value of 10 µGy/h for macroalgae in the Norwegian Sea and surrounding waters in 2006*

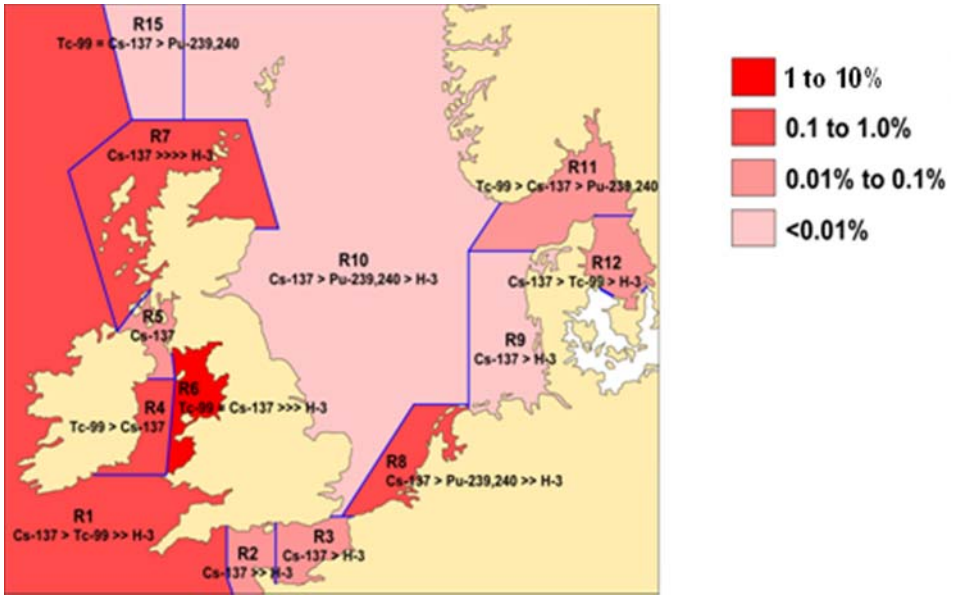


Figure 5.5: *Graphical representation (colour coded) of the average maximum total dose rates (sum on detected radionuclides) as a percentage of the screening value of 10 µGy/h for invertebrates (crab) in the North Sea and surrounding waters in 2006*

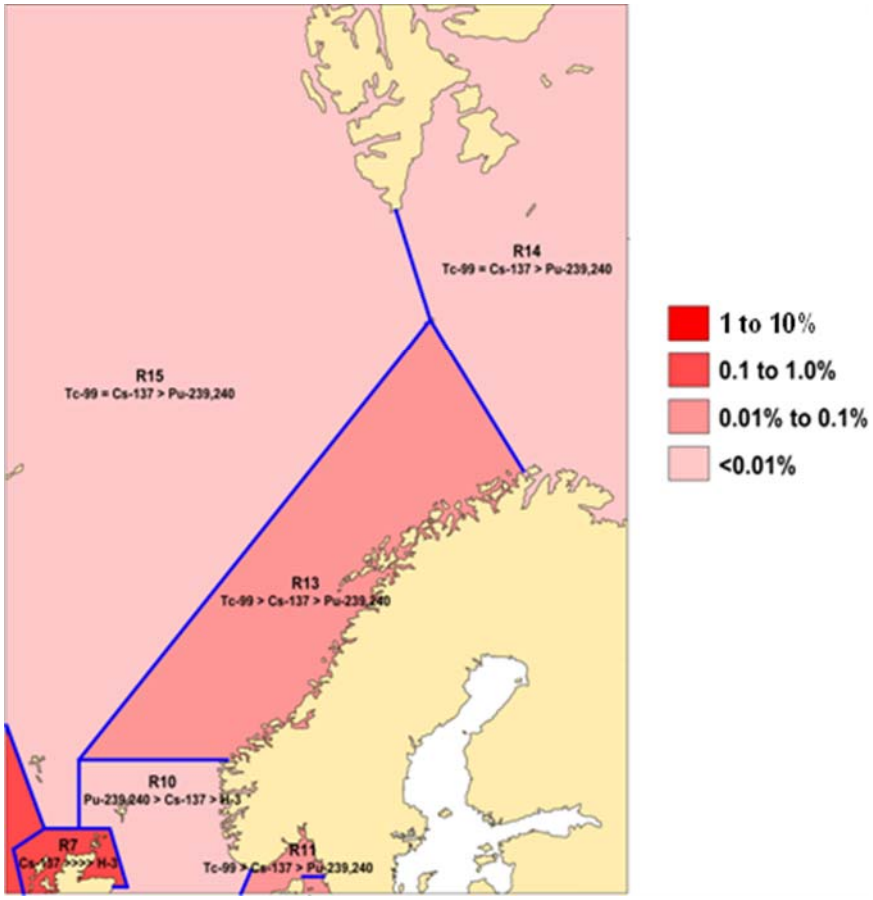


Figure 5.6: *Graphical representation (colour coded) of the average maximum total dose rates (sum on detected radionuclides) as a percentage of the screening value of 10 µGy/h for invertebrates (crab) in the Norwegian Sea and surrounding waters in 2006*

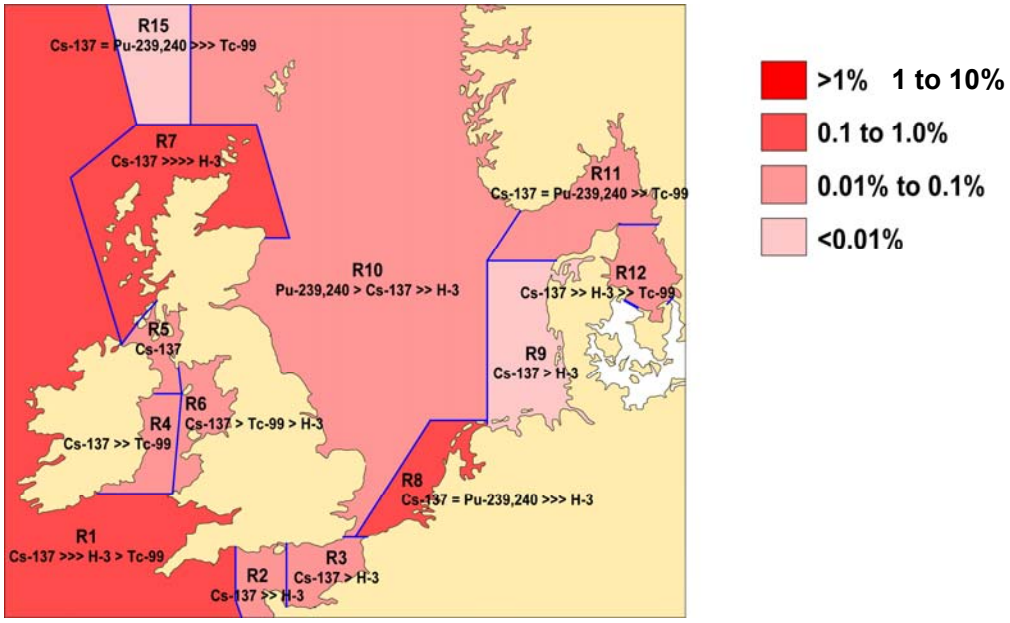


Figure 5.7: *Graphical representation (colour coded) of the average maximum total dose rates (sum on detected radionuclides) as a percentage of the screening value of 10 µGy/h for vertebrates (plaice) in the North Sea and surrounding waters in 2006*

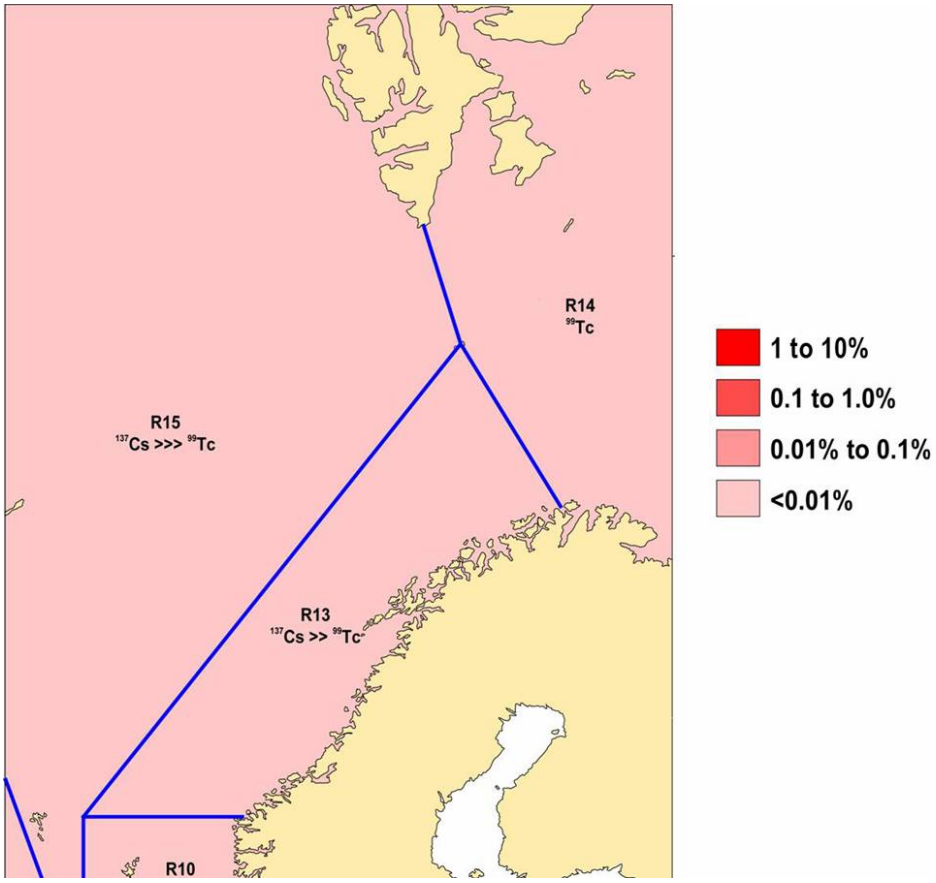


Figure 5.8: *Graphical representation (colour code) of the average maximum total dose rates (sum on detected radionuclides) as a percentage of the screening value of 10 µGy/h for vertebrates (plaice) in the Norwegian Sea and surrounding waters in 2006.*

6 Overall conclusions and next steps

6.1 Background

This Third Periodic Evaluation of Progress towards the Objective of the Radioactive Substances Strategy sets out to answer the questions:

- what are the discharges of radioactive substances to the marine environment?
- what are the consequences of these discharges in terms of environmental concentrations of radionuclides?
- what are the radiological consequences (doses) to the human population of these marine concentrations?
- what are the radiological consequences (doses) to non-human species of these marine concentrations?

In order to provide answers to these questions, the approach taken in this evaluation is to compare baseline values (the means, “averages”, of annual values for the period 1995 to 2001) with values for the assessment period (2002 to 2006). This process has been able to provide clear and robust conclusions for a limited number of discharges from the nuclear industry but, as yet, no firm overall conclusion as to whether the objective of the OSPAR Radioactive Substances Strategy is being delivered, for the following main reasons:

- the short run of data for the assessment period;
- a lack of data on discharges from the non-nuclear sector, which has been insufficient to allow the establishment of a comprehensive baseline element for discharges, concentrations and doses;
- the difficulty of demonstrating clear links between discharges and environmental concentrations due to legacy inputs (weapon testing, the Chernobyl accident, past discharges) and to the time lag between the discharge and resulting concentration;
- the relatively high number of concentration values below limits of detection, which have prevented statistical analysis being undertaken in some cases.

Taking these limitations into account, the following conclusions can be drawn for discharges, concentrations, doses to man and impacts on biota.

6.2 Discharges

In relation to discharges from the nuclear sector:

- There has been a 38% reduction in total-β (excluding H-3) discharges during the assessment period compared with the baseline value and the statistical tests indicate that this change is statistically significant.
- There has been a 15% increase in total-α discharges during the assessment period compared with the baseline value but the statistical tests indicate that this change is not statistically significant.

- Since 2002, reductions have been achieved in discharges of Tc-99, a radionuclide to which both the 1998 and 2003 OSPAR Ministerial Meetings drew special attention. Discharges of Tc-99 are expected to reduce further and be maintained at low levels.

For discharges from the non-nuclear sector, no baseline could be developed and currently it is not possible to draw conclusions on whether the strategy is being delivered effectively. However, there are some indications that appropriate actions are being taken. The phosphate fertiliser industry, which in 1997 was identified as the predominant source of radioactive discharges from the non-nuclear sector, ceased all such discharges prior to 2005, representing a major reduction in discharges of radioactive substances to the marine environment. However, historic discharges from this industry continue to contribute to concentrations of radioactive substances in the marine environment and their resulting doses.

Overall, for discharges, since the evaluation is based on data for only five years (2002 – 2006) and since discharge data for the non-nuclear sector has only been collected by OSPAR since 2005 and is not yet comprehensive for all Contracting Parties, at present, it is not possible to draw any general conclusions on whether the aims of the OSPAR Radioactive Substances Strategy are being delivered. However, there is evidence to suggest that progress is being made towards this objective for the nuclear sector, in particular in significant reductions in total beta discharges from the nuclear sector, including Tc-99 discharges.

6.3 Concentrations

Sufficient data are available for the development of a baseline element for certain aspects of concentrations of radioactive substances, both in seawater and in biota (fish, shellfish, and seaweed). However, baseline values could not be derived for all monitoring areas, radionuclides and all selected biota. Based on the evidence presented, the following conclusions can be drawn:

From the data that are available, the following conclusions can be drawn:

- For seawater concentrations, in 6 out of 27 datasets there has been a statistically significant change (*i.e.* both the Student's t Welch Aspin and Mann-Whitney test probabilities are below 0.05), with the average concentrations in the assessment period being lower than the baseline values. For a further 7 datasets there is some evidence indicating change (*i.e.* either the Student's t Welch Aspin or Mann-Whitney test probability is below 0.05), with 4 instances where the assessment period average is lower than the baseline value and 3 instances where it is higher.
- For concentrations in marine biota, there are eighteen instances of statistically significant changes in marine biota concentrations. In seventeen of these cases the average concentrations in the assessment period were lower than the baseline and for one instance, it was higher (Cs-137 in fish in monitoring area 12). There is also some evidence of change for 4 datasets, with 2 instances where the assessment period average is above the baseline value and 2 instances where it is above).
- Some OSPAR regions are still experiencing elevated concentrations due to outflowing Baltic water that has been contaminated with fallout from the Chernobyl accident or due to remobilisation of radionuclides from Irish Sea sediments as a result of past discharges.
- Overall, due to the limited availability of reported data, in particular for the radionuclides discharged by the non-nuclear sector, it is not possible to come to firm conclusions as to whether the aims of the OSPAR Radioactive Substances Strategy are being delivered.

However, there is an indication of a reduction in average marine concentrations for the radionuclides discharged by the nuclear sector; where the statistical tests indicated a difference between the baseline period and the assessment period, the change was a reduction in every case but one.

6.4 Doses to man

Doses to members of the public have been estimated using two different approaches derived from the MARINA II model. One uses data on concentrations of radionuclides in seawater and the other uses concentrations in biota (fish or molluscs). Both methods follow a conservative approach by only including values above the detection limits.

Although a small number of simple comparisons of the data can be made, which show a possible increase in two datasets and a possible decrease in one dataset, the data are based on the scalar treatment of concentrations data so do not lend themselves to meaningful statistical analysis.

It is nevertheless important to note that all the evidence available suggests that doses to humans from radioactivity linked to the North-East Atlantic are well within (and in the large majority of cases, are a small fraction of) the limits set by the International Commission on Radiological Protection (ICRP) and, where appropriate, comply with the Basic Safety Standards for those Contracting Parties within the European Union. The ICRP dose limits are intended to ensure that no individual is exposed to radiation risks that are judged to be unacceptable in any normal circumstances.

Overall, for doses, sufficient data have been collected to allow a baseline to be established for doses to members of the public from radionuclides discharged by the nuclear sector. All doses calculated to date from concentrations of nuclear sector radionuclides are well below accepted international standards. Doses to man during the assessment period have not been assessed separately against the baseline values but are a scalar function of the respective environmental concentrations from seawater and biota, *i.e.* doses to members of the public decrease when environmental concentrations decrease.

However, because data on environmental concentrations of radionuclides from the non-nuclear sector have not been collected by OSPAR, it is not possible to come to firm conclusions regarding doses to members of the public.

6.5 Impacts on biota

The radionuclides of highest radiotoxicity, and hence greatest significance, have been selected in estimating impacts on biota. This makes it possible to characterise the potential risk to the structure and function of the marine ecosystems in each monitoring area, even though this does not represent the total biological effect of ionising radiation in the OSPAR maritime area.

The dose rates summed for the selected radionuclides can be expressed as a percentage of the ERICA screening value of 10 µGy/h. On this basis, the following can be seen:

Percentage of the screening value (%)	Macroalgae	Invertebrates (crab)	Vertebrates (plaice)
1 to 10	MA6	MA6	-
0.1 to 1	MA1-MA4-MA7-MA8	MA1-MA4-MA7-MA8	MA1-MA7-MA8
0.01 to 0.1	MA2-MA3-MA5-MA10-MA11-MA12-MA13-MA14-MA15	MA2-MA3-MA5-MA11-MA12-MA13	MA2-MA3-MA4-MA5-MA6-MA10-MA11-MA12
< 0.01	MA9	MA9-MA10-MA14-MA15	MA9-MA13-MA14-MA15

Such an assessment indicates that the calculated dose rates to marine biota from the selected radionuclides from the nuclear sector are low and are below the lowest levels at which any effects are likely to occur.

6.6 Overall conclusion of the Third Periodic Evaluation

As an overall conclusion to the Third Periodic Evaluation, because data on non-nuclear discharges have only been collected by OSPAR since 2005, there are as yet insufficient data to enable firm conclusions to be drawn as to whether the objective of the OSPAR Radioactive Substances Strategy is being fully delivered.

However, there is evidence to suggest that progress is being made towards this objective, including:

- a reduction in total beta discharges from the nuclear sector, including Tc-99 discharges;
- an indication of a reduction in average marine concentrations for the radionuclides discharged by the nuclear sector;
- estimated doses to humans within (and in the large majority of cases, well within) international and EU limits;
- an indication that the calculated dose rates to marine biota from the selected radionuclides from the nuclear sector are low and are below the lowest levels at which any effects are likely to occur.

This Third Periodic Evaluation forms part of an integrated series of thematic assessments that together contribute to a wider assessment of the quality status of the marine environment of the OSPAR maritime area.

On the basis of this evaluation, there is some evidence to suggest that the effect of discharges and concentrations of radioactive substances on the overall quality status of the OSPAR maritime area is low.

6.7 Progress to date and next steps

Since the OSPAR Radioactive Substances Strategy was agreed in 1998, the Radioactive Substances Committee has taken important steps to promote and monitor progress towards the objective of the Strategy. These have included:

- regular reporting on the application by Contracting Parties of Best Available Techniques (BAT) to minimise and, as appropriate, eliminate pollution of the marine environment caused by radioactive discharges from nuclear industries;
- the production by each Contracting Party of a national report setting out how it intends to meet the Strategy objective;
- agreeing how progress towards the objective of the Strategy will be measured, against a baseline for discharges of radioactive substances from the nuclear industry, their concentrations in the marine environment and the resulting doses to members of the public;
- the development of a data collection format for data on discharges from the non-nuclear sector from 2005;
- a monitoring agreement identifying 15 monitoring areas and the radionuclides and environmental compartments for which data are to be collected, as a basis for the reporting and evaluation of concentrations of radioactive substances in the OSPAR maritime area;
- the development of appropriate statistical techniques for the evaluation of data relating to radioactive substances, including cases where a relatively large number of values are below the detection limit.

Although RSC has made considerable progress in evaluating the extent to which the objective of the Radioactive Substances Strategy is being met, the limitations noted above demonstrate that further work is needed before a future evaluation of progress can be expected to deliver robust overall conclusions. RSC recommends that its future work should include consideration of ways in which:

- the quantity of data reported by all Contracting Parties on discharges of radioactive substances from the non-nuclear sector could be increased; in particular, reporting from all Contracting Parties on discharges from the medical sub-sector could be improved;
- the presentation of data on discharges from the nuclear sector could be improved, to identify the contributions of exceptional discharges from decommissioning and clean-up and the effects of variability in the level of operation of installations;
- data on concentrations in the marine environment could be improved in terms of availability and of consistency in the use of limits of detection and other measurement protocols; the quantity of data reported by the Contracting Parties on concentrations of naturally-occurring radioactive substances could be improved (this is currently provided voluntarily by Contracting Parties and is outside the scope of the OSPAR monitoring agreement on radioactive substances);and
- more comprehensive estimation of impacts on non-human biota can be achieved.

RSC 2009 will further review reporting arrangements, data management, statistics and quality assurance for concentrations and evaluations of radioactive substances in the marine environment as part of the review of the OSPAR Monitoring Programme for Concentrations of Radioactive Substances in the Marine Environment) (OSPAR, 2005).

References

Adam, C., 2007. Genotoxic effects of radionuclides on aquatic organisms – State of the art and critical review of existing methods. Report DEI/SECRE 2004-022.

Anderson, S., Belfiore N. and Harrison F., 1998. Genotoxic effects in aquatic organisms: methodologies, field-related applications and the role of genetic diversity. S.R. Hansen and associates. Atomic Energy Control Board and Environment Canada.

Basic Safety Standards Directive (96/29/Euratom)

Beresford, N.A. & Howard, B.J. (eds.), 2005. Application of FASSET framework at case study sites. Deliverable for the EC Project F16R-CT-2003-508847 (ERICA). Centre for Ecology and Hydrology, Lancaster.

Beresford, N.A., Balonov, M., Beaugelin-Seiller, K., Børretzen, P., Brown, J., Cheng, J-J., Copplestone, D., Doi, M., Gaschak, S., Golikov, S., Horyna, J., Hosseine, A., Howard, B.J., Jasserand, F., Kamboj, S., Nedveckaite, T., Olyslaegers, G., Sazykina, T., Vives i Batlle, J., Yankovich, T. & Yu, C., 2005. Models and approaches available to estimate the exposure of non-human biota: An international comparison of predictions. In Proceedings of the 2nd International Conference on Radioactivity in the Environment (eds P. Strand, P Børretzen & T. Jølle). p146-149. Norwegian Radiation Protection Authority, Østerås.

Copplestone, Johnson and Jones, 2001. Behaviour and transport of radionuclides in soil and vegetation of a sand dune ecosystem. *Journal of Environmental Radioactivity*. **55** (1). 93-108.

ERICA, 2005. (Adam, C., Agüero, A., Björk, M., Copplestone, D., Jarowska, A., Garnier-Laplace, J., Gilek, M., Larsson, C.M., Oughton D., Pérez Sánchez, D., Salbu, B., Wilkinson, H.). Overview of Ecological Risk Characterization Methodology. Deliverable 4b. European Commission, 6th Framework, Contract N°FI6R-CT-2003-508847. Björk, M. & Gilek, M. (Eds)

ERICA, 2007. D-ERICA: An integrated approach to the assessment and management of environmental risk from ionising radiation. Final Deliverable. European Commission, 6th Framework, Contract N°FI6R-CT-2003-508847. Beresford, N., Brown, J., Copplestone, D., Garnier-Laplace, J., Howard, B., Larsson, C.M., Oughton, D., Pröhl, G., Zinger, I. (Eds).

EURATOM, 2000. Article 5(1). EURATOM Legislation, 2000.

FASSET, 2004. Framework for assessment of environmental impact of ionising radiation in major European ecosystems. Delivrable 6. Euratom, Contract N°FIGE-CT-2000-00102, EC 5th Framework Programme, Larsson CM (Eds). Report nr Deliverable 6. A project within the EC 5th Framework Programme.

Forbes VE, Calow P., 2002. Population growth rate as a basis for ecological risk assessment of toxic chemicals. *Philosophical Transactions of the Royal Society of London Series B Biological Sciences,* **357**(1425):1299-1306.

Garnier-Laplace, Della-Vedova, Gilbin, Copplestone, Hingston, and Ciffroy, 2006 First Derivation of Predicted-No-Effect Values for Freshwater and Terrestrial Ecosystems Exposed to Radioactive Substances *Environ. Sci. Technol.,* **40** (20), 6498 -6505.

Helsel, D.R., 2005. Nondetects and data Analysis. Statistics for censored environmental data.

Hunt and Kershaw, 1990. Remobilisation of artificial radionuclides from the sediment of the Irish Sea. *Journal of Radiological Protection*. **10**, 147-151.

IAEA, International Atomic Energy Agency, 1979. Methodology for Assessing Impacts of Radioactivity on Aquatic Ecosystems. Technical Report Series 190. IAEA Vienna, Austria.

IAEA, International Atomic Energy Agency, 1988. Assessing the Impact of Deep Sea Disposal of Low Level Radioactive Waste on Marine Living Resources. Technical Report Series n°288. IAEA Vienna, Austria.

IAEA, International Atomic Energy Agency, 2003. The president's findings. In: International Conference on the protection of the environment from the effects of ionizing radiation, International Atomic Energy Agency, Vienna, Austria, 2003 .

ICRP, 1991. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60.

ICRP, 2003. A framework for assessing the impact of ionising radiation on non-human species. ICRP Publication 91. Elsevier, 70 Pages, Published October 2003.

ICRP, 2007. Recommendations of the International Commission on Radiological Protection. ICRP Publication 103, Adopted by the main commission in March 2007.

Jones and Gilek, 2004. Overview of programmes for the assessment of risks to the environment from ionising radiation and hazardous chemicals *J. Radiol. Prot.* **24** A157-A177.

Köster, Marwitz, Berge, van Weers, Hagel & Nieuwenhuize, 1992. Po-210, Pb-210, Ra-226 in aquatic ecosystems and polders, anthropogenic sources, distribution and enhanced radiation doses in the Netherlands. *Radiation Protection Dosimetry* **45** (1-4). 715-719.

Lee, L., and Helsel, D., 2007. Statistical analysis of water-quality data containing multiple detection limits II: S-language software for nonparametric distribution modelling and hypothesis testing. *Computers & Geosciences* 33:696-704.

Leonard, K. S., McCubbin, D., Blowers, P. & Taylor B.R., 1999. Dissolved Plutonium and Americium in surface waters of the Irish Sea. J. Environ. Radioact. 44 129-158.

National Council on Radiation Protection, 1991. Effects of ionizing radiation on aquatic organisms. NCRP report n°109, Bethesda, USA, 115

NPRA, 2006. Radioactivity in the Marine Environment (2004). Results from the Norwegian National Monitoring programme (RAME). NRPA report 2006:14 Østerås.

NRPA Unpublished monitoring data

MARINA II. European Commission (2003). Update of the MARINA Project on the radiological exposure of the European Community from radioactivity in North European marine waters.

OSPAR, 1972. Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft, Oslo, 15 February 1972.

OSPAR, 1974. Convention for the Prevention of Marine Pollution from Land-Based Sources, Paris, 4 June 1974.

OSPAR, 1992. OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, Paris, 22 September 1992.

OSPAR, 1997. Discharges of Radioactive Substances by Non-Nuclear Industries/ Rejets de substances radioactives par les industries non-nucléaires, Publication 1997/68, ISBN 0 946955 65 4.

OSPAR, 2001a. Programme for the More Detailed Implementation of the OSPAR Strategy with regard to Radioactive Substances. OSPAR Agreement 2001-03.

OSPAR, 2001b. OSPAR Recommendation 2001/1 on the Management of Produced Water.

OSPAR, 2002a. Discharges of radioactive substances into the maritime area by non-nuclear industry. Publication No. 161/2002.

OSPAR, 2002b. OSPAR Coordinated Environmental Monitoring Programme (CEMP). OSPAR Agreement 2008-08.

OSPAR, 2003a. OSPAR Radioactive Substances Strategy In: Revised Strategies of the OSPAR Commission for the Protection of the Marine Environment of the North East Atlantic. OSPAR Agreement 2003-21.

OSPAR, 2003b. Strategy for a Joint Assessment and Monitoring Programme (JAMP). OSPAR Agreement 2003-22.

OSPAR, 2005. OSPAR Monitoring Programme for Concentrations of Radioactive Substances in the Marine Environment. OSPAR Agreement 2005-8.

OSPAR, 2006. Revised First Periodic Evaluation of Progress towards the Objective of the OSPAR Radioactive Substances Strategy (JAMP product RA-1). Publication 302/2006.

OSPAR, 2007. Second Periodic Evaluation of Progress towards the Objective of the OSPAR Radioactive Substances Strategy (JAMP product RA-2). Publication 338/2007.

OSPAR, 2008a. Assessment on Impact of Anthropogenic Sources of Radioactive Substances on Marine Biota. Publication 381/2008.

OSPAR, 2008b. OSPAR Report on Discharges, Spills and Emissions from Offshore Oil and Gas Installations in 2006. Publication 380/2008.

OSPAR, 2008c. Assessment of the 4th Round of Reporting on the Implementation of PARCOM Recommendation 91/4 on radioactive discharges. Publication 351/2008.

OSPAR, 2009a. Assessment on Statistical techniques applicable to the OSPAR Radioactive Substances Strategy. Publication 454/2009.

OSPAR, 2009b. Discharges of radioactive substances for the non-nuclear. Publication 457/2009.

OSPAR, 2009c. Liquid discharges from the nuclear installations in 2007. Publication 456/2009.

Plater A.J., Ivanovich M. & Dugdale R.E., 1995. Ra-226 contents and Ra-228/Ra-226 activity ratios of Fenland rivers and the Wash, Eastern England: Spatial and seasonal trends. Chemical Geology 199(1-4): 275-292.

Pröhl, G., Brown, J., Gomez-Ros, J.-M., Jones, S., Woodhead, D., Vives, J., Taranenko, V., Thørring, H., 2003. Dosimetric models and data for assessing radiation exposure to biota. Deliverable 3 to the Project “FASSET” Framework for the assessment of Environmental Impact, contract No. FIGE-CT-2000-00102. Swedish Radiation Protection Authority.

Suter, 1993. A critique of ecosystem health concepts and indexes. *Environmental Toxicology and Chemistry* **12** (9) 3–1539.

Suter, Efroymson, Sample, and Jones, 2000. Ecological risk assessment for contaminated sites. *Lewis Publishers, Boca Raton,* pp438.

Schmidt J.-L., Reyss, F., Landré & Boust D., 1998. Distributions and fluxes of Ra-226 and Ra-228 in the Irish Sea and in the English Channel, in relation to hydrological conditions and sediment interactions. *Radiation Protection Dosimetry* **75**(1-4): 65-67.

Spencer, Bacon & Brewer, 1980. The distribution of Pb-210 and Po-210 in the North Sea. *Thalassia Jugosl*. **16**: 125-154.

UNSCEAR, 1996. Sources and Effects of Ionizing Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the General Assembly, with scientific annex. United Nations sales publication E.96.IX.3. United Nations, New York.

UNSCEAR (in preparation). Effects of ionizing radiation on non-human biota. United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the General Assembly, United Nations, New YorkUSEPA, United States Environmental Protection Agency (1998). Guidelines for Ecological Risk Assessment. EPA/630/R-95/002F. US EPA, Washington DC, USA.

Woodhead, 2003 .A possible approach for the assessment of radiation effects on populations of wild organisms in radionuclide-contaminated environments? *Journal of Environmental Radioactivity* **66**, (1-2), 81-213.

Glossary of terms and acronyms

AGR oxide fuel – Advanced gas cooled reactor with uranium dioxide-based fuel.

Anthropogenic – Resulting from any human activity

BAT – Best Available Technique

Biota – Any non-human species.

ERICA – Environmental Risk from Ionising Contaminants: Assessment and Management.

EPIC – Environmental Protection from Ionising Contaminants

FASSET – Framework for the Assessment of Environmental Impact

FRED – The FASSET Radiation Effects Database

IAEA – **International Atomic Energy Agency**

IAEA EMRAS – International Atomic Energy Agency Environmental Modelling for Radiation Safety

ICRP – International Commission on Radiological Protection

IUR – **International Union of Radioecology**

LET – Linear Energy Transfer

LWR – Light Water Reactor

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

NRP – Nuclear fuel reprocessing plant

OECD – **Organisation for Economic Cooperation and Development**

PNEC – Predicted no effect concentration

PWR– Pressurised Water Reactor

RBE – Relative Biological Effectiveness

RO – Reference Organisms

RSC – Radioactive Substances Committee

RWF – Radioactive Weighting Factor

UNSCEAR – United Nations Scientific Committee on the Effects of Atomic Radiation

Units for radiation and doses:

Bq	Becquerel
MBq	Megabecquerel
TBq	Terabecquerel
mSv/yr	Millisieverts per year, a measure of equivalent dose
µSv/yr	Microsieverts per year (1 mSv = 1000 µSv)
µGy/h	Micrograys per hour, a measure of absorbed dose rate

Annex 1 – Summary of statistical methods used in the Periodic Evaluations

Introduction

OSPAR 2006 adopted the First Periodic Evaluation of Progress towards the Objective of the OSPAR Radioactive Substances Strategy (concerning progressive and substantial reductions in discharges of radioactive substances, as compared with the agreed baseline) (OSPAR, 2006). The Second Periodic Evaluation concerns concentrations in the environment as compared with the agreed baseline and includes an assessment (for those regions where information is available) of the exposure of humans to radiation from pathways involving the marine environment (OSPAR, 2007). In 2007, RSC established an Intersessional Correspondence Group (ICG-Stats) to further consider statistical techniques to be used in future OSPAR Periodic Evaluation Reports, firstly for this Overall Assessment of Radionuclides in the OSPAR maritime area (the Third Periodic Evaluation). Recommendations from RSC have been published in the assessment on statistical techniques applicable to the OSPAR radioactive substances strategy (OSPAR, 2009a).

This annex summarises the key points relating to statistical treatment as set out in the First Periodic Evaluation, supplemented by recommendations from ICG-Stats.

PART I – Techniques employed for the First and Second Periodic Evaluations.

Background to the statistical approach

The Programme for the Further Implementation of the Radioactive Substances Strategy required a baseline to be established as a fixed point against which to measure progress. Comparisons with this baseline are therefore the primary method to measure progress. Techniques of the kind which are used in other OSPAR fields should be used to investigate the presence of trends, such that there is a common approach to the implementation of all the OSPAR strategies.

Whether the focus is on comparison with the baseline, or on examining for the presence and nature of a trend, the aim is to establish, for a chosen level of probability, whether there is a difference between the data for the earlier years (*i.e.* the baseline element) and the data for the later years. That is, the null hypothesis (H0) to be tested is that there is ***no*** difference between the earlier data and the later data, as against the positive hypothesis (H1), that there ***is*** a difference. The risks that must be guarded against are the two different types of error:

- ***Type I error*** – concluding that there is a difference (or trend) when in truth there is no difference (or trend); and
- ***Type II error*** – concluding that there is no difference (or trend) when in truth there is a difference (or trend).

Comparison with the baseline element

OSPAR has agreed that the baseline element is to be the mean (average) of the observed values for the years 1995 to 2001, with an […] interval centred on this mean of 1.96 times the standard deviation, giving a “bracket”. This “bracket” would contain 95% of the observed discharge values if they were normally distributed.

Comparing subsequent data with a baseline (especially a baseline constructed from several years' data) is fundamentally different from examining data for the presence and nature of a trend. The nearest statistical analogy is with considering samples to see whether they have been drawn from statistically significantly different populations. In effect, the data from which the baseline has been derived are considered as one sample, and the question is whether the subsequent data are from the same population or from a different one. If the true levels (of discharges, concentrations or doses) have changed sufficiently, they can be regarded as a different population. The question is to define the criterion to be used to justify the conclusion that the two samples come from a single, homogeneous population or not, as well as the way this criterion should be used.

Population and sample

A very large population of individuals may be characterised by some measurement. The measurement can be anything from a length or a surface area to an age, or any other characteristic that can be summarised by a value. A sample of this population is just a set of individuals characterised by their measurement. These individuals are chosen at random in the population and independently of the measurement […]. The measurements in the sample are random variables, but it should be clear that in some sense they behave in the same way because they are sampled from the same population. We say that they are independent and identically distributed (IID).

To understand why this description applies to the successive discharge levels, for instance, we use an analogy. Suppose that the discharge levels were in fact the output of a very complex machine. Then (if the machine did not change with time), the first seven outputs of this machine can be considered as a sample from a population of a very large number of outputs of this machine. The sample that we have in mind in what follows consists of the successive discharge levels for the years 1995 to 2001 (so the size of this sample is 7).

True and empirical mean

An important element that characterises the population as well as the sample is their respective arithmetical mean. There is no reason why these two values should be identical. Although it is not very probable, it could be the case that the measurements selected for the sample are all unusually large, or unusually small, and the mean of the observations of the sample would then be larger or smaller than the mean of the values of the population. Thus we have to distinguish between the *true mean* (μ) which is the mean of the population, and the *sample mean* or *empirical mean* (***m***) which is the mean of the sample. As the sample gets larger and larger, ***m*** should approach μ.

Usually, the characteristics of the sample are known, whereas the characteristics of the underlying population are unknown (for instance because it would need an infinite number of observations to know them). The aim is to estimate these unknown characteristics. In such case, ***m*** is said to be the estimator of μ.

It is the best (though imperfect) immediate knowledge that we have of μ.

Though ***m*** is an actual known value, it has to be considered as a random value, since it depends on the values of the sample that have been chosen at random among the whole population (another sample set would select other individuals, and so ***m*** would be different).

Standard deviation

The mean value μ of the measurements is not the only value that is needed to describe a set of measurements. We also need to describe how the measurements are spread out around their mean μ. Are they scattered far away from μ, or do they cluster very closely around μ? This aspect of the distribution of the measurements is described by their "standard deviation". As for

the mean, there is a *true* standard deviation for the population (σ) and an *empirical* standard deviation (***s***) for the sample. For the same reasons as for the mean, ***s*** is an estimator of σ.

Normal (Gaussian) distribution

Many random natural or usual phenomena can be modelled with the help of the normal (or Gaussian) distribution, which is characterised by its well-known bell shape when presented graphically. A Gaussian distribution is completely characterised by its mean μ and its standard deviation σ, which define respectively the position and the width of the bell.

There are two rationales for supposing that the observations in OSPAR discharge samples are Gaussian:

- Levels of discharge are the sum of many small causes; hence the Gaussian approximation might be a reasonable choice.
- There is very little loss of generality in making this choice because results that are true for Gaussian populations can be extended to the populations of other distributions when these are large enough.

For OSPAR concentration samples, other considerations (for example, where the baseline value has been calculated using all or some/most results below analytical detection limits) may lead to considering that the Gaussian approximation applies to the logarithm of the observations instead of the concentration samples themselves.

Gaussian distribution: prediction interval and confidence interval

Considering a range of values according to a Gaussian distribution, if the true mean μ and the true standard deviation σ were known we could then be sure that 95% of the values have or will (under the same conditions) fall in the prediction interval $PI = [\mu - 1.96\sigma ; \mu + 1.96\sigma]$. This results from the properties of the Gaussian distribution. This interval is called the *true* prediction interval.

However, the true values of μ and σ are generally not known and *PI* can only be estimated. As ***m*** and ***s*** are themselves random values, the determination of the interval is not a straightforward matter. Taking $PI = [m - 1.96s; m + 1.96s]$ is *not* the best choice because it has the same radius (*i.e.* half-width) as if ***m*** and ***s*** were the true values, which is not the case. Instead, one should choose an interval still centred on ***m*** but with a larger radius in order to take into account the further independent variability of ***m*** and ***s***.

The *prediction interval* (*PI*) should not be confused with the *confidence interval* around the mean (*CI*).The 95% confidence interval (*CI*) about the mean is defined as the interval such that there is a 95% probability that the true mean μ falls within it. The confidence interval gives a better knowledge of the unknown value of μ. There are problems in using it in relation to the values of past observations or future predictions.

It is intuitively clear that there is much more uncertainty about the size of the next measured value than about the true mean μ (the larger the sample, the more precise is our estimation of μ, but our prediction for the next measured value will not get any better). This is why *PI* is much larger that *CI*. But above all, it must be remembered that *PI* and *CI* are not of the same nature: *PI* is the prediction interval of an isolated observation performed in the same conditions as the ones in the sample, *CI* is the confidence interval of the unknown value of the true mean μ of the whole population (both for a given level of probability).

How to compare new observations with the baseline element

Suppose now that we consider a second sample of observations (for instance, the second sample contains the levels of discharge for years from 2002 to a subsequent year). We suppose that those two samples are both Gaussian (they are made of independent and identically distributed observations following a Gaussian distribution). They may come from different populations having different true characteristics, *i.e.* the true mean μ1 of the first population may be different from the true mean μ2 of the second population. We want to test whether the true means are equal (μ1=μ2) at a given probability level, generally chosen to be equal to 95%. We postulate that there is no statistically significant difference between them unless the two samples are so different that we must reject this hypothesis. This way of proceeding, as opposed to the assumption that there is a statistically significant difference, is the one that minimises the risk of errors of type I (a difference is detected when there is no statistically significant difference).

OSPAR has defined baseline elements based on the values from the reference period 1995 – 2001. The point value of each baseline element is obviously ***m***, the empirical mean of the reference sample. The question remains of how to use the empirical standard deviation of the reference sample in the comparison of a subsequent sample with the baseline element. To answer it, we must define with precision the method by which we compare the observations in the subsequent sample with the baseline element.

Simple comparison

The first approach is to make a simple comparison: that is, we will simply compare the observations, suitably averaged, of the second sample to the baseline element. Then we should use the prediction interval of an isolated observation performed in the same conditions as the ones in the reference sample: PI, computed with the reference sample values 1995 – 2001.

We will look at each average level of discharge from the baseline period to whatever is the subsequent assessment period chosen, and check whether it falls within PI or not. The idea is that if there has been no statistically significant change in the levels of discharge, there is a good probability that subsequent observations will fall within PI, whereas a true change in these levels should result in subsequent observations lying outside of this interval.

Under the hypothesis that no change has happened, we know that the probability for one given subsequent observation falling outside PI is at most 5%. So observing this improbable event might well be the sign that our hypothesis is false and that a change has happened.

The problem is that there is no clear way of interpreting globally several observations of the second sample. The prediction interval of an isolated observation does not give any information on this kind of combination. For instance, what would be the conclusion if only one or two of the observations of the second sample were below the prediction interval PI? Could we conclude that there is a statistically significant decrease between the two samples? The answer is no. Even if no change has happened, for a second sample of 7 observations, for example, the probability that at least one of the observations of the second sample will fall outside of PI can be as important as (1− 95%)7 = 30%. Hence the chances that we would conclude that progress has been made even though this is false (a Type I error), would be approximately one in three, which is not acceptable.

In conclusion, the simple comparison method described above is not very sensitive, and it includes a major risk of type I error. This method should, therefore, only be used as a first simple indicator for the comparison of individual annual releases with the baseline. Because of its serious limitations, other, more precise, methods are more appropriately used.

Nevertheless, since the “bracket” was included in the baseline agreed by the 2003 Ministerial Meeting of the OSPAR Commission, it has been retained as a method of comparison. Because the baseline “bracket” was not calculated in the way described above for the PI, any comparison with it cannot be described as giving “statistically significant” results. In the sections where simple comparisons can be made, therefore, the results have been described as indicating (or not) some evidence of a change (reduction or increase).

Other comparison methods

An efficient comparison of two samples to detect a potential difference between them requires us to treat the second sample as a whole, and to use all the information it contains.

The only values we can compare are the empirical means m1 and m2 of the two samples. As we have to take into account the fact that these two values are random variables (they depend on a selection of the observations in the respective samples that is made at random), we have to take into account the confidence intervals of both samples. Because there is a high probability (95%) that each of the two empirical means is within its respective confidence interval, we can reject the hypothesis that the two means are equal if the two confidence intervals have no common part (that is, do not intersect).

Comparison methods can be divided into parametric methods and non-parametric methods. The difference between the two sets of methods is that parametric methods need to make assumptions about the nature (parameters) of the two data sets that are being compared. The non-parametric methods do not. The assumption that is most usually made in parametric methods of comparison is that both samples are drawn from two populations where the variables are independent and share an identical normal distribution.

For both types of comparison, it is necessary to assume that within each of the two samples the observations are independent and randomly distributed; that is, that the value of one observation has no influence on the value of the other observations of the same sample.

Parametric methods can be more powerful, in the sense that they can give clearer answers with less data. However, they run the risk that, because they make assumptions that may not be justified, the answers, although clear, may be wrong. Thus they are more likely to lead to a Type I mistake (asserting a difference when it does not, in truth, exist). Non-parametric methods are more robust, in the sense that, when they give an answer that there is a difference between the two samples, they are less likely to be wrong. They are therefore more likely to lead to a Type II mistake (denying a difference when, in truth, it exists).

The classic parametric test for whether two samples are drawn from populations with different characteristics is one of the forms of the Student’s ‘t’ test. This test is parametric and assumes that the populations underlying the two samples have variables that are normally distributed. There are different versions of the t-test depending on whether the two samples are:

- Independent of each other (for example, individuals randomly assigned into two groups).

or

- Paired, so that each member of one sample has a unique relationship with a particular member of the other sample (for example, the same value measured before and after an intervention).

The comparison being made here is between two populations where the members of each population are not related to each other. The comparison is between the observations in the baseline period, and the observations since the baseline period. It is the unpaired test which is therefore appropriate.

There are two forms of the unpaired test: the homoscedastic, where the variances of the two populations are or are assumed to be) the same, and the heteroscedastic, where the variances of the two populations are (or are assumed to be) different. Using the homoscedastic form if the variances are not the same could lead to a Type I error. In the comparison being made here, there is no reason to think that the variances are the same; therefore, the heteroscedastic form seems more appropriate, and has been chosen for use as the parametric test.

The statistic "t" can then be judged against the calculated probability distribution of 't', which has a distribution varying according to the number of "degrees of freedom". The degrees of freedom are the number of variables that can have different values; essentially, the larger the sample, the larger the number of degrees of freedom. The distribution of 't' is specified in terms of the degrees of freedom and not in terms of the mean or variance of the sample. It is therefore invariant between comparisons, and can be calculated in a table or by a computer. The larger the number of degrees of freedom, the nearer the distribution of 't' approaches the normal distribution.

The t-test offers a very simple and rigorous way to test with a single computation whether or not we can reject the hypothesis that no change has happened ($\mu 1=\mu 2$) while controlling precisely the risk of being wrong when we choose to reject it (Type I error). However, this test in its general form can be regarded as not entirely suited to the present evaluation, since both there can be no discharge values less than zero (the distribution of the data may be a truncated normal distribution) and the number of data points available in the sample is very small. At this stage, nevertheless, the broad-brush results of the general Student's t-test have been used to facilitate progress. The results of the Student's t-test must, however, be regarded with some caution.

For the non-parametric comparison methods, a widely used method is the Wilcoxon rank-sum test (also known as the Wilcoxon-Mann-Whitney test). This test is mathematically equivalent to the Mann-Whitney U statistic test and belongs to the wider family of the rank test which comprise Kendall's Tau or S test. This group of tests is most appropriate when it is desired to see whether the means of two samples represent different populations and no assumption is (or can be) made on how the observations are distributed.

These tests do not use directly the estimators ***m*** and ***s***, though they implicitly take into account the average level of the values and their scatter. The most widely used are called rank tests, because they are based on the values of the rank of the observations sorted by size.

The Wilcoxon rank-sum test is carried out by ranking the combined data set of the two samples in ascending sequence, and assigning a rank to each data element (1, 2, 3…), irrespective of the sample to which it belongs. If two or more data elements are equal, they are given their average rank. The ranks for the data elements of the smaller of the two samples (or either sample if they have the same number of data elements) are then summed to give the statistic 'Wrs' (the rank-sum). For small samples, Wrs is compared to what would result if the data were ranked in a single data set and assigned at random to two groups having the same number of observations as the original samples. The random-assignment calculation gives a probability α for any given rank sum for two samples of the given sizes. If the probability α for the rank-sum calculated is less than the chosen probability cut-off level (normally 0.05, or 5%), then the null hypothesis should be rejected, and the conclusion should be that the two samples are from different populations.

Widespread Wilcoxon Rank-Sum tables give directly, for a given level of probability and for each pair of numbers of observations in each sample, a range of values defined by a lower tail LT and an upper tail UT. If the sum of the ranks of the smaller sample falls in this range, there is no statistically significant difference between the samples, with the given probability. If the sum

of the ranks of the smaller sample falls outside this range, there is a statistically significant difference between the samples, with the given probability.

The equivalent Mann-Whitney method uses the statistic U, which is defined as follows. First, we form all the possible pairs of observations between the observations in each sample (pairing each observation in one sample with all the observations in the other. (If the sizes of the samples are respectively n1 and n2 there are n1 x n2 possible pairs). Then the statistic U is simply the number of those pairs where the observation belonging to the first sample is smaller than the observation belonging to the second sample (the order is arbitrary). This approach is resistant to being over-influenced by outliers (since it deals in ranks, rather than absolute values), but has the weakness that it does not recognise trends that are not monotonic (that is, trends that change from positive to negative or vice versa) and therefore slope in more than one direction). For reasons of availability of the software, the Mann-Whitney U-statistic was used in the first Periodic Evaluation.

By comparison of the U-statistic with the a priori probabilities calculated for the U-statistic, a probability is derived that the two populations being compared are the same. If, for example, this probability is below 0.05, then there is a 95% or greater probability that the two populations are different.

These ranking tests are more robust than parametric methods: that is to say, they are more likely to lead to Type II errors than to Type I errors that should be prevented. These methods can be selected as another reference for the comparison of a sample of subsequent values with the OSPAR baseline element for discharges.

Trend identification

Trend-detection methods also can be divided between parametric and non-parametric approaches. In both cases, the aim is to treat the whole set of available data (including the baseline data) as a single sample, and to see whether a trend (downward or upward) can be identified over time (this issue being fundamentally different from the objective of the radioactive strategy that requires the comparison of a sample of subsequent values to the baseline element sample).

OSPAR has used a number of techniques to identify trends in the data which it has collected and which are relevant to the Hazardous Substances Strategy and the Eutrophication Strategy. Thorough assessments of this work were adopted for publication in 2005, covering the Comprehensive Atmospheric Monitoring Programme (CAMP), the Comprehensive Environmental Monitoring Programme (CEMP) and the Riverine and Direct Inputs Study (RID). For example, the CEMP assessment examined 2772 time-series of observations of hazardous substances in biota (fish and shellfish), and 9151 time-series of hazardous substances in sediments. These time-series varied in length from 3 to 25 years. Statistically significant trends, showing either increasing or decreasing concentrations, were found in 962 time-series. The large majority of these, 688 (72%) showed downward trends. 274 (28%) showed increasing trends.

The statistical methods used for these assessments were developed over several meetings of the OSPAR Working Group on Monitoring. They have responded to the need to be:

- ***Robust*** – that is, to be both routinely applicable to many data-sets and as insensitive as possible to statistical assumptions
- ***Intuitive*** – that is, for the results of the analysis to be understandable without a detailed understanding of statistical theory;

- ***Revealing*** – that is, to provide easy access to several layers of information about the major features of the data.

For each time series with 7 or more years, trends were summarised by a loess smoother, a nonparametric curve fitted to the annual data. This summary was supported by a formal statistical test of the significance of the fitted smoother, and by tests of the linear and non-linear components of the trend. Few statistical assumptions are required for the fitted smoother to be valid. Mainly, the annual contaminant indices should be independent with a constant level of variability. The validity of the statistical tests also requires the residuals from the fitted model to be normally distributed.

A simpler analysis was adopted for time series with fewer than 7 years. For time series of 3 or 4 years, the average of the annual data was computed. For time series of 5 or 6 years, a linear regression was fitted to the annual data and the significance of the linear trend assessed.

Linear regression is the simplest form of estimating a trend. It proceeds by establishing the line through the scatter of data which produces the smallest sum of the squares of the deviations of the individual data elements from the line. Its weaknesses are primarily the fact that (because of the squaring) it can be over-influenced by outlying values, and that the trend line developed may be misleading because of oversimplification.

If it is possible to assume that the characteristics of the sample are independent, identically distributed, random variables with a centred normal distribution, the limits of the confidence interval of the slope can be used to determine significance. If both limits are positive or negative, then the conclusion can be that there is a statistically significant trend (upwards or downwards). If one limit is negative and the other positive, then there is no statistically significant trend.

The loess smoothers operate by using low-level polynomial functions (usually linear or quadratic) to fit curves to small sections of the data, and then integrating these small sections to produce a smooth, but not necessarily simple, curve.

Other forms of trend detector and trend estimator can be used:

- ***Trend-y-tector:*** this is a programme developed under the auspices of OSPAR. The most notable feature is the trend-estimation aspect. The consideration started from the observation that in water-pollution data, the distribution was commonly non-normal; the “tails” above and below the 1 or 2 standard-deviation boundaries were commonly larger than in a normal distribution. Alternative approaches were therefore considered for this aspect of trend estimation.
- ***Theil slope:*** this is a non-parametric method of detecting and estimating a linear trend. It is applied by calculating the slopes of the lines joining every possible pair of data elements in the time series and then taking the median of all these slopes. It is generally considered less powerful than the loess smoother.
- ***Ranking tests:*** Non-parametric methods based on the idea of ranking data are also available, such as Spearman’s rank correlation coefficient and the Mann-Kendall rank correlation statistic (or S-test).

These have, however, not been used in the major assessments in other OSPAR fields.

Summary of statistical techniques used for the First and Second Periodic Evaluations.

It is not sensible to make an a priori selection of comparison methods or trend detection techniques, since each has advantages and disadvantages.

Subject to the qualifications expressed regarding the Student's t-test, both Student's heteroscedastic two-sided non-paired t-test and Mann-Whitney U statistic (or the equivalent Wilcoxon-Mann-Whitney test) can be selected for the comparison of a sample of subsequent values with the OSPAR baseline element for discharges. The selection of two different methods is a complementary guarantee against the risk of Type I errors, since there is very little probability that data which would challenge one of the methods would challenge the other. As a result, this leaves open the possibility of finding discrepancies between the outputs of these methods. The likely conclusion, in such a case, will be that the difference between the two samples is very near to the limit of significance, without the possibility of deciding on which side it lies.

In the longer term, it will promote a consistent approach to all OSPAR strategies if techniques similar to those used for the CAMP, CEMP and RID assessments are used as a secondary method to look at the existence and scale of trends. This, however, requires methods that keep the global nature of the baseline element and probably a longer run of observations than is available for this first evaluation. Trend assessment has not therefore been attempted.

PART II – The work and recommendations of ICG-Stats

Introduction

The Intersessional Correspondence Group (ICG-Stats) comprises France (lead), Ireland, Norway, the United Kingdom and the World Nuclear Association. RSC 2007 agreed that this ICG should further consider applicable statistical techniques. In particular this should focus on trend analysis and appropriate methodologies for treatment of results where relatively large numbers of values are below the detection limit.

The ICG was asked to prepare a report that serves to strengthen the statistical analysis of radioactive substances to be applied by RSC, which should be available to the Overall Assessment of Radionuclides in the Third Periodic Evaluation. The report was to include:

- Identification of problems, including:
  i. Difficulties associated with the interpretation of means in certain instances;
  ii. Recognition of significant differences in the order of magnitude of data submitted by different Contracting Parties;
  iii. Acknowledgment that, with time, additional data points make trend analysis valid;
  iv. Insufficient data.
- A selection of acceptable methodologies. This should also advise on, for example:
  v. How many position data points are needed to achieve statistical significance in different circumstances;
  vi. Those methodologies appropriate to different contexts;
- Example or trial applications, for at least one OSPAR Region for concentrations and one nuclear sector for discharges, that would be indicative of what any statistical application can achieve in practice.
- Production of guidelines for the statistical analysis of future assessments.

Identification of problems

As required by the Programme for More Detailed Implementation of the Strategy with regard to Radioactive Substances (the “RSS Implementation Programme”), the main statistical data processing used in the First and Second Periodic Evaluations consists of comparing the assessment period 2002 – 2005 with baseline elements corresponding to the reference period 1995 – 2001. Both periods are characterised by a mean value with the associated standard deviation, and statistical tests are performed to compare the two mean values at a given level of confidence.

Difficulties associated with the interpretation of means in certain instances

Time series measurements of radionuclide concentrations in compartments of the marine environment provided by Contracting Parties (CPs) may include indeterminate values when the concentrations are below the measurement detection limits (DL). Those data are reported as "< DL value" (the DL value being determined for each measurement), which means that the actual radionuclide concentration value is somewhere between zero and the DL value. Such data are referred to as "non-detects values". When data include non-detects values (<DL), annual means are derived by substituting the non-detects value by the value of the DL itself. This precluded any statistical analysis to assess the significance of observed differences. Dealing with those data is further complicated because DL values are not constant within each dataset and between different datasets. Last but not least, the proportion of non-detects values in datasets is highly variable, depending on locations, compartments and radionuclides.

A summary of strategies proposed by United States Environmental Protection Agency (EPA) and International Council for the Exploration of the Sea (ICES WGSAEM Report 2007) to deal with non-detect data has been produced. In summary, these strategies generally recommend either to discard non-detect values when they carry little information because they are far above actual concentrations, or to substitute non-detect values by the DL values (or DL/2 value). The ICG-Stats does not agree with these recommendations because they have been shown to introduce some important bias in many circumstances.

In the Second Periodic Evaluation, when present in datasets, non-detects values are substituted by the LD values itself and the resulting mean values are preceded by the "<" sign (lower-than) with no component to describe variability. Beside the considerable bias introduced when LD values are far above actual concentration levels, such mean values cannot be compared statistically. For example, data provided for OSPAR Regions 1, 2 and 3, corresponding to French coasts, do not allow estimating the changes in radionuclide concentrations between the baseline and the assessment periods. This methodology, which consists in substituting non-detects values by LD values, is highly controversial. More relevant and consistent methods are available.

Acknowledgment that, with time, additional data points make trend analysis valid

Trend analysis is a statistical approach that could be applicable to radioactive substances, in addition to the comparison of means and ranking tests. However it should be noted that trend analysis will consider data with a time resolution of a year (for discharge data) or less (a month if such data are available for discharges or exact day of sampling for concentrations). It may require using all available data from 1995 to 2005. The method would explore the presence, or otherwise, of trends in the data. There would be no distinction made between the baseline and assessment period. Trend analysis would form a complementary approach which could be carried out in parallel with the comparison of means.

As there would be no distinction made between the baseline and assessment period, and no evaluation against the agreed baseline, it should be pointed out that such methods do not agree with the Programme for More Detailed Implementation of the Strategy with regard to Radioactive Substances (the “RSS Implementation Programme”). On the other hand, it should be recognised that an evaluation period from 1995 would coincide with the addition of the baseline period and the assessment period selected by OSPAR in the RSS Implementation programme.

Trend analysis could form a complementary approach which could be assessed in more detail by the RSC in order to be proposed at the next Ministerial meeting for implementation within the Implementation Programme for future evaluations when additional data points make it valid.

Insufficient data

There are definitely some cases where the quantity of data is not sufficient to perform any assessment. They include, for example, monitoring areas where there are no data available for the baseline, or datasets where the vast majority of data are non-detects values.

There are cases where data are not sufficient to date to perform an assessment. They include the inputs of radioactive substances to the sea from the offshore oil and gas industry de-scaling operations. Data are being collected which will make assessments possible in the future.

There are cases where data are not detailed enough to perform an assessment but where the addition of realistic assumptions make assessments possible. They include the inputs of radioactive substances to the sea from the offshore oil and gas industry from discharges of produced water and displacement water. For the latter discharges, estimated average daily quantities of discharges of produced water and displacement water have been published for

each year from 1996. Assuming that the average concentrations of the U-238 and Th-232 decay chains (for example, the longer lived radionuclides Pb-210, Po-210, Ra-226 and Ra-228) remain fairly constant over the long term (as it is suggested by measurements reported by Norway in the First Periodic Evaluation), statistical techniques may be used to assess the trend of the inputs of radioactive substances to the sea from the offshore oil and gas industry from discharges of produced water and displacement water. This should also be assessed in more detail by the RSC.

Selection of acceptable methodologies

Proposed method to deal with datasets including non-detect values

The methods proposed by ICG-Stats to deal with datasets which include non-detects values (< DL) come from recent works by environment scientists, Dr Dennis Helsel and co-workers, published in the book "Nondetects And Data Analysis: Statistics for Censored Environmental Data" (Helsel, 2005). The statistical techniques are inspired by those widely used in the fields of medical sciences or in systems-engineering (reliability analysis) (Lee and Helsel, 2007).

The authors recommend considering two cases, depending on the proportion of non-detects values present in the dataset:

- Up to 80% of non-detects values.
- More than 80% of non-detects values.

These methods can be used to describe the datasets with relevant statistical parameters and to make comparisons amongst datasets, for example, the baseline and the assessment period datasets.

Methodologies appropriate to different contexts

Three distinct contexts may now be identified:

- Dataset including NO non-detect values (<DL).The methodology adopted in the First and Second Periodic Evaluations is kept (comparisons of means from the assessment period with the baseline using statistical parametric test and ranking of the two samples using non-parametric statistical test).
- Dataset including up to 80% non-detect values (<DL). The methods published in Helsel (2005) are proposed.
- Dataset including more that 80% non-detect values (<DL). Data are considered as insufficient and no assessment is performed.

Trend identification techniques

Trend identification techniques have been discussed several times in the context of OSPAR. A number of statistical tests have been identified as possibly being using for the Radioactive Substances Strategy. These include: Kendall's Tau Correlation, Mann-Kendall test, Theil Slope test, Pearson's Correlation, Model Utility Test for Simple Linear Regression Model, Spearman Correlation, Independent two sample heteroscedastic "t" test, Wilcoxon Rank Sum test, Mann-Whitney test, Fryer and Nicholson Lowess test , and Lag 1 autocorrelation test. They can be divided in two categories: comparison of means between two periods; and trend analysis on the whole period.

In accordance with the RSS implementation programme, which states that progress should be evaluated against a fixed baseline represented by the period 1995 – 2001, tests based on comparison between the baseline and the assessment period were the only methods used in the First and Second Periodic Evaluations. ICG went further in the application of trend analysis and examples of the application of both 'comparison of means' and 'trend analysis' techniques to OSPAR discharge data are presented in their report. No attempt has been made at this stage

of preliminary investigation to apply trend analysis techniques to OSPAR concentration and dose data. This should be done if such techniques were to be included in the RSS Implementation Programme.

Conclusions, recommendations and guidelines for the statistical analysis of future assessments

Statistical techniques for concentrations

Datasets provided by Contracting Parties (CPs) fall into three categories:

- datasets with all radionuclide concentrations above detection limits
- datasets including less than 80% of values below detection limits
- datasets with more than 80% of values below detection limits

For datasets with no values below detection limits, the choice was made in the Second Periodic Evaluation to aggregate original data as annual means prior to deriving two means corresponding to the baseline and the assessment period, with their associated standard deviations. Those two means are then compared using statistical tests, with or without any assumption regarding the distribution of data around the means. This strategy was primarily designed to stick with the yearly basis of data processing for discharges. Chapter 3 of the First Periodic Evaluation is devoted to the statistical methods used to compare the assessment period with the agreed baseline and for consistency purpose the ICS-Stats recommended the same methods in the Second Periodic Evaluation.

Both parametric and non-parametric tests are run in parallel:

- Welch-Aspin (heteroscedastic form of Student t test). Data are supposed to be normally distributed but no assumption is made regarding homogeneity of variances.
- Wilcoxon-Mann-Whitney (rank test). No assumption is made regarding data distribution.

When both tests show either evidence for a significant difference or for no significant difference (5% threshold level), the conclusion is "There is a significant difference" or "There is no significant difference", respectively. When one test shows evidence for a significant difference whilst the other one does not, the conclusion is "There is some evidence of a difference".

When more than 80% of values are below detection limits, no statistical method is proposed because the reliability of conclusions drawn from such datasets would be tenuous and controversial.

For datasets including up to 80% of non-detects values (<DL), statistical methods (Helsel, 2005), which are relevant, consistent, published and commonly accepted, are proposed. They make it possible to better use some datasets, in particular in monitoring areas corresponding to the coasts of France.

Further considerations on trend detection techniques

In addition to the statistical methods used in the First and Second Periodic Evaluations, which are based on comparison of means against the baseline and ranking test, trend analysis techniques have been explored for discharges of radioactive substances into the marine environment. A number of tests have been studied and applied to two examples: Sellafield and La Hague.

Trend analysis tests make no distinction between the baseline and assessment period. This clearly deviates from the Programme for More Detailed Implementation of the Strategy with regard to Radioactive Substances (the “RSS Implementation Programme”). However, provided they are applied on an evaluation period from 1995 to present, it would coincide with the

addition of the baseline period and the assessment period selected in the RSS Implementation programme. Trend analysis techniques have therefore been studied as a possible complementary approach.

Ten statistical tests representing four main types of techniques have been studied. None of them have proven robust, intuitive and revealing in all situations. However, statistical tests of three types have been found informative provided that their results are interpreted with care. Most statistical tests will be more valid when additional data will be available with time. It should be noted that trend analysis techniques have not been tested for concentration and doses to man and biota. It is recommended to perform a more detailed assessment on the implementation of trend analysis techniques on OSPAR data, particularly on concentrations and doses.

Provided trend analysis tests prove enough robust, intuitive and revealing for concentrations and doses, they might be used for future evaluations, when more data are available, as complements to statistical tests used in the Periodic Evaluations to evaluate progress against the baseline.

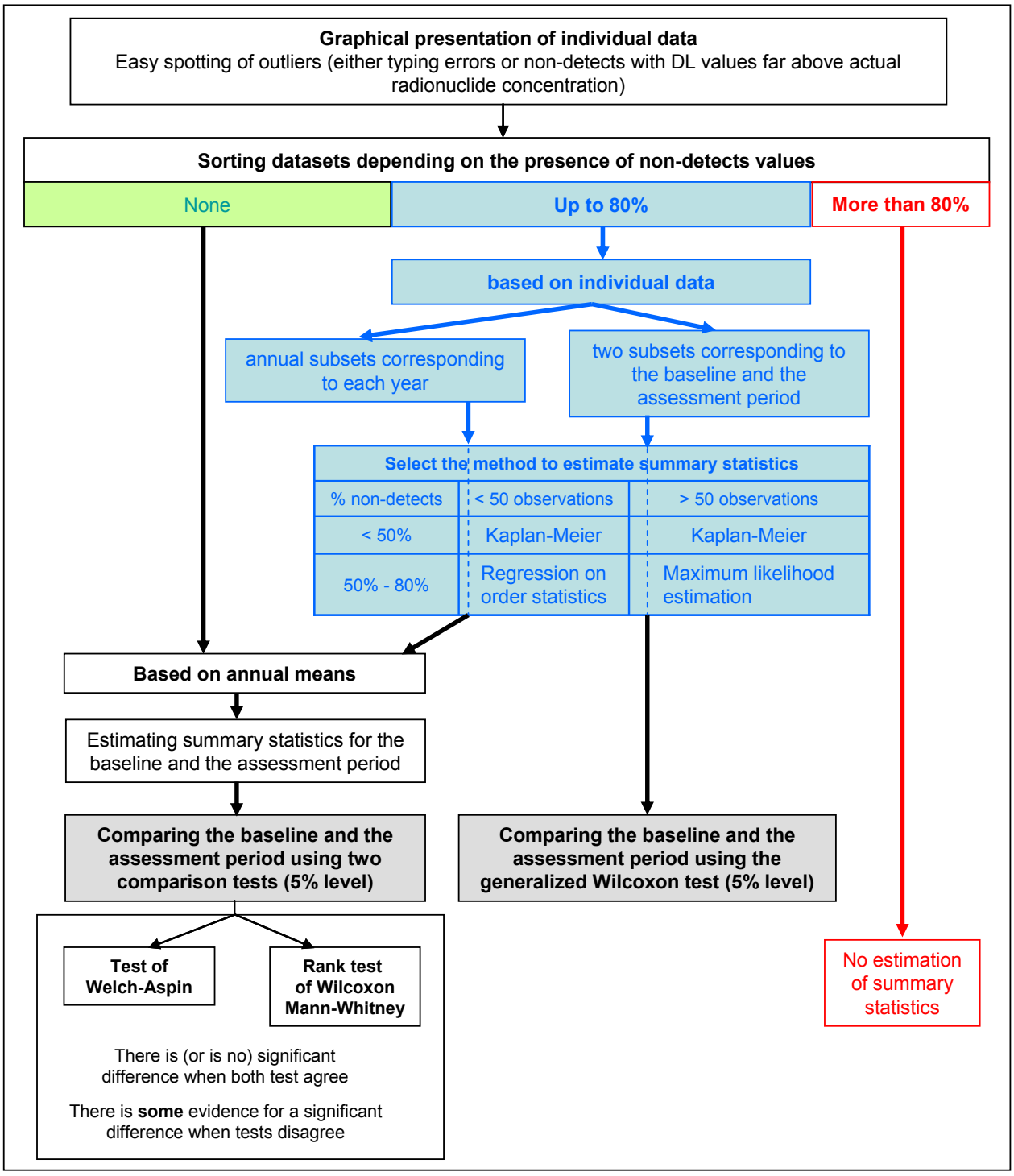


Figure: *Decision Flowchart depicting the general data processing for datasets.*

PART III – Techniques employed for the Third Periodic Evaluation.

Following agreement by RSC2008 (Luxembourg) of recommendations by the ICG-Stats set out above, the database was re-analysed. Individual values, in addition to annual means, were requested from contracting parties.

When the dataset did not include any non-detects (<DL) values, the baseline and the assessment period were compared using the same methods as in the Second Periodic Evaluation Report. The annual means were derived from individual data. For the mean comparison:

- The baseline mean and standard deviation were derived by calculating the mean of the annual means between 1995 and 2001
- The assessment period mean was derived by calculating the mean of the annual means between 2002 and 2006
- A simple comparison of the baseline mean and assessment period mean was conducted where the brackets could be calculated for the baseline mean (*i.e.* if it was possible to calculate the standard deviation)
- The two means were compared using the heteroscedastic version of the Student t test (assuming no homogeneity of the variances), the Welch Aspin test (5% level)
- For the rank test, the baseline and the assessment period were compared using the Wilcoxon rank test (5% level)

When dataset included some non-detects, annual means were estimated using Helsel (2005) methods. Then, mean comparison and rank test were performed as described above

When both the Welch-Aspin and Wilcoxon tests disagreed, it was concluded that there is "SOME evidence" for a change. However, because this may be confusing, homogeneity of variance, as well as normality of data distribution, was tested and, depending on the result, it was credence was given to either the mean comparison test (Student t or Welch-Aspin) or the non parametric rank test (Wilcoxon).

These methods were applied to the Discharges and Concentration data for the Third Periodic Evaluation. For the data on doses to humans, only simple comparisons have been carried out at this stage, due to current lack of complete data. For doses to non-human biota, insufficient data is available to carry out a proper comparison, although values for a baseline have been proposed.

Annex 2 – Case studies

Contents

1. The statistical treatment of datasets that include values below detection limits

Data on radionuclide concentrations in the marine environment may include indeterminate values when the concentrations are below the measurement detection limits (DL). Such data are reported as "< DL value", which means that the actual radionuclide concentration value is somewhere between zero and the DL value. These data are referred to as "non-detect values".

In the Second Periodic Evaluation, when datasets included non-detect values (<DL), annual means were derived by substituting the non-detect value by the value of the DL itself. The resulting annual means were then reported preceded by a "lower than" sign (<) without any component for variability. This approach precludes any statistical analysis to assess the significance of observed differences, particularly where DL values are far higher than actual concentration levels. Dealing with such datasets is further complicated because DL values are not constant within each dataset and between different datasets. Furthermore, the proportion of non-detect values in datasets is highly variable, depending on locations, compartments and radionuclides.

ICG-Stats was tasked with considering statistical techniques for the treatment of results containing a relatively large number of non-detect values and identified relevant and consistent methods for dealing with such datasets. The approach proposed by ICG-Stats, to follow the recommendations by Helsel (2005), was endorsed by RSC 2008 and is used in the present Third Periodic Evaluation. These methods provide a means of including in the statistical analysis data that would otherwise have been considered unsuitable. They may also have wider application in other OSPAR monitoring and assessment activities. This case study provides an example of the use of statistical tools and methods to improve the effectiveness of a thematic assessment.

Graphical presentation of datasets

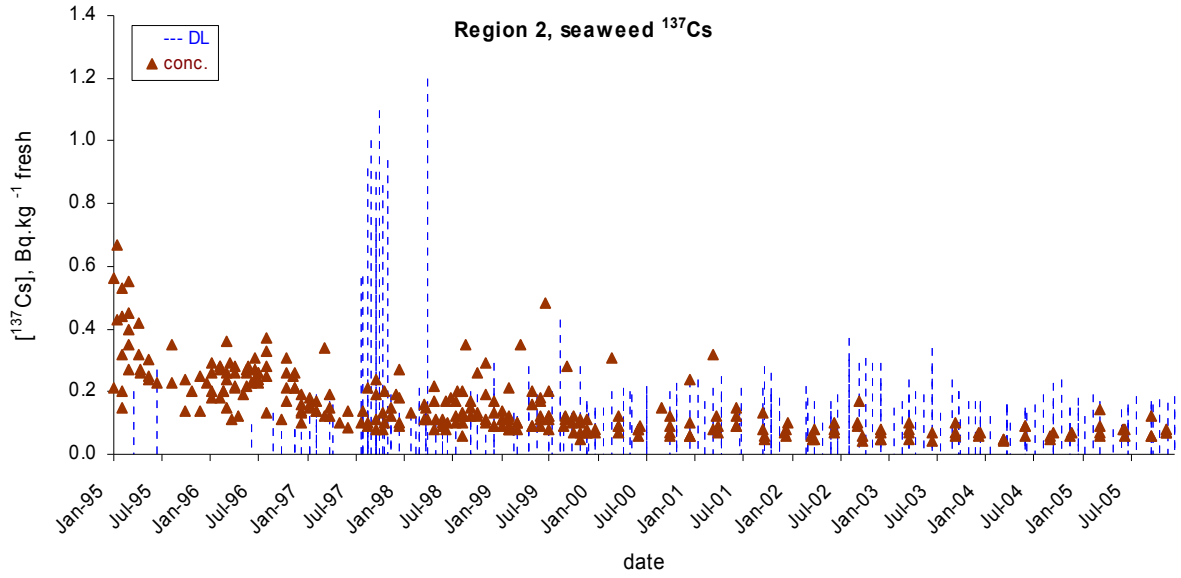


Figure A2.1: *Time series measurements of Cs-137 concentrations (Bq.kg^{-1} fresh) in seaweed from monitoring area 2 (triangle symbols). Non-detects values are represented by a vertical dotted line between zero and the DL value which means that the actual value lies within this interval.*

To show how the methods of treating datasets that include "non-detect" values can be applied in practice, ICG-Stats analysed data for concentrations of Cs-137 in seaweed in monitoring area 2 between 1995 and 2005. ICG-Stats proposed that, before any statistical processing, a graphical presentation of the dataset should be produced in order to outline its essential characteristics. The advantages of doing this are that:

- a clear distinction can be drawn between data corresponding to actual radionuclide concentrations and non-detect values (<DL);
- outliers can be identified and a view taken on whether these correspond to radionuclide concentrations (for example, transcription errors) or to DL values (far above concentrations); and
- the dispersion of data, as regards date of sampling and/or concentration level can be clearly seen.

Figure A2.1 shows a graphical presentation of the data for concentrations of Cs-137 in seaweed in monitoring area 2.

Statistical description of datasets

Depending on the total number of observations and the proportion of non-detect values, the statistical parameters can be estimated using the following methods (Table A2.1, from Helsel, 2005).

Table A2.1: *Methods to estimate statistical parameters for each dataset, depending on the total number of observations and the proportion of non-detects values.*

	< 50 observations	**> 50 observations**
< 50% of non-detects values	Kaplan Meier	Kaplan Meier
50% – 80% of non-detects values	Robust ros (regression on order statistics)	mle (maximum likelihood estimation)
> 80% of non-detects values	Not enough information to draw any robust conclusion	

Statistical parameters for the example dataset are given in Table A2.2. Firstly, two datasets are compared: annual means reported during the baseline period (1995 – 2001) and those reported during the assessment period (2002 – 2005).

Table A2.2: *Statistical parameters describing dataset Cs-137 in seaweed from monitoring area 2. (1) Total number of observations; (2) percentage of non-detects values; (3) number of different detection limit values, [min; max] lowest and highest DL values; (4) lowest and highest detected (>DL) values.*

Period	**Tot No.** (1)	**non-detects (%)** (2)	**Nb DLs [min;max]** (3)	**Detects [min;max]** (4)	**median**	**mean**	**Standard Deviation**
Baseline (1995 – 2001)	337	96 (28.49%)	33 [0.08;1.20]	[0.05;0.67]	0.12	0.16	0.10
Assessment (2002 – 2005)	118	66 (55.93%)	21 [0.07;0.37]	[0.04;0.17]	0.07	0.07	0.02

Alternatively, datasets can be assessed by calculating the statistical parameters on an annual basis. Two mean values with their associated standard deviation can then be derived; annual means and period means for the baseline and assessment periods, as given in Table A2.3. It should be noted that annual means are calculated from series which may include non-detect values (Table A2.3, column 2) whilst means for the baseline and the assessment periods are derived from annual means which are considered as true values (means for the baseline do not include non-detect values).

Table A2.3: *Statistical parameters describing dataset of Cs-137 in seaweed from monitoring area 2 on an annual basis. (1) Total number of observations; (2) percentage of non-detects values; (3) number of different detection limit values, [min; max] lowest and highest DL values; (4) lowest and highest detected (>DL) values.*

period	Tot No. (1)	non-detects (%) (2)	Nb DLs [min;max] (3)	Detects [min;max] (4)	median	annual mean	Ann. Std. Dev.	Period Mean	Period Std. Dev.
1995	32	2 (6.3%)	2 [0.20;0.27]	[0.14;0.67]	0.26	0.31	0.14		
1996	60	6(10.0%)	4 [0.08;0.17]	[0.10;0.37]	0.23	0.22	0.07		
1997	59	25 (42.4%)	19 [0.08;1.10]	[0.08;0.34]	0.12	0.13	0.06		
1998	60	19 (31.7%)	12 [0.09;1.20]	[0.06;0.35]	0.11	0.13	0.06	**0.16**	**0.08**
1999	64	18 (28.1%)	11 [0.12;0.43]	[0.05;0.48]	0.10	0.12	0.07		
2000	31	12 (38.7%)	8 [0.15;0.24]	[0.06;0.31]	0.09	0.10	0.06		
2001	32	15 (46.9%)	10 [0.14;0.28]	[0.05;0.32]	0.09	0.10	0.06		
2002	32	16 (50.0%)	13 [0.07;0.37]	[0.04;0.17]	0.04	0.07	0.02		
2003	29	17 (58.6%)	10 [0.11;0.34]	[0.04;0.10]	0.07	0.07	0.02	**0.06**	**0.01**
2004	28	17 (60.7%)	11 [0.10;0.24]	[0.04;0.09]	0.06	0.06	0.02		
2005	28	15 (53.6%)	6 [0.08;0.17]	[0.08;0.15]	0.06	0.06	0.01		

This alternative methodology on an annual basis is consistent with the method used in the Second Periodic Evaluation to compare two mean values for the baseline and the assessment periods. For this reason, ICG-Stats proposed that statistical parameters should be calculated on an annual basis, as set out in Table A2.3, prior to comparison of the baseline period and assessment period means and standard deviations.

Comparison of the baseline and the assessment periods

Further comparison of the data from the baseline and assessment periods can be made using the following statistical techniques:

- non-parametric generalised Wilcoxon test;
- parametric Welch-Aspin method – a heteroscedastic form of the Student t test; and
- non-parametric Wilcoxon-Mann-Whitney Rank test.

In addition, empirical cumulative probability distribution function estimates by the Kaplan-Meier method can provide a useful visual representation of the baseline and assessment period datasets. In the following paragraphs these techniques are applied to the Cs-137 in seaweed dataset from monitoring area 2.

Starting from individual data

Starting with individual measurement results, two data subsets, corresponding to the baseline and the assessment periods, can be statistically compared with the non-parametric generalised Wilcoxon test (see Helsel, 2005), with no assumption regarding data distribution. Hypothesis H_0 that both subsets are distributed according to the same law of probability is tested. In other words, if H_0 is verified, this means that no significant difference exists between the assessment

period and the baseline (significance threshold at the 5% level), *i.e.* no statistical increase or decrease. Conversely, rejection of hypothesis H_0 indicates that the difference (increase or decrease) between both periods is statistically significant.

Comparison of the two periods with the non-parametric generalised Wilcoxon test gives: *Chisq = 84.7 on 1 degrees of freedom, p ≈ 0,* indicating that a significant difference exists between the two periods at the 5% threshold level. So it can be concluded that concentrations have decreased between the baseline and the assessment period.

Figure A2.2 shows the empirical cumulative probability distribution function estimates using the Kaplan-Meier method. This probability distribution graph also indicates that concentrations have decreased between the baseline and the assessment period.

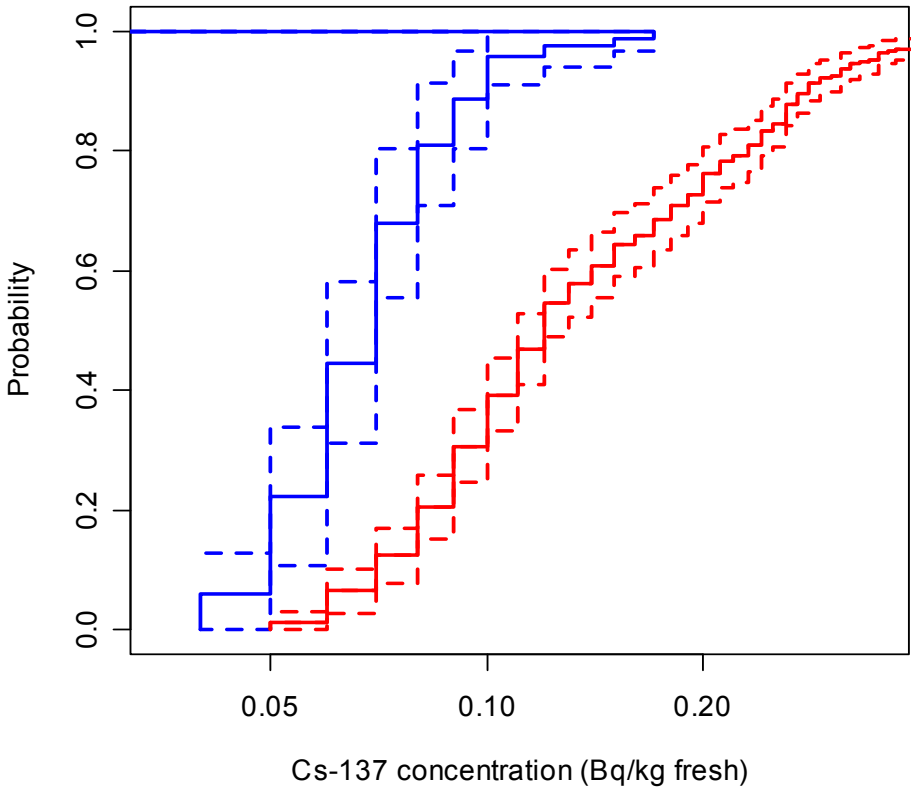


Figure A2.2: *Empirical cumulative probability distribution functions estimates by Kaplan-Meier method (right and red: baseline; left and blue: assessment period). Dotted lines correspond to 95% confidence intervals on probability values. For the assessment period (left and blue), lower values are more probable.*

Starting from annual means

With the two "period means", derived from annual means, the same statistical tests as those used in the First Periodic Evaluation can be performed:

- Parametric: Welch-Aspin (heteroscedastic form of Student t test)
- Non-parametric (rank test): Wilcoxon-Mann-Whitney

Running the Welch-Aspin test gives:

t = 3.0726, df = 6.187, p-value = 0.02103,

Running the Wilcoxon-Mann-Whitney Rank test gives:

W = *28, p-value = 0.006061,*

In this example, both tests indicate that the difference in the concentrations recorded between the baseline and assessment periods is statistically significant (5% level), confirming that concentrations have decreased between the baseline and the assessment period.

References

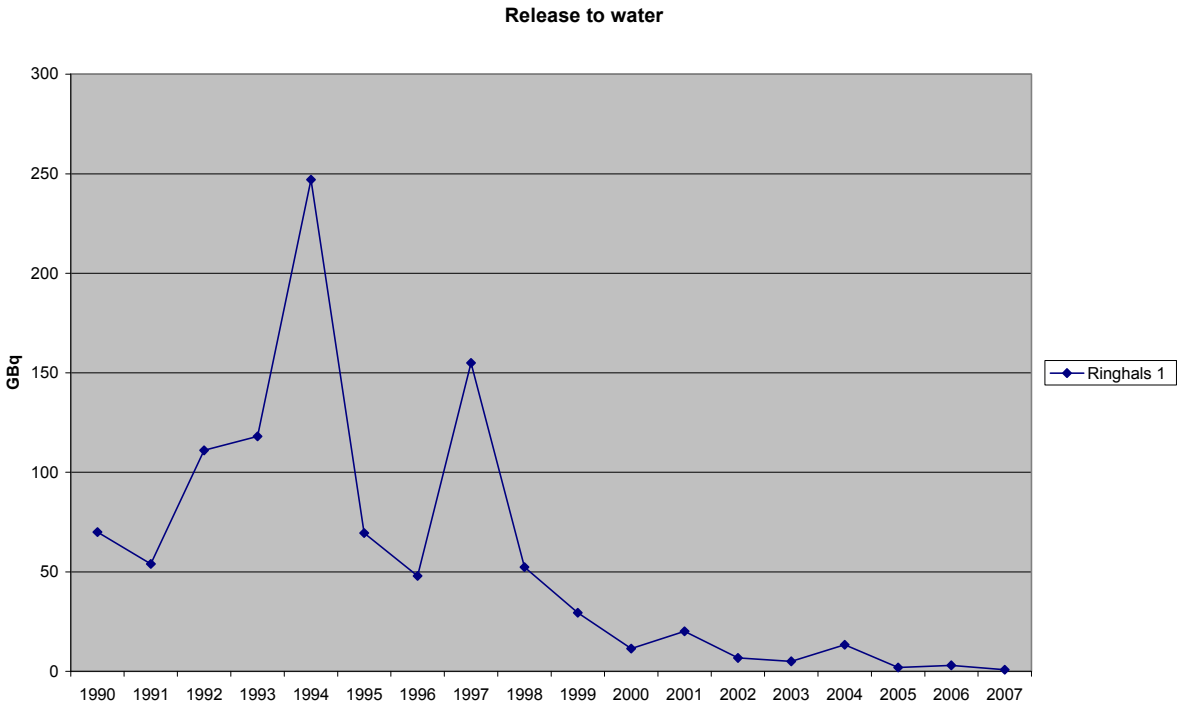
Helsel, D.R. (2005). Nondetects and Data Analysis. Statistics for censored environmental data (Hoboken, NJ, Wiley & Sons).

2. Reduction of discharges from Ringhals nuclear power plant as a result of the OSPAR Strategy, also leading to reduced discharges into the Baltic

The substantial reduction of the releases from the Ringhals site in Sweden during the last decade illustrates how Contracting Parties work in order to reduce anthropogenic discharges of radioactive substances to the North-East Atlantic, in line with the commitments in the OSPAR Radioactive Substances Strategy. It also provides an example of how the reduction of discharges as a result of OSPAR measures can benefit adjacent marine areas, in this case the Baltic Sea.

Background

The Ringhals power plant (Ringhals AB) consists of four reactors (Ringhals 1, 2, 3 and 4). Ringhals 1 (BWR) was brought into commercial operation in 1976. The three PWRs – Ringhals 2, 3 and 4 – began operations in 1975, 1981 and 1983 respectively. Major fuel damage in Ringhals 1 in 1992 has affected the releases from the Ringhals1 reactor up to the present.



In 1999 the Environmental Code entered into force in Sweden. The Code specifically identifies Best Available Techniques (BAT) as a means for achieving the goal of preventing, eliminating or reducing the impact on health and the environment of human activities resulting from radioactivity.

Licensing process according to the Environmental Code

In 2003 Ringhals AB applied for a licence according to the Environmental Code. The application also included power uprates at all reactors at the site.

Thermal installed effect

	Installed (MW)	Increase (MW)	After Uprate (MW)
Ringhals 1	2500	50	2550
Ringhals 2	2660	50	2710
Ringhals 3	2783	376	3159
Ringhals 4	2783	376	3159

During the licensing process according to the Code, Ringhals AB was obliged to present their plan for implementation of BAT for the reduction of releases from the facility before, as well as after, the planned power up-rates. The plan was discussed with the competent authorities and also reviewed several times during the licensing process. The regulators demanded that the measures proposed by Ringhals should lead to substantial reduction in the releases of radionuclides to water as well as to air. However the main focus of the measures should be on more long-lived radionuclides. The measures should follow the time schedule for the power uprates and the actions should be implemented simultaneously with or before each stepwise power uprate. An increase in power should not lead to an increase of the overall releases from the site as a whole.

The Swedish Environmental Court decided to formalise the plan for implementation of BAT with the list of measures, and included them in the licence according the Environmental Act as legally binding licence conditions. The license was issued in 2006. The Swedish Radiation Safety Authority will follow the implementation of the agreed action plan during routine inspections and surveillance programs.

Plan for implementation of BAT

Ringhals 1

Discharge	Measure	Reduction efficiency	Cost
To be implemented			
1.Noble gas	Reduction due to reduced contamination of reactor core will lead to a decrease in noble gaseous 2006-08	4 times	0
2. Noble gas	Measures to reduce air leakage to the turbines		Operational costs
3. Discharge to water	Reduce the releases from the laundries	10 times. Method will be decided later on	
4. Discharge to water	Good housekeeping; separation of waste flows; optimisation of process		5 – 10 MSEK
5. Discharge to water	Develop methods for the safe final disposal of evaporator concentrates		20 MSEK (Capital) + 5 MSEK/year
6. Discharge to water	To investigate large buffer tanks to recycle water from the reactor pools		10 – 15 MSEK
To be investigated			
7.Iodine to air	Charcoal filtration of off gas	2 times	5 – 10 MSEK
8. Aerosols to air	Filtration of off gasses from certain areas (starting with reactor building)	2 times	5 – 10 MSEK
9. Tritium to water	Extended investigations of tritium leakage from control rods.	2 times	10 – 15 MSEK
10. Noble gas	Charcoal columns with delay systems	10 times	40 MSEK
Too expensive - will not be implemented			
11. Noble gas	Non active steam (spärrånga)	10 times	40 MSEK

Ringhals 2

Discharge	Measure	Reduction efficiency	Cost
To be implemented			
12.Discharge to water	New method for water filtration – research facility in operation using cross-flow filtration	Improving	25 MSEK
13. Noble gas	1)investigate methods for Argon reduction or 2)gaseous separation improved delay tanks	2 times or 2 – 10 times	5 MSEK or 10 MSEK
To be investigated			
7.Iodine to air	Charcoal filtration of off gas from fuel storage	2 times	5 – 10 MSEK
Too expensive - will not be implemented			
11. Noble gas	Extended storage capacity in new decay tanks for gaseous waste	10 – 100 times	50 MSEK

Ringhals 3

Discharge	Measure	Reduction efficiency	Cost
To be implemented			
1. Discharge to water	New method for water filtration – same as Ringhals 2. Requires methods for the safe final disposal of the concentrates.	2 times	25 MSEK
2. Noble gaseous – air	1)Investigate methods for Argon reduction or 2)gaseous separation improved delay tanks	2 times or 2 – 10 times	5 MSEK or 10 MSEK
3. Iodine – air	Filtration of off-gas.	2 times	5 – 10 MSEK
To be investigated			
7.Iodine to air	Charcoal filtration of off gas from fuel storage	2 times	5 – 10 MSEK
Too expensive - will not be implemented			
11. Noble gas	Extended storage capacity in new decay tanks for gaseous waste	10 – 100 times	50 MSEK

Ringhals 4

Discharge	Measure	Reduction efficiency	Cost
To be implemented			
1. Discharge to water	**New method for water filtration – same as Ringhals 2.** Requires methods for the safe final disposal of the concentrates.	2 times	25 MSEK
To be investigated			
2. Noble gas	1)Investigate methods for Argon reduction or 2)gaseous separation improved delay tanks (Will be based on experiences from Ringhals 3)	2 times or 2 – 10 times	5 MSEK or 10 MSEK
7.Iodine to air	Charcoal filtration of off gas from fuel storage	2 times	5 – 10 MSEK
Too expensive - will not be implemented			
11. Noble gasses to air	Extended storage capacity in new decay tanks for gaseous waste	10 – 100 times	50 MSEK

3. Integration the OSPAR strategy in French regulation – application to the nuclear fuel processing plant of La Hague

Updating of French regulations

As early as 1992, the French Authorities required licensees to optimise radioactive substance discharges. Licensees implemented technical and organisational programmes which resulted in a large decrease in discharges of radioactive substances in the marine environment.

Following the adoption of the OSPAR Strategy in 1998, the French Authorities introduced new prescriptions into the discharge regulation. In particular, an order of 26 November 1999 introduced several new requirements:

- Discharge limits are set at a level as low as can be achieved using the best available techniques. This implies that discharge limits are set at levels much lower than those required by public health protection. Headroom has been reduced to minimum values.
- Annual limits are prescribed for all the nuclides discharged in the marine environment, including carbon 14. Moreover, limits are set for an extended number of radionuclides and radionuclide categories: tritium, carbon 14, radioactive iodine, other beta-gamma emitters, and alpha emitters. The French Authorities underline that the control and limitation of discharges of carbon 14 to the marine environment is a major improvement, set in the French regulation.

In 1998, a review of the discharge authorisations of all nuclear installations was planned. This review has been achieved for 90% of French establishments, and should be completed in 2012. The limits for beta-gamma emitters (called total beta discharges in the RSC reports) and alpha emitters (called total alpha discharges in the RSC reports) have been substantially reduced for nearly all installations. Limits for radioactive iodine and carbon 14 have been prescribed where appropriate, at low levels.

In conclusion, the French Authorities updated the French regulations on discharges in line with the OSPAR strategy. Limits for all nuclear installations are being reviewed; new limits are set as low as can be achieved using the best available techniques. The limits have been substantially reduced for beta-gamma emitting fission/activation products and alpha emitters. Annual limits have been set for all the nuclides discharged to the marine environment. Notably, limits have been set for carbon 14 where appropriate.

Moreover, on June 13th 2006, the French Parliament issued a law on transparency and security in the nuclear field. It provides an integrated approach to nuclear safety, radiation protection and environmental concerns which all share the same goal of protecting workers, patients, the public and the environment against the risks linked to nuclear activities and to ionising radiation. The law reinforces the right of access to information for all citizens, particularly on issues relating to the environment.

The licence of a nuclear installation now includes a discharge authorisation, following an integrated approach principle. This authorisation can be issued only if, taking into account scientific and technical knowledge, the licensee can demonstrate that technical and organisational issues are likely to prevent or adequately limit the risks or inconveniences caused by the installation. This must be verified at the design, construction, operating and decommissioning stages.

The law requires that, every ten years, a safety review of the nuclear installation be carried out, taking into account international best practice. The review requires a thorough analysis of the facility with regard to the requirements, and an updating of the risk or inconvenience assessment of the installation, taking into account the state of the installation, feedback of experience during operation, latest developments in knowledge, and rules for similar plants.

The La Hague nuclear fuel reprocessing plant

From 1992, many technical and organisational improvements have been implemented at the La Hague reprocessing plant to reduce the radioactive discharges to the marine environment. Namely, the so-called "new management of liquid effluents" (Nouvelle Gestion des Effluents – NGE), has been developed and implemented since 1992. This management includes the reduction of:

- volumes of liquid effluents sent for chemical treatment;
- associated chemical waste;
- radioactivity of effluents.

NGE is mainly based on a maximal use of evaporation (adding evaporating steps) to maximise the extraction of radionuclides contained in concentrates intended for vitrification (solid waste). This optimised liquid effluent management has resulted in large reductions in discharges, and provides an optimal containment of solid waste in the long term.

In line with the OSPAR strategy, the updating of the La Hague discharge authorisation has been considered as a priority by the French Authorities. The La Hague plant discharge authorisation has therefore been updated in 2003 and in 2007.

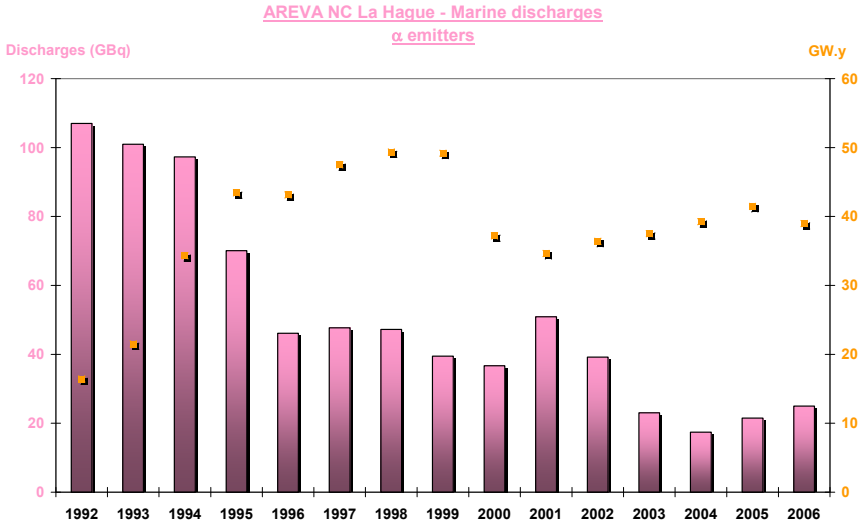
The 2003 and 2007 reviews have resulted in a large reduction of the annual limits for liquid discharges. Regulatory limits have been reduced by a factor of:

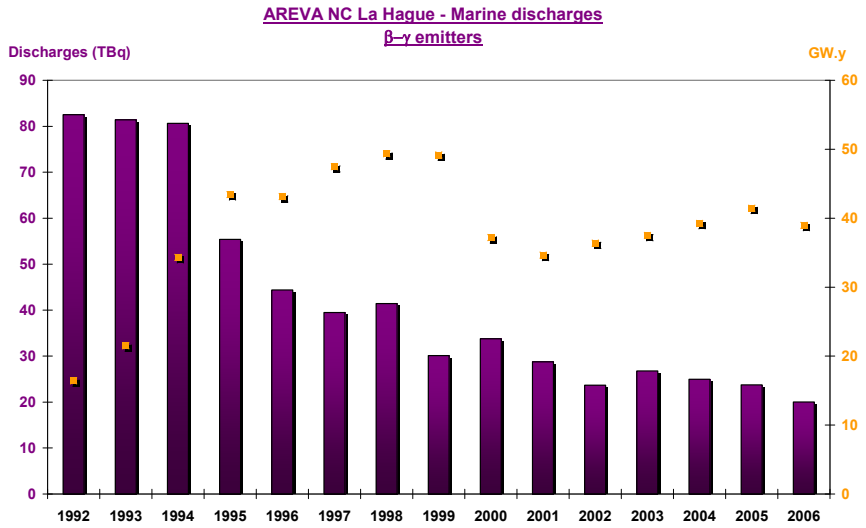
- 2 for tritium;
- 10 for alpha emitters;
- 12 for the other radionuclides.

In order to meet the OSPAR strategy commitment, a periodic review by the licensee has been prescribed every four years.

Since 2002, French regulations have also required the monitoring of carbon 14 in the liquid effluents, for reasons of transparency. Exceptional discharges must be distinguished from normal discharges and must be subject to an explicit authorisation delivered by the nuclear safety regulatory body. Finally, French regulations focus on an optimisation process specific to each installation, in order to reduce overall volume and toxicity of radiological, chemical and biological waste products and discharges.

Discharges of total alpha emitters and total beta-gamma emitters are shown on Figures 1 and 2. These figures show that the total alpha discharges in 2006 have been reduced approximately by a factor of 4 since 1992 and a further factor of 2 since 1998, and that the total beta discharges in 2006 have been reduced by a factor of 11 since 1992 and a further factor of 3 since 1998.





The combined effect of the reduction of total alpha and total beta discharges to the marine environment resulted in a reduction of the dose received by the local population. The radiological impact of the La Hague reprocessing plant liquid discharges on the marine reference group (Goury fishermen) has decreased and remains at a low level as assessed according the method developed by the independent expert group GRNC (Groupe Radioécologie Nord-Cotentin). Since the 1990s, the dose due to liquid discharges is lower than 6 µSv/y and the total dose (from liquid and gaseous discharges) is also lower than the 10 µSv/y (so-called “trivial dose”) mentioned in the European Directive EURATOM 96/29 for the exemption of practices.

In conclusion, in line with the OSPAR commitments, the La Hague reprocessing plant discharge authorisation has been updated. Limits have been progressively and substantially reduced. Technological and organisational improvements have been implemented. The result is a substantial reduction of total alpha and total beta discharges into the marine environment, and subsequently of the impact of these discharges. These reductions meet the OSPAR strategy requirements.

4. Tc-99 Discharges from Sellafield

Introduction

Technetium-99 (Tc-99) occurs in the environment almost entirely as a result of human activities. The reprocessing of spent nuclear fuel is the dominant source of Tc-99 discharges to the marine environment and the past testing of nuclear weapons is an additional contributor. Tc-99 has a half-life of 213,000 years.

One of the waste products from the reprocessing of spent Magnox fuel at Sellafield in the UK is a liquid “medium active concentrate” (MAC). This contains a range of fission products, including Tc-99, and actinides. The treatment of MAC was the dominant source of Tc-99 liquid discharges from Sellafield, although this has now ceased and current discharges of Tc-99 from the site are small. In recent years, the regulatory and management decisions taken in the UK on MAC and Tc-99 have been linked to OSPAR measures and have been effective in achieving a substantial reduction in discharges of Tc-99 to the OSPAR maritime area.

Background

Prior to 1981, MAC was discharged directly to sea after several years of decay storage. From 1981, following concern over the level of actinide discharges and the UK Government’s consequent decision to suspend the discharge of untreated MAC to sea, MAC was retained in storage tanks.

In 1984, the UK Government approved the construction of a plant to remove actinides from discharges to sea – the Enhanced Actinide Removal Plant (EARP). It was recognised at that time that EARP would not remove Tc-99 from discharges. The radiological risk from Tc-99 discharges was considered to be small, even though it has a long half-life and can bioaccumulate in certain marine fauna. EARP started operation in 1994 and began to clear the backlog of MAC stored since 1981, as well as new arisings. The authorised discharge limit for Tc-99 was increased from 10 TBq y^{-1} to 200 TBq y^{-1} and both Tc-99 discharges and Tc-99 levels in the marine environment increased (see Figure A2.3). In particular, there was a significant increase in Tc-99 concentrations in lobsters, brown seaweeds and other environmental media in the Irish Sea and at more distant locations, for example, in Scandinavian coastal waters, albeit at lower levels.

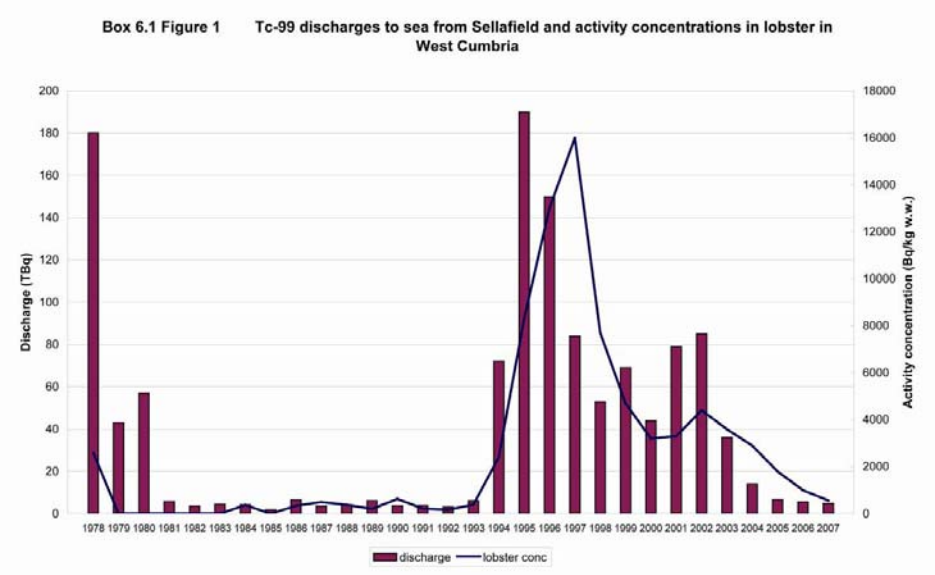


***Figure A2.3**. Tc-99 discharges to sea from Sellafield and activity concentration in lobster in west Cumbria.*

This caused concern among stakeholders, NGOs and politicians in some OSPAR Contracting Parties. Norway, one of the world's leading seafood exporting countries, made representations to the UK about the potential effects on its seafood industry. At the 1997 OSPAR Commission meeting, Ireland called for immediate measures to reduce and ultimately eliminate Tc-99 discharges. The "Sintra Statement" from the 1998 OSPAR Ministerial Meeting set out the objective of the OSPAR Radioactive Substances Strategy and highlighted the importance that Ministers placed on reducing Tc-99 discharges.

Review of regulation of Tc-99 discharges

In response to these concerns, British Nuclear Fuels plc (BNFL), the operator of Sellafield at that time, began to reduce the rate at which MAC was treated in order to lower the annual discharges. On 1 January 2000, the Environment Agency (EA) reduced Sellafield's Tc-99 discharge limit from 200 TBq y^{-1} to 90 TBq y^{-1}. The EA also proposed to carry out a full review of the Sellafield discharge authorisations, as a part of which the UK Environment Minister asked for a "fast track" review of the regulation of Tc-99 discharges to the Irish Sea.

BNFL, the EA and others had already examined a range of potential abatement techniques for Tc-99 and the EA's review focussed on those which appeared to be the most promising. The options considered in depth were:

1. To re-route the low-salt/high technetium fractions of MAC to vitrification (MAC Diversion).
2. To use an organic chemical, tetraphenylphosphonium bromide (TPP) to precipitate technetium to enable its removal by ultrafiltration in EARP.
3. To construct a new 'end of pipe' abatement plant, using either ion exchange or chemical reduction, for the removal of Tc-99 from EARP effluent.

The EA decided that diversion of low-salt MAC to vitrification was the most practicable technique and that it should be put in place by 2003. BNFL went on to successfully implement MAC diversion in July 2003. Following this success, attention focussed on the residual MAC left in the storage facility, which was unsuitable for vitrification due to its high salt content and would still need to be treated in EARP.

Although the TPP technique seemed promising, there were concerns that the resulting solid waste may not be suitable for eventual disposal in a repository, since the chemical form of Tc-99 would be potentially mobile. The EA asked BNFL to continue to develop the TPP technique by modifying it to make the solid waste more suitable for disposal. The third option, of constructing a new 'end of pipe' plant solely for the abatement of Tc-99, at a cost of more than £100 million, was considered to be too costly in relation to its likely benefits and was not pursued.

The success of TPP abatement

An important impetus towards resolution of the issue came from a meeting in London in May 2003 between the two environment ministers Børge Brende (Norway) and Michael Meacher (UK) and their regulatory authorities. Norway pointed out that a comparison between dose assessments for discharge of Tc-99 to sea compared to the option of storage on land, for critical groups in the UK, had shown that doses were higher via discharge to sea and stated that this should lead to a new evaluation of the option of final disposal of Tc-99 on land.

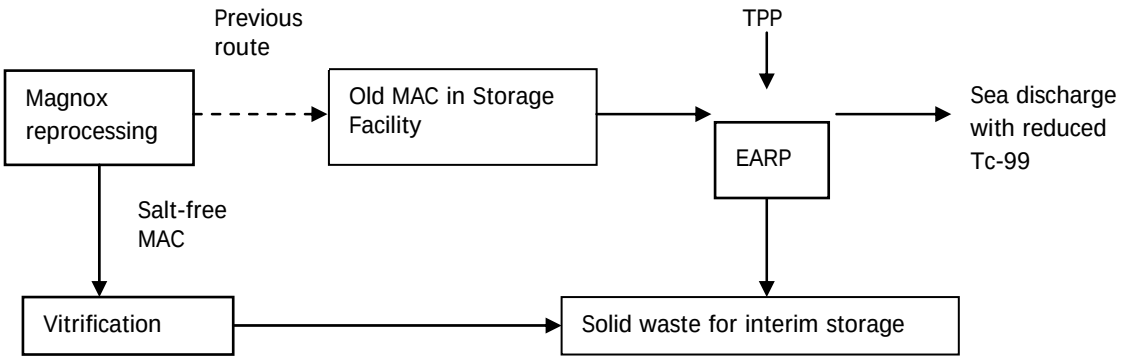
One month later, UK Nirex Ltd, the organisation responsible for the disposal of intermediate-level radioactive wastes, published a new evaluation showing that disposal of the Tc-99 solid waste resulting from TPP treatment would not adversely affect the risk assessment for a repository. As a consequence, a full-scale trial on the removal of Tc-99 from MAC liquor using TPP was initiated. A nine-month moratorium on discharges from MAC treatment was announced while this work went ahead, a decision that was welcomed in the Bremen Statement at the OSPAR Ministerial Meeting, in June 2003."

The trial of TPP abatement of Tc-99 in EARP started in October 2003. It was designed to test the feasibility and efficiency of the technique, including:

- the decontamination factors achieved for Tc-99 and other radionuclides (it was crucial that there was no adverse impact on the ability of EARP to remove actinides),
- the environmental impact of excess TPP discharged to sea,
- impacts on the long term use of EARP, for example, potential corrosion effects, and
- the acceptability of the resulting solid waste.

The trial was a success and BNFL implemented the abatement technology on a permanent basis. Figure A2.4 shows the modified process for the management of MAC.

Figure A2.4: *Management of MAC from Magnox reprocessing following MAC diversion and implementation of TPP*



The success of MAC diversion and TPP abatement allowed the EA to further reduce the annual site limit for discharges of Tc-99 to 20 TBq a year initially, from October 2004, and to 10 TBq from April 2006 when MAC treatment had been completed. Actual discharges of Tc-99 to sea fell below 10 TBq in 2005 and were less than 5 TBq in 2007. In November 2007 Sellafield Ltd completed the processing through EARP of a small quantity of residual effluent from the bottom of the MAC storage tanks. This represented the final stage of the successful work to remove the stored MAC legacy.

The positive outcome of efforts to reduce Tc-99 discharges from Sellafield has culminated in wide acceptance internationally. The news was well received in Norway and resulted in the UK's Secretary of State for Environment, Food and Rural Affairs being given an environmental award by the Norwegian government. Ireland also welcomed the reduction in Tc-99 discharges into the Irish Sea.

The Tc-99 review by the EA and the innovative approach of BNFL led to a very substantial reduction in Tc-99 discharges to the OSPAR maritime area, which in turn has led to other benefits including:

- a gradual decline of Tc-99 levels in seafoods;
- a reduction in discharges of other radionuclides, since MAC was also a significant source of Sr-90 and Cs-137 discharges; and
- radiation dose reduction – the prospective dose from discharges at the limit has reduced by about 30 μSv y^{-1}.

The reduction of Tc-99 discharges from Sellafield provides an example of regulatory and management decisions being taken to reduce a site-specific source of discharges, as a result of OSPAR measures and associated consideration by Contracting Parties.

5. Limitations in establishing links between current authorised discharges and observed concentrations of radionuclides in the OSPAR marine environment.

Plutonium-239,240 concentrations in the Irish Sea.

The OSPAR Radioactive Substances Strategy sets objectives in terms of discharges of radioactive substances and their resulting concentrations in the marine environment. The Second Periodic Evaluation of Progress noted some limitations in the interpretation of concentrations of H-3, Tc-99, Cs-137 and Pu-239,240 in the marine environment. Some of these limitations lead to problems when one attempts to link current authorised discharges with observed concentrations of radionuclides in the marine environment.

These limitations are of various kinds, including:

- time lags between discharges and transport of radionuclides to different OSPAR regions;
- additional sources of radionuclides such as from global nuclear fall-out from atmospheric weapons tests and from the Chernobyl accident; and
- the remobilisation of radionuclides from marine sediments resulting from authorised discharges that have occurred in the past.

With regard to the last, the importance of remobilisation in determining the fate of radionuclides in the marine environment is of particular significance when trying to understand the currently observed concentrations of plutonium in seawater in the OSPAR region.

Decay-corrected cumulative authorised discharges of plutonium (Pu-239,240) to the Irish Sea from the Sellafield nuclear reprocessing plant in the United Kingdom since 1952 are of the order of ~ 600 TBq, with peak discharges of 54 TBq/a occurring in the 1970s (Gray *et al*., 1995). Peak discharges in the 1970s were associated with increased reprocessing of spent fuel, while subsequent decreases in discharges resulted from changes in waste management practices and the development of additional waste treatment facilities. Current plutonium discharges from Sellafield are of the order of 0.1 TBq/a.

Plutonium discharged to the marine environment is rapidly removed from seawater through association with particulate matter, leading to accumulation in marine sediments. The amount of Pu-239,240 in Irish Sea sub-tidal sediments in 1995 was estimated to be 360 TBq, about 60% of the total decay-corrected discharges (Kershaw *et al*., 1999).

Plutonium associated with marine sediments can be transported further afield as suspended or re-suspended particulate matter. However, it has been suggested that the main mechanism for redistribution of plutonium in the Irish Sea is its release from sediments back into the water column through the process of desorption (Aldridge *et al*., 2003). The impact of remobilisation on plutonium seawater concentrations was demonstrated in the study by Leonard *et al*. (1999). This found that, while authorised discharges of Pu-239,240 from Sellafield between 1973 to 1996 had decreased by about 40-fold, concentrations of Pu-239,240 in the dissolved phase of the Irish Sea in the same time period had decreased by only about 4-fold.

Since current plutonium discharges to the Irish Sea are relatively low (~ 0.1 TBq/a), the major contributor to observed concentrations of plutonium at present is remobilisation from Irish Sea sediments. Furthermore, water flowing out of the Irish Sea is likely to remain as one of the major sources of this radionuclide to the OSPAR region for a considerable time. This prediction is

based on the current estimated inventory of plutonium in Irish Sea sediments and the time dependent nature of plutonium's dissolution kinetics (Leonard *et al*., 1999).

Since the process of plutonium remobilisation is dynamic (*i.e.* plutonium desorbed into the dissolved phase may later reabsorb onto particulate material), this process may lead to the accumulation of plutonium in sediments farther afield (it has been estimated that 7% of all plutonium discharged from Sellafield is contained within North Sea sediments (Beks, 2000)) which may in turn become sources of plutonium in the future.

The process of plutonium remobilisation, together with the other limitations referred to in the Second Periodic Evaluation, means that for some radionuclides the observed concentrations in the marine environment cannot be used as a direct indication of the impact on the OSPAR region of current discharges or recent discharge trends.

References

Aldridge, J.N., Kershaw, P., Brown, J., McCubbin, D., Leonard, K.S., Young, E.F. 2003. Transport of plutonium (239/240Pu) and caesium (137Cs) in the Irish Sea: Comparison between observations and results from sediment and contaminant transport modelling. Continental Shelf Research 23: 869-899.

Beks, J.P. 2000. Storage and distribution of plutonium, ^{241}Am, ^{137}Cs and $^{210}Pb_{xs}$ in North Sea sediments. Continental Shelf Research 20: 1941-1964.

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

Kershaw, P.J., Denoon, D.C., Woodhead, D.S. 1999. Observations on the redistribution of plutonium and americium in the Irish Sea sediments, 1978 to 1996: Concentrations and inventories. Journal of Environmental Radioactivity 44: 191-221.

Leonard, K.S., McCubbin, D., Blowers, P., Taylor, B.R. 1999. Dissolved plutonium and americium in surface waters of the Irish Sea, 1973-1996. Journal of Environmental Radioactivity 44: 129-158.

6. Geographical distribution of radionuclides in the North Sea.

Background

The German Radiation Protection Office (BfS) funded a research project at the Federal Maritime and Hydrographic Agency between 2005 to 2009, to establish the geographical distribution of various artificial radionuclides in the North Sea and adjacent sea areas. The distributions of strontium-90 (Sr-90) , Cs-137, tritium, Tc-99 and I-129 were mapped. Iodine has only one stable isotope, I-127, which was used as a reference value for I-129 concentrations.

These data supplement those reported by OSPAR Contracting Parties and demonstrate how concentrations of the measured radionuclides are distributed in the North Sea and their patterns of transport.

Findings

The distribution of Sr-90 and Cs-137 is relatively homogeneous throughout the North Sea area, but with a clear indication of an outflow from the Baltic Sea. The Baltic Sea contains higher concentrations of these radionuclides resulting from the Chernobyl accident in 1986. The lowest concentrations are seen in the English Channel and the North Western inflow of Atlantic water into the North Sea. Figure A2.5 illustrates this distribution for Cs-137 (the distribution for Sr-90 is very similar, but with lower concentrations).

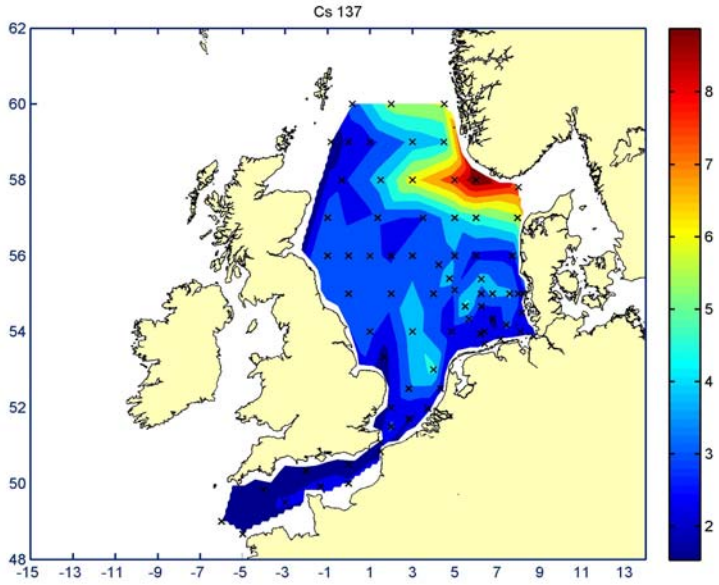


Figure A2.5: *Spatial distribution of Cs-137 in the North Sea monitoring area in Summer 2005 (Bq/m^3)*

Measurements taken at almost monthly intervals in the German Bight area between 1988 and 2004 show that there has been a more or less continuous decrease of the activity concentration of Sr-90 and Cs-137 during this period. However, there is always additional delivery of “background” contamination of surface water from the Northeast Atlantic, due to global fallout from the atmospheric nuclear tests in the fifties and sixties.

Tritium is both a natural and an artificially-produced radionuclide. Its natural cycle has been significantly influenced by discharges from nuclear power stations and nuclear reprocessing plants. In recent years, there has been a general increase of discharges from the nuclear fuel reprocessing plant (NRP) La Hague, which can be seen in elevated levels in the channel area. Increased levels are also associated with the estuaries of the Rhine, Thames and Elbe. In the Skagerrak, are there are elevated concentrations due to the Baltic outflow.

Concentrations of Tc-99 are highest in the central North Sea and are indicative of earlier higher levels of discharges from the reprocessing plant at Sellafield, which have since reduced. Concentrations in the English Channel are low, corresponding with the low discharges of this radionuclide from the La Hague reprocessing plant (see Figure A2.6).

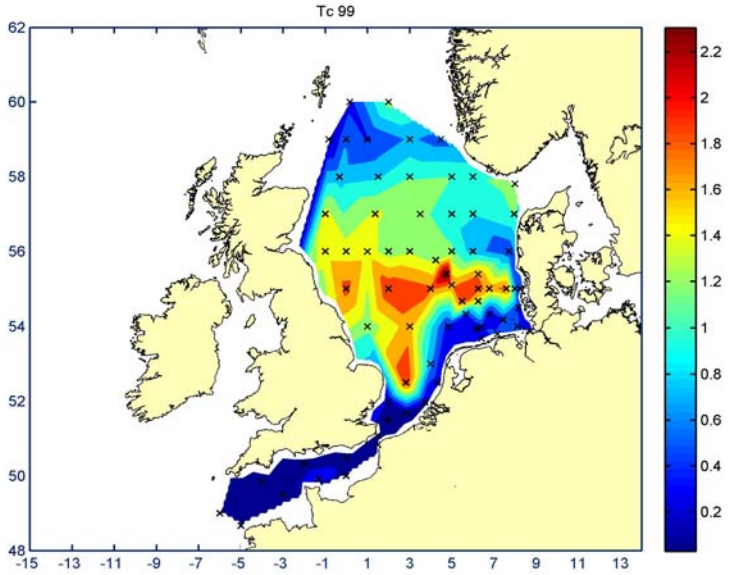


Figure A2.6: *Spatial distribution of Tc-99 in the North Sea monitoring area in summer 2005 (Bq/m^3)*

The main source of I-129 is the La Hague reprocessing plant and concentrations are correspondingly highest in the southern English Channel. This influence can be traced along the coastal current system along the southern North Sea, through the German Bight into the Skagerrak area and even further to Arctic monitoring areas. However, activity concentrations are much lower than for Cs-137 or Tc-99.

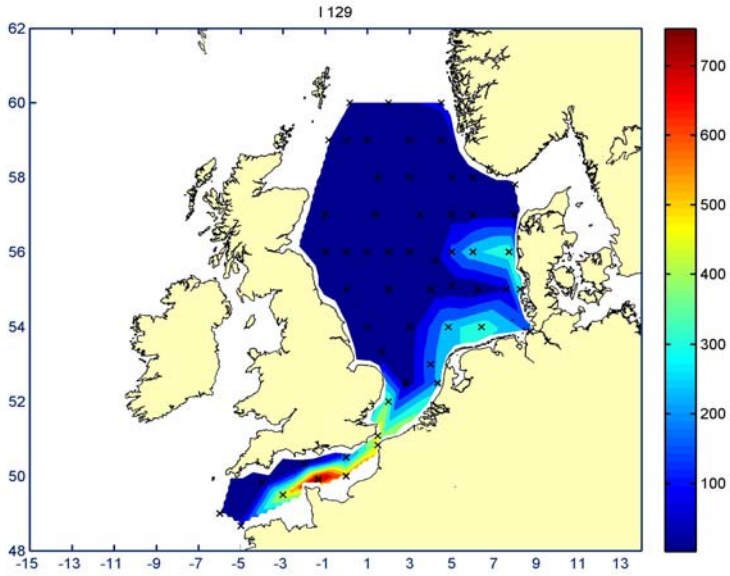


Figure A2.7: *Spatial distribution of I-129 in the North Sea monitoring area in Summer 2005 (mBq/m^3)*

Conclusion

In the measured concentrations of radionuclides in the North Sea monitoring area, there are strong indications of influences from the nuclear reprocessing plants at La Hague and Sellafield. These installations have characteristic discharge patterns in that Tc-99 is indicative for Sellafield and I-129 is indicative for La Hague. From the monitoring carried out, it is possible to trace the transport of these discharges by the prevailing marine current system through the North Sea monitoring area and on into Arctic waters.

Towards the Radioactive Substances Strategy objectives

As expected, the levels of Cs-137 and Sr-90 show little association with nuclear installations, but a marked contribution from the Baltic as a legacy of the Chernobyl accident. Elevated levels of tritium were measured in the English Channel area, linked to discharges from La Hague. Increased levels were also seen in the Skagerrak, due to the Baltic outflow, and associated with inputs of river water.

References:

Kartierung von Tc-99, I-129 und I-127 im Oberflächenwasser der Nordsee (Mapping of Tc-99, I-129 and I-127 in surface water of the North Sea), Research project StSch 4481 funded by the BfS. H. Nies, I. Goroncy, J. Herrmann, R. Michel, A. Daraoui, M. Gorny, D. Jakob, R. Sachse, L. Tosch, S.P. Nielsen, M. Dawdall, A.L. Rudjord, T. Gäfert, H.-A. Synal, M. Stocker, V. Alvimov. BSH, Hamburg and Rostock, Germany, December 2008, 178 pages.

7. Assessment of doses to marine biota arising from the discharges of the La Hague facility

Background

Historically, radiological protection has been based on the protection of people and it has been assumed that if humans are adequately protected then "other living things are also likely to be sufficiently protected" (ICRP, 1977) or that "other species are not put at risk" (ICRP, 1991). Until recently, our ability to test this assumption has been limited.

Over the last few years, ecological risk assessments (ERAs) have been carried out for a number of sites with enhanced radiation levels and releases of radioactivity. The ERAs have been conducted for different purposes, ranging from their use to test assessment tools during their development to complete assessments of the impact of ionising radiation on non-human species. As a consequence, a variety of approaches has been followed, often using different assumptions, including different choices for a reference radiation benchmark against which the estimated dose rates can be compared to determine the likely risk to non-human species.

A selection of ERAs for a range of activities and sites at various locations throughout the world was reviewed in a report compiled by SENES consultants for the World Nuclear Association. The ERAs considered in this review relate to the range of nuclear fuel cycle activities from uranium mining to nuclear power generation and reprocessing. In addition, sites involving enhanced levels of naturally occurring radioactive materials (NORM), the management and disposal of radioactive wastes, and the impacts of the Chernobyl nuclear accident were considered.

Based on the ERAs included in the SENES report, it is possible to conclude that the variety of standard protective practices for containing radioactive sources, controlling and limiting radioactive releases to the environment and protecting people used in these examples have also provided an adequate level of protection to populations of non-human biota. However, the SENES report considers more modern sites which have good effluent treatment etc. And it cannot be assumed that an equivalent study of older sites would result in the same conclusion.

Some of the ERAs in the SENES report relate to locations releasing radioactivity into the OSPAR region, *i.e.*:

- a terrestrial assessment for the Sellafield nuclear fuel reprocessing plant;
- offshore oil and gas platforms which were assessed during the development phase of the ERICA assessment tool; and
- a comprehensive assessment of the impact of the radioactive discharges on marine organisms from a list of over 90 radionuclides released from the La Hague nuclear fuel reprocessing plant.

The La Hague study is the most relevant of these in the context of the OSPAR Third Periodic Evaluation. Doses to the non-human species inhabiting the aquatic environment around La Hague were estimated to be highest for crustaceans and molluscs, but the predicted dose rates were 2-3 orders of magnitude lower than the reference benchmark dose rate used (taken from UNSCEAR, 1996, IAEA, 1992). Consequently, it was concluded that there would be no effects on marine biota attributable to radioactive discharges to the sea from the La Hague facility. Further details of this study are provided in the SENES report (SENES, 2007) or from COGEMA (1996).]

Description of Facility and Study:

The La Hague spent nuclear fuel reprocessing facility is located in the north-west part of France, on the north-west tip of the Nord-Cotentin Peninsula, along the south shore of the English Channel. This is a major nuclear site involving a wide range of supporting nuclear facilities. Operations started in the late 1950s at La Hague and have been upgraded on several occasions over time through the addition of new facilities and the decommissioning of older facilities. The La Hague nuclear fuel reprocessing plant is currently operating.

Sea currents in the La Hague area are very strong, among the most intense in Europe, especially at the north-west tip of the peninsula, where the off-shore discharge pipe outfall of the La Hague facility is located. Because of the strong sea currents, marine biota tend to concentrate and flourish in rocky areas along the peninsula coast, which offer protection. Away from the coast, this protection is reduced, especially in sandy and muddy areas where it can be more difficult for biota to stay and survive. Sessile algae are particularly important along the coast and are a key part of the habitat structure for many organisms. A number of important food species such as lobsters, crabs, whelks, scallops, squid, and fish are also present along the coast.

Radionuclides and Environmental Levels:

The radioactive discharge source terms derived by the Nord-Cotentin Radioecology Group (GRNC) and the related environmental transfer models covered a comprehensive list of over 90 radionuclides.

Basis of Assessment:

The assessment was largely based on the results of the comprehensive environmental studies conducted by the Nord-Cotentin Radioecology Group (GRNC), which provided a very large knowledge base of environmental measurements (of sea water, sediment and marine biota) and environmental transfer models for radionuclides in the La Hague coastal area (GRNC 1999a, GRNC 1999b).

Species and Pathways:

In general terms, the first step was to develop a conceptual model for the Nord-Cotentin Peninsula coastal area. The conceptual model for the marine coastal environment identified various biota categories and defined representative biota species (“reference biota”) for each biota category; namely, crustaceans, filtrating molluscs, non-filtrating molluscs, round fish, flat fish and algae.

Methodology:

The base case assessment was carried out for a reference location (Goury), which in general had the highest radionuclide concentrations along the coast. Dose rates for marine biota were estimated using the IAEA dose assessment model which included geometry factors and occupancy factors to account for body sizes, and habits of the region-specific organisms, respectively. Both the internal dose rates from the radionuclide concentrations in the organisms and the external dose rates from the radionuclide concentrations of the media in which the organism lives (*i.e.* water and sediments) were estimated. A uniform radionuclide distribution was assumed in the organisms and in environmental media. Crustaceans, filtrating molluscs, and non-filtrating molluscs were assumed to spend all of their time in sediment. This is very conservative since these organisms tend to live at the sediment/water interface with some time away from the sediments. Flat fish were assumed to spend half of their time in the water column and the other half in sediment. This is very conservative since flat fish do spend a significant amount of time away from the sediments. Round fish and algae were assumed to spend all their lives in the water column.

For the base case coastal zone (Goury), the marine biota dose rates were very small (by at least 2 to 3 orders of magnitude) compared to the lowest generic guidance values for the protection of populations of marine biota. Since the radionuclide concentrations in biota, water and sediments for other coastal locations are lower than from Goury, the dose rates to biota in

other coastal monitoring areas are also expected to be lower. The highest dose rate determined for the base case was estimated for filtrating molluscs and the radionuclide contributing the most to dose rate was 106Rh. The results from this study were compared to those from the MARINA II report (Sazykina and Kryshev 2002), which also provided estimates of the dose rate to various marine organisms in the Cap de La Hague coastal area.

A number of sensitivity analyses were performed and compared to an assessment of the base case reference location (Goury). The base case dose rate estimates were expressed in units of absorbed dose but did not account for the differences in radiation weighting factors that account for the relative biological effectiveness of alpha, beta and gamma radiations developed using the U.S. NCRP dose estimation methodology (Blaylock, Frank and O'Neil 1993). Included in the sensitivity analyses performed in this study, were an evaluation of alternative radiation weighting factors for internally deposited alpha emitters and comparison with alternative approaches to dose estimation, in particular, the approach used by the U.K. Environmental Agency (Copplestone and Bielby 2001) and in the MARINA II report (Sazykina and Kryshev 2002). In addition, doses from background levels of radioactivity (both natural and man-made, but excluding contributions from the La Hague facility itself) were also estimated. For man-made radiation other than from La Hague (for example, from past nuclear weapon test fallout), the assessment included contributions: from H-3, C-14, Co-60, Sr-90(+Y), Ru-106(+Rh), Sb-125, I-129, I-131, Cs-134, Cs-137(+Ba), Pu-238, Pu-239, Pu-240, Pu-241, and Am-241 were evaluated. For natural radioactivity, H-3, C-14, K-40, Po-210 and U-238 were considered.

Dose Rate Criteria:

The radiation dose rates to marine biota in the study area were estimated and compared to guidance values for the protection of populations of marine biota. The reference guidance values for this assessment were based on generic criteria published by international organizations (for example, UNSCEAR 1996, IAEA 1992, NCRP 1991) and on applicable data from the FASSET database on biological effects of ionizing radiation on non-human biota (FASSET Deliverable 4, 2003). A range of generic dose-effect guidance values (from about 0.01 to 10 Gy/d) were developed from the FASSET dose-effect database (FASSET 2002) for the protection of populations of marine biota, and from the conventional international generic guidance values of 10 mGy/day for the protection of biota.

Conclusions:

The contributions from man-made background radionuclides (other than from the La Hague facility) to the dose rates were also found to be very low in comparison to those from the natural radionuclides, for which most of the dose came from Po-210. The highest radiation dose rate from natural and man-made background was estimated for crustaceans and molluscs, respectively. The dose rates estimated from background levels of radiation (*i.e.* natural and man-made radionuclides) were higher, by about 1 to 2 orders of magnitude, than the base case dose rates predicted for the discharges from the La Hague facility.

Overall, the assessment showed that the predicted dose rates to marine biota attributable to radioactive discharges to the sea from the La Hague facility are small, well below comparison guidance levels at which deleterious and observable health effects to populations of marine biota might be expected and well below dose rates from background radioactivity in the region.

References

Compagnie Générale Des Matières Nucléaires (COGEMA) 1996. Dossier d'Enquête Publique – La Hague – Étude d'impact

SENES Consultants Ltd, Overview of Representative Ecological Risk Assessments

Conducted for Sites with Enhanced Radioactivity, ICRP, November (2007). http://www.world-nuclear.org/reference/pdf/wna-senes-1107.pdf

ICRP 1977. 1977 Recommendations of the International Commission on Radiological Protection. ICRP Publication 26. International Commission on Radiation Protection, Oxford, England: Pergamon Press

IAEA Report 332 (1992). Effects of Ionising Radiation on Plants and Animals at Levels Implied by Current Radiation Protection Standards.

Annex 3 – Considerations with regard to C-14, I-129 and H-3

To date, OSPAR has made progress in the way that the three isotopes, C-14, 1-129 and H-3, and in particular H-3, should be considered. Since the start of reporting on discharges of radioactive substances, there has been consensus that H-3 is sufficiently significant, in terms of becquerels discharged, to merit annual reporting of H-3 discharges from nuclear installations.

RSC agreed in 2007 that (annex 5 of the Second Periodic Evaluation):

a. H-3 is a natural product produced by cosmic rays, accounting for approximately 20 – 30% of the radionuclide measured in the North Sea;

b. H-3 has a very low dose coefficient and therefore exhibits a very low radiotoxicity to humans and inherently low radiotoxicity to biota;

c. nevertheless, there is a need to look into the effects of discharges on marine biota.

However, because further resolution is still required, this report does not include any evaluation of H-3 against this baseline element. RSC therefore agreed to continue to build on the constructive level of consensus so far achieved on the evaluation of H-3, with the aim of reaching agreement on how to assess tritium by 2010.

RSC 2008 established a working group, ICG-Bremen, to further examine the issues referred to RSC by the 2003 OSPAR Ministerial Meeting. Based on this work, RSC 2009 reached consensus on the following points with respect to tritium:

a. concentrations and doses may be evaluated against the baseline;

b. discharge data can be included in the periodic evaluation report;

c. explanations should be put forward to increase transparency;

d. there is currently no 'technical feasibility' for the industrial scale abatement in the liquid effluent of NPP and reprocessing plant; and

e. the need for periodic review of the development of abatement techniques.

ICG-Bremen agreed that in respect of I-129 and C-14 potential doses are low and therefore there do not appear to be any concerns currently that would merit assessing these particular radionuclides on an individual basis. Currently, total beta adequately addresses the evaluation needs of I-129 and C-14 and this is currently the most appropriate way of dealing with those radionuclides. However, this should be kept under review. The marker/key radionuclides should be reviewed periodically.

RSC 2009 noted:

a. the agreement of ICG-Bremen that I-129 and C-14 should be accounted for in measuring total beta;

b. the need to review which are the key radionuclides for future consideration post 2010;

c. a requirement to examine the relative importance of C-14 in terms of collective doses over an extended period of time from nuclear liquid discharges (Source: Cook *et al.*, 2004).

In relation to abatement techniques available for H-3, Ireland amended its position. Ireland has agreed that the potential for realistic, practical, economic and workable abatement techniques is currently limited, but agrees with ICG Bremen that there is a need for a periodic review of the potential for development of suitable abatement techniques.

References

Cook et al., 2004: Reconstructing the history of 14C discharges from Sellafield. Journal of Radioanalytical and Nuclear Chemistry, Vol. 260, No. 2 (2004), 239-247 pp.

Annex 4 – Data tables

Discharges data tables

Table A4.1: *Individual Contracting Party discharges from nuclear fuel production and enrichment plants.*

Country	Year	Total-α (TBq)
Germany	1995	3.10E-04
	1996	1.30E-04
	1997	1.80E-04
	1998	2.60E-04
	1999	2.00E-04
	2000	1.68E-04
	2001	1.40E-04
	2002	1.30E-04
	2003	3.70E-05
	2004	8.40E-06
	2005	7.60E-06
	2006	2.30E-09

Country	Year	Total-α (TBq)
Spain	1995	2.20E-05
	1996	3.70E-05
	1997	1.80E-05
	1998	2.03E-05
	1999	1.24E-05
	2000	3.54E-05
	2001	2.55E-05
	2002	2.10E-05
	2003	2.83E-05
	2004	1.75E-05
	2005	2.88E-05
	2006	3.70E-05

Country	Year	Total-α (TBq)	Total-β (excluding H-3) (TBq)
The Netherlands	1995	1.60E-06	1.40E-05
	1996	3.30E-06	2.00E-05
	1997	2.60E-06	1.20E-05
	1998	1.80E-06	1.00E-05
	1999	1.70E-06	7.40E-06
	2000	3.40E-06	8.50E-06
	2001	2.70E-06	1.52E-05
	2002	4.60E-06	5.30E-06
	2003	3.50E-06	1.00E-06
	2004	2.10E-06	7.10E-06
	2005	3.10E-06	2.50E-06
	2006	2.20E-06	1.74E-05

Country	Year	Total-α (TBq)	Total-β (excluding H-3) (TBq)	Tc-99 (TBq)
United Kingdom	1995	1.22E-01	1.12E+02	3.53E-02
	1996	1.21E-01	1.50E+02	3.60E-02
	1997	1.21E-01	1.40E+02	3.30E-02
	1998	1.96E-01	1.50E+02	4.08E-03
	1999	2.40E-01	1.28E+02	3.98E-02
	2000	1.74E-01	7.13E+01	3.65E-02
	2001	1.62E-01	8.51E+01	1.90E-02
	2002	2.20E-01	1.06E+02	1.80E-02
	2003	1.81E-01	9.70E+01	5.29E-02
	2004	2.27E-01	1.16E+02	1.22E-01
	2005	2.50E-01	1.03E+02	6.32E-02
	2006	8.01E-02	2.07E+01	6.51E-02

Table A4.2: *Individual Contracting Party discharges from nuclear power plants.*

Country	Year	Total-β (excluding H-3) (TBq)	Cs-137 (TBq)
Belgium	1995	4.73E-05	1.22E-02
	1996	6.62E-05	7.12E-03
	1997	6.79E-05	1.16E-02
	1998	8.48E-05	7.72E-03
	1999	2.52E-04	9.71E-03
	2000	1.37E-04	3.84E-03
	2001	2.31E-05	3.14E-03
	2002	9.20E-06	4.16E-03
	2003	8.51E-05	4.64E-03
	2004	0	3.50E-03
	2005	3.70E-06	1.85E-03
	2006	6.60E-06	2.13E-03

Country	Year	Total-β (excluding H-3) (TBq)	Cs-137 (TBq)
France	1995	9.21E-02	1.06E-02
	1996	6.80E-02	8.81E-03
	1997	5.46E-02	3.45E-03
	1998	4.15E-02	3.74E-03
	1999	3.81E-02	4.75E-03
	2000	3.00E-02	1.70E-03
	2001	3.05E-02	1.40E-03
	2002	2.81E-02	1.93E-03
	2003	2.00E-02	1.20E-03
	2004	1.62E-02	9.40E-04
	2005	1.09E-02	5.95E-04
	2006	1.02E-02	5.24E-04

Country	Year	Total-β (excluding H-3) (TBq)	Cs-137 (TBq)
Germany	1995	2.08E-03	1.10E-04
	1996	2.93E-03	2.46E-04
	1997	2.99E-03	1.45E-04
	1998	4.86E-03	4.58E-04
	1999	2.35E-03	3.04E-04
	2000	2.80E-03	3.60E-04
	2001	1.70E-03	2.60E-04
	2002	2.20E-03	2.70E-04
	2003	1.70E-03	1.70E-04
	2004	1.03E-03	6.80E-05
	2005	1.36E-03	1.46E-04
	2006	1.12E-03	1.11E-04

Country	Year	Total-β (excluding H-3) (TBq)	Cs-137 (TBq)
The Netherlands	1995	7.80E-03	6.20E-04
	1996	7.31E-03	6.41E-04
	1997	6.80E-03	5.71E-04
	1998	1.15E-03	8.00E-06
	1999	4.22E-03	2.00E-05
	2000	1.00E-03	1.60E-05
	2001	5.80E-04	2.00E-05
	2002	1.16E-03	1.00E-05
	2003	1.53E-03	8.80E-06
	2004	5.29E-03	1.90E-05
	2005	1.60E-04	9.44E-06
	2006	4.74E-04	2.76E-05

Country	Year	Total-β (excluding H-3) (TBq)	Cs-137 (TBq)
Spain	1995	2.53E-02	2.04E-03
	1996	1.54E-02	2.04E-03
	1997	1.42E-02	1.96E-03
	1998	1.16E-02	1.56E-03
	1999	1.35E-02	7.23E-04
	2000	1.30E-02	1.20E-03
	2001	1.00E-02	1.39E-03
	2002	6.75E-03	8.50E-04
	2003	5.00E-03	8.10E-04
	2004	2.56E-03	3.55E-04
	2005	5.04E-03	4.63E-04
	2006	4.33E-03	3.40E-04

Country	Year	Total-β (excluding H-3) (TBq)	Cs-137 (TBq)
Sweden	1995	1.19E-01	7.00E-03
	1996	7.02E-02	2.29E-03
	1997	1.61E-01	5.51E-03
	1998	7.88E-02	1.01E-02
	1999	7.13E-02	2.31E-03
	2000	3.60E-02	4.50E-04
	2001	6.90E-02	6.00E-04
	2002	2.60E-02	6.90E-04
	2003	2.30E-02	6.20E-04
	2004	3.30E-02	6.99E-04
	2005	1.68E-02	4.27E-04
	2006	7.85E-03	1.32E-04

Country	Year	Total-β (excluding H-3) (TBq)	Cs-137 (TBq)
Switzerland	1995	1.13E-02	8.47E-04
	1996	3.44E-02	5.30E-03
	1997	3.74E-02	3.03E-03
	1998	9.05E-02	7.35E-03
	1999	3.41E-02	1.23E-02
	2000	5.00E-02	5.10E-03
	2001	3.60E-02	4.10E-03
	2002	3.10E-02	1.70E-03
	2003	1.60E-02	9.50E-04
	2004	1.76E-02	5.35E-04
	2005	3.48E-02	2.56E-03
	2006	8.99E-03	4.02E-04

Country	Year	Total-β (excluding H-3) (TBq)	Cs-137 (TBq)
United Kingdom	1995	8.99E+00	1.88E+00
	1996	8.71E+00	1.78E+00
	1997	8.72E+00	1.62E+00
	1998	7.33E+00	1.68E+00
	1999	7.53E+00	1.25E+00
	2000	6.18E+00	1.14E+00
	2001	9.14E+00	2.25E+00
	2002	8.29E+00	2.03E+00
	2003	8.25E+00	2.18E+00
	2004	5.80E+00	1.83E+00
	2005	1.88E+00	1.19E+00
	2006	1.48E+00	1.04E+00

Table A4.3: *Individual Contracting Party discharges from nuclear fuel reprocessing plants.*

Country	Year	Total-α (TBq)	Total-β (excluding H-3) (TBq)	Tc-99 (TBq)	Cs-137 (TBq)	Pu- 239, 240 (TBq)
France	1995	7.01E-02	5.29E+01	1.00E-01	4.62E+00	5.69E-03
	1996	4.60E-02	2.94E+01	1.17E-01	2.41E+00	4.61E-03
	1997	4.77E-02	2.66E+01	1.30E-01	2.46E+00	4.97E-03
	1998	4.72E-02	2.65E+01	2.19E-01	2.51E+00	6.00E-03
	1999	3.95E-02	1.59E+01	4.27E-01	1.29E+00	4.00E-03
	2000	3.70E-02	2.10E+01	3.88E-01	8.71E-01	3.31E-03
	2001	5.10E-02	1.83E+01	2.47E-01	1.49E+00	3.41E-03
	2002	3.90E-02	1.28E+01	1.40E-01	9.59E-01	4.85E-03
	2003	2.30E-02	1.36E+01	1.77E-01	7.58E-01	2.19E-03
	2004	1.74E-02	1.31E+01	7.90E-02	7.87E-01	1.38E-03
	2005	2.15E-02	1.15E+01	6.01E-02	7.12E-01	1.08E-03
	2006	2.50E-02	7.55E+00	4.47E-02	6.23E-01	1.75E-03

Country	Year	Total-α (TBq)	Total-β (excluding H-3) (TBq)	Tc-99 (TBq)	Cs-137 (TBq)	Pu- 239, 240 (TBq)
United Kingdom	1995	4.00E-01	1.90E+02	1.90E+02	1.20E+01	3.11E-01
	1996	2.70E-01	1.40E+02	1.50E+02	1.00E+01	2.09E-01
	1997	1.80E-01	1.40E+02	8.40E+01	7.90E+00	1.47E-01
	1998	1.74E-01	8.55E+01	5.27E+01	7.54E+00	1.40E-01
	1999	1.33E-01	1.10E+02	6.88E+01	9.11E+00	1.15E-01
	2000	1.20E-01	7.70E+01	4.40E+01	6.90E+00	1.20E-01
	2001	2.00E-01	1.20E+02	7.90E+01	9.60E+00	1.55E-01
	2002	3.50E-01	1.12E+02	8.54E+01	7.69E+00	3.40E-01
	2003	4.07E-01	8.33E+01	3.70E+01	6.24E+00	3.58E-01
	2004	2.91E-01	7.33E+01	1.43E+01	9.67E+00	2.92E-01
	2005	2.48E-01	4.29E+01	6.70E+00	5.86E+00	2.03E-01
	2006	2.05E-01	2.90E+01	5.62E+00	5.93E+00	1.47E-01

Table A4.4: *Individual Contracting Party discharges from nuclear research facilities.*

Country	Year	Total-β (excluding H-3) (TBq)
Belgium	1995	1.07E-02
	1996	7.87E-03
	1997	2.54E-03
	1998	2.32E-03
	1999	1.43E-03
	2000	2.44E-03
	2001	2.11E-03
	2002	1.37E-03
	2003	5.15E-04
	2004	2.82E-04
	2005	2.14E-04
	2006	1.29E-04

Country	Year	Total-β (excluding H-3) (TBq)
Denmark	1996	1.10E-04
	1997	7.10E-05
	1998	8.48E-05
	1999	9.10E-05
	2000	1.50E-04
	2001	1.30E-04
	2002	2.50E-04
	2003	9.00E-05
	2004	1.10E-04
	2005	1.18E-04
	2006	1.45E-04

Country	Year	Total-α (TBq)	Total-β (excluding H-3) (TBq)
France	1995	1.73E-04	1.93E-04
	1996	1.23E-04	1.15E-04
	1997	1.13E-04	1.09E-04
	1998	1.24E-04	1.24E-04
	1999	1.56E-04	1.53E-04
	2000	1.60E-04	1.50E-03
	2001	1.70E-04	1.50E-03
	2002	1.30E-04	1.00E-03
	2003	1.10E-04	1.00E-03
	2004	1.07E-04	8.58E-04
	2005	9.59E-05	8.31E-04
	2006	1.06E-04	1.13E-03

Country	Year	Total-β (excluding H-3) (TBq)
Germany	1995	9.25E-04
	1996	6.92E-04
	1997	5.40E-04
	1998	1.53E-03
	1999	1.14E-03
	2000	3.50E-04
	2001	4.20E-04
	2002	3.60E-04
	2003	1.90E-04
	2004	3.70E-04
	2005	3.18E-04
	2006	1.29E-04

Country	Year	Total-α (TBq)	Total-β (excluding H-3) (TBq)
The Netherlands	1995	1.00E-07	1.20E-01
	1996	5.00E-06	1.59E-01
	1997	4.00E-06	4.41E-02
	1998	2.00E-06	6.15E-02
	1999	6.24E-07	5.91E-02
	2000	6.18E-07	7.82E-02
	2001	7.00E-06	9.14E-02
	2002	9.00E-07	8.08E-02
	2003	1.76E-06	4.06E-02
	2004	5.24E-05	6.70E-02
	2005	<3.71E-06	7.55E-02
	2006	8.90E-06	5.48E-02

Country	Year	Total-α (TBq)	Total-β (excluding H-3) (TBq)
Norway	1995	1.00E-06	2.95E-03
	1996	7.82E-07	4.04E-03
	1997	1.59E-05	2.42E-03
	1998	2.98E-06	2.08E-03
	1999	3.20E-08	3.02E-03
	2000	1.40E-07	1.89E-03
	2001	4.07E-08	1.56E-03
	2002	3.80E-08	8.60E-04
	2003	3.57E-08	4.43E-04
	2004	1.60E-07	7.95E-04
	2005	1.87E-07	5.02E-04
	2006	6.53E-08	7.79E-04

Country	Year	Total-β (excluding H-3) (TBq)
Portugal	1995	8.43E-04
	1996	4.27E-04
	1997	5.15E-04
	1998	6.57E-04
	1999	1.16E-03
	2000	9.59E-04
	2001	8.05E-04
	2002	8.50E-05
	2003	7.85E-05
	2004	3.05E-04
	2005	4.10E-06
	2006	9.60E-05

Country	Year	Total-α (TBq)	Total-β (excluding H-3) (TBq)
Switzerland	1995	4.40E-06	3.13E-04
	1996	2.10E-06	2.31E-04
	1997	5.80E-07	1.70E-04
	1998	1.28E-05	1.57E-04
	1999	2.01E-05	8.72E-04
	2000	3.34E-05	8.45E-04
	2001	7.18E-07	3.58E-04
	2002	5.86E-07	4.23E-05
	2003	2.17E-06	5.50E-05
	2004	1.40E-05	6.13E-05
	2005	7.95E-07	2.05E-04
	2006	2.70E-06	3.26E-04

Country	Year	Total-α (TBq)	Total-β (excluding H-3) (TBq)
United Kingdom	1995	8.80E-02	7.03E+00
	1996	7.30E-02	6.30E+00
	1997	2.69E-02	9.52E-01
	1998	1.35E-02	6.07E-01
	1999	1.76E-03	3.14E-01
	2000	1.70E-03	3.20E-01
	2001	1.60E-03	3.23E-01
	2002	2.32E-03	3.09E-01
	2003	4.28E-03	3.69E-01
	2004	9.60E-04	4.74E-01
	2005	1.03E-03	3.82E-02
	2006	5.65E-04	2.05E-02

Table A4.5: *Offshore Installations capable of discharging or emitting radionuclides to the OSPAR Maritime area (OSPAR, 2008b)*

Numbers of installations												
Installation type	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Oil	99	133	120	135	137	174	152	153	146	148	148	151
Gas	204	207	171	164	186	239	223	225	254	257	257	259
Sub-sea	75	5	6	87	44	65	81	120	143	179	184	190
Drilling	7	43	47	9	4	69	76	86	45	58	71	75
Other	0	0	0	0	0	0	5	2	4	11	11	8
TOTAL	385	388	344	395	371	489	537	586	592	653	671	683

Measurements are made of the quantity of water discharged. From 1996 (the second year of the baseline period), OSPAR has collected and published data on the estimated average daily quantities of these discharges. From 1996 to 2001, the statistics covered only the totals of production water and displacement water together. Since 2002, figures for the annual totals of produced water discharges have also been collected separately, and so it has been possible to look specifically at the figures most relevant to the discharge of radioactive substances. Table 2.12 shows the combined water discharges for each Contracting Party from 1996 to 2006. Table 2.13 shows the discharges of produced water.

Table A4.6: *Estimated average daily quantities of discharges of produced water and displacement water*[13]

								(m^3/day)			
Country	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Denmark	13 425	14 630	18 000	27 435	43 909	46 273	44 158	54 243	67 578	74 522	76 677
Germany	0	0	0	0	14	14	19	18	22	22	26
Ireland	7	7.52	6.69	5	6	7	8	NI[14]	8	7	591
Netherlands	35 214	33 895	30 303	25 000	31 820	38 117	24 263	21 381	23 313	24 275	26 429
Norway	412 283	438 779	462 969	442 225	461 323	493 342	490 826	524 910	537 342	533 349	510 618
UK	567 540	642 973	693 151	716 130	652 188	696 482	738 082	719 950	690 481	642 967	603 112
Total	**1 028 469**	**1 130 285**	**1 204 430**	**1 210 795**	**1 189 260**	**1 274 236**	**1 297 356**	**1 320 502**	**1 318 745**	**1 275 143**	**1 216 873**

13 Calculated from the national reports on which are based the annual OSPAR Reports on Discharges, Spills and Emissions from Offshore Oil and Gas Installations.

14 NI = No information available

Table A4.7: *Annual total discharges of produced water*

millions of cubic metres (m^3)					
Country	**2002**	**2003**	**2004**	**2005**	**2006**
Denmark	12.437	15.934	19.647	23.177	25.128
Germany	0.007	0.006	0.008	0.008	0.010
Ireland	0.003	NI*	0.003	0.003	0.214
Netherlands	8.856	7.804	8.509	8.861	9.647
Norway	118.933	134.730	142.803	147.269	144.742
United Kingdom	266.745	260.761	251.956	234.548	218.889
TOTAL	406.981	419.235	422.926	413.866	398.630

Concentration data tables

Table A4.8: *Seawater concentrations, based on calculations of the mean concentration for the period 1995 – 2006*

Key to the table:

- *Empty box: no data available.*
- *Baseline seawater value in italic denotes that all measurements on which the value has been based were below the detection limit.*
- *Baseline seawater value in bold italic denotes that some/most measurements on which the value has been based were below the detection limit.*
- *Dash: Standard deviation not calculated because baseline seawater value has been based on all or some/most measurements below the detection limit.*

Monitoring area	Radionuclide	Average / Standard Deviation (Bq/l)	Year											
			1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1	H-3	n	27	32	38	38	38	37	38	37	38	37	35	38
		Average	***<2.43E+00***	***<2.16E+00***	***<3.09E+00***	***<2.83E+00***	***<3.03E+00***	***<3.62E+00***	***<2.63E+00***	***<2.74E+00***	***<2.58E+00***	***<2.54E+00***	***<2.70E+00***	***<2.45E+00***
		SD	-	-	-	-	-	-	-	-	-	-	-	-
	Cs-137	n	27	32	38	38	38	37	38	40	41	41	38	41
		Average	*<2.23E-01*	*<2.39E-01*	*<2.94E-01*	*<8.82E-02*	*<8.60E-02*	*<7.06E-02*	*<7.61E-02*	***<5.51E-02***	***<6.90E-02***	***<7.52E-02***	***<1.02E-01***	***<7.62E-02***
		SD	-	-	-	-	-	-	-	-	-	-	-	-
	Tc-99	n								2	2		3	
		Average								*<1.00E-04*	*<1.00E-04*		2.40E-03	
		SD								-	-		1.23E-03	
2	H-3	n	34	34	34	34	33	34	34	35	35	33	34	29
		Average	***<1.43E+01***	***<1.51E+01***	***<1.40E+01***	***<1.28E+01***	***<1.46E+01***	***<1.22E+01***	***<1.25E+01***	***<1.35E+01***	***<1.11E+01***	***<1.32E+01***	***<1.07E+01***	***<1.04E+01***
		SD	-	-	-	-	-	-	-	-	-	-	-	-
	Cs-137	n	34	34	34	34	33	34	34	35	35	33	34	29
		Average	*<3.09E-02*	***<3.35E-02***	*<2.94E-02*	*<3.04E-02*	***<2.64E-02***	***<3.06E-02***	*<3.10E-02*	***<2.89E-02***	***<2.43E-02***	***<2.37E-02***	***<2.39E-02***	***<2.38E-02***
		SD	-	-	-	-	-	-	-	-	-	-	-	-

Monitoring area	Radionuclide	Average / Standard Deviation (Bq/l)	Year											
			1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
3	H-3	n			4	4	4	4	4	6	6	6	6	6
		Average			*<1.09E+01*	*<1.04E+01*	*<1.10E+01*	*<9.53E+00*	*<9.48E+00*	***<7.30E+00***	***<7.55E+00***	***<6.98E+00***	***<2.16E+01***	***<7.93E+00***
		SD			-	-	-	-	-	-	-	-	-	-
	Cs-137	n	4	4	4	4	4	4	4	4	4	4	4	4
		Average	*<8.33E-03*	*<9.18E-02*	*<2.70E-02*	*<2.55E-02*	*<2.45E-02*	*<3.33E-02*	*<3.05E-02*	*<3.13E-02*	*<2.40E-02*	*<2.63E-02*	*<2.55E-02*	*<2.55E-02*
		SD	-	-	-	-	-	-	-	-	-	-	-	-
4	Cs-137	n	24	27	26	18	13	20	15	29	34	28	32	24
		Average	4.38E-02	2.74E-02	2.88E-02	2.62E-02	2.88E-02	2.81E-02	1.21E-02	1.60E-02	1.14E-02	1.63E-02	1.79E-02	2.04E-02
		SD	1.79E-02	1.24E-02	9.97E-03	9.75E-03	5.52E-03	4.30E-03	3.71E-03	5.63E-03	5.07E-03	4.50E-03	9.52E-03	4.51E-03
	Tc-99	n	13	19	8	6	8	10	6	18	16	7	7	24
		Average	2.23E-02	2.19E-02	4.25E-02	2.18E-02	2.06E-02	2.01E-02	1.30E-02	2.05E-02	1.83E-02	1.73E-02	1.21E-02	1.09E-02
		SD	9.24E-03	9.47E-03	1.55E-02	1.10E-02	6.39E-03	5.55E-03	4.82E-03	7.56E-03	1.00E-02	7.41E-03	4.88E-03	3.55E-03
5	Cs-137	n	12	11	12	12	12	12	12	12	14	12	14	12
		Average	4.58E-02	2.66E-02	2.84E-02	2.77E-02	2.88E-02	2.52E-02	1.41E-02	1.88E-02	1.74E-02	1.68E-02	1.74E-02	1.73E-02
		SD	1.16E-02	2.31E-03	1.25E-02	4.83E-03	7.36E-03	8.13E-03	3.50E-03	6.09E-03	2.67E-03	5.34E-03	6.14E-03	5.53E-03
6	H-3	n	15	18	15	14	14	14	14	18	41	16	40	18
		Average	1.23E+01	1.17E+01	***<1.62E+01***	***<1.45E+01***	***<1.17E+01***	***<1.63E+01***	***<2.24E+01***	***<2.17E+01***	***<1.29E+01***	***<1.81E+01***	***<1.17E+01***	8.82E+00
		SD	9.38E+00	7.65E+00	-	-	-	-	-	-	-	-	-	4.79E+00
	Cs-137	n	6	6	6	6	6	6	6	6	29	6	28	6
		Average	2.21E-01	2.19E-01	2.00E-01	1.58E-01	1.42E-01	1.68E-01	1.18E-01	9.72E-02	7.34E-02	1.47E-01	7.75E-02	1.17E-01
		SD	1.31E-01	9.91E-02	9.18E-02	7.78E-02	6.43E-02	7.54E-02	6.24E-02	6.98E-02	4.97E-02	7.31E-02	4.79E-02	5.76E-02
	Tc-99	n	4	4	4	4	4	4	4	4	4	4	2	4
		Average	4.80E-01	1.07E+00	2.78E-01	1.12E-01	1.60E-01	1.13E-01	2.88E-01	2.56E-01	2.30E-01	1.04E-01	7.32E-02	4.46E-02
		SD	2.45E-01	1.28E+00	3.91E-02	5.74E-02	8.52E-02	2.18E-02	2.44E-01	1.74E-01	1.35E-01	5.38E-02	2.96E-02	3.47E-02

Monitoring area	Radionuclide	Average / Standard Deviation (Bq/l)	Year											
			1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
7	H-3	n			4	2	4	4	4	6	4	6	4	4
		Average			*<1.59E+00*	2.40E+00	*<1.38E+00*	*<1.25E+00*	***<1.66E+00***	*<1.16E+00*	***<1.08E+00***	*<1.15E+00*	*<1.00E+00*	***<2.15E+00***
		SD			-	2.83E-01	-	-	-	-	-	-	-	-
	Cs-137	n	4	4	3	3	4	4	3	6	4	6	4	4
		Average	2.56E-02	2.37E-02	5.00E-02	5.00E-02	5.00E-02	7.50E-02	1.00E-01	***<6.82E-02***	*<1.00E-01*	***<6.78E-02***	*<1.00E-01*	*<1.00E-01*
		SD	9.16E-03	1.12E-02	8.50E-18	8.50E-18	0	2.89E-02	1.70E-17	***<4.93E-02***	*<0.00E+00*	***<4.98E-02***	*<0.00E+00*	*<0.00E+00*
8	H-3	n	34	41	42	40	39	40	39	23	20	22	20	36
		Average	3.02E+00	3.75E+00	4.50E+00	4.27E+00	4.80E+00	4.82E+00	3.30E+00	3.70E+00	3.70E+00	4.95E+00	5.04E+00	5.88E+00
		SD	1.16E+00	1.14E+00	1.16E+00	1.50E+00	1.22E+00	1.10E+00	1.17E+00	1.07E+00	9.00E-01	1.07E+00	1.37E+00	1.12E+00
	Cs-137	n		21	29	15	22	34		23	15	22	15	21
		Average		5.53E-03	4.98E-03	4.57E-03	3.47E-03	3.03E-03		***<8.93E-02***	*<1.07E-01*	***<9.43E-02***	*<1.17E-01*	***<7.86E-02***
		SD		1.12E-03	1.41E-03	1.03E-03	2.60E-04	3.30E-04		-	-	-	-	-
	Pu-239/240	n			23	2	13	23					15	18
		Average			1.19E-05	1.66E-05	9.93E-06	1.41E-05					***<3.73E-04***	*<3.28E-04*
		SD			3.82E-06	4.17E-06	1.83E-06	3.69E-06					-	-
9	H-3	n	9	13	18	11	13	13		7	4	6	4	6
		Average	2.80E+00	1.43E+00	3.15E+00	4.03E+00	2.72E+00	3.44E+00		***<2.79E+00***	4.05E+00	4.33E+00	4.25E+00	5.41E+00
		SD	4.50E-01	9.00E-02	4.00E-01	7.00E-01	7.50E-01	8.50E-01		-	7.77E-01	1.48E+00	1.08E+00	1.11E+00
	Cs-137	n	46	34	37	45	50	42	38	22	24	24	24	36
		Average	8.80E-03	7.36E-03	5.27E-03	4.54E-03	4.85E-03	3.61E-03	3.20E-03	3.38E-03	3.22E-03	2.92E-03	2.61E-03	2.57E-03
		SD	4.40E-03	2.13E-03	1.50E-03	1.67E-03	1.87E-03	1.18E-03	8.80E-04	1.02E-03	7.37E-04	6.36E-04	3.84E-04	4.59E-04
	Tc-99	n			7	1	11	1						
		Average			1.03E-03	7.00E-04	1.53E-03	3.40E-03						
		SD			4.60E-04	-	1.00E-03							

Monitoring area	Radionuclide	Average / Standard Deviation (Bq/l)	Year											
			1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
	Pu-239/240	n	30		19	19	17	14		8	7	10		9
		Average	1.94E-05		7.42E-06	1.13E-05	8.44E-06	1.05E-05		5.96E-06	7.50E-06	1.26E-05		6.32E-06
		SD	5.54E-06		1.72E-06	2.43E-06	2.55E-06	2.63E-06		2.56E-06	1.51E-06	3.72E-06		2.18E-06
10	H-3	n	5	6	6	6	2	4	4	37	9	36	9	40
		Average	***<1.01E+00***	***<1.30E+00***	*<1.00E+00*	***<5.58E-01***	8.50E-01	***<7.13E-01***	***<4.88E-01***	***<1.85E+00***	***<1.85E+00***	***<1.47E+00***	***<1.15E+00***	***<2.31E+00***
		SD	-	-	-	-	4.95E-01	-	-	-	-	-	-	-
	Cs-137	n	2	13	12				23	30	1	29	6	31
		Average	1.19E-02	7.03E-03	5.93E-03				4.29E-03	4.49E-03	4.17E-03	4.50E-03	4.19E-03	4.08E-03
		SD	9.90E-04	3.03E-03	3.02E-03				2.00E-03	1.66E-03	-	1.37E-03	8.98E-04	1.19E-03
	Tc-99	n		14	15		3		23					
		Average		3.24E-03	2.32E-03		3.55E-03		2.00E-03					
		SD		2.62E-03	1.63E-03		1.08E-03		1.79E-03					
	Pu-239/240	n						1	11			10	4	
		Average						3.30E-06	2.90E-05			8.74E-06	2.03E-05	
		SD						-	2.02E-05			5.73E-06	1.17E-05	
11	Cs-137	n	1	3	5				4	1	2	3	3	
		Average	2.52E-02	9.47E-03	1.71E-02				6.65E-03	5.00E-03	4.80E-03	8.77E-03	7.43E-03	
		SD	-	6.43E-04	8.27E-03				2.36E-03	-	2.55E-03	2.55E-03	2.25E-03	
	Tc-99	n		2	2		2	4	9	3	3	3	6	6
		Average		1.15E-03	1.70E-03		5.95E-03	1.18E-03	1.23E-03	1.69E-03	1.50E-03	1.93E-03	1.11E-03	6.03E-04
		SD		4.95E-04	0		1.77E-03	2.06E-04	4.70E-04	3.76E-04	2.65E-04	1.49E-03	2.69E-04	1.27E-04
	Pu-239/240	n						4	4		3	2	1	
		Average						2.98E-06	4.68E-06		4.97E-06	4.50E-06	7.70E-06	
		SD						1.44E-06	8.30E-07		1.69E-06	1.41E-06	-	

Monitoring area	Radionuclide	Average / Standard Deviation (Bq/l)	Year											
			1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
12	H-3	n								4	4	4	4	
		Average								*<3.07E+00*	***<2.33E+00***	***<2.85E+00***	2.25E+00	
		SD								-	-	-	6.07E-01	
	Cs-137	n	20	16	20	20	31	27	20	14	14	14	14	14
		Average	4.45E-02	3.01E-02	4.16E-02	2.83E-02	2.32E-02	1.34E-02	3.09E-02	***<6.01E-02***	5.37E-02	4.50E-02	4.81E-02	2.49E-02
		SD	1.08E-02	1.40E-02	1.63E-02	1.72E-02	1.59E-02	1.21E-02	1.50E-02	-	2.60E-02	3.10E-02	2.84E-02	9.18E-03
	Tc-99	n				14	14	8	8	4	4	4	3	4
		Average				1.51E-03	1.87E-03	1.08E-03	8.47E-04	5.30E-04	5.95E-04	5.00E-04	5.29E-04	4.11E-04
		SD				1.19E-03	1.14E-03	2.81E-04	4.07E-04	2.82E-04	1.51E-04	1.21E-04	2.03E-04	2.02E-04
13	Cs-137	n	12					16		2	4	3	2	1
		Average	4.93E-03					4.71E-03		4.45E-03	3.10E-03	2.10E-03	2.95E-03	2.56E-03
		SD	2.72E-03					2.21E-03		1.77E-03	6.38E-04	7.00E-04	2.12E-04	#DIV/0!
	Tc-99	n			6	11	10	9	12	12	12	12	12	12
		Average			6.00E-04	9.23E-04	1.47E-03	1.27E-03	1.24E-03	9.79E-04	8.46E-04	8.21E-04	8.83E-04	6.11E-04
		SD			1.30E-04	3.61E-04	3.05E-04	2.93E-04	3.28E-04	1.59E-04	1.16E-04	1.23E-04	9.61E-05	9.61E-05
	Pu-239/240	n					1	3		4	11	3	3	
		Average					8.10E-06	5.00E-06		4.25E-06	8.09E-06	5.87E-06	4.27E-06	
		SD					-	4.58E-07		1.82E-06	4.23E-06	1.97E-06	1.10E-06	

Monitoring area	Radionuclide	Average / Standard Deviation (Bq/l)	Year											
			1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
14	Cs-137	n					7				1	1	2	2
		Average					3.51E-03				3.40E-03	2.80E-03	2.10E-03	2.30E-03
		SD					3.98E-04				-	-	0	2.83E-04
	Tc-99	n					8	3	2	4	4	2	5	3
		Average					7.29E-04	1.20E-03	1.55E-04	1.78E-04	2.30E-04	4.45E-04	4.02E-04	3.60E-04
		SD					3.63E-04	2.47E-04	3.54E-05	7.41E-05	8.16E-05	3.61E-04	3.35E-04	2.15E-04
	Pu-239/240	n					6	3		5	2	1	18	
		Average					8.32E-06	6.13E-06		6.48E-06	6.90E-06	5.10E-06	5.82E-06	
		SD					1.26E-06	3.16E-06		2.24E-06	8.49E-07	-	4.25E-06	
15	Cs-137	n	31	18	22	9	11	16	14	13	16	9	18	14
		Average	3.93E-03	4.32E-03	3.91E-03	5.53E-03	5.53E-03	5.20E-03	3.02E-03	3.15E-03	2.72E-03	3.00E-03	2.09E-03	2.67E-03
		SD	1.81E-03	2.24E-03	1.78E-03	2.03E-03	2.09E-03	1.68E-03	1.14E-03	1.16E-03	1.41E-03	8.78E-04	6.83E-04	7.32E-04
	Tc-99	n								11	11	11	14	6
		Average								1.37E-04	1.07E-04	1.12E-04	1.01E-04	8.36E-05
		SD								6.96E-05	6.68E-05	6.25E-05	6.35E-05	3.87E-05
	Pu-239/240	n					2	4	4	6	5		1	
		Average					7.35E-06	5.30E-06	7.03E-06	3.83E-06	9.74E-06		3.80E-06	
		SD					1.06E-06	3.84E-06	1.39E-06	2.11E-06	2.16E-06		-	

Table A4.9: *Biota concentrations, based on calculations of the mean concentration for the period 1995 – 2006*

Key to the table:

- *Empty box: no data available.*
- *Baseline biota value in italic denotes that all measurements on which the value has been based were below the detection limit.*
- *Baseline biota value in bold italic denotes that some/most measurements on which the value has been based were below the detection limit.*
- *Dash: Standard deviation not calculated because baseline biota value has been based on all or some/most measurements below the detection* limit.

Moni-toring area	Biota	Radionuclide	Average / Standard Deviation	Year											
				1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
1	Fish	Cs-137	N								3	3	3		
			Average								2.33E-01	3.33E-01	2.73E-01		
			SD								5.77E-02	1.15E-01	6.43E-02		
	Seaweed	Cs-137	N	36	31	36	33	36	12	12	15	15	10	8	10
			Average	***<1.40E-01***	***<1.40E-01***	***<1.00E-01***	***<8.00E-02***	***<8.00E-02***	***<7.00E-02***	6.00E-02	***<6.00E-02***	***<6.00E-02***	6.00E-02	***<6.00E-02***	***<7.00E-02***
			SD	-	-	-	-	-	-	2.00E-02	-	-	2.00E-02	-	-
	Seaweed	Tc-99	N								2	3			
			Average								2.16E+00	1.56E+00			
			SD								7.60E-01	2.70E-01			
2	Molluscs	Pu-239,240	N	16	16	15	16	15	14	16	17	15	17	17	16
			Average	1.65E-02	1.68E-02	2.18E-02	1.77E-02	1.81E-02	1.55E-02	1.21E-02	9.30E-03	1.04E-02	***<1.23E-02***	1.22E-02	***<1.10E-02***
			SD	8.50E-03	1.33E-02	3.32E-02	1.36E-02	2.10E-02	1.01E-02	5.90E-03	3.60E-03	7.10E-03	-	6.90E-03	-
	Seaweed	Cs-137	N	63	60	59	60	64	31	32	36	33	32	32	32
			Average	***<3.40E-01***	***<2.20E-01***	***<2.50E-01***	***<1.60E-01***	***<1.40E-01***	***<1.40E-01***	***<1.50E-01***	***<1.40E-01***	***<1.30E-01***	***<1.10E-01***	***<1.10E-01***	***<1.10E-01***
			SD	-	-	-	-	-	-	-	-	-	-	-	-
	Seaweed	Tc-99	N	12	12	10	12	12	12	4	6	4	4	3	2
			Average	8.44E+00	7.06E+00	8.15E+00	6.47E+00	1.39E+01	1.11E+01	8.64E+00	4.90E+00	5.57E+00	3.79E+00	2.06E+00	1.11E+00
			SD	3.95E+00	1.53E+00	1.67E+00	1.47E+00	4.72E+00	3.32E+00	3.69E+00	3.16E+00	5.30E+00	3.90E+00	2.73E+00	6.10E-01

Moni-toring area	Biota	Radionuclide	Average / Standard Deviation	Year											
				1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
3	Fish	Pu-239,240	N	3	3	8	8	1							
			Average	***<3.90E-05***	4.80E-05	***<4.40E-05***	***<7.30E-05***	*<2.60E-05*							
			SD	-	1.40E-05	-	-	-							
	Seaweed	Cs-137	N	24	22	24	23	24	8	8	9	9	9	9	9
			Average	2.60E-01	***<2.20E-01***	***<1.20E-01***	***<1.00E-01***	***<1.10E-01***	8.00E-02	7.00E-02	***<1.10E-01***	***<1.70E-01***	***<2.40E-01***	***<1.90E-01***	***<1.80E-01***
			SD	6.00E-02	-	-	-	-	2.00E-02	2.00E-02	-	-	-	-	-
	Seaweed	Tc-99	N	24	21	20	9	8	7	5	6	3	5	3	1
			Average	7.25E+00	6.75E+00	6.48E+00	6.83E+00	8.71E+00	8.69E+00	6.33E+00	5.71E+00	5.51E+00	5.93E+00	***<4.13E+00***	2.75E+00
			SD	2.76E+00	9.30E-01	1.37E+00	1.12E+00	2.41E+00	2.55E+00	1.41E+00	1.13E+00	5.80E-01	1.55E+00	-	-
4	Molluscs	Pu-239,240	N	1	4	4	4	4	4	4	3	1	1	1	
			Average	2.84E-01	1.85E-01	1.98E-01	2.57E-01	1.81E-01	1.01E-01	1.16E-01	4.97E-02	2.83E-02	3.40E-02	3.32E-02	
			SD	-	4.39E-02	3.78E-02	7.26E-02	5.67E-02	7.75E-02	1.04E-01	1.30E-02	-	-	-	
	Seaweed	Cs-137	N	24	22	22	23	21	20	16	18	19	19	18	18
			Average	1.20E+00	9.00E-01	9.70E-01	8.20E-01	9.60E-01	1.05E+00	6.50E-01	6.40E-01	6.40E-01	6.50E-01	6.70E-01	6.70E-01
			SD	4.40E-01	3.40E-01	3.50E-01	2.50E-01	4.10E-01	2.60E-01	1.50E-01	3.10E-01	2.80E-01	2.90E-01	2.60E-01	2.00E-01
	Seaweed	Tc-99	N	12	16	11	15	12	14	13	11	10	4	4	4
			Average	4.55E+02	6.91E+02	9.27E+02	9.64E+02	6.41E+02	5.79E+02	4.04E+02	3.73E+02	6.05E+02	3.76E+02	3.79E+02	2.22E+02
			SD	1.73E+02	2.53E+02	3.93E+02	4.55E+02	2.61E+02	2.47E+02	2.16E+02	2.27E+02	4.36E+02	1.87E+02	1.56E+02	3.80E+01
5	Fish	Cs-137	N	6	4	4	3	4	4	4	5	6	6	6	5
			Average	3.13E+00	3.18E+00	2.51E+00	2.28E+00	2.71E+00	2.94E+00	1.90E+00	2.39E+00	1.44E+00	1.70E+00	1.51E+00	***<2.29E+00***
			SD	5.70E-01	7.30E-01	6.50E-01	7.90E-01	1.38E+00	6.90E-01	1.00E+00	6.70E-01	3.90E-01	3.80E-01	7.40E-01	-
	Molluscs	Pu-239,240	N	2	2	1	1	1	1	1	2	2	2	2	2
			Average	2.16E-01	1.65E-01	2.01E-01	1.55E-01	1.59E-01	1.64E-01	1.48E-01	1.31E-01	3.83E-01	1.92E-01	1.31E-01	1.46E-01
			SD	5.16E-02	1.98E-02	-	-	-	-	-	3.46E-02	3.57E-01	0	4.86E-02	4.20E-03
	Seaweed	Tc-99	N	2	3	4	4	4	4	4	4	4	4	4	4
			Average	1.74E+02	1.60E+02	3.65E+02	3.14E+02	3.34E+02	4.35E+02	2.28E+02	2.69E+02	2.55E+02	3.04E+02	1.73E+02	5.35E+02
			SD	1.91E+02	2.15E+02	3.03E+02	3.42E+02	3.23E+02	5.21E+02	2.05E+02	2.89E+02	2.68E+02	3.22E+02	1.72E+02	6.00E+02

Moni-toring area	Biota	Radionuclide	Average / Standard Deviation	Year											
				1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
6	Molluscs	Cs-137	N	18	19	19	19	19	20	20	20	20	20	20	20
			Average	8.79E+00	7.37E+00	6.73E+00	5.11E+00	5.34E+00	5.03E+00	4.39E+00	4.30E+00	3.73E+00	3.80E+00	3.79E+00	3.16E+00
			SD	8.70E+00	6.68E+00	7.09E+00	6.21E+00	5.83E+00	5.89E+00	5.61E+00	5.49E+00	4.02E+00	3.57E+00	4.34E+00	4.09E+00
		Pu-239,240	N	7	7	8	8	7	8	8	8	8	8	8	7
			Average	1.29E+01	1.15E+01	9.20E+00	9.30E+00	1.03E+01	8.80E+00	1.06E+01	9.70E+00	9.40E+00	7.20E+00	1.04E+01	9.30E+00
			SD	1.14E+01	1.03E+01	1.03E+01	9.50E+00	9.00E+00	1.02E+01	1.31E+01	1.18E+01	1.15E+01	6.50E+00	1.29E+01	9.70E+00
	Seaweed	Tc-99	N	8	8	8	8	9	9	9	10	10	9	10	10
			Average	1.53E+04	1.75E+04	1.09E+04	5.69E+03	5.68E+03	4.12E+03	5.67E+03	6.53E+03	6.39E+03	2.34E+03	2.28E+03	1.28E+03
			SD	1.01E+04	1.01E+04	6.57E+03	3.89E+03	4.31E+03	2.27E+03	4.48E+03	5.00E+03	4.66E+03	1.52E+03	1.95E+03	8.94E+02
7	Molluscs	Pu-239,240	N	2	2	2	2	2	3	3	3	3	3	3	3
			Average	3.95E-01	4.65E-01	2.19E-01	1.99E-01	1.03E-01	1.22E-01	1.13E-01	6.75E-02	1.18E-01	8.93E-02	1.05E-01	5.91E-02
			SD	1.34E-02	1.77E-02	8.80E-03	8.50E-03	4.70E-03	5.85E-02	4.27E-02	2.82E-02	3.93E-02	2.99E-02	7.31E-02	3.14E-02
	Seaweed	Cs-137	N	8	8	8	8	8	14	16	14	16	16	14	16
			Average	1.19E+00	1.19E+00	4.00E-01	3.70E-01	5.30E-01	3.10E-01	4.80E-01	***<2.00E-01***	***<2.00E-01***	***<2.10E-01***	***<1.70E-01***	***<2.50E-01***
			SD	3.10E-01	4.90E-01	1.80E-01	1.30E-01	2.60E-01	1.60E-01	2.60E-01	-	-	-	-	-
	Seaweed	Tc-99	N	4	1	3	4	4	6	4	6	6	6	6	6
			Average	2.50E+02	3.45E+02	2.20E+02	4.24E+02	3.13E+02	2.68E+02	1.90E+02	1.58E+02	2.38E+02	1.70E+02	1.94E+02	9.50E+01
			SD	1.90E+01	-	8.40E+01	3.35E+02	1.19E+02	1.59E+02	4.60E+01	7.20E+01	1.24E+02	1.13E+02	1.01E+02	4.30E+01
8	Fish	Cs-137	N	1	4	2	2	1	0	0	25	25	26	24	27
			Average	4.40E-01	6.40E-01	3.40E-01	4.50E-01	6.80E-01	-	-	***<1.50E-01***	***<1.50E-01***	***<1.40E-01***	***<2.20E-01***	***<1.80E-01***
			SD	-	3.30E-01	1.00E-01	1.30E-01	-	-	-	-	-	-	-	-
		Pu-239,240	N		24	25	21	17	24	25				24	27
			Average		***<2.06E-02***	***<1.75E-02***	***<2.51E-02***	***<2.26E-02***	***<2.24E-02***	***<1.95E-02***				***<2.73E-02***	***<2.31E-02***
			SD		-	-	-	-	-	-				-	-

Moni-toring area	Biota	Radionuclide	Average / Standard Deviation	Year											
				1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
	Molluscs	Pu-239,240	N		9	9	9	9	9	9	6	4	3	4	11
			Average		***<2.16E-02***	3.59E-02	***<4.50E-02***	***<4.31E-02***	5.46E-02	6.52E-02	***<1.91E-01***	*<2.50E-01*	*<2.17E-01*	*<1.25E-01*	***<7.84E-02***
			SD		-	2.62E-02	-	-	1.65E-02	1.78E-02	-	-	-	-	-
9	Fish	Cs-137	N	5	9	7	6	4	3	1	2	2	1	4	3
			Average	5.90E-01	5.70E-01	5.30E-01	4.70E-01	4.00E-01	2.10E-01	2.10E-01	2.90E-01	3.30E-01	1.20E-01	1.80E-01	1.80E-01
			SD	1.80E-01	2.90E-01	3.40E-01	2.60E-01	3.10E-01	7.00E-02	-	1.00E-02	1.70E-01	-	9.00E-02	6.00E-02
		Pu-239,240	N	4	6		1	2	2	1	1	1	1	2	
			Average	*<2.80E-05*	***<4.40E-05***		*<3.00E-05*	***<3.20E-05***	***<3.90E-05***	*<2.20E-05*	*<4.60E-05*	*<2.80E-05*	*<3.20E-05*	5.70E-05	
			SD	-	-	-	-	-	-	-	-	-	-	-	
10	Fish	Cs-137	N	23	27	13	19	15	16	15	11	17	16	13	13
			Average	1.01E+00	8.00E-01	7.10E-01	6.80E-01	4.70E-01	4.40E-01	4.10E-01	4.80E-01	3.60E-01	3.40E-01	3.50E-01	4.20E-01
			SD	5.70E-01	4.30E-01	3.60E-01	3.50E-01	9.00E-02	1.90E-01	1.70E-01	2.20E-01	1.70E-01	2.10E-01	2.60E-01	3.30E-01
	Molluscs	Pu-239,240	N				1	1	1	1	1	1	1	1	1
			Average				5.20E-02	4.94E-02	6.24E-02	6.29E-02	8.28E-02	7.94E-02	7.89E-02	5.75E-02	7.12E-02
			SD				-	-	-	-	-	-	-	-	-
	Seaweed	Tc-99	N	2	2	2	2	2	2	2	3	3	3	3	3
			Average	1.64E+01	3.02E+01	5.67E+01	6.15E+01	4.33E+01	2.86E+01	3.62E+01	4.34E+01	2.52E+01	2.38E+01	7.36E+01	4.86E+01
			SD	1.97E+01	3.58E+01	5.78E+01	6.86E+01	2.07E+01	2.14E+01	4.59E+01	5.60E+01	1.95E+01	3.53E+01	7.83E+01	4.76E+01
11	Seaweed	Cs-137	N	3				1	3	2	4	4	4	7	4
			Average	8.40E-01				9.40E-01	5.30E-01	2.60E-01	6.70E-01	3.40E-01	5.20E-01	4.50E-01	5.70E-01
			SD	3.00E-01				-	2.10E-01	3.00E-02	3.70E-01	1.60E-01	1.90E-01	1.80E-01	3.10E-01
	Seaweed	Tc-99	N						3	2	4	4	4	7	3
			Average						6.85E+01	3.54E+01	2.62E+01	3.40E+01	3.10E+01	4.26E+01	2.17E+01
			SD						1.65E+01	6.20E+00	1.09E+01	1.22E+01	8.10E+00	1.27E+01	1.21E+01

Moni-toring area	Biota	Radionuclide	Average / Standard Deviation	Year											
				1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
12	Fish	Cs-137	N	6	3	3	3	3	3	3	9	9	9	9	9
			Average	2.52E+00	3.31E+00	3.22E+00	3.63E+00	2.71E+00	2.86E+00	2.41E+00	7.12E+00	6.14E+00	5.66E+00	5.42E+00	4.78E+00
			SD	3.01E+00	2.25E+00	1.76E+00	3.79E+00	1.54E+00	1.42E+00	8.30E-01	3.92E+00	3.29E+00	3.05E+00	2.79E+00	2.62E+00
	Seaweed	Cs-137	N	5	3	3	4	5	4	4	4	4	4	4	4
			Average	2.26E+00	1.86E+00	1.68E+00	1.56E+00	1.68E+00	1.42E+00	1.51E+00	1.33E+00	1.35E+00	1.20E+00	1.21E+00	1.16E+00
			SD	5.10E-01	5.50E-01	4.20E-01	4.50E-01	5.00E-01	4.60E-01	3.60E-01	8.40E-01	3.40E-01	3.20E-01	4.40E-01	2.80E-01
	Seaweed	Tc-99	N	2	3	3	4	4	4	4	4	4	4	2	
			Average	3.70E+00	8.50E+00	1.49E+01	2.07E+01	2.80E+01	3.25E+01	2.29E+01	2.31E+01	2.47E+01	2.34E+01	2.51E+01	
			SD	1.40E+00	2.80E+00	3.50E+00	7.20E+00	7.10E+00	7.30E+00	5.00E+00	7.10E+00	9.60E+00	7.20E+00	6.00E+00	
13	Seaweed	Cs-137	N			4	11	9	11	7	16	15	14	15	15
			Average			9.00E-02	1.10E-01	1.20E-01	9.00E-02	1.90E-01	1.20E-01	1.10E-01	1.10E-01	1.10E-01	***<1.50E-01***
			SD			6.00E-02	4.00E-02	1.00E-02	3.00E-02	1.70E-01	6.00E-02	1.00E-01	1.00E-01	1.10E-01	-
	Seaweed	Tc-99	N			4	10	10	11	12	16	15	16	16	15
			Average			1.65E+01	2.78E+01	4.64E+01	6.35E+01	6.43E+01	4.56E+01	3.83E+01	3.78E+01	3.89E+01	3.29E+01
			SD			3.70E+00	6.30E+00	9.40E+00	7.10E+00	1.37E+01	1.52E+01	1.07E+01	1.03E+01	1.03E+01	1.05E+01
14	Fish	Cs-137	N		12	11	6	32	7	17	8	21	16	7	
			Average		3.00E-01	3.30E-01	3.40E-01	2.40E-01	2.90E-01	2.50E-01	1.70E-01	2.30E-01	2.80E-01	2.70E-01	
			SD		3.00E-02	5.00E-02	9.00E-02	1.00E-01	7.00E-02	6.00E-02	8.00E-02	8.00E-02	5.00E-02	4.00E-02	
15	Fish	Cs-137	N		2	5	7	7	4	4	12	5	8	6	9
			Average		1.60E-01	1.50E-01	1.50E-01	1.20E-01	1.30E-01	1.50E-01	***<1.40E-01***	***<1.70E-01***	***<1.60E-01***	***<1.20E-01***	***<1.10E-01***
			SD		3.00E-02	6.00E-02	5.00E-02	6.00E-02	5.00E-02	2.00E-02	-	-	-	-	-
	Seaweed	Cs-137	N	6	6	6	6	21	23	18	17	20	23	25	25
			Average	4.60E-02	4.90E-02	4.10E-02	4.70E-02	4.90E-02	4.20E-02	4.40E-02	***<4.80E-02***	***<4.20E-02***	***<3.90E-02***	***<3.40E-02***	***<4.20E-02***
			SD	2.50E-02	2.10E-02	1.20E-02	1.60E-02	2.00E-02	1.70E-02	6.00E-03	-	-	-	-	-

Moni-toring area	Biota	Radionuclide	Average / Standard Deviation	Year											
				1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
	Seaweed	Tc-99	N				4	12	12	7	13	7	3	1	4
			Average				7.70E-01	6.70E-01	8.20E-01	9.10E-01	8.40E-01	1.60E+00	6.70E-01	2.80E-01	2.10E-01
			SD				7.50E-01	4.90E-01	6.10E-01	5.50E-01	5.00E-01	2.59E+00	3.90E-01	-	6.00E-02

Table A4.10: *Seawater concentrations of naturally occurring radionuclides in OSPAR monitoring areas*

Key to the table:

- *n – number of observations; SD – standard deviation.*
- *Empty box: no data available.*
- *Dash: Standard deviation not calculated because n=1.*

		Seawater											
Monitoring area	**Year**	**Ra-226 (mBq/l)**			**Ra-228 (mBq/l)**			**Pb-210 (mBq/l)**			**Po-210 (mBq/l)**		
		n	**Mean**	**SD**	**n**	**Mean**	**SD**	**n**	**Mean**	**SD**	**n**	**Mean**	**SD**
1. Wider Atlantic Iberian Coast Biscay and Channel West	1994[a]	7	1.29	3.60E-01	7	7.70E-01	4.50E-01						
2. Channel (Cap de la Hague)	1994[a]	6	1.48	2.00E-01	6	1.92	6.90E-01						
3. Channel East	1994[a]	5	1.19	2.60E-01	5	1.48	3.60E-01						
4. Irish Sea (Rep. of Ireland)	1994[a]	7	1.22	2.40E-01	7	1.09	5.10E-01						
5. Irish Sea (Northern Ireland)	1994[a]	1	1.44	-	1	2.12	-						
6. Irish Sea (Sellafield)	1994[a]	4	1.84	3.30E-01	4	3.58	9.30E-01						
8. North Sea South (Belgian and Dutch Coast)	1985-86[b]	2	5.15	2.10E-01				1	8.00E-01	-	2	6.00E-01	1.40E-01
9. German Bight	1976[c]												
10. North Sea (Northwest, Southeast and Central)	1986-87[d]	11	2.80	7.00E-01	11	3.80	1.50	11	8.90E-01	5.70E-03	11	7.70E-01	4.60E-01
	2004[e]	19	1.70	5.00E-01	10	9.00E-01	1.00				10	1.80	5.00E-01
	2004[e]	4	2.10	5.00E-01									
12. Kattegat	1976[c]												
13. Norwegian Coastal Current	2005[f]	3	1.37	7.00E-01				1	1.97	-	1	1.49	-
	2005[f]	18	1.60	5.00E-01									

a – Schmidt *et al*, 1998
b – Köster *et al*, 1992
c – Spencer *et al*, 1980
d – Plater *et al*, 1995
e – NPRA (2006)
f – NRPA Unpublished monitoring data

Human dose data tables

Table A4.11: *Doses from seawater by monitoring area*

Key to the table:

- *SD: standard deviation.*
- *Empty box: no data available.*
- *Baseline dose value in italics denotes that all measurements on which the corresponding baseline seawater value has been based were below the detection limit.*
- *Baseline dose value in bold italics denotes that some/most measurements on which the corresponding baseline seawater value has been based were below the detection limit.*
- *Dash: Standard deviation not calculated because the baseline dose value has been derived from a baseline seawater value that has been based on all or some/most measurements below the detection limit.*

MA1	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
Year	Dose (µSv/y)	SD	Dose (µSv/y)	SD	Dose (µSv/y)	SD	Dose (µSv/y)	SD
1995	***<2.49E-03***	-	*<1.18E+01*	-				
1996	***<2.21E-03***	-	*<1.27E+01*	-				
1997	***<3.17E-03***	-	*<1.56E+01*	-				
1998	***<2.91E-03***	-	*<4.69E+00*	-				
1999	***<3.11E-03***	-	*<4.57E+00*	-				
2000	***<3.72E-03***	-	*<3.75E+00*	-				
2001	***<2.70E-03***	-	*<4.05E+00*	-				
Baseline	***<2.90E-03***	-	*<8.18E+00*	-				
2002	***<2.81E-03***	-	***<2.93E+00***	-	*<1.54E-03*	-		
2003	***<2.65E-03***	-	***<3.67E+00***	-	*<1.54E-03*	-		
2004	***<2.61E-03***	-	***<4.00E+00***	-				
2005	***<2.77E-03***	-	***<5.40E+00***	-	3.69E-02	1.84E-02		
2006	***<2.51E-03***	-	***<4.05E+00***	-				
Assessment	***<2.67E-03***		***<4.01E+00***		***<1.33E-02***			

MA2	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
Year	Dose (µSv/y)	SD	Dose (µSv/y)	SD	Dose (µSv/y)	SD	Dose (µSv/y)	SD
1995	***<1.47E-02***	-	*<1.64E+00*	-				
1996	***<1.55E-02***	-	***<1.78E+00***	-				
1997	***<1.44E-02***	-	*<1.56E+00*	-				
1998	***<1.31E-02***	-	*<1.62E+00*	-				
1999	***<1.50E-02***	-	***<1.40E+00***	-				
2000	***<1.25E-02***	-	***<1.63E+00***	-				
2001	***<1.28E-02***	-	*<1.65E+00*	-				
Baseline	***<1.40E-02***	-	***<1.61E+00***	-				
2002	***<1.39E-02***	-	***<1.54E+00***	-				
2003	***<1.14E-02***	-	***<1.29E+00***	-				

MA2	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
2004	***<1.36E-02***	-	***<1.26E+00***	-				
2005	***<1.10E-02***	-	***<1.27E+00***	-				
2006	***<1.07E-02***	-	***<1.26E+00***	-				
Assessment	***<1.21E-02***		***<1.33E+00***					

MA3	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
Year	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**
1995			*<4.43E-01*	-				
1996			*<4.88E+00*	-				
1997	*<1.11E-02*	-	*<1.44E+00*	-				
1998	*<1.07E-02*	-	*<1.36E+00*	-				
1999	*<1.13E-02*	-	*<1.30E+00*	-				
2000	*<9.77E-03*	-	*<1.77E+00*	-				
2001	*<9.72E-03*	-	*<1.62E+00*	-				
Baseline	*<1.05E-02*	-	*<1.83E+00*	-				
2002	***<7.49E-03***	-	*<1.66E+00*	-				
2003	***<7.74E-03***	-	*<1.28E+00*	-				
2004	***<7.16E-03***	-	*<1.40E+00*	-				
2005	***<2.21E-02***	-	*<1.36E+00*	-				
2006	***<8.13E-03***	-	*<1.36E+00*					
Assessment	***<1.05E-02***		*<1.41E+00*					

MA4	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
Year	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**
1995			2.33E+00	9.54E-01	3.43E-01	1.42E-01		
1996			1.46E+00	6.57E-01	3.37E-01	1.46E-01		
1997			1.53E+00	5.30E-01	6.53E-01	2.38E-01		
1998			1.39E+00	5.19E-01	3.36E-01	1.70E-01		
1999			1.53E+00	2.94E-01	3.16E-01	9.82E-02		
2000			1.49E+00	2.29E-01	3.09E-01	8.53E-02		
2001			6.42E-01	1.97E-01	2.00E-01	7.40E-02		
Baseline			1.48E+00	4.89E-01	3.56E-01	1.40E-01		
2002			8.49E-01	2.99E-01	3.15E-01	1.16E-01		
2003			6.04E-01	2.69E-01	2.81E-01	1.54E-01		
2004			8.66E-01	2.39E-01	2.66E-01	1.14E-01		
2005			9.50E-01	5.06E-01	1.87E-01	7.50E-02		
2006			1.08E+00	2.40E-01	1.67E-01	5.45E-02		
Assessment			8.70E-01		2.43E-01			

MA5	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
Year	Dose (µSv/y)	SD	Dose (µSv/y)	SD	Dose (µSv/y)	SD	Dose (µSv/y)	SD
1995			2.44E+00	6.17E-01				
1996			1.41E+00	1.23E-01				
1997			1.51E+00	6.64E-01				
1998			1.47E+00	2.57E-01				
1999			1.53E+00	3.92E-01				
2000			1.34E+00	4.32E-01				
2001			7.47E-01	1.86E-01				
Baseline			1.49E+00	4.97E-01				
2002			9.98E-01	3.24E-01				
2003			9.26E-01	1.42E-01				
2004			8.92E-01	2.84E-01				
2005			9.26E-01	3.26E-01				
2006			9.18E-01	2.94E-01				
Assessment			9.32E-01					

MA6	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
Year	Dose (µSv/y)	SD	Dose (µSv/y)	SD	Dose (µSv/y)	SD	Dose (µSv/y)	SD
1995	1.26E-02	9.62E-03	1.17E+01	6.95E+00	7.38E+00	3.77E+00		
1996	1.20E-02	7.85E-03	1.17E+01	5.27E+00	1.65E+01	1.96E+01		
1997	***<1.66E-02***	-	1.06E+01	4.88E+00	4.27E+00	6.01E-01		
1998	***<1.49E-02***	-	8.38E+00	4.13E+00	1.72E+00	8.83E-01		
1999	***<1.20E-02***	-	7.53E+00	3.42E+00	2.46E+00	1.31E+00		
2000	***<1.67E-02***	-	8.94E+00	4.01E+00	1.73E+00	3.35E-01		
2001	***<2.30E-02***	-	6.30E+00	3.32E+00	4.43E+00	3.75E+00		
Baseline	***<1.54E-02***	-	9.31E+00	2.10E+00	5.49E+00	5.23E+00		
2002	***<2.22E-02***	-	5.17E+00	3.71E+00	3.94E+00	2.68E+00		
2003	***<1.32E-02***	-	3.90E+00	2.64E+00	3.54E+00	2.08E+00		
2004	***<1.85E-02***	-	7.83E+00	3.89E+00	1.60E+00	8.27E-01		
2005	***<1.20E-02***	-	4.12E+00	2.55E+00	1.13E+00	4.54E-01		
2006	9.05E-03	4.92E-03	6.23E+00	3.06E+00	6.86E-01	5.34E-01		
Assessment	***<1.50E-02***		5.45E+00		2.18E+00			

MA7	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
Year	Dose (µSv/y)	SD	Dose (µSv/y)	SD	Dose (µSv/y)	SD	Dose (µSv/y)	SD
1995			1.36E+00	4.87E-01				
1996			1.26E+00	5.98E-01				
1997	*<1.63E-03*	-	*<2.66E+00*	-				
1998	2.46E-03	2.90E-04	*<2.66E+00*	-				

MA7	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
1999	*<1.41E-03*	-	*<2.66E+00*	-				
2000	*<1.28E-03*	-	*<3.99E+00*	-				
2001	***<1.70E-03***	-	*<5.32E+00*	-				
Baseline	***<1.70E-03***	-	***<2.84E+00***	-				
2002	*<1.19E-03*	-	***<3.63E+00***	-				
2003	***<1.10E-03***	-	*<5.32E+00*	-				
2004	*<1.18E-03*	-	***<3.61E+00***	-				
2005	*<1.03E-03*	-	*<5.32E+00*	-				
2006	***<2.21E-03***	-	*<5.32E+00*	-				
Assessment	***<1.34E-03***		***<4.64E+00***					

MA8	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
Year	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**
1995	3.10E-03	1.19E-03						
1996	3.85E-03	1.17E-03	2.94E-01	5.96E-02				
1997	4.62E-03	1.19E-03	2.65E-01	7.50E-02			1.15E-01	3.71E-02
1998	4.38E-03	1.54E-03	2.43E-01	5.48E-02			1.61E-01	4.04E-02
1999	4.93E-03	1.26E-03	1.84E-01	1.38E-02			9.63E-02	1.78E-02
2000	4.94E-03	1.13E-03	1.61E-01	1.75E-02			1.37E-01	3.58E-02
2001	3.39E-03	1.20E-03		-				
Baseline	4.17E-03	7.39E-04	2.29E-01	1.98E-01			1.27E-01	2.79E-02
2002	3.80E-03	1.10E-03	***<4.75E+00***	-				
2003	3.80E-03	9.23E-04	*<5.71E+00*	-				
2004	5.08E-03	1.10E-03	***<5.01E+00***	-				
2005	5.17E-03	1.40E-03	*<6.21E+00*	-			***<3.62E+00***	-
2006	6.04E-03	1.15E-03	***<4.18E+00***	-			*<3.18E+00*	-
Assessment	4.78E-03		***<5.17E+00***				***<3.40E+00***	

MA9	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
Year	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**
1995	2.87E-03	4.62E-04	4.68E-01	2.34E-01			1.88E-01	5.37E-02
1996	1.47E-03	9.23E-05	3.91E-01	1.13E-01				
1997	3.23E-03	4.10E-04	2.80E-01	7.98E-02	1.58E-02	7.07E-03	7.20E-02	1.67E-02
1998	4.13E-03	7.18E-04	2.41E-01	8.88E-02	1.08E-02		1.09E-01	2.36E-02
1999	2.79E-03	7.70E-04	2.58E-01	9.94E-02	2.35E-02	1.54E-02	8.19E-02	2.47E-02
2000	3.53E-03	8.72E-04	1.92E-01	6.27E-02	5.23E-02		1.02E-01	2.55E-02
2001			1.70E-01	4.68E-02				
Baseline	3.00E-03	8.98E-04	2.86E-01	1.07E-01	2.56E-02	1.85E-02	1.11E-01	4.58E-02
2002	***<2.86E-03***	-	1.80E-01	5.43E-02			5.78E-02	2.49E-02
2003	4.16E-03	7.97E-04	1.71E-01	3.92E-02			7.28E-02	1.46E-02

MA9	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
2004	4.45E-03	1.52E-03	1.55E-01	3.38E-02			1.22E-01	3.61E-02
2005	4.36E-03	1.11E-03	1.39E-01	2.04E-02				
2006	5.55E-03	1.14E-03	1.36E-01	2.44E-02			6.13E-02	2.12E-02
Assessment	***<4.28E-03***		1.56E-01				7.86E-02	

MA10	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
Year	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**
1995	***<1.03E-03***	-	6.33E-01	5.26E-02				
1996	***<1.33E-03***	-	3.74E-01	1.61E-01	4.97E-02	4.03E-02		
1997	*<1.03E-03*	-	3.15E-01	1.60E-01	3.57E-02	2.50E-02		
1998	***<5.73E-04***	-						
1999	8.72E-04	5.08E-04			5.46E-02	1.65E-02		
2000	***<7.31E-04***	-					3.20E-02	-
2001	***<5.00E-04***	-	2.28E-01	1.06E-01	3.07E-02	2.76E-02	2.82E-01	1.96E-01
Baseline	***<8.67E-04***	-	3.87E-01	1.74E-01	4.27E-02	1.13E-02	1.57E-01	1.76E-01
2002	***<1.90E-03***	-	2.39E-01	8.82E-02				
2003	***<1.90E-03***	-	2.22E-01	-				
2004	***<1.51E-03***	-	2.39E-01	7.30E-02			8.48E-02	5.56E-02
2005	***<1.18E-03***	-	2.23E-01	4.77E-02			1.97E-01	1.14E-01
2006	***<2.37E-03***	-	2.17E-01	6.31E-02				
Assessment	***<1.77E-03***		2.28E-01				1.41E-01	

MA11	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
Year	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**
1995			1.34E+00	-				
1996			5.03E-01	3.42E-02	1.77E-02	7.61E-03		
1997			9.10E-01	4.40E-01	2.61E-02	0		
1998								
1999					9.15E-02	2.72E-02		
2000					1.81E-02	3.17E-03	2.89E-02	1.40E-02
2001			3.54E-01	1.25E-01	1.90E-02	7.22E-03	4.53E-02	8.05E-03
Baseline			7.77E-01	4.43E-01	3.45E-02	3.21E-02	3.71E-02	1.17E-02
2002			2.66E-01	-	2.60E-02	5.78E-03		
2003			2.55E-01	1.35E-01	2.31E-02	4.07E-03	4.82E-02	1.64E-02
2004			4.66E-01	1.36E-01	2.97E-02	2.29E-02	4.37E-02	1.37E-02
2005			3.95E-01	1.20E-01	1.70E-02	4.14E-03	7.47E-02	-
2006					9.27E-03	1.95E-03		
Assessment			3.46E-01		2.10E-02		5.55E-02	

MA12	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
Year	Dose (µSv/y)	SD	Dose (µSv/y)	SD	Dose (µSv/y)	SD	Dose (µSv/y)	SD
1995			2.37E+00	5.75E-01				
1996			1.60E+00	7.42E-01				
1997			2.21E+00	8.65E-01				
1998			1.50E+00	9.17E-01	2.32E-02	1.83E-02		
1999			1.23E+00	8.46E-01	2.88E-02	1.76E-02		
2000			7.12E-01	6.45E-01	1.66E-02	4.31E-03		
2001			1.64E+00	7.99E-01	1.30E-02	6.25E-03		
Baseline			1.61E+00	5.62E-01	2.04E-02	7.01E-03		
2002	*<3.14E-03*	-	***<3.19E+00***	-	8.14E-03	4.33E-03		
2003	***<2.39E-03***	-	2.86E+00	1.38E+00	9.14E-03	2.32E-03		
2004	***<2.92E-03***	-	2.39E+00	1.65E+00	7.69E-03	1.85E-03		
2005	2.31E-03	6.23E-04	2.56E+00	1.51E+00	8.13E-03	3.12E-03		
2006			1.32E+00	4.88E-01	6.31E-03	3.11E-03		
Assessment	***<2.69E-03***		***<2.46E+00***		7.88E-03			

MA13	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
Year	Dose (µSv/y)	SD	Dose (µSv/y)	SD	Dose (µSv/y)	SD	Dose (µSv/y)	SD
1995			2.62E-01	1.45E-01				
1996								
1997					9.22E-03	2.00E-03		
1998					1.42E-02	5.56E-03		
1999					2.26E-02	4.69E-03	7.86E-02	-
2000			2.50E-01	1.17E-01	1.95E-02	4.50E-03	4.85E-02	4.45E-03
2001					1.91E-02	5.04E-03		
Baseline			2.56E-01	8.47E-03	1.69E-02	5.25E-03	6.35E-02	2.13E-02
2002			2.37E-01	9.40E-02	1.51E-02	2.44E-03	4.12E-02	1.76E-02
2003			1.65E-01	3.39E-02	1.30E-02	1.78E-03	7.85E-02	4.10E-02
2004			1.12E-01	3.72E-02	1.26E-02	1.90E-03	5.69E-02	1.91E-02
2005			1.57E-01	1.13E-02	1.36E-02	1.48E-03	4.14E-02	1.06E-02
2006			1.36E-01	-	9.39E-03	1.48E-03		
Assessment			1.61E-01		1.27E-02		5.45E-02	

MA14	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
Year	Dose (µSv/y)	SD	Dose (µSv/y)	SD	Dose (µSv/y)	SD	Dose (µSv/y)	SD
1995								
1996								
1997								
1998								

MA14	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
1999			1.87E-01	2.11E-02	1.12E-02	5.58E-03	8.07E-02	1.22E-02
2000					1.85E-02	3.79E-03	5.95E-02	3.07E-02
2001					2.38E-03	5.44E-04		
Baseline			1.87E-01	-	1.07E-02	8.07E-03	7.01E-02	1.50E-02
2002					2.73E-03	1.14E-03	6.29E-02	2.17E-02
2003			1.81E-01	-	3.54E-03	1.26E-03	6.69E-02	8.23E-03
2004			1.49E-01	-	6.84E-03	5.54E-03	4.95E-02	-
2005			1.12E-01	0	6.18E-03	5.15E-03	5.65E-02	4.12E-02
2006			1.22E-01	1.50E-02	5.53E-03	3.31E-03		
Assessment			1.41E-01		4.96E-03		5.89E-02	

MA15	Seawater							
	H-3		Cs-137		Tc-99		Pu-239,240	
Year	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**
1995			2.09E-01	9.62E-02				
1996			2.30E-01	1.19E-01				
1997			2.08E-01	9.49E-02				
1998			2.94E-01	1.08E-01				
1999			2.94E-01	1.11E-01			7.13E-02	1.03E-02
2000			2.77E-01	8.92E-02			5.14E-02	3.73E-02
2001			1.61E-01	6.08E-02			6.81E-02	1.35E-02
Baseline			2.39E-01	5.10E-02			6.36E-02	1.07E-02
2002			1.67E-01	6.15E-02	2.11E-03	1.07E-03	3.72E-02	2.04E-02
2003			1.45E-01	7.52E-02	1.65E-03	1.03E-03	9.45E-02	2.09E-02
2004			1.59E-01	4.67E-02	1.72E-03	9.61E-04		
2005			1.11E-01	3.63E-02	1.55E-03	9.77E-04	3.69E-02	-
2006			1.42E-01	3.89E-02	1.29E-03	5.95E-04		
Assessment			1.45E-01		1.66E-03		5.62E-02	

***Table A4.12**: Doses from biota by monitoring area*

Key to the table:

- *SD: standard deviation.*
- *Empty box: no data available.*
- *Baseline dose value in italics denotes that all measurements on which the corresponding baseline seawater value has been based were below the detection limit.*
- *Baseline dose value in bold italics denotes that some/most measurements on which the corresponding baseline seawater value has been based were below the detection limit.*
- *Dash: Standard deviation not calculated because the baseline dose value has been derived from a baseline seawater value that has been based on all or some/most measurements below the detection limit.*

MA1	Biota								
	Cs-137			Cs-137			Pu-239,240		
Year	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD
1995									
1996									
1997									
1998									
1999									
2000									
2001									
Baseline									
2002				F	1.02E-01	2.65E-02			
2003				F	1.46E-01	5.30E-02			
2004				F	1.19E-01	2.65E-02			
2005									
2006									
Assessment				F	1.22E-01				

MA2	Biota								
	Cs-137			Tc-99			Pu-239,240		
Year	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD
1995							M	4.53E-02	2.35E-02
1996							M	4.63E-02	3.66E-02
1997							M	5.99E-02	9.13E-02
1998							M	4.88E-02	3.73E-02
1999							M	4.97E-02	5.79E-02
2000							M	4.26E-02	2.79E-02
2001							M	3.33E-02	1.62E-02
Baseline							M	4.65E-02	8.00E-03
2002							M	2.55E-02	9.83E-03
2003							M	2.86E-02	1.95E-02
2004							M	***<3.39E-02***	-
2005							M	3.36E-02	1.89E-02
2006							M	***<3.02E-02***	-
Assessment							M	***<3.04E-02***	

MA3	Biota								
	Cs-137			Tc-99			Pu-239,240		
Year	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD
1995							F	***<3.28E-04***	-
1996							F	4.07E-04	1.18E-04
1997							F	***<3.71E-04***	-
1998							F	***<6.23E-04***	-
1999							F	*<2.23E-04*	-
2000									
2001									
Baseline							F	***<3.90E-04***	-
2002									
2003									
2004									
2005									
2006									
Assessment									

MA4	Biota								
	Cs-137			Tc-99			Pu-239,240		
Year	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD
1995							M	7.81E-01	
1996							M	5.07E-01	1.21E-01
1997							M	5.45E-01	1.04E-01
1998							M	7.05E-01	2.00E-01
1999							M	4.96E-01	1.56E-01
2000							M	2.78E-01	2.13E-01
2001							M	3.18E-01	2.86E-01
Baseline							M	5.19E-01	1.84E-01
2002							M	1.37E-01	3.58E-02
2003							M	7.78E-02	-
2004							M	9.35E-02	-
2005							M	9.13E-02	-
2006									
Assessment							M	9.98E-02	

MA5	Biota								
	Cs-137			Tc-99			Pu-239,240		
Year	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD
1995	F	1.38E+00	2.54E-01				M	5.93E-01	1.42E-01
1996	F	1.40E+00	3.24E-01				M	4.54E-01	5.44E-02
1997	F	1.11E+00	2.87E-01				M	5.53E-01	-
1998	F	1.01E+00	3.51E-01				M	4.26E-01	-

MA5	Biota								
	Cs-137			Tc-99			Pu-239,240		
Year	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD
1999	F	1.20E+00	6.10E-01				M	4.37E-01	-
2000	F	1.30E+00	3.07E-01				M	4.51E-01	-
2001	F	8.42E-01	4.40E-01				M	4.07E-01	-
Baseline	F	1.18E+00	2.06E-01				M	4.74E-01	6.99E-02
2002	F	1.06E+00	2.94E-01				M	3.59E-01	9.51E-02
2003	F	6.35E-01	1.71E-01				M	1.05E+00	9.82E-01
2004	F	7.52E-01	1.68E-01				M	5.28E-01	0
2005	F	6.68E-01	3.25E-01				M	3.59E-01	1.34E-01
2006	F	***<1.01E+00***	-				M	4.02E-01	1.17E-02
Assessment	F	***<8.25E-01***					M	5.40E-01	

MA6	Biota								
	Cs-137			Tc-99			Pu-239,240		
Year	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD
1995	M	1.26E+00	1.24E+00				M	3.54E+01	3.14E+01
1996	M	1.05E+00	9.55E-01				M	3.15E+01	2.83E+01
1997	M	9.63E-01	1.01E+00				M	2.54E+01	2.83E+01
1998	M	7.30E-01	8.89E-01				M	2.55E+01	2.62E+01
1999	M	7.64E-01	8.33E-01				M	2.83E+01	2.48E+01
2000	M	7.19E-01	8.42E-01				M	2.41E+01	2.80E+01
2001	M	6.28E-01	8.02E-01				M	2.92E+01	3.61E+01
Baseline	M	8.74E-01	2.25E-01				M	2.85E+01	3.98E+00
2002	M	6.16E-01	7.85E-01				M	2.67E+01	3.25E+01
2003	M	5.33E-01	5.75E-01				M	2.59E+01	3.15E+01
2004	M	5.43E-01	5.10E-01				M	1.97E+01	1.78E+01
2005	M	5.42E-01	6.20E-01				M	2.87E+01	3.55E+01
2006	M	4.51E-01	5.85E-01				M	2.54E+01	2.66E+01
Assessment	M	5.37E-01					M	2.53E+01	

MA7	Biota								
	Cs-137			Tc-99			Pu-239,240		
Year	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD
1995							M	1.08E+00	3.69E-02
1996							M	1.28E+00	4.86E-02
1997							M	6.03E-01	2.43E-02
1998							M	5.47E-01	2.33E-02
1999							M	2.82E-01	1.30E-02
2000							M	3.35E-01	1.61E-01
2001							M	3.11E-01	1.17E-01
Baseline							M	6.34E-01	3.97E-01
2002							M	1.86E-01	7.74E-02

MA7	Biota								
	Cs-137			Tc-99			Pu-239,240		
Year	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD
2003							M	3.25E-01	1.08E-01
2004							M	2.46E-01	8.21E-02
2005							M	2.89E-01	2.01E-01
2006							M	1.63E-01	8.65E-02
Assessment							M	2.41E-01	

MA8	Biota								
	Cs-137			Pu-239,240			Pu-239,240		
Year	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD
1995	F	1.94E-01	-						
1996	F	2.82E-01	1.47E-01	M	***<5.93E-02***	-	F	***<1.75E-01***	-
1997	F	1.51E-01	4.59E-02	M	9.87E-02	7.20E-02	F	***<1.49E-01***	-
1998	F	2.01E-01	5.69E-02	M	***<1.24E-01***	-	F	***<2.13E-01***	-
1999	F	3.00E-01	-	M	***<1.19E-01***	-	F	***<1.92E-01***	-
2000				M	1.50E-01	4.54E-02	F	***<1.90E-01***	-
2001				M	1.79E-01	4.90E-02	F	***<1.66E-01***	-
Baseline	F	2.26E-01	6.28E-02	M	***<1.22E-01***	-	F	***<1.81E-01***	-
2002	F	***<6.62E-02***	-	M	***<5.25E-01***	-			
2003	F	***<6.48E-02***	-	M	*<6.88E-01*	-			
2004	F	***<6.36E-02***	-	M	*<5.96E-01*	-			
2005	F	***<9.79E-02***	-	M	*<3.44E-01*	-	F	***<2.32E-01***	-
2006	F	***<8.12E-02***	-	M	***<2.16E-01***	-	F	***<1.96E-01***	-
Assessment	F	***<7.47E-02***		M	***<4.73E-01***		F	***<2.14E-01***	

MA9	Biota								
	Cs-137			Tc-99			Pu-239,240		
Year	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD
1995	F	2.59E-01	8.10E-02				F	*<2.42E-04*	-
1996	F	2.53E-01	1.27E-01				F	***<3.74E-04***	-
1997	F	2.35E-01	1.52E-01						
1998	F	2.06E-01	1.14E-01				F	*<2.52E-04*	-
1999	F	1.77E-01	1.39E-01				F	***<2.74E-04***	-
2000	F	9.43E-02	3.14E-02				F	***<3.28E-04***	-
2001	F	9.15E-02	-				F	1.83E-04	-
Baseline	F	1.88E-01	7.07E-02				F	***<2.75E-04***	-
2002	F	1.27E-01	6.25E-03				F	*<3.91E-04*	-
2003	F	1.46E-01	7.56E-02				F	*<2.36E-04*	-
2004	F	5.48E-02	-				F	*<2.72E-04*	-
2005	F	7.86E-02	3.87E-02				F	4.82E-04	4.44E-04
2006	F	7.84E-02	2.65E-02						
Assessment	F	9.70E-02					F	***<3.45E-04***	

MA10	Biota								
	Cs-137			Tc-99			Pu-239,240		
Year	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD
1995	F	4.45E-01	2.54E-01						
1996	F	3.55E-01	1.91E-01						
1997	F	3.15E-01	1.58E-01						
1998	F	3.01E-01	1.56E-01				M	1.43E-01	-
1999	F	2.08E-01	4.18E-02				M	1.36E-01	-
2000	F	1.95E-01	8.35E-02				M	1.72E-01	-
2001	F	1.83E-01	7.70E-02				M	1.73E-01	-
Baseline	F	2.86E-01	9.68E-02				M	1.56E-01	1.92E-02
2002	F	2.10E-01	9.84E-02				M	2.28E-01	-
2003	F	1.59E-01	7.62E-02				M	2.18E-01	-
2004	F	1.52E-01	9.16E-02				M	2.17E-01	-
2005	F	1.55E-01	1.15E-01				M	1.58E-01	-
2006	F	1.87E-01	1.45E-01				M	1.96E-01	-
Assessment	F	1.73E-01					M	2.03E-01	

MA12	Biota								
	Cs-137			Cs-137			Tc-99		
Year	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD
1995				F	1.11E+00	1.33E+00			
1996				F	1.46E+00	9.95E-01			
1997				F	1.42E+00	7.76E-01			
1998				F	1.61E+00	1.67E+00			
1999				F	1.20E+00	6.81E-01			
2000				F	1.27E+00	6.29E-01			
2001				F	1.07E+00	3.68E-01			
Baseline				F	1.30E+00	1.98E-01			
2002				F	3.15E+00	1.73E+00			
2003				F	2.71E+00	1.45E+00			
2004				F	2.50E+00	1.35E+00			
2005				F	2.40E+00	1.23E+00			
2006				F	2.11E+00	1.16E+00			
Assessment				F	2.57E+00				

MA14	Biota								
	Cs-137			Tc-99			Pu-239,240		
Year	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD
1995									
1996	F	1.32E-01	1.43E-02						
1997	F	1.47E-01	2.18E-02						
1998	F	1.48E-01	3.98E-02						

MA14	Biota								
	Cs-137			Tc-99			Pu-239,240		
Year	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD
1999	F	1.08E-01	4.32E-02						
2000	F	1.27E-01	2.96E-02						
2001	F	1.13E-01	2.48E-02						
Baseline	F	1.29E-01	1.69E-02						
2002	F	7.51E-02	3.40E-02						
2003	F	1.02E-01	3.50E-02						
2004	F	1.23E-01	2.15E-02						
2005	F	1.18E-01	1.96E-02						
2006									
Assessment	F	1.05E-01							

MA15	Biota								
	Cs-137			Tc-99			Pu-239,240		
Year	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD	Type	Dose (µSv/y)	SD
1995									
1996	F	6.91E-02	1.44E-02						
1997	F	6.76E-02	2.84E-02						
1998	F	6.54E-02	2.35E-02						
1999	F	5.35E-02	2.59E-02						
2000	F	5.75E-02	2.01E-02						
2001	F	6.63E-02	9.55E-03						
Baseline	F	6.32E-02	6.24E-03						
2002	F	6.39E-02	2.58E-02						
2003	F	7.52E-02	2.90E-02						
2004	F	7.24E-02	2.30E-02						
2005	F	5.35E-02	1.65E-02						
2006	F	4.69E-02	2.18E-02						
Assessment	F	6.24E-02							

Table A4.13: *Assessment of the doses from seawater*

Key to the table:
- *SD – standard deviation.*
- *Empty box: no data available.*
- *Dash: Standard deviation not calculated because n=1.*
- *indicates values derived from the concentration values extracted from literature (see Table A4.10)*

		Seawater							
Monitoring area	**Year**	**Ra-226**		**Ra-228**		**Pb-210**		**Po-210**	
		Dose (µSv/y)	**SD**	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**
1. Wider Atlantic Iberian Coast Biscay and Channel West	1994*	1.05E+01	2.90E+00	1.55E+01	9.10E+00				
2. Channel (Cap de la Hague)	1994*	1.21E+01	1.60E+00	3.87E+01	1.39E+01				
3. Channel East	1994*	9.70E+00	2.10E+00	2.98E+01	7.30E+00				
4. Irish Sea (Rep. of Ireland)	1994*	1.00E+01	2.00E+00	2.20E+01	1.03E+01				
5. Irish Sea (Northern Ireland)	1994*	1.18E+01	-	4.27E+01	-				
6. Irish Sea (Sellafield)	1994*	1.50E+01	2.70E+00	7.21E+01	1.87E+01				
8. North Sea South (Belgian and Dutch Coast)	1985-86*	4.21E+01	1.70E+00			1.64E+01	-	1.00E+03	2.34E+02
10. North Sea (Northwest, Southeast and Central)	1976*					1.83E+01	1.17E+01	1.28E+03	7.67E+02
	1986-87*	2.29E+01	5.70E+00	7.66E+01	3.02E+01				
	2004*	1.39E+01	4.10E+00	1.81E+01	2.01E+01			3.00E+03	8.34E+02
11. North Sea (Skagerrak)	2004*	1.72E+01	4.10E+00						
13. Norwegian Coastal Current	1976*					4.05E+01	-	2.49E+03	-

		Seawater							
Monitoring area	**Year**	**Ra-226**		**Ra-228**		**Pb-210**		**Po-210**	
		Dose (µSv/y)	**SD**	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**	**Dose (µSv/y)**	**SD**
	2005*	1.12E+01	5.70E+00						
14. Barents Sea	2005*	1.31E+01	4.10E+00						

Annex 5 – Dose assessment methodology for measured concentrations in seawater and biota

Dose assessment method for measured concentrations in seawater

The method for dose assessment for seawater uses a simplified version of the MARINA II dose assessment model. Activity concentrations in seafoods are calculated from seawater activity concentrations using element specific concentration factors. Doses to individuals due to consumption of seafoods (fish, crustaceans, molluscs) are assessed by multiplying the calculated concentration of radioactivity in the seafoods by the amounts of seafood consumed and by dosimetric factors which convert intake of radioactivity into dose.

This is represented by the following basic equation:

$$D_{indS} = \Sigma (C_R \times CF_{SR} \times I_S \times DPUI_R)$$

where:

D_{indS} is the individual dose due to seafood consumption (Sv y^{-1});

C_R is the concentration of radionuclide R in seawater (Bq L^{-1}),

CF_{SR} is the concentration factor of radionuclide R in seafood type S (for example, fish) (L kg^{-1}),

I_S is the consumption rate for seafood type S (kg y^{-1});

$DPUI_R$ is the dose per unit intake of radionuclide R (Sv Bq^{-1}).

Concentration factors for fish, crustaceans and molluscs are those presented in Table A5.1.

Table A5.1: *Concentration factors (Bq/kg to Bq/l)*

	H	Tc	Cs	Pb	Po	Ra	Pu
Fish	1	30	100	200	20000	500	100
Crustaceans	1	1000	30	1000	50000	100	200
Molluscs	1	1000	30	1000	10000	1000	3000

Mean ingestion rates of fish, crustaceans and molluscs are those presented in Table A5.2.

Table A5.2: *Ingestion rates*

Ingestion rates	Fish	Crustaceans	Molluscs
kg/y	34	12	11

Dose coefficients (committed effective dose per unit intake via ingestion) used are those published in the Directive 96/29 EURATOM and are presented in Table A5.3.

Table A5.3: *Dose coefficients*

	H-3 (Sv/Bq)	Tc-99 (Sv/Bq)	Cs-137 (Sv/Bq)	Pb-210 (Sv/Bq)	Po-210 (Sv/Bq)	Ra-226 (Sv/Bq)	Ra-228 (Sv/Bq)	Pu-239, 240 (Sv/Bq)
Dose Coefficients	1.8×10^{-11}	6.4×10^{-10}	1.3×10^{-8}	6.9×10^{-7}	1.2×10^{-6}	2.8×10^{-7}	6.9×10^{-7}	2.5×10^{-7}

Dose assessment method for measured concentrations in biota

Doses to individuals due to consumption of seafoods are assessed by multiplying the concentration of radioactivity in the seafoods by the amounts of seafood consumed and by dosimetric factors which convert intake of radioactivity into dose. This is represented by the following basic equation:

$$D_{indS} = \Sigma (C_{SR} \times I_S \times DPUI_R)$$

where:

D_{indS} is the individual dose due to seafood consumption (Sv y^{-1});

C_{SR} is the activity concentration of radionuclide R in seafood type S (for example, fish) (Bq kg^{-1}),

I_S is the consumption rate for seafood type S (kg y^{-1});

$DPUI_R$ is the dose per unit intake of radionuclide R (Sv Bq^{-1}).

Mean ingestion rates of fish and molluscs are those assumed in section 6 of the MARINA II Report of Working Group B (S.P. Nielsen and M. Keith-Roach). The ingestion rates are presented in Table A5.4.

Table A5.4: *Ingestion rates*

Ingestion rates	Fish	Molluscs
kg/y	34	11

Dose coefficients (committed effective dose per unit intake via ingestion) used are those published in the EURATOM directive 96/29 and are presented in Table A5.5.

Table A5.5: *Dose coefficients*

	H-3 (Sv/Bq)	Tc-99 (Sv/Bq)	Cs-137 (Sv/Bq)	Pu-239,240 (Sv/Bq)
Dose Coefficients	1.8×10^{-11}	6.4×10^{-10}	1.3×10^{-8}	2.5×10^{-7}

Annex 6 – ERICA Integrated Approach

The Ecological Risk Assessment (ERA) methodology is implemented in a number of approaches and/or tools, which are achieved, complete and documented to varying degrees. Among these, the ERICA approach is the only European reference project that allows an integrated assessment of doses to biota and that has also been tested in a number of case studies. More than 60 European scientists, regulators, policy makers and environmental experts have contributed to the ERICA Integrated Approach through the ERICA project (ERICA, 2007). In addition, a large number of experts in different areas have contributed views on the Integrated Approach and its associated Tool from the user's perspective, through participation in the End Users Group.

Moreover, this flexible approach may be adapted to user needs, especially in terms of organisms and radionuclides. It was selected as corresponding to the requirements for JAMP product RA-3, the assessment of impacts on marine biota. The justification of this choice was argued for each decisive criterion, on an inter-comparison basis, in the assessment of impacts on marine biota (OSPAR, 2008a).

The development of the ERICA Integrated Approach has coincided with the work of the ICRP in the field of protection of the environment against the harmful effects of ionising radiation [ICRP 2003, 2007]. The ERICA Integrated Approach and the ICRP approach are consistent. In both cases, the databases are developed around certain ecosystem representatives (Reference Organisms, ROs, in ERICA; Reference Animals and Plants, RAPs, in ICRP).

The ERICA Integrated Approach has adopted an ERA-tiered methodology to demonstrate the provision of an appropriate level of protection for ecosystems. It evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors. According to this methodology, any risk assessment applicable to biota from exposure to radionuclides comprises:

- problem formulation, comprising source-term characterisation and environmental release scenario, the ecological target to be protected (for example, a given ecosystem, a given species), and any further question requiring a resolution;
- the exposure analysis,
- the effects analysis at different levels of individual or ecosystem organisation, resulting in the derivation of 'no-effect' values; and
- risk characterisation where, for instance, risk can be calculated in the simplest way as the ratio between predicted concentrations in the source of exposure and estimated 'no-effect' concentrations (FASSET, 2004; ERICA, 2007). This approach is recommended by the European Commission (EC, 2003).

Problem formulation

The problem formulation is intended to identify the scope, context and purpose of the assessment framework (Suter, 1993). This includes relevant ecological, political and societal issues, and integrates the process of choosing appropriate assessment endpoints, identifying sources and type of exposure situations (*i.e.* chronic or acute; past, present or future) and describing the receiving ecosystem. Commonly, a conceptual model is described at first to gather existing knowledge about the site/ecosystems (for example, geographical limits, radionuclides of interest, natural background, pathways of exposure, receptors, the problem faced, and existing monitoring data).

Exposure analysis

The exposure analysis stage is the process of estimating the exposure of biota. It involves estimating or measuring activity concentrations in environmental media and organisms, defining exposure conditions, and estimating radiation dose rates to selected biota.

Although dynamic models have been employed to describe the dispersion and dilution of radionuclides in marine ecosystems, the transfers to sediments and to living organisms are very often modelled as equilibrium processes, using simple distribution coefficients and concentration factors. The value of equilibrium based values may be limited because temporal variation in concentrations and consequently in dose rate due to short-term fluctuations in discharge rate or in any short-term environmental processes (for example, seasonality), is neglected. However using an equilibrium based approach, as in the assessment reported here, is appropriate, given that the input data to the dosimetric model is based on annually reported data and this work is concerned with long term changes in the activity concentrations of radioactive substances in the environment.

Figure A6.1 summarises the main transfer pathways and ROs for a generic marine ecosystem. This ROs concept constitutes an attempt to strike a balance between the level of simplification required for the methodology to be workable, the level of complexity needed to provide useful information and the basic data that can be made available as input for the models. The biological environment includes phytoplankton, zooplankton, macro-invertebrates, sessile aquatic plants, molluscs, crustaceans and vertebrates (fish, marine mammals and marine birds). The physical environment includes tidal zones, coastal waters and marine sediments. Connections with terrestrial and/or freshwater ecosystems may be included in the conceptual model of interest. Implicitly, the corresponding exposure pathways include external irradiation from contaminated water and sediments as well as internal contamination resulting from both direct and trophic transfers.

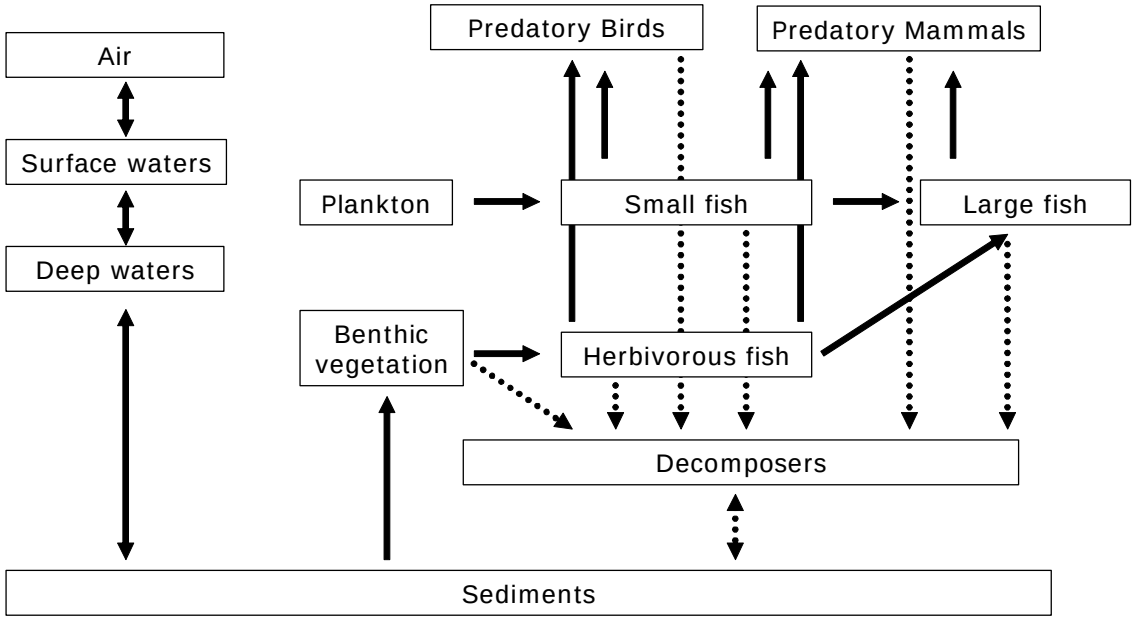


Figure A6.1: *Example of a conceptual model for a marine generic ecosystem (from ERICA 2007).*

Radioactive substances in marine water are subject to several processes that lead to a modification of their activity concentrations, in addition to radioactive decay. Of greatest importance is dilution due to mixing effects during transport, driven by local, regional and global currents; and sedimentation after binding to suspended particles.

Fractions of dissolved and particle-bound radionuclides are determined by the distribution coefficient Kd, which is defined as the equilibrium ratio of radionuclides in normally filtered water and adsorbed onto particulate matter. Kd-values are dependent on the radio-element. Low Kd values result in high dissolution, whereas high Kd values favour adsorption. Once deposited, radionuclides are involved in further processes which may potentially have an impact on their long-term behaviour.

For marine biota, activity concentrations can be estimated using a Concentration Ratio (CR) approach. This CR, also called concentration factor or bioaccumulation factor, is defined as the equilibrium ratio between the activity concentration within an organism and the activity concentration in normally filtered seawater. It may be calculated for a given organ (muscle) or for the whole body of the organism, as it is done in ERICA.

The main gaps identified within the field of exposure analysis are mainly the lack of dynamic transfer models and, even for equilibrium models, knowledge related to the associated transfer parameters. A number of extrapolations are then needed at present to fill in gaps of knowledge to quantify the transfer for a list of combinations (radionuclide, exposure pathway, reference organism). Large information gaps exist in the derivation of transfer factors for all combinations needed to describe properly any ecosystem model.

Dosimetry

The proposed method of dosimetry is based on the measured environmental activity concentrations of radioactive substances, combined with modelling of the absorbed radiological dose rates delivered to living organisms representative of the marine ecosystems within the OSPAR area. In brief, exposure to ionising radiation is estimated as the absorbed dose rate (*i.e.* the quantity of energy imparted by ionising radiation to the tissue of a whole organism per unit time in μGy/h). To determine this, the activity concentrations in both media and biota are required together with a method for converting these into estimates of external and internal exposure. Radionuclide activity concentrations in media and/or biota may be known, or may need to be estimated by transport/transfer models from discharges.

The radiation exposure received by biota (or some organ or tissue of the biota) is the sum of both external and internal exposure. External exposures of biota are the result of complex and often non-linear interactions of various factors, such as the levels of radionuclides in the habitat, the geometrical relationship between the radiation source and the target, the shielding properties of materials in the environment, the size of the organism and the radionuclide-specific decay properties (characterised by the radiation type, the energies emitted and their emission probabilities). Internal exposures of plants and animals are determined by the activity concentration in the organism, the size of the organism, the radionuclide distribution and the specific decay properties of the radionuclide. Factors to account for the relative biological effectiveness of α, β and γ-radiation are applied. Some approaches, like ERICA, involve a more precise description of the radiation categories by distinguishing low and high beta radiation categories. The high beta radiation category is then treated in the same way as gamma radiation.

Dosimetric models are needed to convert concentrations expressed in Bq per unit of mass or volume into absorbed dose rates for living organisms, including both external and internal irradiation pathways. The absorbed dose reflects the interaction of all types of radiation with any kind of material. Dosimetric models take into account the radiation type, the specific geometry of the target, sources of exposure, and their relative position with regards to the target. To reach this goal, it would be impossible to consider the whole diversity of life forms in an ecosystem. The ROs concept simplifies the approach and allows the basic data required as input for the models to be determined. This approach is limited by additional sources of complexity such as those arising from the behaviour of mobile organisms. Nuclide-specific dose conversion factors

for internal and external exposure of ROs are provided in literature (for example, [ERICA 2007]) and some intercomparisons have been performed (Battle *et al*., 2007).

Table A6.1: *Selected reference organisms for the marine ecosystems within the OSPAR Maritime Area.*

Type of organism	Feeding habit	Representative species
Large fish	Predatory Omnivorous	Cod *Gadus morhua*
	Benthivorous	Haddock *Melanogrammus aeglefinus*
Medium-size fish	Planktinovorous	Herring *Clupea harengus*
	Benthivorous	Plaice *Pleuronectes platessa*
Small fish	Planctonivorous	Pilchard/Sardine *Sardina pilchardus*
Very small fish	Planctonivorous	Sprat *Sprattus sprattus*
Mollusc bivalve	-	Mussel *Mytilus edulis*
Mollusc gastropoda	-	Winkle *Littorina litorea*
Crustacean	-	Crab *Cancer pagurus*
Crustacean	-	Shrimp *Pnadalus borealis*
Bird	-	Gull *Larus sp.*
Mammal	-	Seal *Phoca sp.*
Macroalgae	-	Macroalgae *Fucus sp.*

To support the dosimetric calculations, the concept of using a limited set of ROs was developed within the FASSET project, based on some earlier papers (Pentreath 1999). The ROs are defined as “a series of entities that provide a basis for the estimation of radiation dose rate to a range of organisms which are typical, or representative, of a contaminated environment. These estimates, in turn, would provide a basis for assessing the likelihood and degree of radiation effects”. The main criteria for the selection of ROs within the FASSET project were the habitat and feeding habits of an organism that maximised its potential exposure to radionuclides, and the potential accumulation by an organism of any radionuclides that were likely to maximise

internal exposures. The ROs are selected to be representative of large components of common ecosystems and for which models are adopted for the purpose of deriving dose and dose rates, mainly for the whole organism.

Dose quantities are specific to human radiation protection. In the absence of corresponding dosimetric concepts and quantities for application to non-human species, the absorbed doses from low-linear energy transfer (LET) radiations (beta particles, x rays and gamma rays) and from high-LET radiation (alpha particles) are assessed separately and added for a given radionuclide if needed. The absorbed doses retain the SI unit joule per kilogram (J kg^{-1}) and the unit name gray (Gy) as used for human doses (UNSCEAR, in press). A radiation field that deposits 1 joule of energy in 1kg of material has an absorbed dose of 1Gy.

The relationship between the activity concentration of an organism or media and absorbed dose rates is described by the Dose Conversion Coefficient (DCC). The method used to derive the DCC values is the one selected in the ERICA Tool, previously described by Pröhl *et al*. (2003). Application of the DCC allows the estimation of unweighted absorbed dose rate from media and organism activity concentrations. The total radiation effects are not only dependent upon unweighted absorbed dose, but also on the type of radiation. For example, for a given unweighted absorbed dose rate, γ-radiation may result in a more significant effect than α or β radiation. Therefore, Radiation Weighting Factors (RWF) may be introduced to account for the Relative Biological Effectiveness (RBE) of the different types of radiation.

The issue of using the concept of RBEs and derived RWFs in assessing dose rate to non-human biota is still under debate. It is widely accepted that a number of factors affect RBE values, for example, the endpoint, the species/tissue/cell, the type of particle and its LET distribution, the exposure pathway, the dose and the type of radiation used as reference. Even so, no consensus has been reached on the way to derive robust RBE values at the individual level. Furthermore, understanding of how RBE values could change for populations within an ecosystem is still limited. This has motivated some authors to consider this factor as a contributor to the uncertainty associated to the final dose estimates. For the purposes of this Periodic Evaluation a RWF value of 1 has been selected for gamma radiation, 3 for low energy β particles and a value of 10 for α [ERICA 2007].

Dose effects

Responses of individual biological functions to radiation exposure, for example, growth, can be traced to events at the cellular or sub cellular level in specific tissues or organs. Even though mutational events in somatic cells are primarily responsible for tumour formation (hence inducing cancer), there is a strong agreement that cancer is still of low ecological relevance (Adam 2007). Because most cancers (except leukaemia) are associated with older individuals, the effect on the population(s) following the removal of (a fraction of) this cohort is relatively small. On the other hand, mutational effects on germ cells may lead to reproductive impairment, which may affect the population in a more profound way (Anderson *et al*. 1998).

Population-level effects are valuable indicators of ecological hazard (Forbes and Calow, 2002). However, due to experimental constraints, most available data describe effects on individual traits. Many studies have documented the effects of radiation at the cellular, tissue and individual levels, and the likely consequences have been found to be increases in morbidity and mortality, decreases in fertility and fecundity, and increases in mutation rate (Woodhead, 2003). These types of effects observed at the individual level may have consequences on the dynamic of the population of the species.

With the studies undertaken to date, ionising radiation does not appear to have any direct effects at the population or higher ecological levels (*i.e.* community or structure and function of ecosystems) at the levels currently measured in the marine environment. All such effects are mediated at the individual, or lower, levels. In addition, indirect effects through food-web

mediated processes may occur (Garnier-Laplace *et al*, 2004), *i.e.* any detriment on the dynamic of a prey population may impact the population dynamics of its predators.

Even though several factors complicate extrapolations of individual level effects to populations, current knowledge supports the conclusion that measures intended to limit radiation damage in individuals to an acceptable degree will also provide a sufficient degree of protection for populations. Obviously, population level consequences of hereditary mutations might in some cases need to be allowed for in these extrapolations. If and how this is to be done requires additional research and scientific review (Garnier-Laplace *et al*., 2004).

The FASSET project organised a data base on radiation effects on non-human biota under four broad effects categories, referred to by FASSET as "umbrella effects". These include: (i) morbidity (including growth rate, effects on the immune system, and the behavioural consequences of damage to the central nervous system from radiation exposure in the developing embryo) ; (ii) mortality (including the stochastic effect of somatic mutation and its possible consequence of cancer induction, as well as deterministic effects in particular tissues or organs that would change the age-dependent death rate) ; (iii) reduced reproductive success (including fertility and fecundity) ; and (iv) mutation (induced in germ and somatic cells).

Table A6.2 gives an overview of the quality and quantity of available data within the FASSET Radiation Effects Database (FRED), adopting a simplified categorization (ecosystem type, exposure duration and irradiation pathway). Allocation of effects data is strongly weighted in favour of terrestrial ecosystems (73% of all data) and for each ecosystem, the available data appears to be biased roughly 2:1 in favour of acute data and an external gamma irradiation exposure situation. As a consequence, chronic effect data information for marine ecosystems is limited and largely dominated by external gamma irradiation exposure. This brief examination of the available knowledge on effects of radioactive substances on non-human species has demonstrated that only data for effects induced by external gamma irradiation pathways are good enough to be processed as a dose-effect reconstruction (ERICA, 2006; Garnier-Laplace *et al*., 2006). Moreover, species from marine ecosystems were poorly investigated.

Table A6.2: *Examples of data available in FRED*

Ecosystem (number of references)	Total number of data	(%)	Data per exposure duration			Data per exposure irradiation pathway		
				Total number	%	External	Internal	Other[a]
Terrestrial -579	19983	-72.6	Acute	12273	61.4	11564	288	421
			Chronic	6795	34	3449	344	3002
			Transitory[b]	913	4.57	670	40	203
			not stated	2	0.03	0	0	2
Freshwater -195	6067	-22	Acute	4526	74.6	4058	97	371
			Chronic	1484	24.5	970	20	494
			Transitory	54	0.89	12	2	40
			not stated	3	0.01	0	0	3
Marine -45	1470	-5.4	Acute	1116	75.9	995	58	63
			Chronic	353	24.1	286	0	67
			Transitory	0	0	0	0	0
			not stated	1	0	0	0	1

a "Other" means that the experiment reported in the literature was devoted to the study of effects involved by mixed irradiation pathways, and/or not well characterised to be used for the present analysis.

b "Transitory" means in between "acute" and "chronic" in terms of exposure duration.

Risk characterisation

Risk characterisation includes estimation of the probability and magnitude of adverse effects in biota, together with the identification of uncertainties. The risk calculation method has been developed within the ERICA project and constitutes an element of the ERICA Integrated Approach. Risk characterisation is performed by evaluating the output data from the exposure analysis or assessment (estimates of exposure) against an effects analysis. The latter is done on the basis of published effects data, gathered into the FRED-ERICA[15] radiation effects database. This is a compilation of the scientific literature on radiation effect experiments and field studies for different wildlife groups and, for most data, broadly categorised according to four effect umbrella endpoints: morbidity, mortality, reproduction, and mutation.

One of the major difficulties in the implementation of ecological risk assessments for radioactive substances is the lack of data from chronic studies at low levels of exposure. These topics remain a subject for future research. These principles on how to study dose(rate)-effects relationships for chronic (long-term) exposure of organisms to low levels of radioactive substances are of major importance, as a number of quality criteria must be applied to produce new data on effects. The higher their quality and robustness, the higher will be the confidence in their potential use in any methodology to derive benchmark values.

ERICA is organised in three separate tiers, where satisfying certain criteria in Tiers 1 and 2 allows the assessor to have a degree of confidence that the effects on biota are low or negligible, and that the situation requires no further action. Where the effects are shown to be non-negligible, the assessment can continue to Tiers 2 and 3. Situations of concern can be assessed further in Tier 3, by making full use of all relevant information available through the Integrated Approach or elsewhere. As such, the ERICA Integrated Approach attempts to strike a balance between the simplification required for the method to be workable, and the complexity needed to generate useful information. This enables the early screening out of situations of negligible radiological concern, leaving only those of potential or real concern for more in-depth assessment (ERICA, 2007).

This approach requires risk assessment screening dose rate values for the risk characterisation within Tiers 1 and 2. Those screening values were derived from data taken from FRED and compared with some key data from the Environmental Protection from Ionising Contaminants in the Arctic (EPIC) database. The method applied follows the EC recommendations for the estimation of Predicted No Effect Concentrations (PNEC) for chemicals (EC 2003), see ERICA, 2006 and Garnier-Laplace *et al*, 2006. Garnier-Laplace *et al*, 2006 described the methodology used to derive ERICA risk assessment predicted no effect dose (rate) values. This analysis resulted in the ERICA Integrated Approach screening dose rate for incremental exposure of 10 µGy/h, corresponding to a safe level criterion to be applied only for protection of the structure and function of generic ecosystems, including marine ones, and associated with Tier 1 and Tier 2 assessments.

15 Extension of the initial Framework for Assessment of Environmental impact of ionising radiation (FASSET) database, FRED, during the ERICA project.

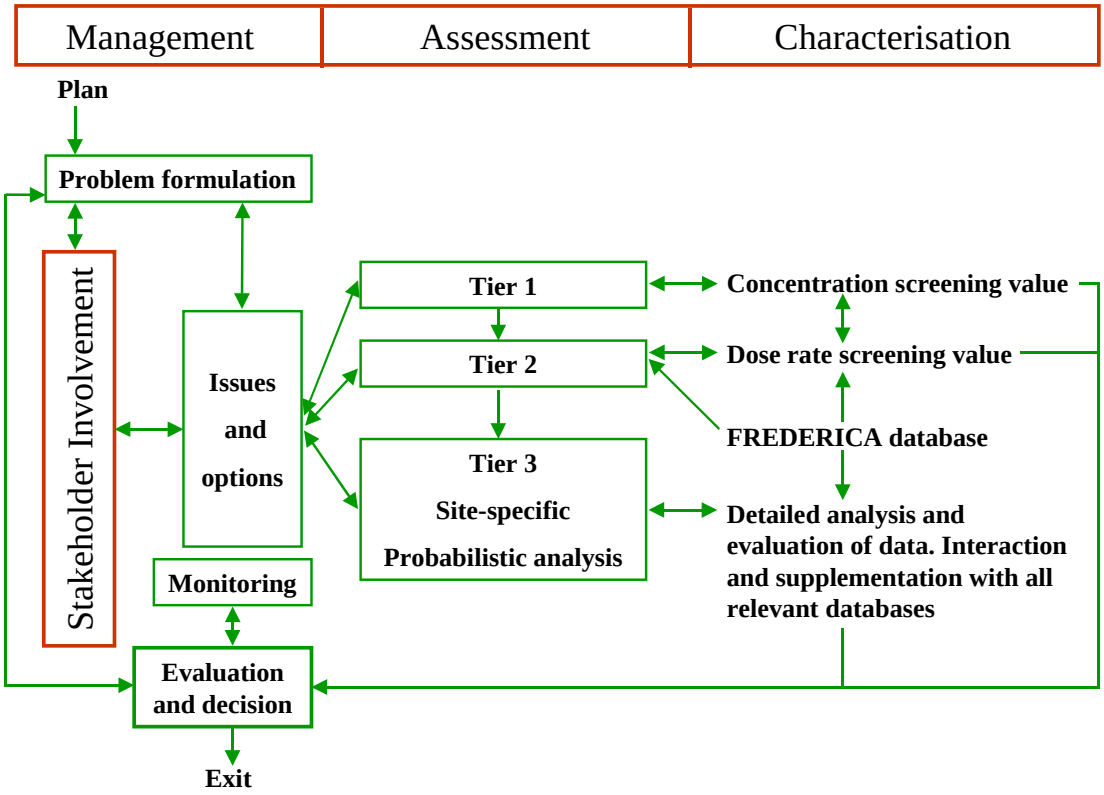


***Figure A6.2**: Overview of the ERICA Integrated Approach, outlining the interactions between assessment, risk characterisation and management (ERICA, 2007).*

A feature of the ERICA approach is that it provides guidance on how to fill data gaps in transfer parameters so that a complete data set can be made available for use in the assessment of any ecosystem model. Where necessary, the use of the guidance approach to derive missing transfer parameters has been used in this current study.

References

EC, European Commission (2003). 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. Luxembourg: Office for Official Publication of the European Communities.pg 193 - Battle *et al*., 2007

Pentreath 1999 : Pentreath, RJ. (1999). A system for environmental protection: some initial thoughts and ideas. *Journal of Radiological Protection,* **19**(2): 117-128.

Garnier-Laplace *et al*, 2004 : Garnier-Laplace J, Gilek M, Sundell-Bergman S, Larsson CM. (2004). Assessing ecological effects of radionuclides: Data gaps and extrapolation issues. *Journal of Radiological Protection*, **24**(4 A):A139-A155

ERICA, 2006. (Agüero, A.; Alonzo, F.; Copplestone, D.; Jarowska, A.; Garnier-Laplace, J.; Gilek, M.; Larsson, C.M., Oughton D.). Derivation of Predicted No-effect Dose rates values for ecosystems and their sub-organisational level exposed to radioactive substances. Deliverable D5 and annexes A & B: ERICA EC project Contract N°FI6R-CT-2003-508847. Garnier-Laplace J. & Gilbin R. (Eds), 2006.

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