OSPAR COMMISSION

Revised First Periodic Evaluation of progress towards the objective of the OSPAR Radioactive Substances Strategy

Radioactive Substances Series

2006

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.

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.

This revised version of the First Periodic Evaluation of Progress towards the Objective of the OSPAR Radioactive Substances Strategy includes information at Annex 7 on electricity generated by the nuclear power-plants in some of the relevant Contracting Parties.

CHAPTER 1 – INTRODUCTION

1. This report aims to show what progress the Contracting Parties to the OSPAR Convention[2] are making in reducing anthropogenic inputs of radioactive substances to the North-East Atlantic, in line with the commitments that they have made in the OSPAR Radioactive Substances Strategy.

2. The possibility of harm to the marine environment and its users (including the consumers of food produced from the marine environment) from inputs of radionuclides caused by human activities was always a subject with which the 1972 Oslo and 1974 Paris Conventions were concerned – a concern taken over by the 1992 OSPAR Convention and taken forward in the work of implementing it. When international action to protect the marine environment from all kinds of pollution was first agreed in 1972, the Oslo Convention[3] acknowledged that radioactive substances were one of the forms of wastes and other matter to be addressed, and committed the Contracting Parties to working in the appropriate UN specialised agencies and other international bodies to promote measures to protect the marine environment against them. When the Paris Convention[4] was adopted in 1974, in order to provide for international action against 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"[5].

3. When the Oslo and Paris Conventions were up-dated and unified in 1992 to form the OSPAR Convention, 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, and radioactivity was included as one of the factors against which the need for control measures on discharges from land-based sources would be judged.

4. 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. a complete and permanent ban on all dumping of radioactive waste and other matter; and

b. 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.

5. This strategy was revised and confirmed by the second Ministerial meeting of the OSPAR Commission at Bremen in 2003. The OSPAR Radioactive Substances Strategy thus now 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."

---

2 OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, Paris, 22 September 1992. The Contracting Parties are Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom, together with the European Community.

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

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

5 Article 5(1).

6. 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[6] in order to achieve by the year 2020 that 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."

7. The logic underlying these commitments is the same as the logic underlying the similar objective and time-frame for hazardous substances. The starting point is the principle enunciated by the 1972 UN Stockholm Conference on the Human Environment: "States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction." There is no generally accepted evidence that the current levels of discharges of radioactive substances by the OSPAR Contracting Parties are causing actual harm to the marine environment. However, given that the marine environment is a common resource of the Contracting Parties, there is a common wish to go, as soon as reasonably practicable, beyond the principle of merely not causing damage. The commitment to reductions in discharges of radioactive substances aims to ensure that such discharges do not add to the load which the marine environment must bear, and thereby to increase the likelihood that the marine environment will be healthy and sustainable.

8. The Programme for More Detailed Implementation of the Strategy with regard to Radioactive Substances (the "RSS Implementation Programme")[7] and the agreements made at the second OSPAR Ministerial meeting, in effect, provide that

a. the Contracting Parties will each prepare a national plan for achieving the objective of the Strategy,

b. they will monitor and report on progress in implementing those plans, and

c. the OSPAR Commission will periodically evaluate progress against an agreed baseline.

This report contains the first of these evaluations.

9. 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. A further general assessment is planned to be produced in 2010, which will concentrate on the extent to which the aims of the thematic strategies of the OSPAR Commission have been delivered. In preparation for this, it in planned to produce in relation to the OSPAR Radioactive Substances Strategy the following thematic assessments:

2006: RA-1 First Periodic Evaluation of Progress towards the Objective of the Radioactive Substances Strategy (concerning progressive and substantial reductions in discharges of radioactive substances, as compared with the agreed baseline) (that is, this report);

2007: RA-2 Second Periodic Evaluation of the Progress towards the Objective of the Radioactive Substances Strategy (concerning concentrations in the environment as compared with the agreed baseline and including an assessment (for those regions where information is available) of the exposure of humans to radiation from pathways involving the marine environment.

2008: RA-3 An assessment (for those regions where information is available) of the impact on marine biota of anthropogenic sources (past, present and potential) of radioactive substances.

---

6 OSPAR agreement reference number: 2001-3.

7 Adopted by the OSPAR Commission in 2000, and slightly revised in 2001, the Programme for the More Detailed Implementation of the OSPAR Strategy with regard to Radioactive Substances is OSPAR Agreement 2001/3.

2009: RA-4 Third Periodic Evaluation of the Progress towards the Objective of the Radioactive Substances Strategy (being an overall assessment of radionuclides in the OSPAR maritime area).

10. Finland is not considered in this evaluation, since there are no discharges of radioactive substances from installations or human activities in Finland in the catchments that discharge to the maritime area of the OSPAR Convention (the North-East Atlantic) – all such discharges are into the Baltic Sea.

11. The Swedish nuclear power station at Bärsebäck is also excluded, although it has been regularly included in the OSPAR Reports on liquid discharges from offshore installations. The reasons for this exclusion are that

a. the installation is now closed down;

b. its discharges were exclusively to waters outside the OSPAR maritime area (the installations discharged into the Baltic Sea area);

c. the data was provided in the OSPAR reports for information only.

CHAPTER 2 – THE BASELINE

Introduction

1. The Radioactive Substances Strategy Implementation Programme made provision for establishing a baseline against which progress with the strategy can be evaluated. Major difficulties in establishing such a baseline were:

a. the inherent variability of the levels of discharges of radioactive substances from the nuclear industry. This gave rise to extensive discussion about ways and means of allowing for the variability (for example, by taking averages over a period of years or by applying statistical techniques such as linear regression) and to consequent debate about the years to be taken into account in such calculations;

b. the limited information available about other anthropogenic discharges of radioactive substances;

c. the comparable lack of information on concentration of radioactive substances in the marine environment, and the doses received by members of the public.

2. The Second Ministerial Meeting of the OSPAR Commission in 2003 agreed on formulations for establishing this baseline for evaluations which will take place in the period from 2003 to the year 2020. This baseline is:

a. to consist of data on discharges of radioactive substances, their concentrations in the marine environment and the resultant radiation doses to members of the public;

b. to be based on the Annual OSPAR Reports on Liquid Discharges from Nuclear Installations, including their expert assessments, in particular the report of 1998, the year the OSPAR Strategy with regard to Radioactive Substances was adopted.

In establishing the baseline, further information from national and other sources is to be taken into account, such as:

(i) the implementation reports submitted by Contracting Parties with respect to PARCOM Recommendation 91/4 on Radioactive Substances, and the summaries of these implementation reports;

(ii) the outcome of the MARINA II study.

3. The Second Ministerial Meeting of the OSPAR Commission in 2003 also agreed on the period 1995-2001 as the reference period for the baseline against which the progress in implementing the strategy can be evaluated, and to refer consideration on the following:

(i) an appropriate method for applying the baseline to the radionuclides iodine-129, carbon-14 and tritium;

(ii) an appropriate method of dealing with exceptional discharges arising either from the decommissioning of nuclear installations or from operations to recover old waste;

(iii) taking account of variability in the level of operation of installations

to the Radioactive Substances Committee for consensus agreement.

4. On this basis, this chapter sets out the way in which the baseline is established. The following terminology is used. The overall **baseline** consists of three **baseline elements**:

a. the baseline element for discharges,

b. the baseline element for concentrations, and

c. the baseline element for doses.

Each of these baseline elements may contain more than one component (relating to different sectors, areas and/or radionuclides or to other means of differentiation). Values may be established for a component.

5. Assessments can be made of the implications of the values established for one or more components without it being necessary to establish values (or the means of establishing them) for all the components of that baseline element.

6. The periodic evaluations of progress will primarily look to the comparison with the baseline. However, in order to maintain the linkages with the other OSPAR strategies (particularly those on eutrophication and hazardous substances), the data should also be examined using trend-detection techniques of the kind used in other fields by OSPAR. The combination of these two types of examination will be able, where appropriate:

a. to consider levels of discharges of radionuclides (or groups of radionuclides), in specific areas or of specific types, thus enabling a review of the progress that is being made at levels below the level of the OSPAR maritime area as a whole;

b. to consider radionuclides, or groups of radionuclides, in addition to total α, total β and tritium.

Baseline element for discharges of radioactive substances

7. This section sets out how the baseline element for radioactive discharges has been established. The work built on OSPAR reports and other international sources.

8. Each year, OSPAR receives a considerable amount of data on radioactive discharges from nuclear installations, particularly on discharges of total-α, total-β and tritium. An Expert Assessment Panel evaluates this information and prepares an overview. This overview is considered by the Radioactive Substances Committee and the OSPAR Commission and is published[8].

9. There is less information of comparable quality on discharges from the non-nuclear sector. In particular, there has been no reporting of discharges to OSPAR. But information presented in 2002 clearly indicates that such discharges make a significant contribution to the total input of radioactivity into the maritime area. OSPAR has now set in place a system for collecting information on discharges of significant radionuclides from the various non-nuclear sectors that discharge radioactive substances[9].

10. Against this background, it is therefore currently difficult to compile an overall accurate baseline element for all the components of the baseline element. The complete baseline element can only be compiled when agreed future OSPAR work for the more accurate quantification of non-nuclear discharges has

---

[8] For the reports published since the beginning of this reporting system, see OSPAR Publications:

17 (Atmospheric Deposition and Inputs of Contaminants, Radioactive Discharges, Mercury Losses from the Chlor-alkali Industry, Waste from the Titanium Dioxide Industry (1991 data), OSPAR 1994, ISBN 0 946956 33 2,

20 (Rejets radioactifs, Pertes de mercure provenant de l'industrie de l'électrolyse des chlorures alcalins, et Déchets de l'industrie du dioxyde de titane (données de 1992), OSPAR 1994, ISBN 0 946955 38 7

62 (Radioactive Discharges in 1993 and 1994, Mercury Losses from the Chlor-Alkali Industry, and Discharges and Emissions from the Pulp and Paper Industry Sector, OSPAR 1997, ISBN 0 946955 54 9);

69 (Liquid Discharges from Nuclear Installations in 1995 and Mercury Losses from the Chlor-Alkali Industry (1982-1995), OSPAR 1997, ISBN 0 946955 64 6);

89 (Mercury Losses from the Chlor-Alkali Industry (1982-1996), Liquid Discharges from Nuclear Installations in 1996, Summary of the Report on Sources, Inputs and Temporal Trends on Radioactive Discharges from Nuclear Installations for the years 1989 to 1995, Résumé du rapport sur les sources, les apports et les tendances chronologiques des rejets radioactifs des installations nucléaires de 1989 à 1995, OSPAR 1998, ISBN 0 946955 85 9);

98 (Liquid Discharges from Nuclear Installations in 1997, Summary of Reports Submitted in the Second Round of Implementation Reporting in Accordance with PARCOM Recommendation 91/4, Mercury Losses from the Chlor-Alkali Industry (1982-1997) and Waste from the Titanium Dioxide Industry, 1979-1997, OSPAR 1999, ISBN 0 946955 91 3)

115 (Liquid Discharges from Nuclear Installations in 1998 and Mercury Losses from the Chlor-Alkali Industry (1982-1998), OSPAR 2001, ISBN 0 946955 97 2);

130 (Liquid Discharges from Nuclear Installations in 1999, OSPAR 2001, ISBN 0 946956 63 4);

158 (Liquid Discharges from Nuclear Installations in 2000, OSPAR 2002, ISBN 0 946956 91 X);

177 (Liquid Discharges from Nuclear Installations in 2001, OSPAR 2003, ISBN 1-904426-11-5);

206 (Liquid Discharges from Nuclear Installations in 2002, OSPAR 2004 ISBN 1-904426-42-5);

224 (Liquid Discharges from Nuclear Installations in 2003, OSPAR 2005, ISBN 1-904426-62-X).

[9] OSPAR agreement 2005/8 on Revised Reporting Procedures for Discharges of Radioactive Substances from Non-nuclear Sectors

provided the necessary data. As a consequence, for the time being, the evaluation of progress towards the objective for discharges from the non-nuclear sector will only be qualitative. For a future stage of the evaluation of progress, it will be necessary to develop quantitative starting points.

Changes in annual radioactive discharges

11. In any event, there are some significant issues to be addressed in making inter-year comparisons. Differences between years in the levels of annual discharges of installations may be caused by random and systematic factors. Random causes lead to some fluctuations in discharges, but do not result in a decreasing or increasing temporal trend even over a long period of time. 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.

12. Random changes in the discharges of an installation can result, for example, by:

a. fluctuations in the technical performance of waste water treatment plants (variation of the decontamination factor);

b. variations in the daily volume of waste water;

c. variations in the radionuclide composition in waste water;

d. fuel failures in nuclear power plants;

e. plant outages for maintenance and engineering modifications or safety inspections;

f. random uncertainties in activity measurements as a result of:

(i) fluctuations in the physical-chemical properties of waste water;

(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.

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

a. changes in the thermal effect of nuclear reactors;

b. changes in the annual volume and burn-up of spent fuel elements in reprocessing plants;

c. technological improvements in existing plants for waste water treatment;

d. use of new plants with higher decontamination factors for waste water treatment;

e. measures to reduce discharges of radioactive substances;

f. decommissioning and closure of nuclear installations;

g. possible future development of new nuclear power plants;

h. 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.

14. A major difficulty in establishing a baseline element has been the resulting variability of discharges of radioactive substances. There were problems in how to allow for the variability (for example, by taking averages over a period of years or by applying statistical techniques such as linear regression) and to consequent debate about the years to be taken into account in such calculations.

Defining the baseline element for discharges

15. The absence of accurate data on discharges from industries other than the nuclear industry, the potential scale of such discharges and the fact that the Strategy addresses equally all anthropogenic discharges are factors that need to be taken into account. To reflect the full implications of the Strategy, a baseline needs to cover all discharges of radioactive substances from all sectors. However, for this periodic evaluation, it has not been possible to construct a baseline for non-nuclear industry.

16. The baseline-element for discharges is to contain two parts, based on the run of annual figures for discharges for the years 1995 - 2001:

a. the first part is the average of the range of these years (arithmetic mean);

b. the second part allows for the inherent variability of the processes giving rise to the discharges;

c. both these parts relate to total-α, total-β and tritium[10] discharges from all sources in the nuclear sector to the OSPAR maritime area as a whole.

17. The variability component is the standard deviation calculated at the 95% probability level of an assumed random normal distribution, of the discharge figures for the selected number of years. This variability component thus allows for the facts that:

a. the figures for these years have been influenced by the factors mentioned above, and

b. the figures for any particular year will deviate to an unknown extent from the underlying progress that is being made towards the objective.

18. 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 (the "marker radionuclides") for each of the sectors, sub-sectors and national groupings as the most significant to observe for the purpose of evaluating, against the baseline element for discharges, progress towards the objective of the OSPAR Radioactive Substances Strategy.

19. The selected radionuclides and groups of radionuclides are as follows:

Non-nuclear sectors:

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

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

Nuclear sector: Tc-99; Cs-137; Pu-239/240; total α; total β (excluding tritium).

20. After further study of the possibility of using Po-210 as a marker radionuclide, it is agreed that reporting from the offshore industry should be confined to Pb-210, since Po-210 is derived from Pb-210, and (although Po-210 is important as a long-term source of radioactive dose) it is Pb-210 that can immediately be managed. When more is known about the pattern of discharges from other non-nuclear sectors, consideration will be given to the marker radionuclides to be chosen for them.

21. Further consideration is also being given to the role of tritium, C-14 and I-129 in judging progress in implementing the OSPAR Radioactive Substances Strategy. 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 activity in discharges. Tritium is excluded from the statistics on total-β activity used in this evaluation[11].

22. Further consideration is, in addition, being given in the process of evaluating implementation of the strategy to the appropriate methods to take into account:

a. changes in the level of operation of installations (for example, the different levels of energy generated by a power station in different years);

b. exceptional discharges arising either from the decommissioning of nuclear installations or from operations to recover old waste.

Total-α and total-β activity

23. In reporting to OSPAR on radioactive discharges, Contracting Parties have adopted two alternative approaches to estimate total-α and total-β activity. These are:

---

[10] The role of tritium in both parts is now subject to the further agreements mentioned in §18 - 22.

[11] The current intention is that data on tritium discharges should be collected and reported separately from discharges of other β-emitting substances. Whether or not this data will be subject to trend assessment as an individual parameter depends on further consideration.

a. the activity-levels 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';

b. a sample is analysed for a 'gross activity'. These gross-activity results provide an estimate of the α or β activity in a sample, and are recorded in OSPAR reports as "total-α" or "total-β", as the case may be.

24. In both cases a limited number of radionuclides will be detected. The choice of measurement technique to be applied in a given sector should be determined by the radionuclides that are present. The 'gross' activity can include a contribution from radionuclides which may not be individually analysed and included in the 'total' activity result. In addition, the 'gross' activity will depend on the mix of radionuclides in the sample, the detection efficiencies for these radionuclides and the energy measurement range of the detector (see annex 1). Hence, a figure for 'total-α' or 'total-β' obtained by summing the results of determinations of individual radionuclides is not directly comparable to the 'gross' activity results.

25. The measurement techniques used by Contracting Parties to quantify total/gross activity values in the different nuclear sub-sectors are summarised in Table 1, and described in more detail Annex 1, together with the detection efficiencies and measurement ranges.

Table 1. Summary of measurement techniques

	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

26. There is no 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, each Contracting Party is consistent in the approaches taken within each sub-sector.

Baseline-element values

27. At this stage, it is possible to calculate the baseline-element component for discharges from the nuclear sector, but further consideration will need to be given on how to develop the baseline-element component related to discharges from the non-nuclear sectors. Until this is done, the evaluation of progress against the baseline can only be partial, qualitative and mainly a comparison with published information already available.

28. Table 2 shows, for the chosen period for baseline-element components for total-α and total-β, how the values work out for the total liquid discharges of the nuclear industry reported to OSPAR as an exemplification and clarification of the statistical techniques used. The "point value" is taken to be the mean that is the first part of the baseline element (see §16 above). The discharge data is 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 values. Given the normal distribution, and assuming a sufficiently large sample, 95% of the cases should therefore lie within 1.96 times the standard deviation[12].

Table 2. Baseline-element components for Total-α and Total-β from the Nuclear Industry

TBq/ year

	Total α		Total β	
Time period	**Bracket**	**Point value**	**Bracket**	**Point value**
1995-2001	0.222 to 0.698	0.460	147 to 406	276

29. Table 3 shows the OSPAR statistics for total discharges from nuclear installations upon which the foregoing table is based. The material used for these calculated annual values is available in the annual reports on liquid discharges from nuclear installations[13].

Table 3. Observations

TBq/ year

Year	Total α	Total β
1995	0.68	365
1996	0.57	332
1997	0.38	315
1998	0.43	265
1999	0.42	256
2000	0.33	171
2001	0.41	231

30. Comparisons made between this baseline-element component and discharge figures for periods after 2001 will only give an approximate and partial view of the progress that is being 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 described in Chapter 3.

31. The time-frame of the OSPAR Radioactive Substances Strategy currently runs until 2020. During the currency of the Strategy, there will periodic evaluations of the way in which the figures reported by the Contracting Parties for discharges of radioactive substances from nuclear and non-nuclear sectors are evolving as compared with the baseline period. This is the first of these evaluations. In due course, the figures will be examined using trend-detection techniques of the kind used in other fields by OSPAR (see chapter 4). These evaluations will, where appropriate:

a. consider discharge 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 at levels below the level of the OSPAR maritime area as a whole;

b. consider radionuclides, or groups of radionuclides, in addition to total α, total β and tritium (and also be subject, in the case of tritium, to the further consideration to be given to the evaluation of this radionuclide);

---

12 The "standard deviation" is the square root of the variance. The variance is a measure of the "scatter" of the data in a sample around the mean of the sample. It is calculated by dividing the sum of the squares of the differences between the sample mean and the individual observations in the sample by the number of those individual observations (or, in the case of a small number of observations, the number of those individual observations less one).

13 See footnote 7 above.

c. consider data from non-nuclear anthropogenic discharges of radioactive substances (to which the objectives of the strategy equally apply).

Baseline element for concentrations of radioactive substances in the marine environment

32. This section presents the approach for establishing the baseline element for concentrations of radioactive substances in the marine environment. It builds on existing information from monitoring data published by Contracting Parties and the results of the Marina II study, which have been made available by the European Commission. This section is included to give a complete description of the baseline elements that have so far been established, but concentrations have not been included in this evaluation.

Structuring the information

33. The definition of the baseline element for concentrations needed to resolve three aspects of the available information. The first step was to divide the OSPAR maritime area into the regions for which sufficient data are available to enable the calculation of some baseline values. The overall approach to deriving baseline values is intended to be one of simplicity.

34. The second step was to identify in each region the radionuclides for which information was available and to select those on which it was appropriate to concentrate. These radionuclides have been selected as tritium, Tc-99, Cs-137 and Pu-239/240. Am-241 was also considered, but the conclusion was that baseline values for this would not be useful because concentrations could increase in the future due to decay of Pu-241 already in the environment. When agreement has been reached on whether polonium should be monitored in discharges from the offshore oil and gas industry, consideration will be given to whether to monitor concentrations of it in the marine environment.

35. 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. Tritium is not considered relevant for biota.

36. The following comments and limitations should be borne in mind:

a. ***representativeness of data:*** in dividing the OSPAR maritime area geographically, compromises had to be made between the number of regions and the monitoring data which were available to use. Too few regions could have meant large ranges on the baseline-element values. Too many regions could have meant that a lot of them did not have any monitoring data. Fifteen regions were selected. 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;

b. ***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;

c. ***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 on the information available. Such assumptions also make it impossible to calculate a component for variability.

37. It has been essential that the baseline element for concentration should mirror the arrangements made for monitoring concentrations in the marine environment. Arrangements were agreed by the OSPAR Commission in 2004, and these have been embodied in OSPAR agreement 2005/8, to which reference can be made for details of the areas, radionuclides and environmental compartments selected.

Establishment of baseline values

38. The calculations of the baseline-element values for concentrations in the marine environment were carried out for the same 7-year period (1995 – 2001) as for the baseline element for discharges. Calculated values were provided for median concentrations[14] and standard deviations based on the calculated mean concentrations.

39. The resulting baseline-element values are set out in Table 4 in Annex 2.

Future application of the baseline element for concentrations

40. Since a new system has had to be established for the regular collection of data on concentrations of radioactive substances in the marine environment, evaluations of progress with respect to the baseline element for concentrations will only be possible at a future evaluation, and not as part of this evaluation. Work will be needed on this in the future evaluation planned as part of the Joint Assessment and Monitoring Programme.

Baseline element for doses to members of the public

41. This section describes the methods adopted to establish a baseline element for doses to members to the public. The material for discharges of radioactive substances and for concentrations in the marine environment have been compared and used so as to establish this baseline element. The baseline element for doses to members of the public is a tool to interpret the other two baseline elements, by showing the relative radiological significance of the radionuclides discharged into the environment or measured in environmental compartments. Since baseline element for doses to members of the public relies upon the baseline element for concentrations, this element also is not included in this evaluation, but its details are set out here for completeness.

42. The establishment of the baseline element for dose assessment takes into account:

a. the need for consistency with the approaches for establishing the other baseline elements;

b. the radionuclides and compartments defined for the baseline element for concentrations in the environment;

c. the methods used by EC project MARINA II and those recommended by EC RAIN working group[15].

Calculation of baseline values

43. The approach for defining the baseline element for doses to members of the public is as follows:

a. a baseline value is defined as the average of the doses for the same seven year period as for the other baseline elements;

b. no attempt has been made to remove any underlying trend. This is consistent with the approaches for the other baseline elements;

c. the variability is quantified as the standard deviation, again consistently with the baseline elements on concentrations;

d. the dose calculation methods are based on those used in the MARINA II project.

44. Two different approaches have been used. The first approach starts from the baseline-element values for concentrations of radioactive substances in seawater and biota (fish, molluscs or seaweed) in the different subdivisions of the OSPAR maritime area. In the second approach, baseline values for doses have been calculated from the baseline values for seawater only, using a simple dose assessment method derived from the MARINA II model. These approaches are described in Annexes 3 and 4, and the resulting values are set out in table 5 in Annex 5.

---

[14] The median is used because the risk of distortion of the mean (average) by the number of observations where measurements were below the detection limit.

[15] Report of the working group on Realistic Assessment of the Impact of Nuclear installations on members of the public (European Commission publication RP 129).

45. 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.

46. Under both approaches, doses are assessed only for ingestion pathways. Both include assessments for consumption of fish and molluscs, and the seawater approach also includes crustaceans. It is important to note that, since the baseline values for concentrations do not distinguish the sources of the radionuclides, the baseline-elements for doses will similarly aggregate together ***all*** sources of the relevant radionuclides, including nuclear-weapons fall-out and natural production, quite apart from nuclear installations. For some situations, there is also a significant component from historic discharges which have long ceased.

47. 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. This applies particularly to the consideration of polonium discharges from offshore oil and gas installations.

Possibility of the use of discharge data to calculate doses

48. Baseline values for doses can in theory be predicted from baseline-element values for discharges from individual installations or sites, using mathematical models (e.g. MARINA II, PC Cream or those used by individual countries). In many Contracting Parties, individual doses are assessed from discharge data in this way within the framework of the national regulations.

49. Dose values calculated in this way are highly dependent on the dose-assessment methods and models. For the time being, it does not seem to be appropriate to pursue this possibility at the OSPAR level. However, the OSPAR Radioactive Substances Committee will review this issue once there has been a further evaluation of the baseline element for doses, derived from data on concentrations of radioactive substances in the marine environment collected under the arrangements established in 2004/05.

Future application of the baseline element for doses

50. In the light of these considerations, the evaluation of progress against the baseline element for doses to the general public will need to await the collection of more information on concentrations in the marine environment.

CHAPTER 3 – STATISTICAL BACKGROUND

Approach to evaluating progress

1. As has been said, the Programme for the Further Implementation of the Radioactive Substances Strategy requires 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. There is also agreement that techniques of the kind which are used in other OSPAR fields should be used to investigate the presence of trends, so that there is a common approach to the implementation of all the OSPAR strategies.

2. 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 and the data for the later years. That is, the null hypothesis (H_0) to be tested is that there is ***no*** difference between the earlier data and the later data, as against the positive hypothesis (H_1), that there ***is*** a difference. The risks that must be guarded against are the two different types of error:

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

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

The process can be summarised as follows:

		Conclusion	
		Reject H_0	**Don't reject H_0**
Truth	**H_0**	Type I Error	Right conclusion
	H_1	Right conclusion	Type II Error

Introduction to the comparison with the baseline element

3. 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.

4. 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 the samples 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. Some basic information will be reminded before broaching this subject.

Population and sample

5. Suppose we have a very large population of individuals (where individuals can be anything from human beings to small rocks in a desert) which are characterized by some measurement. The measurement can be anything from a length or a surface to an age or any other characteristic that can be summarized by a figure.

6. 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, or IID in short (see Part I of Annex 6).

7. 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.

8. 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

9. 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.

10. Thus one has 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 get closer and closer to μ.

11. 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.

12. 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 sampling would select other individuals, and so m would be different).

Standard deviation

13. However, the true mean μ is not the only parameter that characterises a population of measurements. For instance, the mean value μ of the measurements is not the only value that is needed to describe the outputs of a particular machine. One also needs to describe how the measurements are spread out around their mean μ. Are they scattered far away from μ, or on the contrary do they cluster very closely around μ? In the first case the machine is very irregular, whereas in the second case it produces very regular and consistent measurements. This aspect of the distribution of the measurements is described by their "standard deviation". There is a precise mathematical definition for the standard deviation, but here the important point is that it is a measure of how spread out the measurements really are.

14. Exactly as for the mean, there is a *true* standard deviation for the population (σ) and an *empirical* standard deviation (we name it s) for the sample. For the same reasons as for the mean, s is an estimator of σ (see Part II of Annex 6 for the precise computations).

15. To sum things up:

	Applies to	**Mean**	**Standard deviation**
True values	Population	μ	σ
Empirical values (estimators)	Sample	m	s

16. The true values are therefore generally unknown and estimated from the sample values (the only accessible information).

17. See Part 2 of Annex 6 for more details on the estimators m and s.

Normal (Gaussian) distribution

18. 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 it is shown graphically. This distribution has remarkable properties, one of them being that it is completely characterized by its mean μ and its standard deviation σ, which define respectively the position and the width of the bell.

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

1. as levels of discharge are the sum of many small causes, the Gaussian approximation might be a reasonable choice.
2. there is very little loss of generality in doing so because results that are true for Gaussian populations can be extended to the populations of other distributions when these are "large enough".

20. As for OSPAR concentration samples, other considerations may lead to considering that the Gaussian approximation applies to the logarithm of the observations. See Part 3 of Annex 6 for the detail of the definition.

Gaussian distribution: Prediction interval and confidence interval

21. Let us consider again the example of a machine which produces some outputs according to a Gaussian distribution. If the true mean μ and the true standard deviation σ were known (for instance because a very large number of components have already been produced in the same conditions), one would then be sure that 95% of the outputs this machine have or will produce in the same conditions will 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.

22. 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*.

23. 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 - and nothing more. There are problems in using it in relation to the values of past or future observations.

24. It is intuitively clear that there is much more uncertainty about the size of the next component to be produced than about the true mean μ (the larger the sample, the more precise is our estimation of μ, but our prediction for the next value to be produced 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).

25. See Part 4 of Annex 6 for the determination of a confidence interval about the mean and Part 5 for a prediction interval.

How to compare new observations with the baseline element.

26. 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 μ_1 of the first population may be different from the true mean μ_2 of the second population.

27. We want to test whether the true means are equal ($\mu_1=\mu_2$) at a given probability level, generally chosen 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 minimizes the risk of errors of type I (a difference is detected when there is no statistically significant difference).

28. 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

29. The first approach is to make a *simple comparison*: that is, we will simply compare one by one the observations of the second sample to the baseline element. Then one 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.

30. We will look at each level of discharge from the year 2002 to whatever is the subsequent year 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.

31. 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.

32. 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? Actually, 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.

33. 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, such as those described below.

34. 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) a relevant change (reduction or increase).

Other comparison methods

35. 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.

36. The only values we can compare are the empirical means m_1 and m_2 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.

37. The idea is that, since 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).

38. 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 most usually is 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[16].

39. 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.

40. 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 clear answers 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).

41. 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[17]. 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

a. independent of each other (e.g. individuals randomly assigned into two groups), or

b. paired, so that each member of one sample has a unique relationship with a particular member of the other sample (e.g. the same people measured before and after an intervention).

42. 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.

43. 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.

44. 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[18] 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.

45. 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

---

[16] Normal distribution is otherwise known as Gaussian distribution (after the German mathematician who formulated it) – it has the formula $P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/[2\sigma^2]}$ where x is the variable, μ is the mean and σ² is the variance. It approximates many natural distributions, such as that of height in humans.

[17] "Student" was the pen-name of W. S. Gossett (1876-1937), who developed statistical methods to solve statistical problems relating to relatively small samples, stemming from his employment in the Guinness Brewery in Dublin (the management of which insisted on the use of a pen-name).

[18] The precise distribution is:

$$f(t) = \frac{\Gamma((\nu+1)/2)}{\sqrt{\nu\pi}\,\Gamma(\nu/2)}(1+t^2/\nu)^{-(\nu+1)/2}$$

where ν is the degrees of freedom, and Γ is Euler's factorial function.

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. [19]

46. 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[20] 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.

47. 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.

48. 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 'W_{rs}' (the rank-sum). For small samples, W_{rs} 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 (5%)), then the null hypothesis should be rejected, and the conclusion should be that the two samples are from different populations.

49. 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. Annex 6 gives the details of the implementation of this method.

50. 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 n_1 and n_2 there are n_1 x n_2 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 has been used in this first 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[21].

---

[19] Germany would have preferred at this stage not to have used the results of the Student's t-test at all, because the methodology used is not appropriate for such small sample sizes, but would have rather used the Weir approximation or another formula appropriate for the Behrens-Fisher problem. Other Contracting Parties preferred to show the sensitivity of the limited data to the choice of statistical test by using more than one statistical test.

[20] The precise formula is :

$$U = n_1 n_2 + \frac{n_2(n_2+1)}{2} - \sum_{i=n_2+1}^{n2} R_i$$

where n_1 and n_2 are the number of observations in the two samples, and R is the rankings.

[21] The Mann-Whitney U test is completely equivalent to the Wilcoxon-Mann-Whitney test (or Wilcoxon rank-sum test).

51. These ranking tests are more robust, as said above, 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

52. 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.

53. 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)[22]. For example, the CEMP assessment examined 2 772 time-series of observations of hazardous substances in biota (fish and shellfish), and 9 151 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 (688 (72%)) showed downward trends. 274 (28%) showed increasing trends.

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

a. ***robust*** – that is, to be both routinely applicable to many data-sets and as insensitive as possible to statistical assumptions;

b. ***intuitive*** – that is, for the results of the analysis to be understandable without a detailed understanding of statistical theory;

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

55. For each time series with 7 or more years, trends were summarised by a loess smoother[23], a non-parametric 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. The theory and methodology are described in detail in Fryer & Nicholson (1999).

56. A simpler analysis was adopted for time series with less 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.

57. 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 over-simplification. 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.

---

22 OSPAR publications 2005/234, 2005/233 and 2005/235

23 "loess" is a portmanteau word (like the name "OSPAR"), derived from "locally weighted regression estimate". Hence it is sometimes written "lowess".

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

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

a. ***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 being commonly larger than in a normal distribution. Alternative approaches were therefore considered for this aspect of trend estimation. For the purposes of this evaluation, it has no advantages over other techniques;

b. ***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;[24]

c. ***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.

Conclusions

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

61. Subject to the qualifications expressed in paragraph 47 on 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 a 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.

62. The results of the application of these methods are provided in chapters 7 to 11.

63. 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.

[24] Pearson's r and Spearman's rho are respectively the parametric and non-parametric methods of determining the degree of correlation between two qualities of a set of data elements. Since they are concerned with correlation, rather than trend, they are not further considered here.

CHAPTER 4 – NON-NUCLEAR SECTORS

Background

1. When OSPAR prepared a report in 1997[25] on discharges of radioactive substances by non-nuclear industries, it was considered that, excluding activities related to the nuclear-fuel cycle, discharges of radioactive substances arose mainly from:

   a. mining and ore processing;

   b. burning of coal, oil or natural gas in thermal power stations;

   c. the production of phosphate fertilisers;

   d. miscellaneous industries (for example, concrete and ceramics production).

2. The 1997 report concentrated principally on the phosphate fertiliser industry. This industry was then using phosphate ore to produce ammonium phosphate and triple superphosphate for agricultural use, either by chemical processes involving sulphuric, nitric or hydrochloric acids or by thermal processes. The phosphate ore contained natural radionuclides (principally potassium-40, radium-226, thorium-232 and uranium-238, but also including lead-210 and polonium-210) at levels between 3 000 and 4 000 Becquerels per kilogramme, depending on the source of the ore. A large amount of phosphogypsum was produced as a by-product, of which a substantial proportion (40% in 1984) was discharged into the sea and coastal waters. The report noted that, in the 1980s and early 1990s, most OSPAR States had closed down their plants for the production of phosphate fertiliser from phosphate ore, and concluded that for the latest year for which statistics were available (1993), the overall discharge of radionuclides into the marine environment from the phosphate fertiliser industry was 4.024 TBq, broken down as follows:

TBq

Country	Polonium-210	Radium-226	Uranium-238
Belgium/Luxembourg	0.12	0.3	0
Netherlands	1.0	1.0	0
Spain	1.1	0	0.4
United Kingdom	0.003	0.001	0.1
TOTAL	2.223	1.301	0.5

3. By way of comparison, the total discharge by OSPAR States to the OSPAR catchments from nuclear power stations in the same year of radionuclides other than tritium was 14.201 TBq. The phosphate industry discharges therefore represented about 28% of the discharges of the nuclear power plants.

4. By 1998, the discharges from the phosphate fertiliser industry had decreased further, but there were still some discharges from the Netherlands and Spain.

5. By 2005, all discharges of radioactive discharges from the phosphate fertiliser industry in the OSPAR states had ceased, with the closure of the plants involved, or (in the case of Spain) the introduction of operating systems based on recirculation, which do not involve discharges. Compared with the early 1990s (and even with 1998), there had therefore been a major reduction in discharges of radioactive substances to the marine environment.

6. Following the publication of the OSPAR report in 1997, which had been concerned principally with discharges from the phosphate fertiliser industry, OSPAR agreed that further work was required to identify and quantify discharges of radioactive substances from other sectors of non-nuclear industry into the marine environment. The OSPAR report from 2002 indicates broadly the sectors of industry which are the important

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

sources of radioactive discharges. The report also draws on information from the MARINA II study, carried out for the European Commission.

7. Discharges from most non-nuclear sectors (other than the oil and gas industry) are made to public sewers which then discharge, after treatment, to rivers or direct to the sea. Data indicate that the medical sector is dominant in terms of the overall activity in discharges. The most important radionuclides entering the marine environment are technetium 99m and iodine 131.

8. The longer-lived radionuclides are those of natural origin such as radium 226 and radium 228, lead 210 and polonium 210. The premises discharging these are in the extractive (or related) sector, in particular from 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. The MARINA II study showed that non-nuclear sectors were responsible for levels of discharges of radioactive substances that could not be ignored.

9. 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.

10. The situations in the offshore oil and gas industry and in the medical sector are reviewed in Chapters 5 and 6.

CHAPTER 5 – OFFSHORE OIL AND GAS INDUSTRY

General Context

1. Seven OSPAR countries have an offshore oil and gas industry (Denmark, Germany, Ireland, the Netherlands, Norway, Spain and the United Kingdom[26]). The Dutch (predominantly) and Irish (entirely) offshore industries are only for gas production. In Norway, the offshore oil and gas industry is extremely important, being responsible for one quarter of all value creation, and more than one quarter of the State's revenues. In the Netherlands and the United Kingdom, the offshore industry is less economically predominant (representing around 1% of GNP and 2½% of Gross Value Added[27], respectively), but is still very important economically and strategically by providing secure, domestic sources of energy (over 80% of domestic consumption in the United Kingdom). In the other countries (Denmark, Germany, Ireland, Spain), the offshore industry is less significant, but still important because of the access that it gives to secure, domestic energy supplies.

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

a. produced water;

b. de-scaling operations.

3. "Produced water" is the water that comes up from oil and gas wells along with the oil and gas. Some of it is water ("formation water") that has been in the hydrocarbon reservoir for geological time along with the oil or gas. Some of it is water produced by condensation during the production process ("condensation water"). The rest is water which has been injected down the well to facilitate recovery of the oil and gas ("re-produced injection water")[28]. Radioactivity in produced water is 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 come up from the oil/gas reservoir either in solution or as fine mineral suspended solids.

4. "Scale" is deposited on the insides of pipes and tanks through which the oil or gas and produced water passes, as a result of chemical reaction of barium with sulphate ions in sea water. Because of the chemical similarity to barium, radium is co-deposited in this scale. (This scale is analogous to the deposits in kettles from boiling hard water). Periodic de-scaling is often necessary to prevent pipes and tanks becoming obstructed by the scale.

5. The levels of radioactivity in both produced water and scale varies greatly between fields (both for gas and oil). This variation is caused by the different geological histories of the reservoirs. There is also some evidence of substantial variation over time in the levels of radioactivity – see the data given below for Norway. There are also variations as a result of operating practices:

a. variation in which wells within a field are on-stream at the time when samples are taken will produce variations in the level of radioactivity, since the pattern of "breakthrough" (that is, the extent to which seawater has penetrated into the reservoir) will vary between wells;

b. changes in use of scale inhibitors or dissolver at the facility (including in the use of chemical scale removal injected into the well and in the treatment of oil after it has come up from the well), which can cause more or less NORM to pass into the produced water stream.

6. However, in both produced water and scale, the levels are very low (see information given below under individual countries). Nevertheless, the volume of produced water can be very large, resulting in potentially significant discharges. The volumes of produced water that are discharged also tend to increase

---

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

[27] The replacement statistic for the former Gross Domestic Product (GDP).

[28] 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.

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, these increases are important.

Overall situation

Produced water

7. The number of installations in the OSPAR maritime area capable of making discharges to water or emissions to air has grown steadily (by a little over 68%) since the beginning of the baseline period (see Table 6 – details for the individual countries are given below). 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.

Table 6. Offshore Installations capable of discharging or emitting to the OSPAR Maritime area[29]

Numbers of installations

Installation type	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Oil	99	133	120	135	137	174	152	153	146	144
Gas	204	207	171	164	186	239	223	225	254	257
Subsea	75	5	6	87	44	6.5	81	120	143	178
Drilling	7	43	47	9	4	69	76	86	45	58
Other	0	0	0	0	0	0	5	2	4	11
TOTAL	385	388	344	395	371	489	537	586	592	648

8. Measurements are made of the quantities of the 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 production water and displacement water together. Since 2002, figures for the annual total of produced water discharges have also been collected separately, and it is possible to look specifically at the figures most relevant to the discharge of radioactive substances. Table 7 shows the national figures for the combined water discharges (with the overall levels shown in Figure 1). Table 8 shows the discharges of produced water.

9. The differences between countries are caused not only by different regulatory régimes, but also (and significantly) by the differences between oil and gas fields: gas fields result in very much less produced water than oil fields.

[29] OSPAR Report on Discharges, Spills and Emissions from Offshore Oil and Gas Installations in 2004.

Table 7. Estimated average daily quantities of discharges of produced water and displacement water[30]

Cubic metres (m^3)

Country	1996	1997	1998	1999	2000	2001	2002	2003	2004
Denmark	13 425	14 630	18 000	27 435	43 909	46 273	44 158	54 243	67 578
Germany	0	0	0	0	14	14	19	18	22
Ireland	7	7.52	6.69	5	6	7	8	NI	8
Netherlands	35 214	33 895	30 303	25 000	31 820	38 117	24 263	21 381	23 313
Norway	412 283	438 779	462 969	442 225	461 323	493 342	490 826	524 910	537 342
Spain	0	0	0	0	0	0	0	0	0
UK	567 540	642 973	693 151	716 130	652 188	696 482	738 082	719 950	690 481
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**

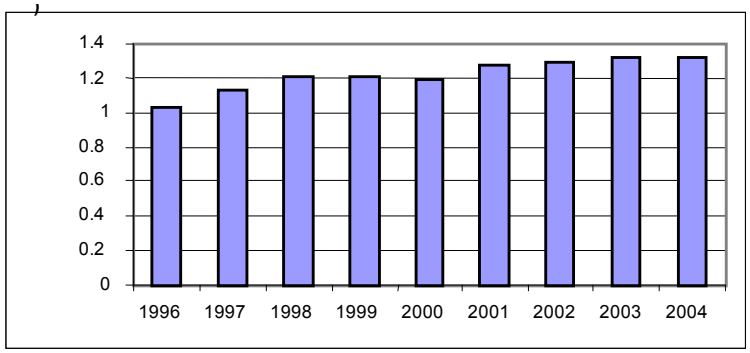


Figure 1. Estimated total average daily quantities of discharges of produced water and displacement water, in millions of cubic metres

Table 8. Annual total discharges of produced water

millions of cubic metres (m^3)

Country	2002	2003	2004
Denmark	12.437	15.934	19.647
Germany	0.007	0.006	0.008
Ireland	0.003	NI	0.003
Netherlands	8.856	7.804	8.509
Norway	118.933	134.730	142.803
Spain	0.000	0.000	0.000
United Kingdom	266.745	260.761	251.956
TOTAL	406.981	419.235	422.926

10. Produced water and displacement water have been of interest to OSPAR since the beginning of the Paris Commission in the 1970s, because of the potential polluting effects of the hydrocarbon content. Contracting Parties have therefore long had commitments to keep the hydrocarbon content below 40 parts per million. As the quantities of produced water and displacement water increased, these concerns over the

[30] Calculated from the national reports on which are based the annual OSPAR Reports on Discharges, Spills and Emissions from Offshore Oil and Gas Installations.

hydrocarbon content also grew. In 2001, OSPAR therefore adopted Recommendation 2001/1[31], which committed Contracting Parties to seek to achieve a 15% reduction in the hydrocarbon content of produced water between 2001 and 2006.

11. 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. The amount of produced water and displacement water discharged has therefore stabilised, halting the rapid rise between 1996 and 2001 (an increase of 24% in five years) (see Table 7). The separate statistics on produced water from 2002 (Table 8) also provides evidence of stabilisation (or, in at least one case) a reduction.[32]

12. This stabilisation in the amount of produced water discharged will also have affected the levels of discharges of radioactive substances, since (allowing for the spatial and temporal variations) the discharges of radioactive substances will be proportionate to the amount of produced water discharged. Displacement water is not significant in this context, since it consists mainly of seawater used in storage installations.

Scale

13. Scale builds up gradually during the life of an installation. Periodic de-scaling operations may well be needed. But the main questions are likely to arise at the end of the life of offshore installations.

14. No OSPAR measures have been developed for dealing with such de-scaling while installations are in service. OSPAR Decision 98/3 on the Disposal of Disused Offshore Installations, however, 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. This includes scale.

15. Except for Denmark (see below), no substantial national regulatory measures have been adopted specifically for de-scaling operations and the disposal of scale during the life of an offshore installation.

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

Denmark

17. In 2004, Denmark had 8 offshore installations producing oil and gas which may produce discharges or emissions to the sea. In addition, there was significant drilling for exploration.

18. Under the 1953 Law on the Use etc of Radioactive Substances[33], a permit from the Health Agency (*Sundhedsstyrelse*) is needed for all handling of radioactive substances over certain threshold limits. By an Executive Order of 2002[34], these threshold limits have been set for naturally occurring radioactive material (NORM) from the offshore oil and gas industry at the following concentrations:

Ra-226: 0.5 Bq/g
Ra-228: 1.0 Bq/g
Po-210: 5.0 Bq/g
Pb-210: 5.0 Bq/g

19. These limits apply to both produced water and disposal of scale. No information is, however, available on the amounts of radioactivity permitted to be discharged or actually being discharged.

Germany

20. In 2004, Germany had three installations in its sector of the North Sea but only one makes discharges to the sea. One produces oil and the other two gas. Produced water is only discharged from one of the gas-

---

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

32 A full assessment of the trends in discharges and injections of produced water will be included in the next assessment report of annual discharges, spills and emissions from offshore oil and gas installations, due in spring 2007. An overview assessment of the implementation of the 15% reduction target of the Produced Water Recommendation is due in spring 2008.

33 Lov om brug m.v. af radioaktive stoffer (Lov 1953/94).

34 Indenrigs- og Sundhedsministeriets bekendtgørelse nr. 192 af 2. april 2002 om undtagelsesregler fra lov om brug m.v. af radioaktive stoffer.

production installations. Since the total amount discharged is so small (8 000 megalitres a year), the levels of radioactivity involved are minimal.

21. Nevertheless, as a one-off exercise in 2003, samples have been taken of the produced water and determinations made of the radioactivity levels and estimates made of the total amounts of radioactivity discharged. These are shown in Table 9.

Table 9. Discharges of radioactive substances from German offshore installations

Radionuclide	Activity levels	Estimated total discharges
Ra 226	0.066 ± 0.005 Bq/l	ca. 0.46 MBq
Ra 228	0.032 ± 0.018 Bq/l	< 0.62 MBq
Pb 210	< 0.090 Bq/l	ca. 0.22 MBq
Th 228	0.020 ± 0.05 Bq/l	ca. 0.14 MBq

Ireland

22. In 2004, Ireland had six installations on its continental shelf which can make discharges to the sea. All of these installations are related to gas production. The amount of produced water discharged is only 3 000 cubic metres a year. The levels of radioactivity involved are again minimal.

The Netherlands

23. At the end of 2004, on the Dutch continental shelf there were 138 platforms involved in gas production, 11 involved in oil production, and two that combine both oil and gas. Of these, 124 installations can make discharges or emissions. 69 actually discharged produced water in 2004. Since 2002, these have been responsible for 85% of oil production and 40% of gas production in the country (the remainder being on land). Since 2000, the level of offshore oil production has been increasing, while the level of offshore gas production has remained more or less constant.

24. In 2000, the levels of radioactivity in the discharges from the offshore installations were estimated by the MARINA II study[35]. In 2003 and 2004, measurements were made of levels of radioactivity in samples, and grossed up by the known volumes of produced water. Table 10 shows the results. Interestingly, the subsequent measurements have tended to confirm the MARINA II estimates.

Table 10. Liquid discharges in the Dutch continental shelf in recent years

GBq

	Ra-226	Ra-228	Pb-210	Th-228
2000	42	32	6.9	-
2003	68	110	6.7	4.4
2004	75	120	12	4.3

Norway

25. In 2004, there were 103 offshore installations on the Norwegian continental shelf which could make discharges. This had risen from 83 in 1995. 39 installations were actually discharging produced water in 2004.

26. Levels of radioactivity in discharges of produced water have been shown to be fairly constant for most fields over the period 1996 - 2004, though one (Sleipner A) has shown a five-fold increase and another (Brage) a 50% decrease, and other fields have shown significant variations in levels in the course of a single year. The average activity concentration in produced water from 41 platforms of Ra-226 and Ra-228 in 2003 was reported to be 3.3 and 2.8 Bq/l, respectively and the total discharged activity was found to be 440 GBq

[35] MARINA II - Radiation Protection 132 (ISBN 92-894-5197-1), Luxembourg, 2003

and 380 GBq, respectively. Some results showed that activity concentrations of Po-210 were in the order of mBq/l. In contrast to the Netherlands, these figures are substantially smaller than the estimates in the MARINA II study, because both the amounts of produced water actually discharged, and the levels of radioactivity it contained, are lower than those assumed for the study.

27. Although the amounts of produced water discharged rose substantially from 1996 to 2001, there is evidence that this rate of increase is levelling off.

28. Liquid waste from scale removal operations offshore are discharged together with the produced water, while most solid waste is transported onshore for temporary storage at coastal bases. The discharges of NORM from these facilities are considered to be insignificant. Besides NORM, radiotracers (tritium and C-14) are also discharged to the marine environment.

Spain

29. Under a Royal Decree adopted in 2000 under Article 32 of the Law on Hydrocarbons, no discharges are now permitted to take place from offshore installations under Spanish jurisdiction. All production water is re-injected or treated onshore. Discharges of radioactive substances in produced water and scale to the marine environment have therefore been eliminated.

The United Kingdom

30. The UK has oil production installations in the North Sea, the Celtic Sea and on the Atlantic Margin, producing 3.6 million barrels of oil equivalent in 2004. There are some 396 offshore installations on the United Kingdom's continental shelf which can make discharges. Of these, 214 are oil and gas production platforms in the UK sector of the North Sea, and 13 in the Irish Sea. Gas production is concentrated predominantly in the southern North Sea, off the English North Sea coastline.

31. The amounts of produced water discharged by United Kingdom installations have levelled off as a result of the efforts to apply OSPAR Recommendation 2001/1, and in 2004 showed a small decrease from earlier levels. The regulatory agencies in the UK have been investigating total radioactivity discharged to sea from produced water. The levels of radioactivity in produced water determined in this study on the basis of samples from 82 production facilities, and the estimated total amounts of radioactivity discharged are shown in Table 11.

Table 11. Radioactivity in UK produced-water discharges

Nuclide	Activity range reported UK	Estimated total discharges
Ra-226	Up to 40 Bq/l, but more generally between 1 and 10 Bq/l; mean ~ 4 Bq/l; limit of detection 1 Bq/l	1 082 GBq
Ra-228	Up to 18 Bq/l, but more generally between 0.4 and 10 Bq/l; mean ~ 1.2 Bq/l; limit of detection 0.4 Bq/l	298 GBq
Pb-210	Not reported	39 GBq
Po-210	Up to 1.1 Bq/l	-

32. In respect of scale, mechanically removed scale from downhole and topsides-scale removal, together with sludges removed from topsides process vessels, are macerated to a particle size of 1mm or less and discharged into the sea under authorisation. There is mandatory reporting of all discharges which exceed the Phosphatic Substances, Rare Earths etc Exemption Order 1962 limits (e.g. 14.8 Bq/g elemental Radium) and additional voluntary reporting of exempt, but still radioactive, discharges of NORM scales. Data from these reporting exercises has not been made available. The amounts of radioactivity are unlikely, however, to be significant.

CHAPTER 6 – MEDICAL SECTOR

Context

1. There are two main themes to the use of artificial radionuclides in medicine: diagnosis and treatment. In diagnosis, radionuclides are used as sources of radiation to produce images for diagnostic purposes: this involves delivering the radionuclide to the part of the body to be examined, and collecting the resulting radiation in some form of scanning device. In treatment (therapeutic use), the radionuclides are delivered to the part of the body to be treated, and the treatment results from the impact of the resulting radiation on the organ concerned.

2. The radionuclides selected for observation by OSPAR in relation to discharges of radioactive substances to the sea are technetium-99m[36] (which is used for diagnosis) and iodine-131 (which is used for treatment). Both aspects of the use of radionuclides in medicine are therefore covered.

Overall situation

Technetium

3. The name of technetium (from the Greek *technetos* "artificial") reflects the fact that it was the first element to be produced artificially. It has no stable isotopes. The most used isotope of technetium is Tc-99m, with a half-life of 6.01 hours – an unusually long half-life for a metastable isotope, the half-lives of which are usually measured in nano-seconds. This is used in many medical radio-isotope 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. Half of its use is for bone scans, and the other half is divided approximately equally between kidney, heart and lung scans, together with a range of other organs. Approximately 85 percent of diagnostic imaging procedures in nuclear medicine currently use this isotope.

4. Technetium-99m is generated from molybdenum-99, which has a half-life of 66 hours, allowing it to be transported over fairly long distances. Molybdenum-99 is easily bound to a type of cartridge. As the molybdenum gradually decays, Tc-99m is formed. This does not bind as well to the cartridge and can be washed out as needed with sterile salt water. The cartridge is delivered to hospitals in a lead container which protects against radiation exposure. The cartridges are called technetium generators, and there are several types and sizes of these. Such generators are popularly known as "technetium cows" and they can be "milked" repeatedly as needed. The other useful aspect of Tc-99m is that it binds easily to various carrier molecules. The trend within nuclear medicine is towards the development of tailor-made or receptor-specific carrier molecules which target specific organs or disease states, and carry Tc-99m or other radionuclides to the sites in the body that the medical practitioner wants to image.

5. Technetium-99m decays by isomeric transition, a process in which it releases gamma rays and low energy electrons, to produce Tc-99 (which has a half life of 210 000 years and which, in turn, decays to give a stable isotope of ruthenium-24). Since there is no high energy beta emission, the radiation dose to the patient is low. The low-energy gamma rays emitted easily escape the human body and are accurately detected by a gamma camera. (Due to the large difference in half lives between Tc-99m and Tc-99, the activity of the resulting Tc-99 will be very low – proportional to the ratio between half-lives, 6 hours to 210 000 years.)

6. Current estimates suggest that there are about 10 000 000 scans a year in Europe that use Tc-99m. This number is thought to be growing at about 2–3% each year. The long-term growth prospects may, however, be limited, because other forms of body-imaging are being developed (particularly magnetic resonance imaging) which have an even less adverse impact on the body. There may, however, be a growing export market, since the low cost of Tc-99m imaging makes it attractive in developing countries[37]. The substantial use of Tc-99 for therapy would not be affected by these developments.

---

36 The suffix "m" indicates "metastable".

37 Oral information from NRG Nuclear Research and Consultancy Group.

Iodine

7. The radioactive isotopes of iodine were first isolated in the 1930s and radioactive iodine has been used for the past half century for both diagnostic and therapeutic purposes, primarily of the thyroid gland: the thyroid is able to accumulate iodine by a factor of 2 000 to 10 000 times greater than normal tissue. Ingested iodine is therefore rapidly concentrated in the thyroid. In small amounts, iodine-131 is used to 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 (benign hyperthyroid conditions) and cause it to function normally. In even higher doses, it has been proven to be a very effective cure for thyroid carcinoma. Portuguese evidence shows that the activity administrated to the patients during, an average treatment, exceeds 740 MBq and can reach 7 400 MBq.

8. No data have yet been found on the scale of the use of iodine-131 in Europe, either for imaging or for treatment. Clinically recognised thyroid carcinomas constitute less than 1% of all human malignant tumours. The annual incidence of thyroid cancer varies world-wide from 0.5 to 10 per 100 000 population. The American Cancer Society estimates that 17 000 new cases of thyroid cancer are diagnosed annually in the United States[38]. This suggests that the level of use of iodine-131 in nuclear medicine in the OSPAR countries is substantially less than that of Technetium-99m.

Specific countries

9. Some further specific information is available on the scale of, and controls over, the use of radionuclides for medical purposes in the following countries.

Belgium

10. In 1999, about 600 000 people were treated with radionuclides for diagnostic purposes, mainly for skeletal (45%) and thyroid (18%) investigations. The use shows an increasing trend. No data is available on therapeutic applications. Where the treatment involves the administration of more than 50mCi, patients are kept in quarantine, and excreta are collected in separate decay storage facilities. The medical staff involved are monitored and doses are in general less than 10 mSv a year. Surveys have shown that staff engaged in sewage treatment and sewer maintenance are not exposed to significant levels, but dry sewage sludge has been found to be contaminated with radiomedical isotopes.

Germany

11. About 3.9 millions diagnostic investigations were carried out in Germany in 2003. The main organs investigated are thyroid (40%), skeleton (31%), heart (9%) and lung (5%). The collective dose is 11 300 man-Sv, the average dose per inhabitant is 0.14 mSv/y.

12. In 2003 about 60 000 thyroid carcinomas were irradiated by intake of I-131. The radioactive excretions of the patients are discharged in collecting tanks of the hospital. After decay of the short-lived radionuclide I-131, the radioactively contaminated waste water is discharged to the public sewer system. Because of the use of collecting tanks, the activity concentrations are very low and the dose for sewage workers is negligible.

13. The doses received by 242 000 members of medical staff are monitored monthly. Only 13% of the staff had radiation exposure which could be detected. In 2003 the collective dose was 15 man-Sv.

Ireland

14. In 2004 a research project was completed to determine the doses arising from exposure to I-131 that had been discharged through hospital sewers. Doses to two critical groups; sewer workers repairing a blockage on the premises of a hospital and staff at the sewage treatment works were calculated. For the worst case scenario, doses received by sewer workers were estimated to be 0.34 $mSv.y^{-1}$, while doses to staff at the sewage treatment works were estimated to be 0.009 $mSv.y^{-1}$. It was concluded that the impact of such

[38] The American Association of Clinical Endocrinologists and the American Association of Endocrine Surgeons Medical/Surgical Guidelines for Clinical Practice: Management of Thyroid Carcinoma, page 2.

hospital discharges do not have a significant impact on the environment, nor are the resulting doses to critical groups of concern from a radiological perspective[39].

Netherlands

15. In the Netherlands there are 113 recognised medical institutions applying ionising radiation. Discharges to water can be expected from the 65 medical institutions with nuclear medicine departments. The number of treatments in 2001 is estimated at approximately 6 000. Treatments with I-131 account for some 80% of the total number of treatments. These were mainly for thyroid problems.

16. Medical institutions providing therapy with radionuclides are not obliged to install delay tanks, since the potential effective dose from discharges of radionuclide directly into the sewer system is below the "secondary level" (<1 μSv). Estimated individual dose from such discharges from a specific hospital was substantially less than 1 μSv[40]. Most hospitals therefore discharge their radionuclides directly into a sewer system, though some hospitals still have their delay tanks in place.

17. Total exposure of medical staff is registered in the National Dose Registration and Information System. The dose of some 12 500 members of the medical staff is monitored. The average staff dose was 0.18 mSv in 2002 [41].

Portugal

18. In 2004 a survey was carried out of discharges from hospitals and medical centres, including monitoring of radionuclides. Based on this survey, a guide was produced with general recommendations for the management of waste water from hospitals, including procedures for the management of radioactive material. Relevant data is available in the General Directorate of Health Installations and Equipment in the Portuguese Ministry of Health.

Spain

19. In Spain as a whole, there were about 222 500 diagnostic and treatment procedures with Tc-99m and I-131 in 2004. In the Autonomous Communities (Asturias, Cantabria, Galicia and the Pais Vasco) and provinces (Cadiz and Huelva) on the Atlantic coast, there were about 16 300 diagnostic procedures involving Tc-99m and about 7 500 involving I-131. The total activity administered was about 1.3 TBq. There were also about 900 treatments with I-131. Again the total activity administered was about 1.3 TBq. For all the thyroid treatments with I-131, collecting tanks are used before excreta are discharged, so that the level of discharges is very low.

Sweden

20. In the parts of Sweden in the OSPAR catchments, about 103 000 patients were treated with radioactive isotopes in 2004, the total activity administered being about 36 TBq. Most of this was the use of Tc-99m for investigating skeletal condition. 3 253 patients were given therapeutic doses (mainly iodine-131 for thyroid conditions), the total activity administered being 2.9 TBq. There is an increase in the use of other radionuclides for nuclear medicine – for example, indium-111 is used with octreotide (a somatostatin analogue accumulated by certain cancers) as a means of locating tumours. The number of applications overall has been fairly stable but is expected to increase in future. There is minimal solid waste, and liquid waste containing the radionuclides are discharged through the sewer systems. The average dose to the medical staff is about 1-2 mSv per year, except for PET[42] scans where the average doses are 3-4 mSv per year. Investigations are in progress on the dose levels at sewage treatment plants, as part of preparations for a major revision of the regulations on hospital waste due in 2006. Preliminary estimations indicate doses slightly above 1 μSv per year for workers in sewage-treatment plants (the critical group), but in some cases the doses can be up to 30-40 μSv.

---

39 R. Akinmboni, C. Mc Mahon, S. Long and T. Colgan. 'Environmental impact assessment of iodine-131 discharged from hospitals in Ireland'. Submitted to the *2nd International Conference on Radioactivity in the Environment, 2 - 6 October 2005, Nice, France*.

40 Eleveld et al., RIVM report 610100001/2002

41 Van Dijk, NRG report K5098/03.IM333, 2003

42 PET = Positron emission tomography

United Kingdom

21. In 2003/04, the number of nuclear medicine procedures carried out in the UK was estimated to be 670 000. The vast majority of procedures are for diagnosis rather than treatment. In the last 10 years there has been an increase of 36% in the annual total number of nuclear medicine procedures performed. This increase has been overwhelmingly in imaging procedures. Tc-99m is used in 80% of nuclear medicine procedures, and makes up 42% of the total activity administered (the total administered is in the region of 200 TBq/y). The most frequent therapeutic procedure is I-131 treatment for thyrotoxicosis, which makes up 75% of all therapy procedures. Together with Kr-81m, these two radionuclides account for 98% of the activity administered.

22. The majority of radionuclides administered to patients are disposed of under authorisation via the sewage system eventually arriving at sewage treatment plants, the exceptions being gaseous radionuclides, such as Kr-81m and Xe-133. The partitioning of radionuclides between sludge (which does not now directly reach the marine environment) and liquid effluent has been studied in the UK. For I-131 and Tc-99m, 10% of discharged activity can be assumed to be associated with the sewage sludge.

23. Dose records show the average annual exposure of medical staff i.e. radiographers, pharmacists, clinicians, nurses etc based on data from 2001 is 0.14 mSv. The average annual dose to medical staff in nuclear medicine departments is higher at 0.4 mSv. The higher doses in these departments are largely due to the close contact with patients and radiopharmaceuticals (largely Tc-99m). In both cases exposures are on average more than an order of magnitude below the permitted annual limits. In a recent dose assessment of sewage workers at two large sewage treatment works (STW), in Leeds and Central London, the predicted doses were below the threshold for optimisation of 20 μSv/y, except for workers spending all day in the sludge pressroom (45μSv/y for the Central London STW) or unblocking small pipes.

CHAPTER 7 – NUCLEAR SECTOR

Background

1. The Programme for More Detailed Implementation of the Strategy with regard to Radioactive Substances (the "RSS Implementation Programme")[43] 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. The first progress report on the more detailed implementation of the OSPAR strategy with regard to radioactive substances was agreed by the 2003 Ministerial Meeting of the Commission.

2. The 2003 report included an assessment of whether the combined effect of the national plans of the Contracting Parties will be to achieve the objective of the Strategy to the extent required by its time frame for 2020. The conclusion was that, at that stage, it was not possible to make a final assessment whether or not the combined effects of the national plans will be to achieve the objective of the Strategy. Despite this general conclusion, Denmark, Ireland and Norway considered that it was already possible to conclude that further measures, additional to those already contained within the national plans, will be necessary in order to meet the objectives of the Strategy within its time frame. Other Contracting Parties disagreed with this conclusion, considered that such a conclusion was premature or took no position on this issue.

3. This first periodic evaluation is limited to the assessment of the combined levels of the total discharges for the nuclear sector and the discharges for the sub-sectors (nuclear power plants, nuclear fuel production and enrichment plants, nuclear fuel reprocessing plants and nuclear research and development facilities) in each of the relevant Contracting Parties. The evaluation looks at total-α and total-β and the individual tracker radionuclides chosen (see chapter 2, §19) where they are relevant to the subsector.

4. The discharge data used have been taken from the Annual OSPAR Reports on Liquid Discharges from Nuclear Installations from 1995 to 2004. It must be recognised that all data on levels of radioactivity has an inevitable degree of uncertainty attached to it. 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%.

Overall situation for the nuclear sector as a whole

5. The principles for calculation of the baseline-element for discharges, the mean values and the bracket are described in Chapter 2. The statistical comparison methods selected are described in Chapter 3. As well as the overall baseline point-value and bracket, point-values (average discharge levels) and brackets have been calculated on the same principles for the four nuclear sub-sectors (power-plants, nuclear-fuel enrichment and production plants, nuclear fuel reprocessing plants and nuclear research and development. Likewise, within each of these sub-sectors, point-values (average discharge levels) and brackets have been calculated for the component provided by each country active in that sector. These are set out in this and the following four chapters. For the whole nuclear sector, OSPAR is still considering how to evaluate discharges of tritium, C-14 and I-129, exceptional discharges arising either from the decommissioning of nuclear installations or from operations to recover old waste, and the variability in the level of operations[44].

6. The observations considered for the nuclear sector as a whole are total-α and total-β (excluding tritium) [45]. The individual radionuclides cannot sensibly be aggregated for the nuclear sector as a whole, since they only appear in some sub-sectors.

7. For total-α, only three sub-sectors are relevant, since (as explained in the next chapter) discharges from nuclear power plants are, in many cases, below the detection limit, which makes the production of data on total-α for this sub-sector impracticable.

---

43 Adopted by the OSPAR Commission in 2000, and slightly revised in 2001, the Programme for the More Detailed Implementation of the OSPAR Strategy with regard to Radioactive Substances is OSPAR Agreement 2001/3.

44 Ireland holds the view that tritium, C-14 and I-129 discharges, exceptional discharges and discharges from old waste should be included in the evaluation. Furthermore, they consider that the Radioactive Substances Strategy relates to absolute levels of discharge, and that variations in operating levels should not be considered.

45 Referred to in this and subsequent chapters simply as "total-β".

8. For the other three sub-sectors, the aggregate total-α discharges, and for all four sub-sectors the aggregate total-β discharges, have been as follows:

TBq

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Total-α	0.68	0.57	0.38	0.43	0.42	0.33	0.41	0.61	0.62	0.54
Total-β	365	332	315	265	256	173	231	235	198	204

9. For total-α, there has in fact been an increase of 28% in the average discharges in 2002 – 2004 over the average for the baseline period. This is not outside the baseline bracket. No indication can therefore be gained from a simple comparison whether there has been an increase. The Student's t-test[46], however, shows it as statistically significant, but not the Mann-Whitney statistic.

10. For total-β, there has been a decrease of 23%, but the average level of discharges in 2002 – 2004 is within the baseline brackets. Again, no conclusion can be drawn from a simple comparison. Although the Student's t-test[46] shows that this is statistically significant, the Mann-Whitney statistic does not.

11. No clear conclusions can therefore be drawn for the nuclear sector as a whole. A longer run of data is needed.

Table 12: Measures of data on the total-α and total-β discharges of the nuclear sector

	Baseline Average	**Baseline Upper Bracket**	**Baseline Lower Bracket**	**2002 – 2004 range Highest – Lowest TBq**	**Student's t probability [47]**	**Mann-Whitney probability [48]**
Total- α	4.60E-01	6.98E-01	2.22E-01	6.20E-01 – 5.4E-01	0.038	0.138
Total- β	2.77E+02	4.05E+02	1.48E+02	2.35E+02 – 1.98E+02	0.047	0.138

46 See Chapter 3, paragraph 45.

47 As explained in Chapter 3, the interpretation of the Student's t test depends on the degrees of freedom". The figure given is the probability that the two "populations" compared (observations for the baseline period 1995-2001 and subsequent observations) have the same mean. It is calculated by comparing the calculated "t" with the *a priori* possibilities for the "t" distribution for the same degree of freedom. If that probability is less than 0.05, it can be concluded that there is a 95% probability that they are significantly different.

48 As explained in Chapter 3, this is the probability that the two "populations" represented by the observations for 1995-2001 (the baseline period) and 2002-2004 are the same. If the probability is below 0.05, it can be concluded that there is a 95% probability that they are significantly different.

CHAPTER 8 – NUCLEAR POWER PLANTS

Context

1. Nuclear power stations provide a substantial part of the electrical energy used by OSPAR States. The proportions are shown in Table 13:

Table 13: Proportion of electricity derived from nuclear power stations

Country	Belgium	France	Germany	Netherlands	Spain	Sweden	Switzerland	United Kingdom
Proportion	55%	75%	32%	4%	23%	52%	40%	26%

2. In international work at European and global levels on protection against ionising radiation, emphasis is laid on the evaluation, against the radiological risks, of the full range of benefits of activities involving such radiation. As a result of such evaluations and for other reasons, OSPAR Contracting Parties have adopted different policies on the use of nuclear power.

3. Nuclear power plants are of various kinds often classified according to their coolant systems and moderators (pressurised water, boiling water, gas-cooled, etc). Their common feature is that they drive electricity-generating turbines from the thermal power produced by nuclear reactors. Radioactive substances in a nuclear power-plant reactor are of three kinds:

a. uranium (and transuranic elements) (actinides) – the fuel;

b. fission products resulting from the breakdown of the actinides;

c. radionuclides resulting from irradiation of non-radioactive substances (activation products).

4. One aim of the construction of the fuel elements in the reactor is to confine the actinides and the fission products within them. This is achieved almost entirely for the actinides and very largely for the fission products. A small part of the fission products (principally those that are gaseous) can escape from the fuel elements and contaminate the primary circuit which takes the thermal power from the reactor. Some of these contaminants can be released from the primary circuit and are then treated in waste handling systems. The effluent treatment systems aim, by filtration, evaporation or and chemical or physical removal of minerals, to convert these fission products and activation products into solid waste for disposal. Some radionuclides, however, are not trapped by these processes and have to be released into the environment as part of liquid discharge or emissions to air. Such liquid discharges, however, undergo further process of storage and checking before discharge. In general, for nuclear power-plants, the focus needs to be on the discharges of total-β, since the discharges of total-α have always been much lower.

5. One activation product, however, tritium (H-3), is not normally captured by these effluent treatment systems. In many nuclear power plants, it is discharged in amounts directly proportional to the amounts of electricity generated. For this reason, OSPAR is studying further the application of the Radioactive Substances Strategy to this radionuclide.

Overall situation for the nuclear power-plant sub-sector

6. In order to keep the number of comparisons required to a manageable number while at the same time ensuring that the evaluation adequately covers the pattern of discharges as a whole, 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 tritium, for the reasons given in paragraph 6) and caesium-137.

7. The annual assessments by OSPAR of the radioactive discharges from nuclear power plants compare the activity values of tritium and of the sum of the following radionuclides: Co-58, Co-60, Zn-65, Sr-90, Zr/Nb-95, Ru-106, Ag-110m, Sb-125, Cs-134, Cs-137 and Ce-144. The activity of the pure β-emitter Sr-90 is determined by measuring its β-radiation after radiochemical separation. All other radionuclides emit γ-radiation, and are thus analysed by gamma ray spectrometry. Since they emit β-radiation as well, the sum of these radionuclides can be considered as an equivalent to total-β.

8. The overall liquid discharges of radionuclides emitting α-radiation have not been evaluated. The total α-activity concentrations in waste waters from nuclear power plants are so low that the greatest part falls below the detection limit associated with the measuring devices. Only a small number of measurements have

actually yielded values, which are subject to high uncertainties. It is impossible to conduct a trend analysis on the basis of these values, many of which are not reported to OSPAR because of these problems. The discharges of α-emitting radioactive substances from nuclear power-plants are also sufficiently low that they have also not been evaluated at the level of individual Contracting Parties. Where reports have regularly been made, however, data is included without analysis.

9. The overall levels of discharges of total-β from nuclear power-plants in the OSPAR catchments were as follows:

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
TBq	3.6	2.1	7.4	2.1	1.9	3.3	4.0	3.7	4.9	1.4

10. As can be seen from the summary table of data measures (Table 14 at the end of this chapter) the range of the level of discharges since the baseline period is lower than the average for the baseline period, but it is not below the baseline bracket. The results of the Student's t-tests[49] and the Mann-Whitney statistic do not show (with the chosen 95% probability level) that the average discharge during 2002 - 2004 are significantly different from those in 1995 - 2001. There is therefore some, but not yet statistically significant, evidence of reductions in discharges of total-β. As with other nuclear sub-sectors, OSPAR is still considering how to evaluate discharges of tritium, C-14 and I-129, exceptional discharges arising either from the decommissioning of nuclear installations or from operations to recover old waste, and the variability in the level of operations. To provide the context for further discussion of the last point, Annex 7 sets out the amounts of electrical power generated by the nuclear power-plants in some of the relevant Contracting Parties. [50]

Belgium

11. In Belgium, there are two sites with nuclear power plants – Doel and Tihange. Overall levels of discharges from the nuclear power-plants have been as follows:

TBq

Year	Total-α	Total β	Cs-137
1995	1.90E-06	5.97E-02	1.22E-02
1996	7.06E-06	5.55E-02	7.12E-03
1997	1.97E-06	5.07E-02	1.16E-02
1998	9.40E-07	3.63E-02	7.72E-03
1999	8.60E-07	4.05E-02	9.71E-03
2000	7.10E-07	3.07E-02	3.84E-03
2001	1.20E-07	3.99E-02	3.14E-03
2002	0.00E+00	3.83E-02	3.85E-03
2003	3.20E-06	3.50E-02	4.64E-03
2004	5.13E-09	3.65E-02	3.50E-03

[49] See Chapter 3, paragraph 45.

[50] Ireland holds the view that tritium, C-14 and I-129 discharges, exceptional discharges and discharges from old waste should be included in the evaluation. Furthermore, they consider that the Radioactive Substances Strategy relates to absolute levels of discharge and that variations in operating levels should not therefore be considered.

12. As can be seen from the summary table of data measures,

    a. for total-β, the discharge levels in 2002 - 2004 were all above the lower bracket of the baseline, although below the baseline average. A simple comparison does not therefore indicate a relevant reduction. Neither the Student's t-test[51] nor the Mann-Whitney statistic points to a different conclusion;

    b. for Cs-137, the level of discharges in 2002-2004 was within the baseline bracket, although again they are lower than the baseline average. A simple comparison does not therefore indicate a relevant reduction. Nor do the Student's t-test[51] or the Mann Whitney statistic suggest that this reduction is statistically significant.

13. Although there have thus been reductions in the levels of discharges compared with the baseline average, none of these is statistically significant.

France

14. In France, the overall levels of discharges from the nuclear power-plants in the catchments of the OSPAR maritime area are as follows:

TBq

Year	**Total-β**	**Caesium-137**
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

15. For total-β (excluding tritium), gamma-spectrometry measurements show that the level of discharges is currently lower than 1GBq per year per reactor, and decreasing. For the two β-emitting radionuclides that cannot be measured in this way, radiochemical analysis shows that discharges of C-14[52] and Ni-63 are 16GBq and 0.4GBq per reactor per year, respectively.

16. As can be seen from the summary table of statistical measures:

    a. the levels of total-β discharges in 2002-2004 are above the lower bracket of the baseline, although they are below the baseline average. A simple comparison does not therefore indicate any relevant reduction. Nevertheless, the Student's t-test[53] and the Mann-Whitney statistic indicate that this reduction is statistically significant;

    b. for Cs-137, the levels of discharges in 2002 – 2004 are above the lower bracket of the baseline, although they are below the baseline average. A simple comparison thus does not indicate any relevant reduction. Nevertheless, the Student's t-test[53] indicates that the reduction has been statistically significant, whereas the Mann-Whitney statistic does not.

---

51 See Chapter 3, paragraph 45.

52 The evaluation of C-14 discharges are, however, a matter to be considered further.

53 See Chapter 3, paragraph 45.

17. This constitutes clear evidence of statistically significant reductions in discharges of total-β since the baseline period, and some evidence of reductions in discharges of Cs-137.

Germany

18. In Germany, the overall levels of discharges from the nuclear power-plants in the catchments of the OSPAR maritime area are as follows:

TBq

Year	Total-α	Total-β	Caesium-137
1995	1.18E-06	2.08E-03	1.10E-04
1996	3.72E-06	2.93E-03	2.46E-04
1997	5.02E-06	2.99E-03	1.45E-04
1998	3.09E-06	4.86E-03	4.58E-04
1999	5.12E-07	2.35E-03	3.07E-04
2000	7.50E-08	2.80E-03	3.60E-04
2001	4.20E-07	1.70E-03	2.60E-04
2002	6.40E-07	2.20E-03	2.70E-04
2003	9.90E-07	1.70E-03	1.70E-04
2004	6.31E-07	1.03E-03	6.80E-05

19. As can be seen from the summary table of data measures, a simple comparison of the levels of total-β and Cs-137 discharges in 2003 – 2004 with the baseline average shows that they are below the baseline average (2.82E-03 TBq and 2.69E-04, respectively)). For total-β, this reduction has not yet taken the discharge level below the lower bracket of the baseline, but is approaching it (the discharge level in 2004 was only 25% above the lower bracket, while the baseline average was 243% above that level). However, this reduction is not statistically significant by the Student's t-test[53] or by the Mann-Whitney statistic. For Cs-137, the situation is much the same: the Student's t-test[53] and the Mann-Whitney do not confirm these reductions as statistically significant.

20. There is therefore some evidence of reductions since the baseline period, but they are not statistically significant.

The Netherlands

21. In the Netherlands, the overall levels of discharges from nuclear power stations have been as follows:

TBq

Year	Total-α	Total-β	Caesium-137
1995	0.00E+00	7.80E-03	6.20E-04
1996	0.00E+00	7.31E-03	6.41E-04
1997	0.00E+00	6.80E-03	5.71E-04
1998	0.00E+00	1.15E-03	8.00E-06
1999	0.00E+00	4.22E-03	2.00E-05
2000	2.60E-07	1.00E-03	1.60E-05
2001	0.00E+00	5.80E-04	2.00E-05
2002	0.00E+00	1.16E-03	1.00E-05
2003	2.40E-07	1.53E-03	8.80E-06
2004	2.50E-07	5.29E-03	1.90E-05

22. In the years when total-α is shown as zero, this reflects the lack of detection of any α-emitting substances above the limit of detection, in spite of regular monitoring.

23. As can be seen from the summary table of data measures, the lower brackets of the baseline for discharges of total-β and Cs-137 are negative. No conclusion can therefore be drawn from a simple comparison. Nevertheless, the total-β discharges were below the baseline average in 2002 and 2003, although they rose again above the average in 2004. Cs-137 discharges in 2002 – 2004 were more than an order of magnitude below the baseline average, but this reduction is not shown as statistically significant by the Student's t-test[54] or the Mann-Whitney statistic. This is probably because of the wide variations in the baseline period, when two years were below the levels of 2002 – 2004.

24. There is therefore some evidence of reductions in discharges, but they are not statistically significant.

Spain

25. In Spain the overall levels of discharges from the nuclear power-plants in the catchments of the OSPAR maritime area has been as follows:

TBq

Year	Total-β	Caesium-137
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	3.16E-04
2002	6.70E-03	8.50E-04
2003	5.00E-03	8.10E-04
2004	2.56E-03	3.55E-04

26. Although discharges are regularly examined for α-emitting substances, no detection above the limits of detection has been made.

27. As can be seen from the summary table of data measures,

a. total-β discharges since the baseline period were below the baseline average by at least an order of magnitude, but only that for 2004 has gone below the lower bracket of the baseline. The Student's t-test[55] and the Mann-Whitney statistic confirm that this reduction is statistically significant;

b. the discharges of Cs-137 in 2002 – 2004 were well below the baseline average, though not yet below the lower bracket of the baseline. The Student's t-test[55] shows these reductions as statistically significant, but this is not confirmed by the Mann-Whitney statistic.

28. There is therefore clear evidence of statistically significant reductions in total-β discharges and some evidence […] of reductions in Cs-137 discharges.

---

54 See Chapter 3, paragraph 45.

55 See Chapter 3, paragraph 45.

Sweden

29. In Sweden, the nuclear power industry has been concentrated at four sites, only one of which (Ringhals) is in the OSPAR catchment. The overall levels of discharges from the Ringhals nuclear power station have been as follows:

TBq

Year	Total-α	Total-β	Caesium-137
1995	1.13E-05	1.19E-01	7.00E-03
1996	1.47E-05	7.02E-02	2.29E-03
1997	8.87E-06	1.61E-01	5.51E-03
1998	1.51E-06	1.29E-01	1.01E-02
1999	3.92E-06	7.13E-02	2.31E-03
2000	4.71E-06	3.60E-02	4.50E-04
2001	3.98E-06	6.90E-02	6.00E-04
2002	1.48E-06	2.60E-02	6.90E-04
2003	1.02E-06	2.30E-02	6.20E-04
2004	7.94E-06	9.18E-03	6.99E-04

30. As can be seen from the summary table of data measures,

a. a simple comparison shows that the average levels of total-β discharges since the baseline period are below the lower bracket of the baseline. This indication of a reduction is confirmed as statistically significant by the Student's t- test and the Mann-Whitney statistic;

b. the lower bracket of the baseline for Cs-137 discharges is negative. No conclusion can therefore be drawn from a simple comparison. Nevertheless, the levels of Cs-137 discharges in 2004 are nearly an order of magnitude lower than the baseline average. The Student's t-test[55] shows this as statistically significant, but this is not confirmed by the Mann-Whitney statistic.

31. There is therefore evidence of statistically significant reductions in total-β discharges, and some evidence of reductions of Cs-137 discharges […].

Switzerland

32. In Switzerland, the overall levels of discharges from nuclear power stations (all of which are in the Rhine catchment and therefore discharge to the OSPAR maritime area) is as follows:

TBq

Year	Total-α	Total-β	Caesium-137
1995	8.50E-07	1.13E-02	8.47E-04
1996	8.70E-07	3.44E-02	5.30E-03
1997	7.00E-07	3.74E-02	3.03E-03
1998	8.90E-07	9.05E-02	7.35E-03
1999		3.41E-02	1.23E-02
2000	1.40E-06	5.00E-02	5.10E-03
2001	6.80E-07	3.60E-02	4.10E-03
2002	2.30E-06	3.10E-02	1.70E-03
2003	7.90E-07	1.60E-02	9.50E-04
2004	6.81E-07	1.76E-02	5.35E-04

33. As can be seen from the summary table of data measures,

a. for total-β and caesium-137, the lower brackets of the baseline are negative. No conclusion can therefore be drawn by a simple comparison […];

b. nevertheless, the levels of both total-β and Cs-137 discharges in 2002 – 2004 have been below the baseline average. The Student's t-test[55] shows both these reductions as statistically significant, although this is not confirmed by the Mann-Whitney statistic.

34. There is therefore some evidence of reductions in discharges of total-β and Cs-137 […].

The United Kingdom

35. There are 23 operational power reactors in the UK, of three types: 4 Magnox twin-reactor power stations, 7 AGR twin-reactor stations, and a single PWR reactor station. All of these reactors are at coastal sites. There are a further 18 power reactors that have been shut down and are now in various stages of decommissioning. This programme of station closures is scheduled to continue.

36. In the United Kingdom, the overall level of discharges from nuclear power-plants (all of which are, of course, in the catchments of the OSPAR maritime area) is as follows:

TBq

Year	Total-α	Total-β	Caesium-137
1995	1.05E-03	3.37E+00	1.88E+00
1996	1.28E-03	1.90E+00	1.78E+00
1997	3.87E-04	7.09E+00	1.62E+00
1998	5.21E-04	1.87E+00	1.68E+00
1999	2.95E-04	1.71E+00	1.25E+00
2000	6.30E-04	3.18E+00	1.14E+00
2001	2.74E-04	3.86E+00	2.25E+00
2002	3.27E-04	3.57E+00	2.03E+00
2003	1.10E-03	4.85E+00	2.18E+00
2004	3.66E-04	1.31E+00	1.83E+00

37. As can be seen from the summary table of data measures,

a. the lower bracket of the baseline for total-β is negative. No conclusion can therefore be drawn from a simple comparison […];

b. the levels of total-β discharges in 2002 and 2003 are slightly higher, and that for 2004 is lower, than the baseline average (3.28E+00 TBq). These variations are not statistically significant by either the Student's t-test[55] or the Mann-Whitney statistic;

c. the levels of Cs-137 discharges since the baseline period are a little higher than during the baseline period. A simple comparison, however, gives no indication of a relevant change. Neither the Student's t-test[55] nor the Mann-Whitney statistic shows a statistically significant change.

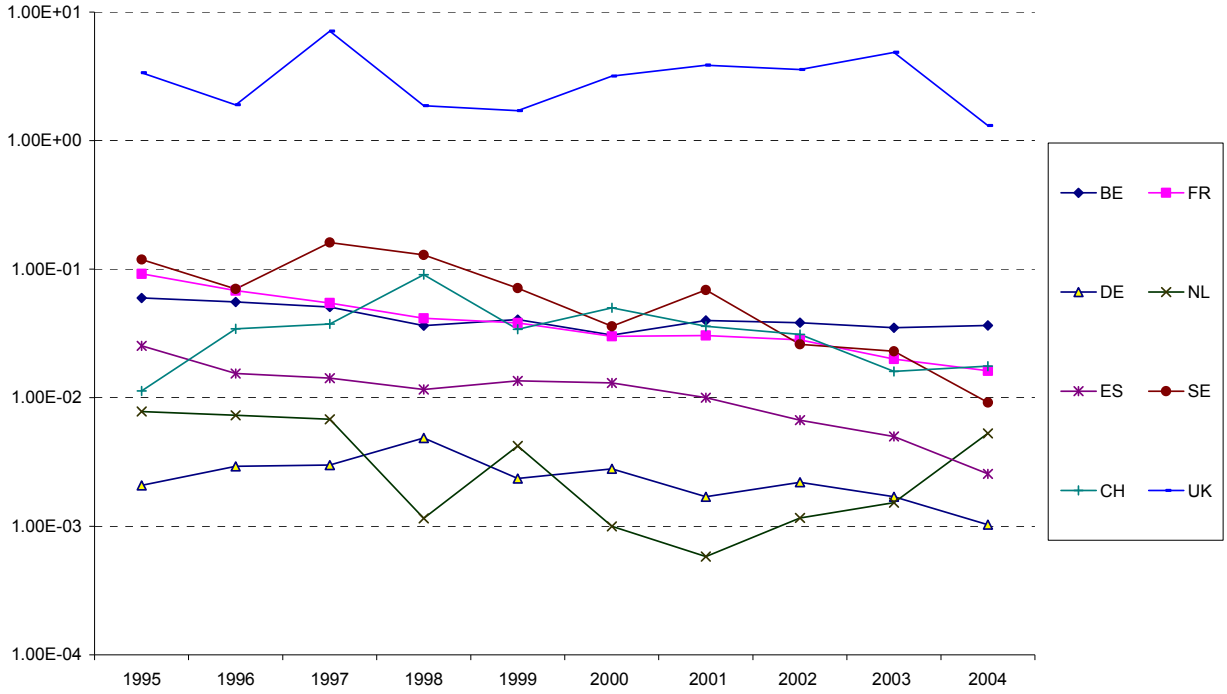
38. There is therefore no evidence so far of any statistically significant change in levels of discharges.

Graphical summary

39. Based on the data given above for the individual Contracting Parties, these developments can be summarised as follows:

TBq

Total b discharges from Nuclear Power Plants



TBq

Cs 137 discharges from Nuclear Power Plants

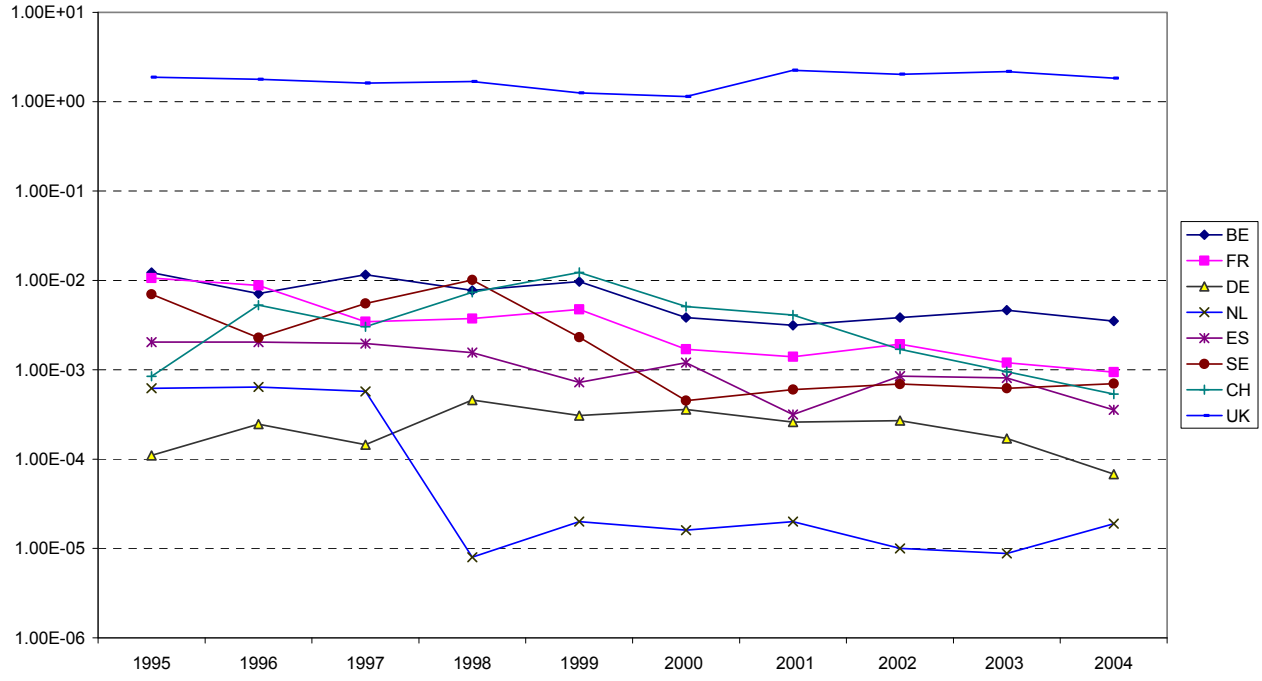


Table 14: Data measures of data on nuclear power-plant discharges[56]

	Baseline Average TBq	Baseline Upper Bracket TBq	Baseline Lower Bracket TBq	2002-2004 Range Highest – Lowest TBq	Student's t probability [57]	Mann-Whitney probability [58]
Overall						
Total- β	3.48E+00	7.22E+00	0[59]	2.19E+00 – 1.84E+00	0.9	0.9
`						
Belgium						
Total-β	8.93E-05	2.38E-04	0[59]	3.20E-02 – 2.30E-05	0.033	0.424
Cs137	7.07E-03	1.31E-02	9.91E-04	4.64E-03 – 3.20E-03	0.485	0.183
France						
Total-β	5.07E-02	9.53E-02	6.07E-03	2.90E-02 – 1.61E-02	0.016	0.017
Cs137	4.29E-03	1.18E-02	0[59]	1.90E-03 – 9.4E-04	0.039	0.053
Germany						
Total-β	2.82E-03	4.81E-03	8.20E-04	2.20E-03 – 1.03E-03	0.057	0.067
Cs137	2.69E-04	5.05E-04	3.38E-05	2.70E-04 – 6.80E-05	0.238	0.383
Netherlands						
Total-β	4.12E-03	1.04E-02	0[59]	5.29E-03 – 1.16E-03	0.448	1.000
Cs137	2.71E-04	8.95E-04	0[59]	1.90E-05 - 8.80E-06	0.076	0.183

[56] This table shows a summary of the data measures of data for the overall discharges from nuclear power plants in the OSPAR States, as well as individual results from the countries using nuclear power as source of energy. The detailed data for each country and the discussion of the evaluation results are given in §§ 11-37, respectively.

[57] As explained in Chapter 3, the interpretation of the Student's t test depends on the degrees of freedom". The figure given is the probability that the two "populations" compared (observations for the baseline period 1995-2001 and subsequent observations) have the same mean. It is calculated by comparing the calculated "t" with the *a priori* possibilities for the "t" distribution for the same degree of freedom. If that probability is less than 0.05, it can be concluded that there is a 95% probability that they are significantly different.

[58] As explained in Chapter 3, this is the probability that the two "populations" represented by the observations for 1995-2001 (the baseline period) and 2002-2004 are the same. If the probability is below 0.05, it can be concluded that there is a 95% probability that they are significantly different.

[59] The baseline lower bracket, as calculated, would be negative. Since a negative discharge is impossible, the bracket is truncated at zero.

	Baseline Average **TBq**	**Baseline Upper Bracket** **TBq**	**Baseline Lower Bracket** **TBq**	**2002-2004 Range** **Highest – Lowest** **TBq**	**Student's t probability** [57]	**Mann-Whitney probability** [58]
Spain						
Total-β	1.47E-02	2.45E-02	4.94E-03	6.70E-03 – 2.56E-03	0.002	0.017
Cs137	1.41E-03	2.75E-03	5.91E-05	8.50E-04 – 3.55E-04	0.042	0.267
Sweden						
Total-β	8.65E-02	1.67E-01	6.38E-03	2.60E-02 - 9.18E-03	0.006	0.017
Cs137	4.04E-03	1.11E-02	0[59]	6.99E-04 – 6.20E-04	0.049	0.383
Switzerland						
Total-β	4.20E-02	8.95E-02	0[59]	3.10E-02 – 1.60E-02	0.005	0.117
Cs137	5.43E-03	1.26E-02	0[59]	1.70E-03 - 5.35E-04	0.019	0.067
United Kingdom						
Total-β	3.28E+00	6.97E+00	0[59]	4.84E+00 – 1.31E+00	0.976	1.000
Cs137	1.66E+00	2.40E+00	9.19E-01	2.18E+00 – 1.83E+00	0.077	0.183

CHAPTER 9 - NUCLEAR SECTOR – NUCLEAR-FUEL PRODUCTION AND ENRICHMENT PLANTS

Context

1. Natural uranium contains only about 0.7% of the isotope U-235. It is this isotope which is needed to achieve fission in a light-water nuclear reactor for the release of thermal energy for electricity generation. To achieve this, the concentration of the U-235 needs to be increased, usually to between 3 – 5%; the process for doing this is known as uranium enrichment. The enrichment process is carried out on uranium hexafluoride (UF_6), since this is a stable compound where the only variation in atomic weight is in the uranium, fluorine having only one isotope. Two main technologies have been used: centrifuges and gaseous diffusion. The latter is now not being used in the OSPAR catchments.

2. The effort necessary to separate U-235 and U-238 is measured in kilograms of separative work (kg SW or Separative Work Units (SWU) – in German called *Urantrennarbeit* (UTA)). The capacity of enrichment plants is measured in tonnes SW per year (t SW/a). A large nuclear power station with a net electrical capacity of 1 300 MW requires annually about 25 t enriched uranium with a concentration of 3.75% U-235. This quantity is produced from about 210 tonnes of natural uranium using about 120 t SW. An enrichment plant with a capacity of 1 000 t SW/a is, therefore, able to enrich the uranium needed to fuel about eight large nuclear power stations.

3. In addition, there is a need to convert the enriched uranium hexafluoride into other, less corrosive forms and assemble the resulting pellets into fuel rods.

4. In the OSPAR catchment areas, there are (or have been) seven installations concentrating on this work.

Overall situation for the nuclear-fuel production and enrichment plants sub-sector

5. In order to keep the number of comparisons to a manageable number, OSPAR has chosen discharges of total-α, total-β (excluding tritium) and technetium-99 as the observations to examine. The radioactive discharges from nuclear fuel production and enrichment plants are mainly characterised by the sum of activities of the alpha radionuclides. A term frequently used for this is the gross alpha activity, which is usually measured with a gas flow proportional counter or a liquid scintillation counter. For the Capenhurst facility, the activities of single alpha radionuclides were determined and summed. The Springfields facility discharges a high level of total beta in addition to gross alpha.

6. The overall levels of discharges of total-α and total-β from the nuclear-fuel sub-sector have been

TBq

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total-α	0.12	0.12	0.12	0.2	0.24	0.17	0.16	0.22	0.18	0.23
Total-β	112	150	140	150	128	71	85	106	97	116

7. As can be seen from the summary table of data measures (Table 15 at the end of the chapter), there has been a 30% increase in the average discharges of total-α since the baseline period, and a 10% decrease in total-β discharges, but neither this increase, nor this decrease, are statistically significant. A comparison of these figures with the data on United Kingdom discharges, shows that the United Kingdom discharges are the predominant influence on the sub-sector in the OSPAR area. As with other nuclear sub-sectors, OSPAR is still considering how to evaluate discharges of tritium, C-14 and I-129, exceptional discharges arising either from the decommissioning of nuclear installations or from operations to recover old waste, and the variability in the level of operations.[60]

[60] Ireland holds the view that tritium, C-14 and I-129 discharges, exceptional discharges and discharges from old waste should be included in the evaluation. Furthermore, they consider that the Radioactive Substances Strategy relates to absolute levels of discharges and that variations in operating levels should not therefore be considered.

Germany

8. Germany has had three nuclear fuel installations. The Gronau uranium-enrichment plant (operated by URENCO) began operations in 1985. It is in North-Rhine-Westphalia, near the Dutch border. Using gas centrifuges, it can now deliver 1 800 UTA a year, sufficient for 13 major nuclear power plants. Authorisation was given in 2005 for its increase in due course to 2 700 tonnes UTA. The levels of discharge of radioactive substances are very low – around 10 000 Bq a year. There is a correspondingly low impact on humans and the natural environment: the highest dose for a reference person is 0.1 μSv a year, and there is no detectable impact on the natural environment.

9. The facility at Lingen (Lower Saxony, again near the Dutch border) is operated by Advanced Nuclear Fuels GmbH. It fabricates nuclear fuel for light-water reactors by converting uranium hexafluoride (UF_6) to uranium dioxide (UO_2), using the dry conversion process: pressing and sintering the UO_2 powder into pellets, sealing the pellets in fuel rods, and assembling the rods into fuel elements. Although there is a discharge-limit of 350g a year for the discharge of uranium, no radioactive waste-water is discharged from the production process, and therefore the data reported from Germany does not include any data on the Lingen plant. No other impact of radioactivity on the environment has been detected.

10. The nuclear-fuel fabrication plant at Hanau, in Hesse, was shut down in 1995. Since then, buildings and production areas have been decontaminated. Much of the site has already been freed from nuclear regulatory control. The end of all the decommissioning activities is scheduled for 2005/2006. The total-α discharges have decreased by several orders of magnitude during decommissioning: from 0.0003 TBq in 1995 to 0.000008 in 2004. The highest dose for a reference person is less than 0.1 μSv a year.

11. The overall levels of discharges from nuclear-fuel enrichment and production plants in Germany have been as follows:

TBq

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total-α	3.10E-04	1.30E-04	1.80E-04	2.60E-04	1.00E-04	1.68E-04	1.40E-04	4.80E-06	3.70E-05	8.40E-6

12. As can be seen from this table, there were reductions of more than an order of magnitude in total-α discharges in 2002 and 2004, and of nearly an order of magnitude in 2003, as compared with the baseline average. The Student's t-test[61] and the Mann-Whitney statistic confirm that these reductions are statistically significant.

The Netherlands

13. The fuel enrichment plant at Almelo (in Overijssel, near the German border) has been operational since 1969. It is now operated by URENCO. It has a current capacity of 2 800 tonne SW per year, but authorisation is being sought for an expansion to 3 500 tonnes SW per year.

[61] See Chapter 3, paragraph 45.

14. The overall levels of discharges from the Almelo plant have been:

TBq

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total-α	1.60E-06	3.30E-06	2.60E-06	1.80E-06	1.70E-06	3.40E-06	2.70E-06	4.60E-06	3.50E-06	2.10E-06
Total-β	1.40E-05	2.00E-05	1.20E-05	1.00E-05	7.40E-06	8.50E-06	1.52E-05	5.30E-06	1.00E-06	7.10E-06

15. As can be seen from the summary table of data measures, the levels of total-α discharges were in 2002 and 2003 were higher than the baseline average (in 2002 by 89%), and in 2004 lower (by 14%). The Student's t-test[62] and the Mann-Whitney statistic do not show these changes as statistically significant. On the other hand, there has been a reduction in the levels of total-β discharges. A simple comparison does not indicate any relevant change, but the Student's t and Mann-Whitney statistic confirm the reduction statistically significant.

16. There is therefore evidence of a statistically significant reduction in total-β discharges, but not in total-α discharges.

Spain

17. Spain has one nuclear-fuel production facility, at Juzbado near Salamanca (operated by ENUSA, which is jointly owned by the *Sociedad Estatal de Participaciones Industriales* (SEPI – State Industrial Investment Company) and the *Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas* (CIEMAT – Energy, Environment and Technology Research Centre). This facility was built in 1980 – 1985 and concentrates on the production of fuel elements for pressurised-water reactors (PWR) and boiling-water reactors (BWR), […] manufacturing them from enriched uranium dust into fuel rods. It is in a fairly remote part of the country, and is significant for the local economy.

18. Regular monitoring is, of course, carried out of the discharges. This has shown the following maximum, minimum and average concentrations of α-activity and β-activity in the surface water to which the discharges are made:

Bq/litre

Radionuclide	Average lower level of detection	Minimum activity level	Maximum activity level
Total-α	0.0235	0.0233	0.0654
Total-β	0.0553	0.0564	0.327

These are therefore one or two orders of magnitude lower than the activity levels of, for example, the NORM in produced water from offshore installations.

19. The overall levels of discharges from the Juzbado plant have been as follows:

TBq

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total-α	2.20E-05	3.70E-05	1.80E-05	2.03E-05	1.24E-05	3.54E-05	2.55E-05	2.10E-05	2.83E-05	1.75E-5

20. This shows a fairly constant, although low, level of total-α discharges. This conclusion is not altered by the various data measures shown in the summary table of data measures. The conclusion must therefore be that there is not yet any evidence of reductions in the level of radioactive discharges.

The United Kingdom

21. Fuel for 22 of the 23 operational nuclear-power reactors is produced at the Springfields site, near Preston, Lancashire, operated by Springfields Fuels Limited, under the management of Westinghouse

[62] See Chapter 3, paragraph 45.

Electric UK Limited. This site has been producing nuclear-fuel; elements since the mid-1940s. Magnox fuel production for the 8 Magnox reactors is expected to cease in March 2006.

22. Uranium enrichment is carried out at URENCO's Capenhurst site, near Chester. URENCO own and operate the centrifuge plants at the Capenhurst site. This site has been in operation since 1965. The centrifuge plants date from 1977, and have a current capacity of about 1 400 tonnes SW a year. The redundant gaseous diffusion plant at Capenhurst is in the process of being decommissioned.

23. Some LWR mixed oxide (MOX) fuel manufacture is also carried out at Sellafield. This is considered in the information on that site under the nuclear-fuel reprocessing sector. Both Capenhurst and Springfields are in the same region as Sellafield and all three sites discharge into the north-eastern Irish Sea. Their impacts cannot therefore be entirely separated.

24. The overall levels of discharges from the nuclear-fuel production and enrichment plants in the United Kingdom have been as follows:

TBq

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total-α	1.20E-01	1.20E-01	1.20E-01	1.95E-01	2.38E-01	1.73E-01	1.60E-01	2.20E-01	1.80E-01	2.27E-01
Total-β	1.12E+02	1.50E+02	1.40E+02	1.50E+02	1.28E+02	7.13E+01	8.51E+01	1.06E+02	1.94E+02	1.16E+02
Tc-99	3.53E-02	3.60E-02	3.30E-02	4.08E-03	3.98E-02	3.65E-02	1.90E-02	1.80E-02	5.29E-02	1.22E-01

25. As can be seen from the summary table of data measures, the levels of discharges for 2002 – 2004 were higher than the baseline average for total-α in 2002, 2003 and 2004 (baseline average 1.61E-01 TBq), for total-β in 2003 (baseline average 1.19+02) and for Tc-99 in 2003 and 2004 (baseline average 2.91E-02). Nevertheless, all these levels were within the baseline bracket, so a simple comparison does not indicate any relevant change, and the Student's t-test[63] and Mann-Whiteney statistic do not show these changes as statistically significant.

26. The conclusion therefore is that there is as yet no evidence of a reduction in the levels of total-α, total-β and Tc-99 discharges from the nuclear fuel enrichment and production plants in the United Kingdom.

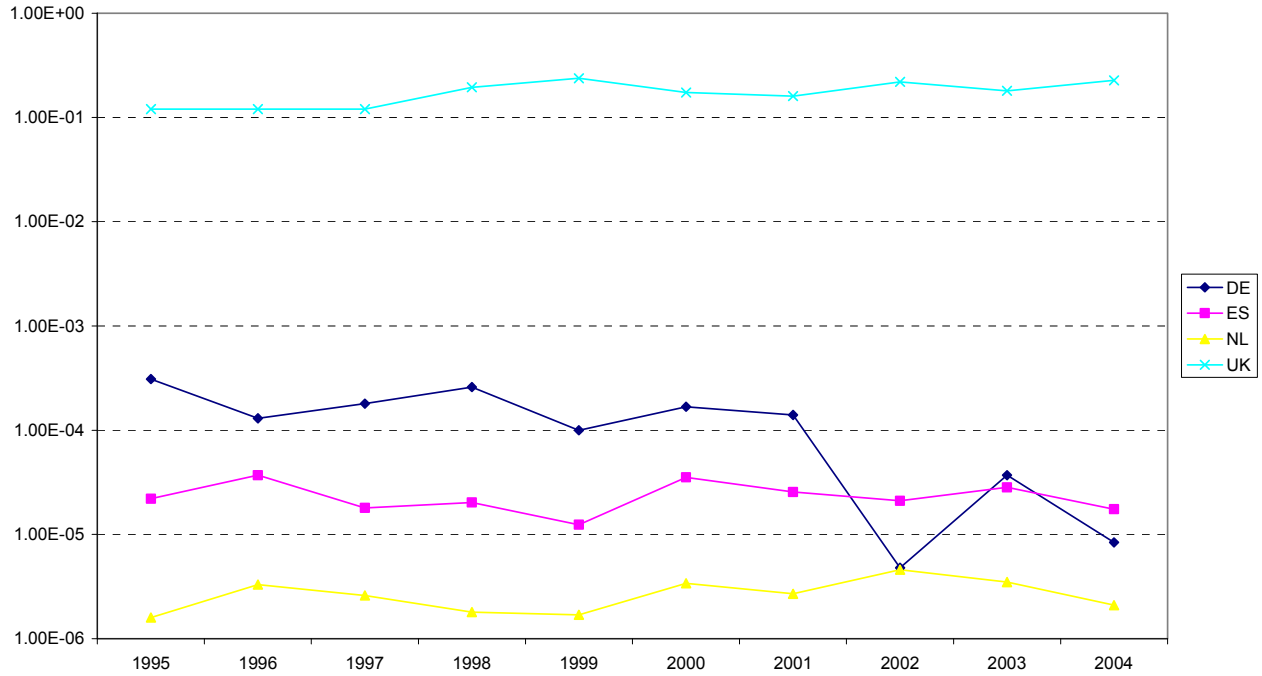
Graphical summary

27. Based on the data given above for the individual Contracting Parties, these developments can be summarised as follows:

[63] See Chapter 3, paragraph 45.

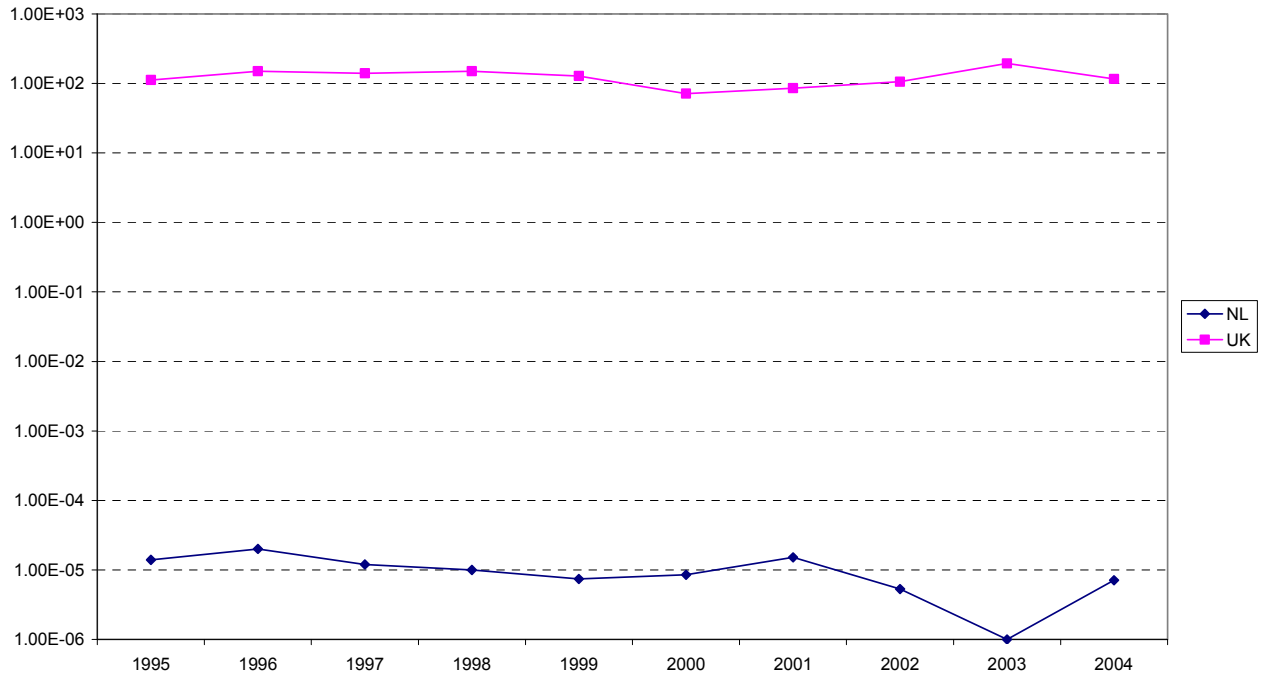
TBq

Total-a discharges from Nuclear Fuel Production and Enrichment Plants



TBq

Total-b discharges from Nuclear Fuel Production and Enrichment Plants



TBq

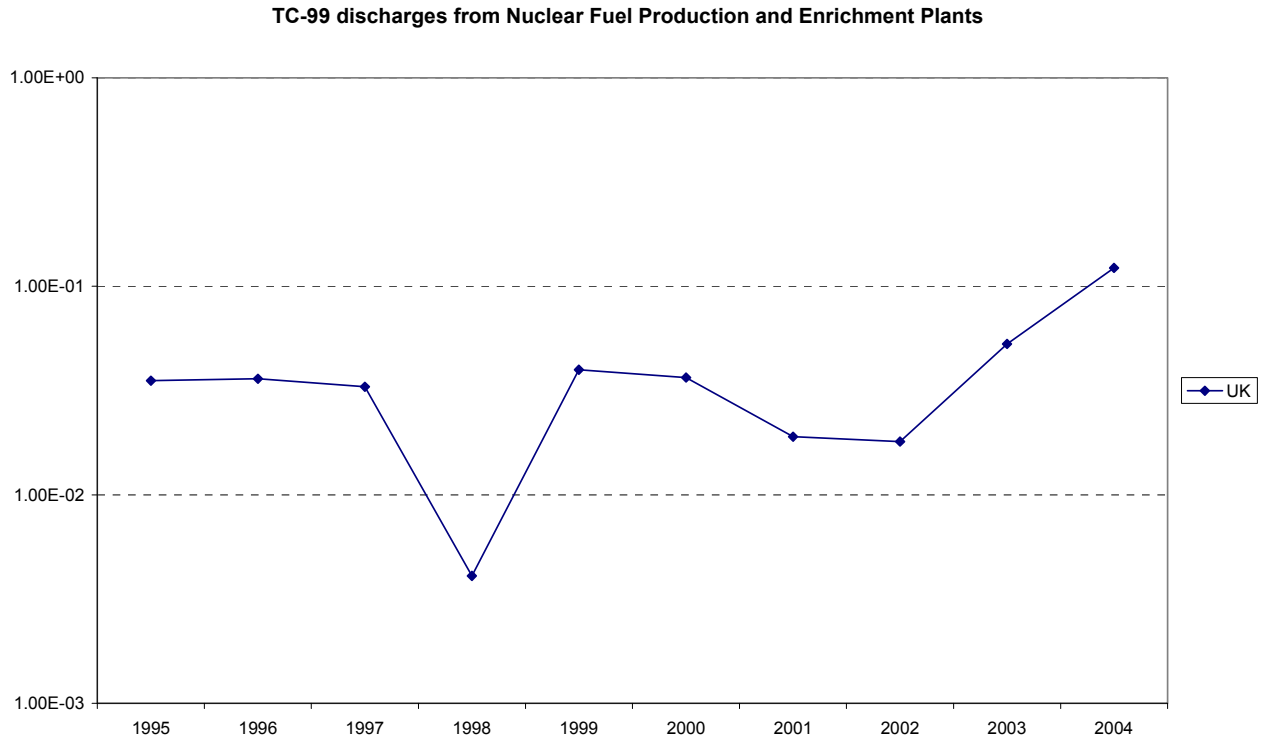

TC-99 discharges from Nuclear Fuel Production and Enrichment Plants
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
UK

Table 15: Data measures of data on nuclear-fuel production and enrichment plant discharges

	Baseline Average TBq	**Baseline Upper Bracket TBq**	**Baseline Lower Bracket TBq**	**2002-2004 Range Highest – Lowest TBq**	**Student's t probability**[64]	**Mann-Whitney probability**[65]
Overall						
Total- α	1.6E-01	5.00E-02	2.5E-01	2.30E-01 – 1.80E-01	0.076	0.134
Total- β	1.19E+02	3.15E-01	1.81E+02	1.16E+02- 9.70+01	0.348	0.630
Germany						
Total- α	1.84E-04	3.40E-04	2.82E-05	3.70E-05 – 4.80E-06	0.001	0.017
Spain						
Total- α	2.44E-05	4.37E-05	5.03E-06	2.83E-05 – 1.75E-05	0.667	0.833
Netherlands						
Total- α	2.44E-06	4.04E-06	8.41E-07	4.60E-06 – 2.10E-06	0.316	0.183
Total- β	1.12E-05	1.98E-05	2.65E-06	7.10E-06 – 1.00E-06	0.020	0.017
United Kingdom						
Total- α	1.61E-01	2.50E-01	7.22E-02	2.27E-01 – 1.80E-01	0.070	0.183
Total- β	1.19E+02	1.81E+02	5.79E+01	1.94E+02 - 1.06E+02	0.575	0.833
Tc-99	2.91E-02	5.44E-02	3.81E-03	1.22E-01 – 1.80E-02	0.368	0.383

64 As explained in Chapter 3, the interpretation of the Student's t test depends on the degrees of freedom". The figure given is the probability that the two "populations" compared (observations for the baseline period 1995-2001 and subsequent observations) have the same mean. It is calculated by comparing the calculated "t" with the *a priori* possibilities for the "t" distribution for the same degree of freedom. If that probability is less than 0.05, it can be concluded that there is a 95% probability that they are significantly different.

65 As explained in Chapter 3, this is the probability that the two "populations" represented by the observations for 1995-2001 (the baseline period) and 2002-2004 are the same. If the probability is below 0.05, it can be concluded that there is a 95% probability that they are significantly different.

CHAPTER 10 – NUCLEAR SECTOR – NUCLEAR-FUEL REPROCESSING PLANTS

Context

1. Spent nuclear fuel contains up to 96% of reusable energy materials (up to 96% uranium, up to 1% plutonium). Reprocessing involves the recovery of these reusable materials and the conditioning of the remaining waste (3% of fission products) into a safe final form for disposal.

2. Spent nuclear-fuel reprocessing is considered a justified practice by both France and the United Kingdom. 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), and 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)[66].

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

   a. BNFL's Sellafield site (with two reprocessing facilities, the Magnox reprocessing plant for Magnox reactor fuels, and the Thorp facility, which deals with AGR and LWR oxide fuels) and

   b. Areva NC's La Hague site (with two facilities UP2-800 and UP3 which deal mainly with PWR oxide fuels).

4. The Sellafield site employs 10 000 people directly and 3 000 indirectly in the locality. Around 3 400 persons are employed by Areva NC on the La Hague site. Local Areva NC subsidiaries employ around 2 000 persons. There are on average around 2 500 subcontractors working on the site. The spin-off jobs (local trade and services) represent around 3 500 people. The total of direct and indirect jobs amounts to around 11 500.

5. Other OSPAR countries with nuclear power plants have in the past used one or other of these plants to have reprocessing of spent nuclear fuel carried out. Germany has now stopped doing so, and Switzerland has a moratorium for 10 years, starting in the middle of 2006. Both BNFL and Areva NC have a number of other international customers for reprocessing.

Radionuclides

6. Detailed reports on all the radionuclides detected in the liquid discharges from Cap de 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, technetium-99, caesium-137 and plutonium-239/240 should be considered.

Tc-99

7. Tc-99 is a long-lived (half-life of 213 000 years) artificial radionuclide. Its presence in the marine environment results in part from atmospheric nuclear-weapon tests, but its principal source is reprocessing plants. It is a β-emitting fission product of low radiotoxicity.

8. At the La Hague plant, this nuclide has been subject since 1996 to a specific removal process (evaporation) and conditioning process (vitrification). Discharges of this radionuclide to the sea have been reduced by a factor of 100 between 1989 and 2004 (decontamination factors have been increased from 10 to 3 500). This radionuclide is thus an indicator of the improvement of the process achieved at the La Hague facilities. Less than 0.06% of the input to the processing plant of this radionuclide is now released.

9. At the Sellafield plants, 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 been reduced by a factor of 13 between 1994 and 2004. It is currently one of the main

[66] The recommendation and the decision were not accepted by France and the United Kingdom.

contributors to the dose to the critical group, but concentrations and doses are now expected to decline in line with the discharges.

10. Tc-99 is a radionuclide that has been highly relevant for the reprocessing sector in the context of OSPAR strategy assessments. As a result of the significant reductions in discharges that have taken place in recent years, this radionuclide is of reducing importance in terms of the selection criteria discussed in chapter 2 (§§18-19).

Cs-137

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

12. At the Sellafield plants, this radionuclide has been the subject of particular attention. The reduction process began in the late 1970's 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.

13. Cs-137 is a significant radionuclide in the context of OSPAR strategy assessments for the reprocessing sector, due principally to the historic discharges.

Pu-239/240

14. Pu-239 and Pu-240 are long-lived (half-lives of 24 100 years and 6 563 years respectively) radionuclides which are artificial. Their presence in the OSPAR marine environment results mainly from reprocessing plants. They are highly radiotoxic.

15. At the La Hague plant, these radionuclides have been the subject of particular attention. The abatement process has been optimised since 1998 by recycling part of the large volumes of low-activity effluents through evaporators (decontamination factor of 10^7). Pu-239/240 releases have been reduced by a factor of 10 between 1989 and 1999.

16. At the Sellafield plants, these radionuclides have also been the subject of particular attention. 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 releases have been reduced by a factor of 190 between the late 1970s and 2004. However, these nuclides remain among the main contributors to the doses to the critical group.

17. Pu-239/240 are significant radionuclides in the context of OSPAR strategy assessments for the reprocessing sector, due principally to the historic discharges.

Overall situation for the nuclear-fuel reprocessing plants sub-sector

18. Total alpha and total beta have been determined on the basis of measurements of the gross alpha activity and/or the gross beta activity.

19. The overall levels of discharges of total-α and total-β have been as follows:

TBq

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Total-α	0.47	0.32	0.23	0.22	0.17	0.16	0.25	0.39	0.43	0.31
Total-β	243	169	167	112	126	98	141	125	97.3	86.4

20. As the summary table of data measures at the end of the chapter shows, there has been an increase of 45% between the average discharge levels of total-α in the baseline period and the average level of discharges in 2002 – 2004. This is due to the discharges from the plants at Sellafield. There has been a decrease of 32% between the average discharge levels of total-β in the baseline period and the average levels in 2002 – 2004. Neither this increase, nor this decrease, are outside the baseline bracket. The Student's t-test[67] and the Mann-Whitney statistic do not show these changes as statistically significant. As with other nuclear sub-sectors, OSPAR is still considering how to evaluate discharges of tritium, C-14 and I-129, exceptional discharges arising either from the decommissioning of nuclear installations or from operations to recover old waste, and the variability in the operation of the level of operations[68].

France

21. The overall levels of discharges of the relevant radionuclides from the reprocessing plants at Cap de la Hague have been as follows:

TBq

Year	**Total-α**	**Total-β**	**Tc 99**	**Cs 137**	Pu 239/240
1995	0.070	52.900	0.100	4.620	0.0057
1996	0.046	29.400	0.117	2.410	0.0046
1997	0.048	26.600	0.130	2.460	0.0053
1998	0.047	26.500	0.219	2.510	0.006
1999	0.040	15.900	0.427	1.290	0.004
2000	0.037	21.000	0.388	0.871	0.0033
2001	0.051	18.300	0.247	1.490	0.0034
2002	0.039	12.800	0.140	0.959	0.0046
2003	0.023	13.600	0.177	0.758	0.0022
2004	0.017	13.100	0.079	0.787	0.0014

22. As the summary table of statistical results shows, the discharge levels in 2002 – 2004 for all the radionuclides and groups of radionuclides chosen for observation are below the baseline averages.

23. For Tc-99 and Cs-137, the lower brackets of the baseline are negative, so that no conclusions […] can be drawn from a simple comparison for those radionuclides. For the other radionuclides, the discharges in 2002 – 2004 were below the baseline average, but not below the lower bracket of the baseline. The results of the two statistical tests show that the reductions in discharges were statistically significant for:

a. total-α (Student's t-test[67]),

b. total-β (Student's t-test[67] and the Mann-Whitney statistic),

c. Cs-137 (Student's t-test[67] and the Mann-Whitney statistic) and

d. plutonium (the Mann-Whitney statistic).

24. There is therefore clear evidence of statistically significant reductions in the levels of total-β and Cs-137 discharges, and some evidence of reductions in total-α and plutonium discharges. If the tests of statistical significance are re-worked with data normalised against the electrical energy provided from the treated fuel, the results are the same. This means that the reductions which have been observed result from actions taken to reduce discharges, not from any decrease in throughput of the plant.[69] [70]

---

67 See Chapter 3, paragraph 45.

68 Ireland holds the view that tritium, C-14 and I-129 discharges, exceptional discharges and discharges from old waste should be included in the evaluation. Furthermore, they consider that the Radioactive Substances Strategy relates to absolute levels of discharges and that variations in operating levels should not therefore be considered.

69 The energy values for the reprocessed fuel are as follows:

The United Kingdom

Overall Situation

25. The overall levels of levels of discharges of the relevant radionuclides from the reprocessing plants and other installations at Sellafield have been as follows:

TBq

Year	Total-a	Total-b	Tc 99[71]	Cs 137	Pu 239/240
1995	0.400	190.000	190.000	12.000	0.230
1996	0.270	140.000	150.000	10.000	0.151
1997	0.180	140.000	84.000	7.900	0.105
1998	0.174	85.500	52.700	7.540	0.096
1999	0.133	110.000	68.800	9.110	0.078
2000	0.120	77.000	44.000	6.900	0.076
2001	0.200	120.000	79.000	9.600	0.100
2002	0.350	112.000	85.400	7.690	0.212
2003	0.407	83.300	37.000	6.240	0.224
2004	0.291	73.300	14.300	9.670	0.182

26. As the summary table of data measures shows, the discharges in 2002 – 2004 have been below the baseline average for total-β and Tc-99 […]. The reductions for total-β do not take the level below the lower bracket of the baseline. The discharges of Tc-99 in 2004 were also below the lower bracket of the baseline, giving an indication of a relevant reduction. The discharges of Cs-137 in 2002 and 2003 were below the baseline average (though in neither case below the lower bracket of the baseline), but those for 2004 were above.[72] However, neither the Student's t-test[73] nor the Mann-Whitney statistic suggests that any of these reductions is statistically significant.

27. Discharges of total-α and plutonium-239/240 increased in 2002 and 2003 for unforeseen reasons, and then reduced from that higher level in 2004. (Although data for 2005 have not yet been reported to OSPAR, the United Kingdom has indicated that there has been a further reduction in the level of plutonium discharges in 2005). The discharges of plutonium in 2002 – 2004 were greater than the average for the baseline period, but were not above the upper bracket of the baseline. A simple comparison therefore gives no indication of a relevant increase. The Student's t-test[74] suggests that these levels of discharge were statistically significantly different from the baseline average, but the Mann-Whitney statistic does not confirm this[75].

Graphical summary

28. Based on the data given above for the individual Contracting Parties, these developments can be summarised as follows:

TBq

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Electrical energy (GW x y)	43.42	43.14	47.48	49.19	37.19	34.64	37.50	36.64	37.50	39.25

70 Ireland considers that the Radioactive Substances Strategy relates to absolute levels of discharges, and that variations in operating levels should not be considered. They do not therefore agree to the use of normalisation in this paragraph, and proposed the deletion of the last two sentences.

71 *The figures in this table have been checked by the UK, but there seems to be an anomaly between "total β" and the sum of Tc-99 and Cs-137 for 1995 – 1996.*

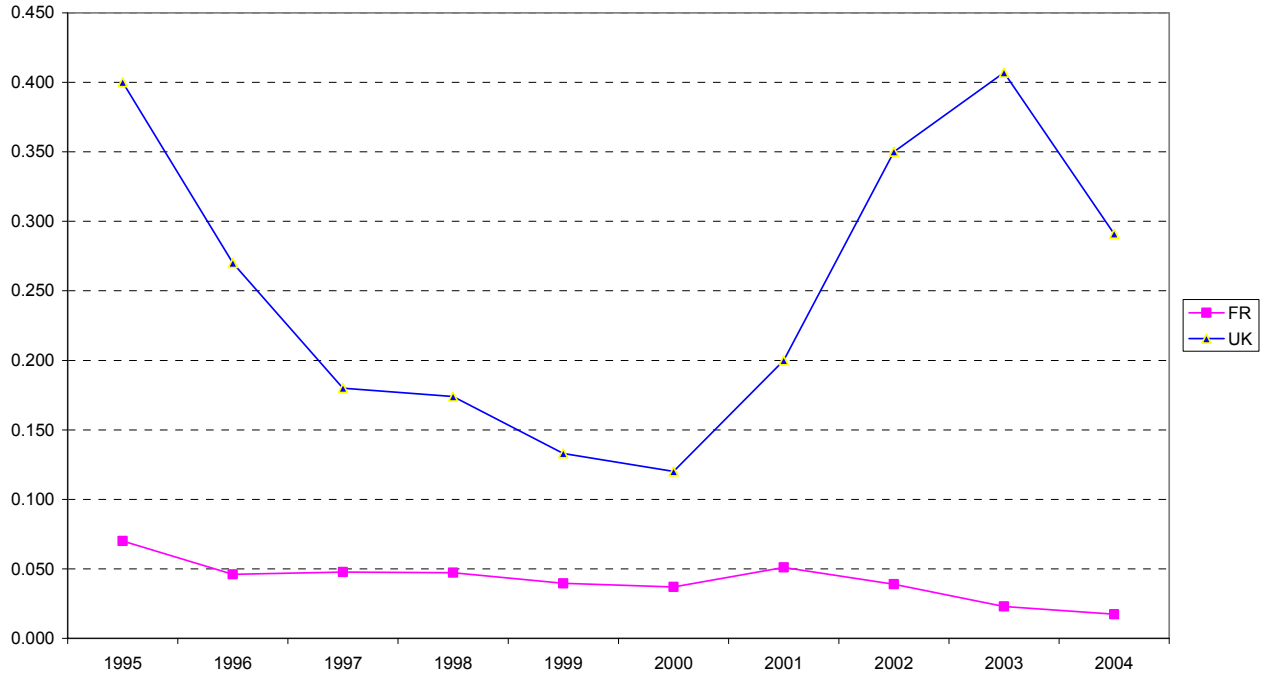
72 *These amendments flow from recalculations done as a result of UK comments.*

73 See Chapter 3, paragraph 45.

74 See Chapter 3, paragraph 45.

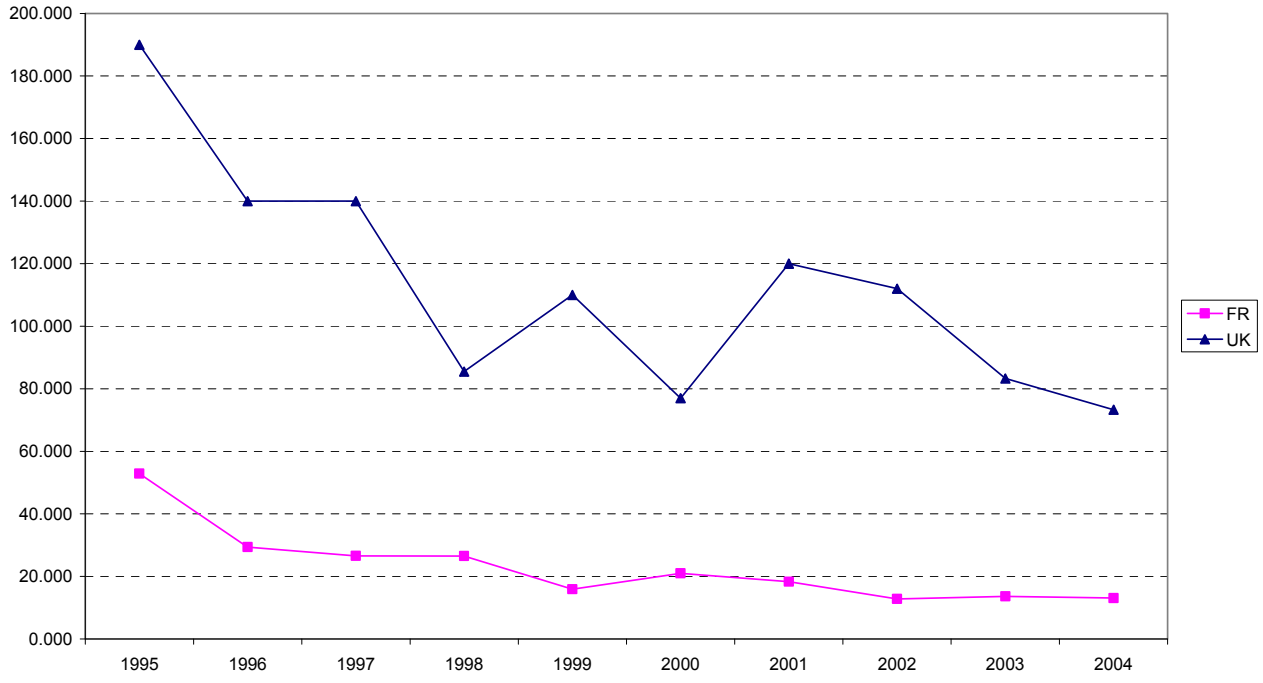
75 *These amendments flow from re-checking the data measures following the corrections in the UK data.*

Total a discharges from Nuclear Fuel Reprocessing Plants



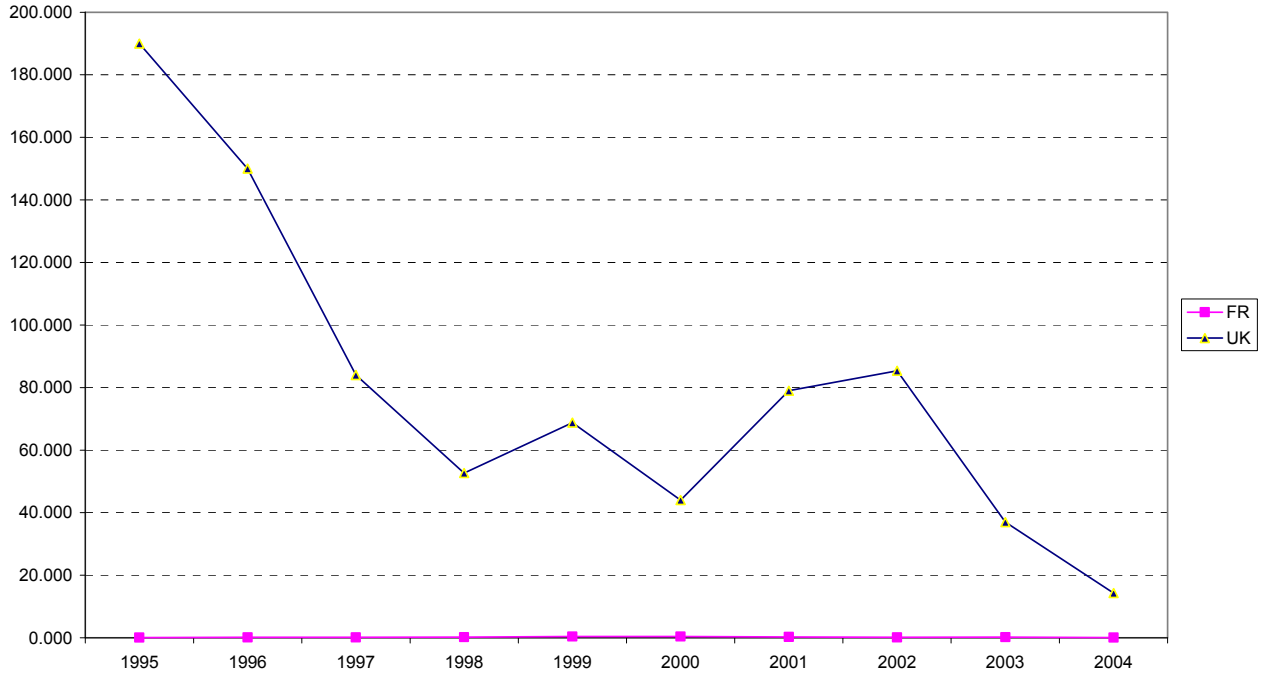
TBq

Total-b discharges from Nuclear Fuel Reprocessing Plants



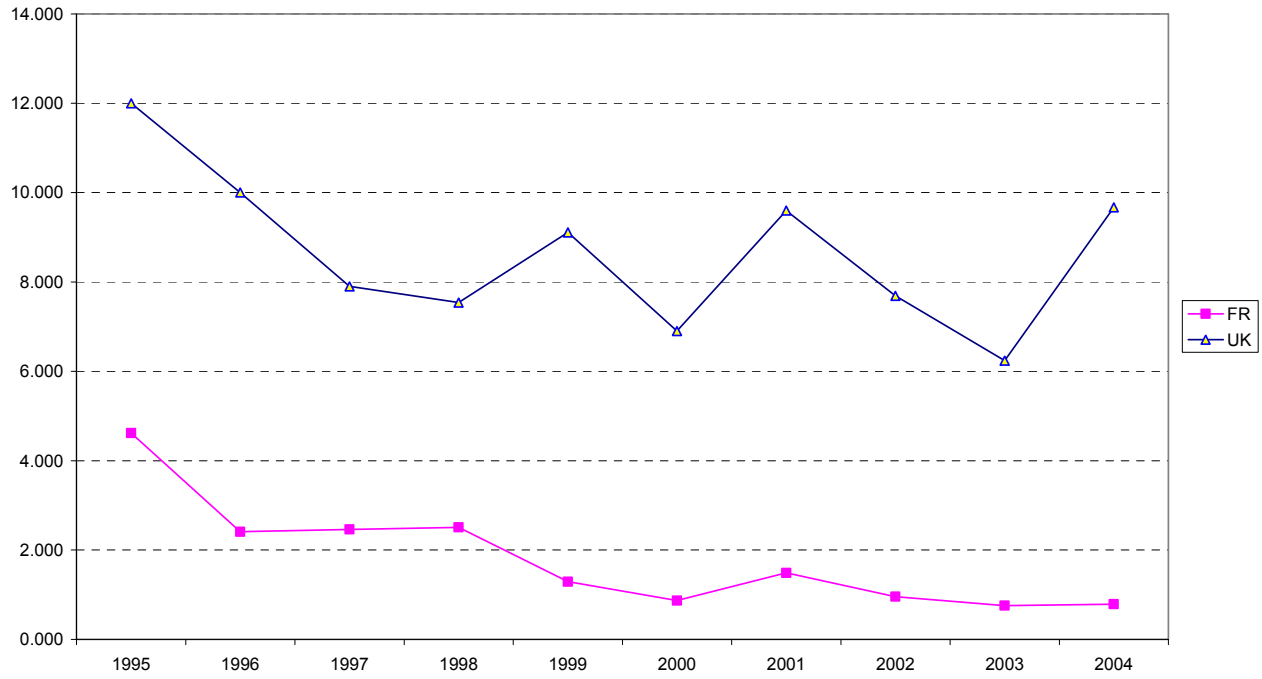
TBq

TC-99 from Nuclear Fuel Reprocessing Plants



TBq

Cs 137 discharges from Nuclear Fuel Reprocessing Plants



TBq

Pu239/240 discharges from Nuclear Fuel Reprocessing Plants

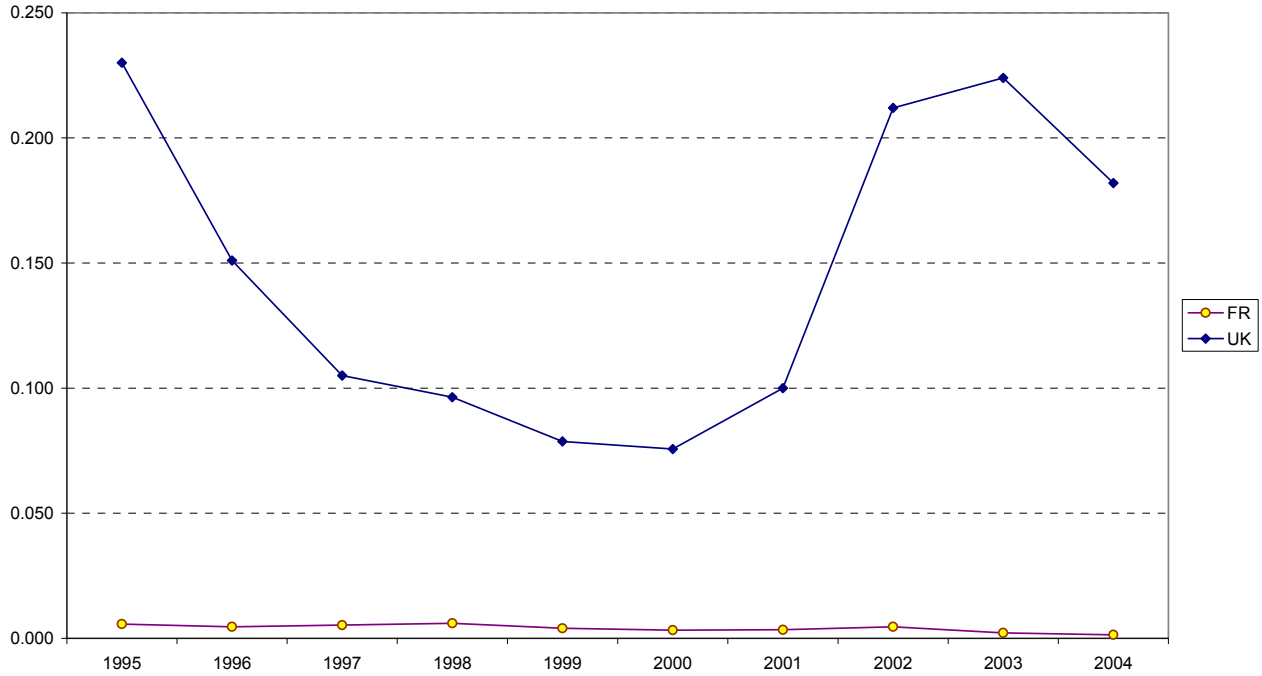


Table 16: Data measures on nuclear-fuel reprocessing plant discharges

	Baseline Average **TBq**	**Baseline Upper Bracket** **TBq**	**Baseline Lower Bracket** **TBq**	**2002-2004 Range Highest – Lowest** **TBq**	**Student's t probability**	**Mann-Whitney probability**
Overall						
Total- α	2.60E-01	4.69E-01	5.07E-02	0.43 – 0.31	0.067	0.183
Total- β	1.51E+02	2.46E+02	5.58E+01	125 – 86.4	0.058	0.67
France						
Total- α	0.048	0.06	0.027	0.39 – 0.17	0.053	0.333
Total- β	27.229	51.388	3.070	13.600 – 12.800	0.023	0.017
Tc-99	0.233	0.491	0[76]	0.180 – 0.079	0.118	0.383
Cs-137	2.237	4.658	0[76]	0.959 – 0.758	0.024	0.033
Pu-239/240	0.005	0.007	0.002	0.0042 – 0.0014	0.180	0.117
United Kingdom						
Total- α	0.211	0.400	0.022	0.407 – 0.291	0.029	0.067
Total- β	123.214	198.135	48.293	112.000 – 73.300	0.111	0.183
Tc-99	95.500	201.358	0[76]	85.400 – 14.300	0.140	0.267
Cs-137	9.007	12.414	5.601	9.670 – 6.240	0.394	0.517
Pu-239/240	0.120	0.227	0.012	0.224 – 0.182	0.007	0.117

[76] The baseline lower bracket, as calculated, would be negative. Since a negative discharge is impossible, the bracket is truncated at zero.

CHAPTER 11 – NUCLEAR RESEARCH AND DEVELOPMENT FACILITIES

Context

1. Many of the nuclear installations considered in the previous chapters 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 chapter is concerned with the sites at which only nuclear research and development give rise to discharges containing radionuclides.

2. These specifically research and development sites cover a wide range of activities. Some (such as Petten in the Netherlands) have a major role in producing radionuclides for nuclear medicine. Others are in the process of being decommissioned. There is therefore no consistent overall picture.

Overall situation for the nuclear research and development facilities sub-sector

3. For the nuclear research and development sub-sector, the overall discharge data for total-α is obtained from the gross α activity values and the summation of activity values of single radionuclides. Total-β is calculated on the basis of the gross β activity and the summed activity values of single radionuclides. The national reports specify either the activity values of single β radionuclides or the sum of activities in the form of "β-emitting radionuclides excluding tritium", "other radionuclides", "total-β" or "weighted activity". Data on the individual radionuclides chosen for consideration in relation to the nuclear sector is reported in detail only by Norway and Switzerland. Given the very low levels involved, this data has not been examined separately.

4. The overall levels of discharges of total-α and total-β reported to OSPAR for the years in question have been as follows[77]:

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Total-α	0.09	0.13	0.03	0.01	0.003	0.0019	0.0016	0.0021	0.0047	0.0005
Total-β	7	8.1	1	0.66	0.36	0.3	0.46	0.46	0.44	0.47

5. As the summary table of data measures at the end of the chapter shows, there has been a 94% reduction between the baseline average discharge levels for total-α and the average discharge level in 2002 – 2004, and similarly an 82% reduction for total-β. However, the lower brackets of the baseline are both negative, so no conclusions can be drawn from a simple comparison about the relevance of these reductions. Nor do the statistical tests suggest that the reductions are significant.

Belgium

6. The Belgian Nuclear Research Centre (SCK/CEN) at Mol was started in 1951. Over the years, the research centre has diversified its activities away from the work on the establishment of the Belgian nuclear power plants that was its original focus. The main nuclear issues now being studied are nuclear safety and the storage of nuclear waste. The focus is increasingly on the production of radio-isotopes for use in medicine and industry. The discharges from the site (which includes other establishments) are treated in the Belgoprocess 2 plant and discharged to the Molse Nete. The waters of this brook eventually flow into the River Scheldt, but it is unclear whether how much of the radioactive substances discharged eventually find their way into the sea.

7. The discharges of radioactive substances from the Mol site are regulated by a monthly limit of 1.99 GBq per month to discharges, measured by a weighted formula (the formula is: [total-β] + 5[total-α] + 3[I-131] + 300[Ra-226] + 0.01[tritium])[78]. The discharges are overwhelmingly of β-emitting substances. The overall levels of discharges, weighted according to this formula have been as follows:

---

[77] Additional data has since been reported by France, which is set out under the section on France below. This data does not change the overall assessment.

[78] In future, Belgium intends to report the underlying data, together with that for previous years. This will make future comparisons within this subsector easier.

TBq

Year	**Total-β + other radionuclides weighted according to formula**
1995	2.60E-02
1996	1.90E-02
1997	5.80E-03
1998	1.03E-02
1999	6.03E-03
2000	6.00E-03
2001	5.80E-03
2002	4.50E-03
2003	1.79E-03
2004	8.24E-04

8. The lower bracket of the baseline is negative. No conclusion is therefore possible from a simple comparison about the significance of the reductions. However, the range of discharge levels in 2002-2004 is at least 60% below the baseline average, and this reduction is confirmed as statistically significant by the Student's t-test[79] and the Mann-Whitney statistic.

9. The conclusion can therefore be drawn that there is evidence of reductions which are statistically significant.

Denmark

10. The national nuclear research centre at Risø is being closed down. All three research reactors have been taken out of operation, and the process of decommissioning has started. As a consequence, the discharge limits and reporting obligations have been revised. The annual discharges reported are now exclusively from the Waste Management Plant.

11. There are no reported discharges of α-emitting radionuclides. The overall levels of discharges of other radioactive substances have been as follows:

TBq

Year	Total-β
1995	0.00E+00
1996	1.10E-04
1997	7.10E-05
1998	8.48E-05
1999	
2000	1.50E-04
2001	1.30E-04
2002	2.50E-04
2003	9.00E-05
2004	1.10E-04

12. The lower bracket of the baseline is negative. No conclusion is therefore possible from a simple comparison about […] the changes. In fact, the levels of discharge have been around, or a little above, the

[79] See Chapter 3, paragraph 45.

baseline average, but neither of the statistical tests suggest that there has been a statistically significant increase.

France

13. France has two research centres in the catchments of the OSPAR maritime area: Fontenay-les-roses and Saclay. Fontenay-aux-roses (located to the south of Paris) has been a research centre for the Commission for Atomic Energy (CEA – *Commissariat à l'Energie Atomique*) since 1946. It is co-located with an establishment of the Institute of Radiological Protection and Nuclear Safety (*Institut de Radioprotection et de Sûreté Nucléaire*), which contributes to the discharges. Apart from research laboratories, the main installations are four plants in course of being decommissioned and cleaned-up. Discharges are made to the local sewerage system, which discharges into the River Seine downstream of Paris.

14. Saclay is the main research centre of the CEA, and lies about 20 km south-west of Paris. It has 5 000 researchers. There are five main areas of research: materials science, applied nuclear research, health, technology, and the environment. Its site is shared with the National Institute of Nuclear Science and Technology. As well as research laboratories, there are 10 main installations. These comprise: a research accelerator (in course of decommissioning), two installations for the production of radio-pharmaceuticals, two laboratories for study of high-level irradiated materials, two swimming-pool reactors, a teaching reactor and two plants for treating liquid radioactive discharges and solid radioactive waste. The discharges pass, through ponds at Saclay and a small stream, into the River Bièvre and thus into the River Seine.

15. France did not report data in early years on discharges from these two plants, but has now provided the following data to cover the period being studied. This is as follows:

TBq

Year	Total α		Other radionuclides[80]	
	Fontenay-aux-Roses	**Saclay**	**Fontenay-aux-Roses**	**Saclay**
1995	1.30E-05	<1.60E-04	3.30E-05	6.90E-03
1996	1.33E-05	<1.10E-04	4.80E-06	3.1E-03
1997	1.30E-05	<1.00E-04	9.00E-06	1.60E-03
1998	4.40E-06	<1.20E-04	4.00E-06	1.1E-03
1999	5.90E-06	<1.50E-04	3.00E-06	1.4E-03
2000	3.60E-06	<1.60E-04	2.20E-06	1.5E-03
2001	2.70E-06	<1.70E-04	1.30E-05	1.50E-03
2002	4.60E-06	<1.26E-04	1.10E-05	0.001026
2003	1.34E-06	<1.04E-04	1.05E-04	8.95E-04
2004	4.34E-06	<1.03E-04	5.00E-06	8.53E-04

16. Since the data for total-α discharges from Saclay are "less than" figures, data measures cannot be calculated to cover both sites for these discharges. It is therefore easier to look at all discharges separately for each site. For Fontenay-aux-roses, the discharges of total-α in 2002 – 2004 are below the average level of discharges in the baseline period, but this is not the case for "other radionuclides". The lower brackets for the discharges from Fontenay-aux-roses are negative, and no conclusions can therefore be drawn from a simple comparison about any reductions. For Saclay, the upper limits of discharges of total-α from Saclay in 2002 – 2004 are higher than the lower bracket of the baseline element for that site. The Student's t-test[81] and the Mann-Whitney statistic do not show any statistically significant changes in the levels of these discharges. The levels of discharges for "other radionuclides" are below the average of discharges in the baseline

80 Data on total-β is not available.

81 See Chapter 3, paragraph 45.

periods. No relevant conclusion can be drawn from a simple comparison, because the lower bracket of the baseline element is negative. The Student's t-test[82] does not show that these reductions are statistically significant, but the Mann-Whitney statistic does.

17. So far, therefore, there is no evidence of reductions in discharges of radioactive substances from the research and development installation at Fontenay-aux-roses. For the installation at Saclay, there is no evidence of reductions in discharges of total-α, but there is some evidence of reductions in discharges of other radionuclides.

Germany

18. There are five centres for nuclear research in Germany: at Berlin (the Hahn-Meitner Institute), Geesthacht, Jülich, Karlsruhe and Rossendorf. At Berlin, Geesthacht and Jülich, there are reactors with thermal capacities of 10 MW, 5 MW and 23 MW respectively. The reactors in Karlsruhe and Rossendorf have been shut down and decommissioning is in progress. Rossendorf is now mainly concerned with nuclear medicine and the impact of radiation on biological structures. .

19. There are no reported discharges of total-α. The overall levels of other discharges have been as follows:

TBq

Year	Total-β
1995	9.25E-04
1996	6.92E-04
1997	5.40E-04
1998	1.53E-03
1999	9.60E-04
2000	3.50E-04
2001	4.20E-04
2002	3.60E-04
2003	1.90E-04
2004	3.70E-04

20. The lower bracket of the baseline is negative. No conclusion is therefore possible from a simple comparison about the significance of any changes. The range of the levels of discharges in 2002-2004 is below the baseline average by at least 52%, and the Student's t-test[82] would confirm this as statistically significant. The Mann-Whitney statistic does not, however, do so.

21. There is therefore some evidence of a reduction in levels of total-β discharges which is statistically significant.

The Netherlands

22. The two research and development sites in the Netherlands are at Delft and Petten. The 2MW reactor at Delft forms part of the Delft Technical University and is mainly used for teaching purposes.

23. There are two reactors at Petten. Both have been in use since 1960. The high-flux (60MW) reactor is the property of the European Commission. It has an important role in the production of radio-pharmaceuticals, providing 60% of the European market. The low-flux (30kW) reactor is owned by ECN-KEMA: the ECN is the Netherlands Energy Research Foundation, and KEMA is an international energy company.

[82] See Chapter 3, paragraph 45.

24. The overall levels of discharges have been as follows:

TBq

Year	Total-α	Total -β
1995	3.70E+00	2.80E-05
1996	5.60E-06	9.50E-06
1997		1.10E-05
1998	2.30E-06	6.30E-02
1999	1.00E-06	6.00E-02
2000	1.00E-06	7.80E-02
2001	7.30E-06	1.30E-01
2002	7.20E-06	1.30E-01
2003	2.10E-06	8.50E-02
2004	5.26E-05	8.28E-02

25. The lower brackets of the baseline for both total-α and total-β are negative, and therefore no conclusions can be drawn from a simple comparison on the relevance of the changes. The levels of discharges of total-α in 2002-2004 are well below the average for this type of discharge in the baseline period, but this is due to the (comparatively) very high level of discharge in the one year of 1995 (almost entirely from the Petten installation). Because of this pattern, none of the statistical tests suggest that the reduction is statistically significant. The range of discharge levels for total-β in 2002-2004 is around the average for the baseline period. No statistically significant change can be observed.

Norway

26. Nuclear research is carried out at two sites in Norway: Kjeller and Halden. Both sites are operated by the Institute for Energy Technology. At Kjeller, the facilities include a heavy water cooled and moderated research reactor (JEEP II, thermal effect 2 MW), medical isotopes production facilities and a radioactive waste treatment plant. Liquid discharges are made to the river Nitelva, approximately 100 km from the sea (Skagerrak area). The Halden Boiling Water Reactor (HBWR) has a maximum heat removal capacity of 25 MW. The heat is transferred and used in a nearby paper factory as steam. Liquid discharges are made to the river Tista, not far from the discharge of the river into Iddefjorden leading further to Skagerrak.

27. The environmental concentrations of anthropogenic radionuclides near the discharge points are very low. In both Nitelva and the river Tista, the observed levels of Cs-137, plutonium and Sr-90 are mainly attributable to bomb test fallout and/or Chernobyl fallout. However, the bottom sediments of the river Nitelva are contaminated, mainly with plutonium, as a result of discharges from a uranium purification plant in the sixties and seventies. The “hot spot” was removed in spring 2000, and only sediments with concentrations lower than 10 kBq/kg (sum of plutonium and Am-241) remains in the river bed.

28. The overall level of discharges has been as follows:

TBq

Year	Total-α	Total -β
1995	1.00E-06	2.95E-03
1996	7.82E-07	4.04E-03
1997	1.59E-05	2.42E-03
1998		1.72E-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	8.54E-04
2003	3.60E-08	2.4E-03
2004	1.60E-07	3.26E-03

29. For total-α, the levels of discharges in 2002-04 are well below the baseline average. No conclusion about the relevance of this can be drawn from a simple comparison, since the lower bracket of the baseline is negative. Neither of the […] statistical tests, however, shows this reduction as significant. For total-β, the level of discharges in 2002 was below the lower bracket of the baseline. However, those for 2003 and 2004 were within the bracket, that for 2004 being above the baseline average. Neither of the […] statistical tests suggests that there has been a significant change.

30. No clear conclusion can be drawn from the data, except that there is no clear evidence of any increase.

Portugal

31. The Portuguese Research Reactor is located at Sacavem to the north of Lisbon. It is mainly used for irradiation. 41% of the irradiation time in 2002 was used for the work of the Atmospheric Elemental Group, and a further 20% was used by scientists from outside Portugal.

32. There are no discharges of α-emitting radionuclides. The overall level of discharges of total-β is as follows:

TBq

Year	Total –β
1995	8.43E-04
1996	8.43E-04
1997	5.15E-04
1998	6.54E-04
1999	1.00E-03
2000	9.00E-04
2001	8.10E-01
2002	8.50E-01
2003	7.90E-05
2004	

33. The lower bracket of the baseline is negative, and no conclusions can therefore be drawn on significance from a simple comparison. As can be seen from the statistical summary table, the discharges in 2002-2003 varied very widely. In 2002, the level was several times higher than the baseline average, although comparable to that of 2001, which was noticeably out of line with the other baseline years. In

2003, the level was several orders of magnitude below the baseline average. No report has yet been made for 2004. No conclusions can be drawn from this as to whether there has been any change.

Switzerland

34. The Paul Scherrer Institute is a multi-disciplinary research institute, founded in 1956 in the Canton of Aargau in the north of Switzerland. Its research programmes cover elementary particle physics, biological sciences, solid state research, materials science, nuclear and non-nuclear energy research and environmental research related to energy production. The nuclear installations include research laboratories, waste-treatment facilities, the Federal interim storage facility for radioactive waste, and three research reactors, two of which are being decommissioned. The remaining active reactor (PROTEUS) has a thermal capacity of 1kW. The site discharges to the River Aare.

34. The overall level of discharges has been as follows:

TBq

Year	Total-α	Total -β
1995	4.40E-06	3.13E-04
1996	2.10E-06	2.31E-04
1997	5.80E-07	1.70E-04
1998	2.01E-05	8.72E-04
1999	3.34E-05	8.45E-04
2000	7.18E-07	3.58E-04
2001	5.86E-07	4.23E-05
2002	2.17E-06	5.50E-05
2003	1.28E-05	1.57E-04
2004	1.40E-05	6.13E-05

35. The lower brackets of the baseline are negative for both total-α and total-β. No conclusions on significance can therefore be drawn from a simple comparison. Total-α discharges in 2002 have fluctuated around the baseline average: lower in 2002 and 2003, higher in 2004. The statistical tests do not suggest that any change is statistically significant. The total-β discharges in 2002=2004 are lower than the baseline average. The Student's t-test[83] and the Mann-Whitney statistic confirm that these reductions are statistically significant.

36. While no conclusions can be drawn about total-α discharges, there is evidence of a statistically significant reduction in total-β discharges.

The United Kingdom

37. The three principal centres for nuclear research in the UK were Harwell, Dounreay and Winfrith. Liabilities on these sites are owned by the Nuclear Decommissioning Authority (NDA), the sites themselves are owned and operated by the UK Atomic Energy Authority (UKAEA). In the past these centres were involved in fission-based reactor design and other civil nuclear research (some defence related nuclear research was also carried out by UKAEA). Two of the sites (Dounreay and Winfrith) are effectively coastal sites, whilst Harwell is located inland, but makes discharges to the non-tidal middle-reaches of the River Thames. All three sites are now fully engaged in decommissioning and site clean-up activities.

38. Government funding is no longer provided for research related to fission-based nuclear power. The emphasis is now on site clean-up, and funding streams are now focussed on decommissioning and radioactive waste management.

[83] See Chapter 3, paragraph 45.

39. The overall levels of discharges have been as follows

TBq

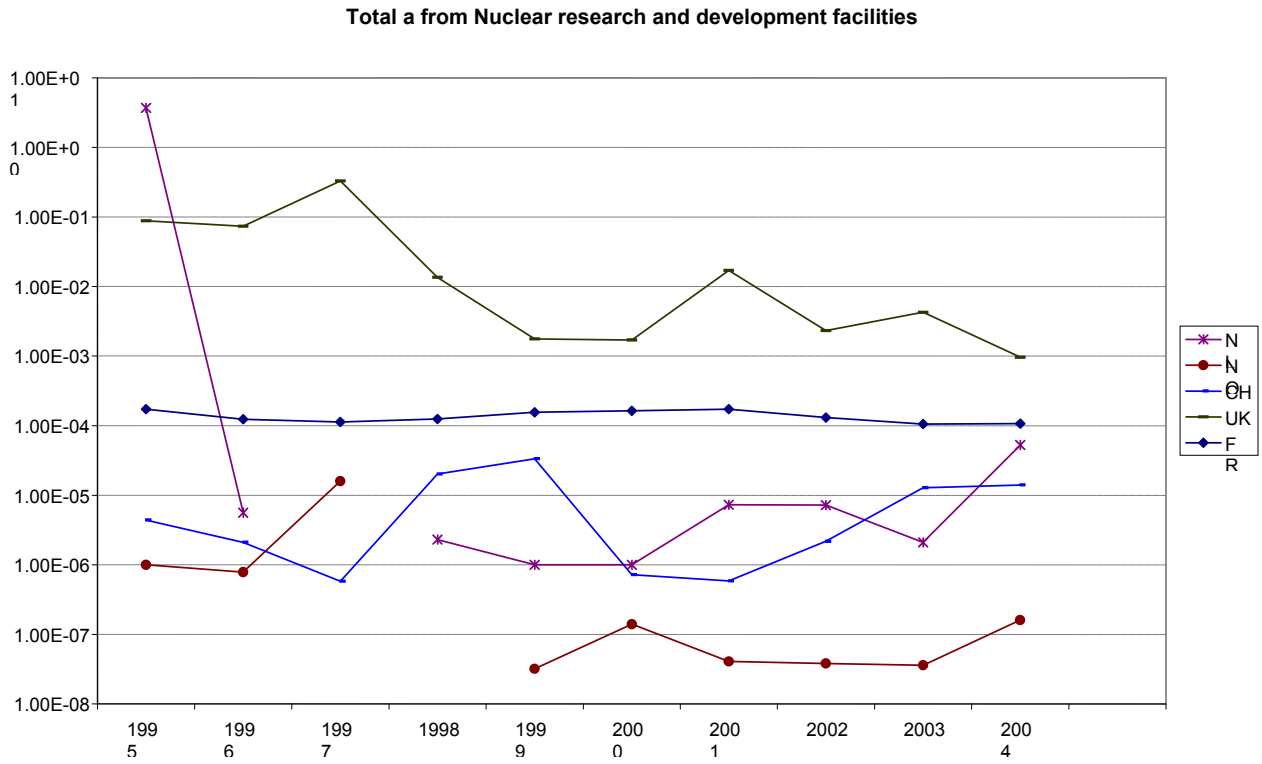
Year	Total-α	Total -β
1995	8.80E-02	7.03E+00
1996	7.30E-02	6.30E+00
1997	3.29E-01	9.52E-01
1998	1.35E-02	6.07E-01
1999	1.76E-03	3.14E-01
2000	1.70E-03	3.20E-01
2001	1.7E-02	1.2E+00
2002	2.32E-03	3.09E-01
2003	4.28E-03	3.69E-01
2004	9.60E-04	1.75E-03

40. The levels of discharges in 2002 – 2004 have been around an order of magnitude lower than the average in the baseline period. Since the lower brackets of the baseline are negative, no conclusions on relevance can be drawn from a simple comparison. The […] statistical tests do not show that the reductions are significant. No clear conclusions can therefore be drawn, except that there is no evidence of any statistically significant increase.

Graphical summary

41. Based on the data given above for the individual Contracting Parties, these developments can be summarised as follows:

TBq



TBq

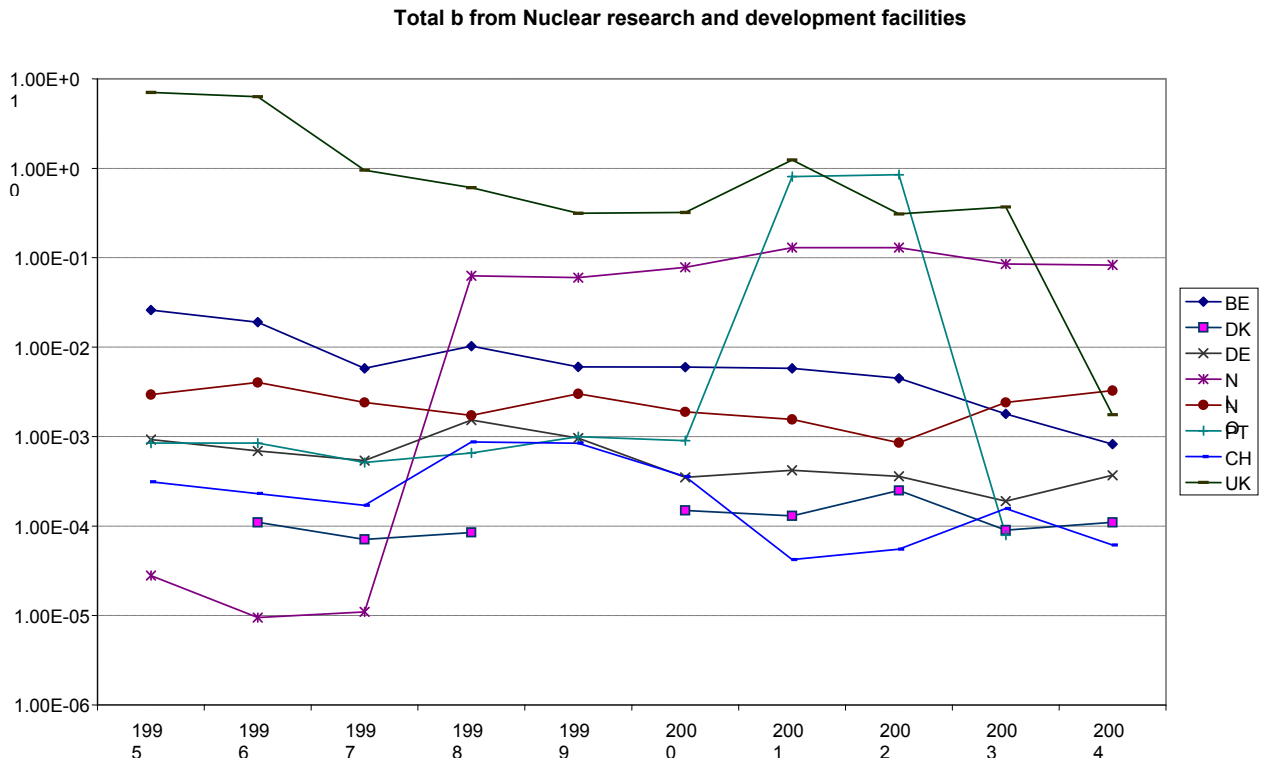

Total b from Nuclear research and development facilities
1.00E+01
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
BE
DK
DE
N
N
PT
CH
UK

Table 17: Data measures of data on discharges from nuclear research and development facilities

	Baseline Average (TBq)	Baseline Upper Bracket	Baseline Lower Bracket	Range of discharges in 2002 – 2004	Student's t probability[84]	Mann-Whitney probability[85]
Overall						
Total- α	3.81E-02	1.39E-01	0[86]	4.70E-03 - 5.00-E04	0.117	0.267
Total- β	2.55E+00	9.29E+00	0[86]	4.70E-01 – 4.40E-01	0.157	0.667
Belgium						
Total-β	1.13E-02	2.71E-02	0[86]	4.50E-03– 8.24E-04	0.028	0.017
Denmark						
Total-β	9.10E-05	1.95E-04	0[86]	2.50E-04– 9.00E-05	0.366	0.383
France						
Total-α						
Fontenay	7.99E-06	1.76E-05	0[86]	4.60E-06 - 1.34E-06	0.063	0.267
Saclay[87]	1.39E-04	1.67E-04	1.11E-04	1.26E-04 – 1.03E-04	0.067	0.267
Other radionuclides						
Fontenay	9.86E-06	3.12E-05	0[86]	1.05E-04 – 5.00E-06	0.446	0.267
Saclay	2.44E-03	4.51E-03	3.74E-04	1.03E-03 – 8.53E-04	0.100	0.017
Germany						
Total-β	7.74E-04	1.57E-03	0[86]	3.70E-04 – 1.90E-04	0.024	0.067
Netherlands						
Total-α	5.35E-01	3.27E+00	0[86]	5.26E-05 – 2.10E-06	0.349	0.383
Total-β	4.73E-02	1.45E-01	0[86]	1.30E-01 – 8.28E-02	0.101	0.167

84 As explained in Chapter 3, the interpretation of the Student's t test depends on the degrees of freedom". The figure given is the probability that the two "populations" compared (observations for the baseline period 1995-2001 and subsequent observations) have the same mean. It is calculated by comparing the calculated "t" with the *a priori* possibilities for the "t" distribution for the same degree of freedom. If that probability is less than 0.05, it can be concluded that there is a 95% probability that they are significantly different.

85 As explained in Chapter 3, this is the probability that the two "populations" represented by the observations for 1995-2001 (the baseline period) and 2002-2004 are the same. If the probability is below 0.05, it can be concluded that there is a 95% probability that they are significantly different.

86 The baseline lower bracket, as calculated, would be negative. Since a negative discharge is impossible, the bracket is truncated at zero.

87 Treating the upper limits of the discharge levels as the discharge levels for this purpose.

	Baseline Average (TBq)	**Baseline Upper Bracket**	**Baseline Lower Bracket**	**Range of discharges in 2002 – 2004**	**Student's t probability[84]**	**Mann-Whitney probability[85]**
Norway						
Total-α	2.98E-06	1.54E-05	0[86]	1.17E-07 – 3.80E-08	0.313	0.267
Total-β	2.51E-03	4.25E-03	7.76E-04	3.26E-03 – 8.54E-04	0.606	0.833
Portugal						
Total-β	1.16E-01	7.16E-01	0[86]	8.50E-01 – 7.90E-05	0.598	(insufficient data)
Switzerland						
Total-α	1.06E-05	3.49E-05	0[86]	1.40E-05 – 5.86E-07	0.456	0.813
Total-β	3.74E-04	9.90E-04	0[86]	6.13E-05 – 4.23E-05	0.019	0.017
United Kingdom						
Total-α	7.48E-02	3.05E-01	0[86]	4.28E-03 – 9.60E-04	0.154	0.383
Total-β	2.39E+00	8.16E+00	0[86]	3.69E-01 – 1.75E-03	0.101	0.067

Chapter 12 – GENERAL CONCLUSIONS

Background

1. This is the first periodic evaluation of progress towards the implementation of the OSPAR Radioactive Substances Strategy, adopted in 1998 and reviewed in 2003. The objective of the OSPAR Commission under this strategy is "[i]n accordance with the general objective [of the OSPAR Convention,] …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."

2. The implementation of this strategy therefore requires attention to ***discharges*** (reductions in which are the main means of action), ***concentrations*** (the measure of the ultimate aim) and ***doses*** (one of the factors to be taken into account).

3. Until recently, OSPAR has concentrated its data collection on radioactive substances in the North-East Atlantic on discharges from the nuclear sector. Arrangements are now in place, however, for collecting information on discharges of radioactive substances from other sectors and on concentrations of radionuclides in sea-water and marine biota.

4. The time-frame for the current Radioactive Substances Strategy runs until 2020. Implementation therefore has to be examined over a period of more than two decades. Consistently with this extended time frame, the baseline for comparisons has been set as the period 1995 – 2001.

5. This first periodic evaluation considers what progress can be identified so far on the commitment to reductions in discharges since 1998. The available evidence is limited, in that data has been collected and reported for only three years (2002 – 2004) since the end of the baseline period. The evaluation is thus limited in scope. The evaluation is also limited to discharges alone. Concentrations and doses, which are an important part of the formulation of the overall objective, will be evaluated in the second periodic evaluation in 2007. The evaluation is further limited by the small amount of data that is available for discharges of radioactive substances from the non-nuclear sectors.

6. As general background to this evaluation of progress on discharges, it is nevertheless important to note that all the evidence available (both from those Contracting Parties which seek to assess doses of radioactivity to identified human reference groups, and from those which calculate such doses to hypothetical reference groups) is that all doses to humans from radioactivity linked to the North-East Atlantic are within (and in the large majority of cases, well within) the limits for such doses set by the International Commission on Radiological Protection and (for those Contracting Parties for whom it is relevant) the European Community, and comply with the Basic Safety Standards of those organisations. And, while the question of doses to non-human biota is under review, it has long been a basic principle that adequate protection of humans will also deliver adequate protection of the environment as a whole.

7. It must be remembered that there will be no reductions in discharges at all unless some action is taken to change the pattern of operations. Reductions (or, indeed, increases) indicate some intervention, by way of either changes in the overall level of operations, or new operating practices (management) or equipment, or increased efficiency of control measures.

8. Whether changes in the level of discharges are statistically significant or not will depend in large part on the past pattern of discharges – where there have been large fluctuations in the past, it will need a longer run of data to be sure that changes lie outside the past pattern of fluctuations. In this first evaluation, which can be based only on three years data since the end of the baseline period, and with a fairly large degree of fluctuations in the data during the baseline period, it is not possible to draw many firm conclusions.

9. Against this background, the main conclusions of this evaluation can be summarised as follows.

Non-nuclear sectors

10. Two non-nuclear sectors are being considered in this evaluation – the offshore oil and gas industry and the medical sector.

11. In the offshore sector, the main discharges that need to be considered are produced water and the disposal of descaling operations.

12. Discharges of radioactive substances in produced water are basically proportionate to the amount of produced water discharged, though the levels of radioactivity can vary greatly between fields and (in the case of some fields) over time. Because the quantity of produced water tends to increase with the age of the oil and gas wells, action is being taken to reduce the quantity of such discharges to reduce the risk of pollution from hydrocarbons. This therefore also tends to reduce the levels of discharges of radioactive substances. The evidence shows that this action has reduced the rate of increase in the discharges of produced water by those Contracting Parties for whom this is a necessary practice (Denmark, Netherlands, Norway and the United Kingdom) and, in the case of the United Kingdom, has produced at least a levelling-off in discharges and possibly the start of a reduction.

13. In the medical sector, the main sources are the use of Tc-99m in diagnosis and I-131 in treatment of thyroid complaints. The impact on the marine environment comes solely from discharges through sewerage collection of excretions of patients. Given that use of radio-medical substances for both diagnostic and therapeutic purposes have been increasing steadily, it is probable that discharges have also been increasing. There is no evidence so far in the form of measurements on how much of that radioactivity is reaching the marine environment, given the removal of sewage sludge and the possibility of sedimentation from sewage effluent before the discharges reach the maritime area.

Nuclear sector

14. In the nuclear sector, discharges are divided between four sub-sectors. In the past, the nuclear-fuel reprocessing sector has been predominant, producing as much as 80% of the radioactivity discharged. Data reported to OSPAR now shows that, in the baseline period (1995 – 2001) and in the subsequent period (2002 – 2004), the contributions (in aggregate levels of radioactivity measured in Bq) of the four sub-sectors have been as follows:

Table 19: Proportions of total discharges from the nuclear sector by sub-sectors

Sub-sector	Average levels of discharges in the Baseline Period				Average levels of discharges in the subsequent period			
	Total-α		Total-β		Total-α		Total-β	
	TBq	%	TBq	%	TBq	%	TBq	%
Nuclear power-plants	-	-	3.89	1	-		2.63	1
Nuclear-fuel production and enrichment plants	0.16	35	119.42	43	0.21	35	106.33	50
Nuclear-fuel reprocessing plants	0.26	56	150.86	55	0.38	64	102.90	48
Nuclear research and development facilities	0.04	9	2.55	1	0.001	<1	0.46	<1

15. In the nuclear power-plant sub-sector as a whole, there is some evidence of reductions in discharges of total-β, but it is not yet statistically significant. The discharges of α-emitting radionuclides from nuclear power-plants are very low, and these sources are therefore of little radiological importance. They have therefore not been evaluated, either overall or for individual countries. For total-β discharges, there is statistically significant evidence of reductions in discharge levels from France, Spain and Sweden, and evidence (though not statistically significant) of reductions from Belgium, Germany, the Netherlands, Switzerland and the United Kingdom. For the specific radionuclide considered (Cs-137), there is no statistically significant evidence of reductions, though there is evidence (not statistically significant) of reductions in Belgium, France, Germany, the Netherlands, Spain, Sweden and Switzerland). There is

evidence of a slight increase in Cs-137 discharges from the United Kingdom, but it is not statistically significant.

16. In the nuclear-fuel enrichment and production plant sub-sector as a whole, there have been no statistically significant changes. With regard to the individual Contracting Parties, the United Kingdom is responsible for the largest share of the discharges, by a substantial factor. There is evidence of increases in the average level of discharges by the United Kingdom of total-α, total-β and Tc-99, but these increases are not statistically significant. Of the other Contracting Parties active in this sub-sector:

a. for total-α discharges, there is evidence of a statistically significant reduction in Germany. There is evidence of a (not statistically significant) increase in the Netherlands, and there is no discernible pattern of change in Spain;

b. for total-β discharges, there is evidence of a statistically significant reduction in the Netherlands[88].

17. In the nuclear-fuel reprocessing sector as a whole, there have been no statistically significant changes in the level of discharges. For France, there have been statistically significant reductions in the levels of total-β and Cs-137 discharges, and reductions (though not equally statistically significant) in the other relevant discharges. For the United Kingdom, there is (non-statistically significant) evidence of reductions in total-β, Tc-99, and Cs-137. There is (non-statistically significant) evidence of an increase in total-α discharges and statistically significant evidence of increases in plutonium discharges, although there was a down-turn in 2004, and the United Kingdom has indicated that this has continued in 2005.

18. The nuclear research and development sub-sector makes a very small contribution to the level of discharges. There have been reductions in both total-α and total-β discharges, but neither is statistically significant. For the individual Contracting Parties, there is evidence of statistically significant reductions from Belgium (weighted average), Germany (total-β) and Switzerland (total-β). In France, there is some evidence of reductions in discharges other than those of total-α at one of the two research sites. No conclusions can be drawn about whether there have been statistically significant changes for other discharges of this kind in France or in any of these discharges in Denmark, the Netherlands, Portugal, Switzerland (total-α) or the United Kingdom.

General Conclusions

19. Overall, the general conclusions are that:

a. for the non-nuclear sectors, there is no evidence whether the Radioactive Substance Strategy is yet being delivered, but some signs that appropriate actions are being taken;

b. for the nuclear sectors, there is a spectrum, both within countries and between countries:

i. for some categories of discharges, levels of discharge in 2002 – 2004 were still above the average of the baseline period (1995 – 2001); for some other categories of discharges, there is statistically significant evidence of reductions and, in a few cases, of substantial reductions; most other categories of discharges lie in between;

ii. the substantial decreases include the very welcome decreases in discharges of technetium-99 since 2002, which are expected to continue. Technetium-99 was an issue to which both the 1998 and 2003 OSPAR Ministerial Meetings drew especial attention;

iii. since the evaluation is based on data for only three years (2002 – 2004), it is not possible to say generally whether the aims of the OSPAR Radioactive Substances Strategy are being delivered.

[88] Germany and Spain do not report on total-β discharges from this sub-sector. Only the United Kingdom reports on TC-99 discharges.

Annex 1 - Total-α and Total-β Measurements

1. Introduction

This report summarises the information provided by OSPAR Contracting Parties (CPs)[89] in response to a questionnaire on total-α and total-β measurements. The objective of the questionnaire was to clarify how CPs measure, calculate or estimate total-α and total-β discharges. The report will assist in putting the data and discharge groupings etc., which are to be used in assessing the progress of the OSPAR Radioactive Substances Strategy, into context.

A method for estimating the total-α and total-β discharges from the non-nuclear sector has yet to be discussed; consequently this report only considers the nuclear sector.

2. Differentiating 'gross' and 'total' activity values

In the wider radiochemistry community, a 'gross' activity value is understood to be the result obtained from a measuring instrument that cannot distinguish between particles of different energies, and where the efficiency for detection may not be the same for all radionuclides i.e. the 'gross' value is operationally defined. The 'gross' activity is usually just a screening (or index) value and gives an indication of the total activity contained in a sample.

For a 'total' activity result, the sample is separately analysed for a number of individual radionuclides and the results summed to give a single 'total' activity. It is more expensive and time consuming to obtain a 'total' activity result.

While the 'total' result contains the (measured) activity of a number of specific radionuclides, the 'gross' activity result can include a contribution from all radionuclides that emit particles with energies contained in the detection range. However, as noted above the efficiency of detection for the gross counting may not be the same for all radionuclides.

3. Measurement approaches

3.1 Gross-α

This measurement is performed using one of the following: (i) a low background gas flow proportional counter, (ii) a liquid scintillation counter, (iii) a zinc sulphide (ZnS) solid scintillation counter or (iv) passivated implanted planar silicon (PIPS) alpha detectors. Table 20 provides a summary of the measurement techniques, used in the various nuclear sectors, that were reported by CPs. Details of the detection efficiencies and the measurement range for all detectors are given in Appendix 1.

Most CPs employ only one type of counter in a particular nuclear sub-sector, e.g. power plants, to obtain a gross-α result. However, different types of counter may be used to measure gross-α in other sub-sectors. Two CPs reported using different types of counters[90] in the same sub-sector.

CPs using the ZnS and/or Gas proportional counters or PIPS detectors reported that gross alpha results (typically) include alpha emitting radionuclides in the energy range 0.1 – 10 MeV. Liquid scintillation has been reported to detect alpha particles in the energy range 0 – 2000 keV.

[89] Eight CPs, from an expected ten, returned a completed questionnaire

[90] CPs reported using gas proportional counters or ZnS counters to obtain gross-α results in a particular nuclear sub-sector

Table 20. **Summary of gross alpha measurements**

Detector	**Sectors**
ZnS	Nuclear Power Plants Nuclear-Fuel Reprocessing Plants
Liquid scintillation	Nuclear Power Plants Nuclear Research and Development
Gas proportional counter	Nuclear Power Plants Fabrication and Enrichment Plants Nuclear-Fuel Reprocessing Plants Nuclear Research and Development
Passivated implanted planar silicon (PIPS) alpha detectors	Nuclear Power Plants

The radionuclides that can be detected include: Pu-238, Pu-239, Pu-240, Am-241, Cm-242, Cm-244, U-238, U-235 and U-234.

One CP reported that radiochemistry and alpha spectrometry are applied to quantify individual alpha emitters if the gross-α result, determined using a low background gas counter, is greater than 0.5 Bq/l.

3.2 Gross-β

Low background gas proportional counters, liquid scintillation counters and Geiger Muller (GM) detectors are used for Gross-β counting.

CPs reported that the gas proportional counter can detect beta particles with energies in the range 0 – 2.5 MeV. The gas proportional counters can be calibrated using one of the following standard sources: Cs-137, Tl-204, or Am-241/Sr-90. The calibration energy is approximately equal to the average energy of the main beta fission products expected in the sample. It should be noted that (i) the activity of beta particles with energies greater than the calibration value will be underestimated and (ii) the activity of beta particles with energies lower than the calibration energy will be overestimated.

Table 21. **Summary of gross beta measurements**

Detector	**Sectors**
Gas proportional counter	Nuclear Power Plants Research and Development Plants Nuclear-Fuel Reprocessing Plants
Liquid scintillation	Nuclear Power Plants
Geiger Muller detector	Nuclear-Fuel Reprocessing Plants Nuclear Power Plants

The GM detector will detect beta particles with energies above 50 keV. Particles with energies below 50 keV will not have enough energy to pass through the detector window. So tritium (19 keV) and Pu-241 (20 keV) will not be detected. Liquid scintillation counting will detect all beta particles with energies in the range 8 to 800 keV with 85 % efficiency.

The gross-β result will thus depend on the detector and the reference standard used.

One CP reported that if the gross-β result exceeds 1 Bq/l then gamma spectrometry and liquid scintillation counting are used to determine the activity of the various beta emitting radionuclides.

3.3 Total-α

As described in § 2, total-α represents the sum of the results of separately analysed alpha emitting radionuclides. These measurements are usually performed using passivated implanted planar silicon (PIPS) alpha detectors. Some CPs also analyse Am-241 by gamma spectrometry.

Table 22. **Summary of total alpha measurements**

Detector	**Sectors**
Alpha Spectrometry (PIPS detectors)	Nuclear Power Plants Nuclear Research and Development Fabrication and Enrichment Plants

The alpha emitting radionuclides detected using these methods include: Pu-238, Pu-239, Pu-239/Pu-240, Am-241, Cm-242, Cm-244, Pa-231, Th-228, Th-230, Th-232, Po-210, U-238, U-235 and U-234

One CP noted that Th-228 activity is adjusted

3.4 Total-β

In the majority of CPs, gamma spectrometry is used to determine the activity of a number of beta/gamma emitters. In addition, some specific beta emitters (strontium 89/90 and tritium) are also quantified by liquid scintillation and/or Cerenkov counting.

Table 23. **Summary of total beta measurements**

Detector	**Sectors**
Gamma Spectrometry	Nuclear Power Plants Nuclear Research and Development Fabrication and Enrichment Plants Nuclear-Fuel Reprocessing Plants
Liquid Scintillation	
Cerenkov Counting	

Radionuclides that are detected by these methods include: Na-22, Na-24, Cr-51, Mn-54, Fe-59, Co-57, Co-58, Co-60, Zn-65, As-76, Sr-89, Sr-90, Nb-95, Zr-95, Ag-110m, Te-123m, Sn-113, Sb-122, Sb-124, Sb-125, I-131, Cs-134, Cs-137, I-131, La-140, Ce-141, Ce-143, Am-241, Cm-242, and Cm-244, Pa-234m, Th-234.

Appendix 1

Table 24. **Summary of the detection efficiencies reported by OSPAR CPs**

Detector	**Efficiency†** **(%)**	**Sectors**	**Measurement**
ZnS	20 – 40	Nuclear Power Plants Nuclear-Fuel Reprocessing Plants	Gross-α
Gas proportional counter	12 – 55	Nuclear Power Plants Fabrication and Enrichment Plants Nuclear-Fuel Reprocessing Plants Nuclear Research and Development	Gross-α Gross-β
Alpha Spectrometry (PIPS detectors)	12 – 23	Nuclear Power Plants Fabrication and Enrichment Plants Nuclear Research and Development	Total-α Gross-α
Gamma Spectrometry	1 – 30	Nuclear Power Plants Fabrication and Enrichment Plants Nuclear Research and Development Nuclear-Fuel Reprocessing Plants	Total-β
Liquid Scintillation Counting	25 – 100	Nuclear Power Plants Nuclear Research and Development	Total-β Gross-α Gross-β
Geiger Muller detector	5 – 16	Nuclear-Fuel Reprocessing Plants Nuclear Power Plants	Gross-β
Cerenkov counting	-	Nuclear Research and Development	Total-β

†**Note:** In most cases radiation detection is not 100% efficient, i.e. the detector may not detect every particle. Thus a correction is applied to the counting results to allow for this.

Table 25. **Summary of the detector energy measurement ranges reported by OSPAR CPs**

Detector	**Energy Measurement Range**			
	Gross-α	Gross-β	Total-α	Total-β
ZnS	> 1MeV	n/a	n/a	n/a
Gas proportional counter	1 – 10 MeV	0.1 – 2.5 MeV	n/a	n/a
Alpha Spectrometry (PIPS detectors)	0.1 – 10 MeV	n/a	r/s	n/a
Gamma Spectrometry	n/a	n/a	n/a	r/s
Liquid Scintillation Counting	0 – 2000 keV	8 – 800 keV	n/a	r/s
Geiger Muller detector	n/a	> 50 keV	n/a	n/a
Cerenkov counting	n/a	n/a	n/a	r/s

n/a = not applicable

r/s = radionuclide specific i.e. the detectors will measure the energy of each individual radionuclide

Table 26. **Details of the measurement techniques applied by each Contracting Party.**

Contracting Party	**Detector**						
	ZnS	**Gas proportional counter**	**Alpha Spectrometry (PIPS detectors)**	**Gamma Spectrometry**	**Liquid Scintillation Counting**	**Geiger Muller detector**	**Cerenkov counting**
Belgium	Ga(P)	Ga(P)(D) Gb(P)(D)	Ga(P)(D)	-	-	Gb(P)	-
France	-	Ga(P)(R) Gb(P)(R)	-	-	-	-	-
Germany	-	Ga(P)(F)(D)	-	Tb(P)	Tb(P)	-	-
Norway	-	-	Ta(D)	Tb(D)	-	-	-
Spain	Ga(P)	Ga(P)(F)(D) Gb (D)	Ta(D)	Tb(D)(P)	Tb(D)	-	-
Sweden	-	-	Ta(P)	Tb(P)	Tb(P)	-	-
Switzerland	-	Ga(P)	Ta(P)(D)	-	Tb(P)(D)	-	-
UK	Ga(R)	Ga(D)(P) Gb(D)(P)	Ta(F)	Tb(F)	Ga(D)(P) Gb(D)(P)	Gb(R)	Tb(D)

Ga = gross α
Gb = gross β
Ta = total α
Tb = total β

P = Nuclear Power Plants
F = Fabrication and Enrichment Plants
R = Nuclear-Fuel Reprocessing Plants
D = Nuclear Research and Development

Please refer to § 2 of the report for a definition of 'gross' and 'total'

Annex 2 - Table 4 - Proposed Baseline Values on Concentrations, based on calculations of the mean concentration in the period 1995-2001

Key to the table:

- Empty box: no data available, or number of available (recent) data too less to derive a baseline value
- N.a.: not applicable
- In case that the unit deviate from the unit in the heading, the unit is reflected in the box
- SD: standard deviation; n: number of observations
- Value in italic denotes that all measurements on which the value has been based were below the detection limit
- Value in bold italic denotes that some/most measurements on which the value has been based were below the detection limit

Region	***Water*** *(Bq/l)*				Biota (Bq/kg wet): **Fish (F) / Fucus Seaweed (S) /** Molluscs (M)			***Region***	***Water*** (Bq/l)				Biota (Bq/kg wet): **Fish (F) / Fucus Seaweed (S) /** Molluscs (M)		
	Tritium	Cs-137	Tc-99	Pu-239, Pu-240	Cs-137	Tc-99	Pu-239, Pu-240		Tritium	Cs-137	Tc-99	Pu-239, Pu-240	Cs-137	Tc-99	Pu-239, Pu-240
1. Wider Atlantic Iberian Coast Biscay and Channel West[91]		*< 0.032* sd - n=60			***< 0.10*** (S) sd - n= 196	n.a.	n.a.	*2. Channel (Cap de la Hague)*	***< 14*** sd - n=229	***< 0.03*** sd - n=229	n.a.		0.21 (S) sd 0.- n=364	46 (S) sd 20 n=74	0.017 (M) (limpets) sd 0.02 n=110

[91] Surface water (upper 500 m)

Region	***Water*** *(Bq/l)*				Biota (Bq/kg wet): **Fish (F) / Fucus Seaweed (S) /** Molluscs (M)			***Region***	***Water*** (Bq/l)				Biota (Bq/kg wet): **Fish (F) / Fucus Seaweed (S) /** Molluscs (M)		
	Tritium	Cs-137	Tc-99	Pu-239, Pu-240	Cs-137	Tc-99	Pu-239, Pu-240		Tritium	Cs-137	Tc-99	Pu-239, Pu-240	Cs-137	Tc-99	Pu-239, Pu-240
3. Channel East	*< 10* sd - n=20	*< 0.034* sd - n=28	n.a.		***< 0.15 (S)*** sd - n=133	36 (S) sd 10 n=95		*4. Irish Sea (Rep. of Ireland)*		28 mBq/l sd 20 n=141	24 mBq/l sd 9 n=66		0.84 (S) sd 0.19 n=136	586 (S) sd 187 n=92	0.13 (M) sd 0.04 n=27
5. Irish Sea (Northern Ireland)		0.03 sd 0.01 n=7			2.9 (F) sd 0.6 n=7	519 (S) sd 280 n=7	0.18 (M) sd 0.04 n=7	*6. Irish Sea (Sellafield)*	***<14*** sd 2 n=7	0.19 sd 0.04 n=7	0.36 sd 0.35 n=7		16 (M) sd 2 n=7	13786 (S) sd 7444 n=7	18 (M) sd 2 n=7
7. Scottish Waters (Dounreay)	***< 1.7*** sd 0.4 n=5	***< 0.05*** sd 0.03 n=7			0.69 (S) sd 0.42 n=7	264 (S) sd 54 n=7	0.23 (M) sd 0.15 n=7	*8. North Sea South (Belgian and Dutch Coast)*	4.0 sd 1.3 n=239 3.6 sd 2.63 n=14	4.32 mBq/l sd 1.86 n=121		13.14 µBq/l sd 4.98 n=61	0.51 (F) sd 0.284 n=10		0.07 (F) n=11 0.04 (M) n=36
9. German Bight	2.93 sd 1.76 n=77	5.38 mBq/l sd 4.04 n=292	1.67 mBq/l sd 2.08 n=20	11.41 µBq/l sd 9.45 n=99	0.426 (F) sd 0.323 n=39			*10. North Sea (Northwest+ Southeast+ Central)*	0.8 sd 0.5 n=33	7.3 mBq/l sd 3.3 n=50 *(only 1995, 1996, 1997 and 2001)*	2.8 mBq/l sd 0.8 n=55 *(only 1996, 1997, 1999 and 2001)*		0.38 (F) [92] sd 0.05 n=7	66 (S)[2] sd 29 n=7	0.054 (M)[2] sd 0.006 n=7

[92] These values are based on UK coastal data

Region	***Water*** *(Bq/l)*				Biota (Bq/kg wet): **Fish (F) / Fucus Seaweed (S) /** Molluscs (M)			***Region***	***Water*** (Bq/l)				Biota (Bq/kg wet): **Fish (F) / Fucus Seaweed (S) /** Molluscs (M)		
	Tritium	Cs-137	Tc-99	Pu-239, Pu-240	Cs-137	Tc-99	Pu-239, Pu-240		Tritium	Cs-137	Tc-99	Pu-239, Pu-240	Cs-137	Tc-99	Pu-239, Pu-240
11. North Sea (Skagerrak) [93]		14.7 mBq/l sd 8.4 n=13 *(only 1995, 1996, 1997 and 2001)*	2.3 mBq/l sd 2.1 n=24 *(only 1996, 1997, 1999, 2000 and 2001)*					*12. Kattegat*							
13. Norwegian Coastal Current			1.1 mBq/l sd 0.4 n=48		0.59 Bq/kg dry (S) Sd 0.21 n=40	218 Bq/kg dry (S) sd 104 n=47		*14. Barents Sea*		3.5 mBq/l sd.0.4 n=7 *(only 1999)*	0.7 mBq/l sd.0.4 n=10 *(only 1999, 2000 and 2001)*		0.3 (F) sd 0 n=84		

[93] Variability of available data set is too large to derive a representative and sound baseline

Region	***Water*** *(Bq/l)*				Biota (Bq/kg wet): **Fish (F) / Fucus Seaweed (S) /** Molluscs (M)			***Region***	***Water*** (Bq/l)				Biota (Bq/kg wet): **Fish (F) / Fucus Seaweed (S) /** Molluscs (M)		
	Tritium	Cs-137	Tc-99	Pu-239, Pu-240	Cs-137	Tc-99	Pu-239, Pu-240		Tritium	Cs-137	Tc-99	Pu-239, Pu-240	Cs-137	Tc-99	Pu-239, Pu-240
15. Norwegian +Greenland Seas+ Icelandic Waters		Icelandic Polar Water 6.4 mBq/l sd 1.7 n=28 Icelandic Atlantic Water 2.7 mBq/l sd 0.4 n=9			Icelandic Coast 0.23 (S) sd 0.08 n=86 0.17 (F) sd 0.03 n=19	Iceland South- and West Coast 1.6 (S) sd 0.3 n=14 Iceland East Coast 8.3 (S) sd 1.5 n=6 Iceland North Coast 3.8 (S) sd 1.2 n=9									

Annex 3 - Dose assessment method for measured concentrations in seawater

1. The method uses a simplified version of the MARINA II dose assessment model.

2. Doses to individuals due to consumption of seafoods (fish, crustaceans, molluscs) 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. Activity concentrations in seafoods are calculated from seawater activity concentrations using element specific concentration factors.

3. 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 (e.g. 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}).

4. Concentration factors for fish, crustaceans and molluscs are those assumed in table 2 of the MARINA II Report of Working Group D (J.R. Simmonds *et al.*). The concentration factors for H, Tc, Cs and Pu are presented in table C1.

Table C1: Concentration factors

2 pt Concentration Factors (Bq/kg)/(Bq/L)	2 pt H	Tc	Cs	Pu
Fish	1	30	100	100
Crustaceans	1	1000	30	200
Molluscs	1	1000	30	3000

5. Average ingestion rates of fish, crustaceans 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 C2.

Table C2: Ingestion rates

Ingestion rates	Fish	Crustaceans	Molluscs
kg/y	34	12	11

Dose coefficients published in the EURATOM directive 96/29 are used.

Annex 4 - Dose assessment method for measured concentrations in biota

1. 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 (e.g. 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}).

2. Average 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 C3.

Table C3: Ingestion rates

Ingestion rates	Fish	Molluscs
kg/y	34	11

Dose coefficients published in the EURATOM directive 96/29 are used.

Annex 5 - Table 5: Baseline values for doses assessed from baseline values for concentration of radionuclides in seawater

Doses (µSv/y) and standard deviation	Tritium	Cs-137	Tc-99	Pu239,240
1. Wider Atlantic Iberian Coast Biscay and Channel West		1.70		
2. Channel (Cap de la Hague)	0.0144	1.6		
3. Channel East	0.0103	1.81		
4. Irish Sea (Rep. of Ireland)		1.49 SD = 1.06	0.369 SD = 0.138	
5. Irish Sea (Northern Ireland)		1.60 SD = 0.532		
6. Irish Sea (Sellafield)	0.0144 SD = 0.00206	10.1 SD = 2.13	5.53 SD = 5.38	
7. Scottish Waters (Dounreay)	0.00174 SD = 0.000412	2.66 SD = 1.60		
8. North Sea South (Belgian and Dutch Coast)	0.00410 SD = 0.00133 0.00369 SD = 0.0027	0.23 SD = 0.0989		0.127 0.0483
9. German Bight	0.00301 SD = 0.00181	0.286 SD = 0.215	0.0257 SD = 0.0320	0.111 SD = 0.0917
10. North Sea (Northwest+Southeast+Central)	0.000821 SD = 0.000513	0.388 SD = 0.175	0.0430 SD = 0.0123	
11. North Sea (Skagerrak)		0.782 SD = 0.447	0.0354 SD = 0.0323	
12. Kattegat				
13. Norwegian Coastal Current			0.0169 SD = 0.00615	
14. Barents Sea		0.186 SD = 0.0213	0.0108 SD = 0.00615	
15. Norwegian+Greenland Seas+Icelandic Waters		Icelandic Polar Water 0.340 SD = 0.0904 Icelandic Atlantic Water 0.144 SD = 0.0213		

Annex 6 - French Statistics

Part 1

We say that a sequence of random variables $(X_i)_{i=1,2,....}$ is IID if the variables have all the same distribution and are independent (i.e. the value of X_k for a given k does not depend on the values of the other X_i). Let us give some examples: if we play head or tail repeatedly with the same fair coin, the sequence of the successive outcomes is a sequence of IID Bernoulli (1/2) variables (a Bernoulli (*p*) variable can take only two values: either X=1, with probability *p*, or X=0 with probability (1-*p*)). If we sample repeatedly from an urn that contains a very large number of balls of which a proportion 1/3 is white and a proportion 2/3 is black, and record the sequence of outcomes by writing a "1" for white and a "0" for black, this gives a sequence of IID Bernoulli (1/3) variables.

Part 2

The standard deviation of a finite set $(X_1,\ldots,X_n)$ is defined as

$$s = \sqrt{\frac{1}{n}\sum (m - X_i)^2}$$

However, if we suppose that $(X_1,\ldots,X_n)$ is a sample from a larger population, or, otherwise said, is a sample from some distribution with true standard deviation σ, this value of *s* is not the best estimator we have of σ. Although it is still true that as the sample size gets larger *s* converges to σ, it is no longer the case that the expectation of *s* is σ. In fact one can show that *s* is negatively biased (i.e. *s* tends to consistently underestimate σ). That is why the standard deviation is usually estimated by

$$s = \sqrt{\frac{1}{n-1}\sum (m - X_i)^2}$$

which is unbiased and is thus a better estimator of σ.

Part 3

The Gaussian distribution is characterized by the following equality: we say that a random variable X is Gaussian with mean μ and standard deviation σ if and only if

$$P(X \le x) = \frac{1}{\sigma\sqrt{2\Pi}} \int_{-\infty}^{x} e^{\frac{-(s-\mu)^2}{2*\sigma^2}} ds$$

The density of the Gaussian law is a very characteristic and well-known bell-shaped curve, symmetrical around μ. Its proportions depend only on μ and σ.

If $(X_1,X_2,\ldots,X_n)$ is a sample of IID variables which are all Gaussian, the expected proportion of X_i which fall between *a* and *b* among the *n* observations will be given by the above integral taken between *a* and *b*

$$\frac{1}{\sigma\sqrt{2\Pi}} \int_{a}^{b} e^{\frac{-(s-\mu)^2}{2*\sigma^2}} ds$$

(illustrated by the area below the curve that is comprised between abscissas *a* and *b*)

In particular, around 68 % of the values of the X_i fall between μ-σ and μ+σ, and 95 % of the individuals have their value comprised between μ-1.96*σ and μ+1.96*σ. These results are specific of a Gaussian distribution and are independent of the values of μ and σ. Percentages corresponding to other intervals can be computed by the same method, and can generally be found in widespread tables.

Part 4

A confidence interval (for the mean) is an interval such that with some level of probability (95% for instance) the true value μ of the mean falls in this interval. We emphasize that although we say that μ should "fall" in this interval, the true value μ is not a random variable. It is in fact the confidence interval itself that is random since it is computed from the random sample $(X_1,\ldots,X_n)$. The probability of 95% means that if we choose many samples from the same population and compute a confidence interval for each of them, 95% of these intervals should cover the true value μ.

If the sample $(X_1,\ldots,X_n)$ is made of IID Gaussian variables, then the empirical mean *m* is itself a Gaussian variable whose mean is μ, the true mean of the sample, and whose standard deviation is $\frac{\sigma}{\sqrt{n}}$ (the standard deviation of *m* is approximately $1/\sqrt{n}$ times smaller than the standard deviation of the sample[94]). Hence if the true value σ is known, the correct confidence interval is $\left[m-1{,}96\frac{\sigma}{\sqrt{n}}, m+1{,}96\frac{\sigma}{\sqrt{n}}\right]$. However when σ is unknown, we cannot simply replace σ by *s* because we have to take the variability about *s* itself into account.

When the sample $(X_1,\ldots,X_n)$ is made of IID Gaussian variables however, the law of *m*/*s* is known and called a Student distribution with *n*-1 degrees of freedom, *n* being the size of the sample. When *n* is large (*n*>30) the Student distribution is very close to a Gaussian distribution. When *n* is small (*n*=7 for instance) we use off-the-shelf table values. Let us denote by $t_{n-1;97.5\%}$ the 97.5 percentile of the Student (*n*-1) distribution. Then the confidence interval is $\left[m-t_{n-1;97{,}5\%}\frac{s}{\sqrt{n}}, m+t_{n-1;97{,}5\%}\frac{s}{\sqrt{n}}\right]$. When *n*=7 this yields

$$\left[m-2{,}246\frac{s}{\sqrt{7}}, m+2{,}246\frac{s}{\sqrt{7}}\right].$$

Part 5

A prediction interval, on the other hand, is an interval computed from the sample $(X_1,\ldots,X_n)$ such that if we draw a new observation X_0 from the same population (i.e. X_0 has the same distribution as the X_i), the probability that it fall in this interval is at a given level, 95% for instance.

The starting point is to observe that if the (X_i) are Gaussian

$$P(X_0 \in [\mu-1{,}96\sigma;\mu+1{,}96\sigma]) = 95\%.$$

[94] The reason is that $(X_1+\ldots+X_n)$ is Gaussian with mean *m* and standard deviation $\sqrt{n}\sigma$, hence the standard deviation of $(X_1+\ldots+X_n/n)$ is $\sigma/\sqrt{n}$.

Thus, $[\mu - 1{,}96\sigma; \mu + 1{,}96\sigma]$ is the true (unknown) 95% prediction interval. The interval $[m - 1{,}96s; m + 1{,}96s]$ estimates this prediction interval but, because of the variability of *s*, the probability that a new observation will fall in this interval is less than 95 %

$$P(X_0 \in [m - 1{,}96s; m + 1{,}96s]) < 95\%.$$

To obtain a correct prediction interval we will use the fact that (X_0-μ) and (μ-*m*) are two independent Gaussian variables with mean 0 and respective standard deviation σ and $\sigma/\sqrt{n}$. Now, recall that if X is Gaussian (μ_1,σ_1) and Y is independent Gaussian (μ_2,σ_2), then X+Y is Gaussian $\left(\mu_1 + \mu_2, \sqrt{{\sigma_1}^2 + {\sigma_2}^2}\right)$. Hence, by decomposing X_0 into $X_0 = (X_0 - \mu) + (\mu - m) + m$, we see that X_0-*m* must be Gaussian with mean 0 and standard deviation $\sigma\sqrt{1 + 1/N}$. From this we deduce that $P\left(X_0 \in \left[m - 1.96\sigma\left(\sqrt{1 + \frac{1}{n}}\right), m + 1.96\sigma\left(\sqrt{1 + \frac{1}{n}}\right)\right]\right) = 95\%$ and hence this is the prediction interval (in which σ is generally unknown).

Informally we could say that we are compounding two intervals: the 95 % confidence interval of the true mean $\mu \in [m - 1.96\sigma\sqrt{1/n}, m + 1.96\sigma\sqrt{1/n}]$, and the 95% prediction interval for X_0, $P(X_0 \in [\mu - 1.96\sigma, \mu + 1.96\sigma]) = 95\%$.

If the sample is large enough (n > 30) one can just replace σ with *s* and the prediction interval is then approximated by $\left[m - 1{,}96s\left(\sqrt{1 + \frac{1}{n}}\right), m + 1{,}96s\left(\sqrt{1 + \frac{1}{n}}\right)\right]$.

When *n* is less than 30, *n*=7 for instance, one should replace the Gaussian distribution with the Student distribution to take into account the variability of *s*.[95] The precise mathematical result which is used there is that X_0/s also follows a Student distribution. The prediction interval to be used is then $\left[m - t_{n-1;97,5\%}s\left(\sqrt{1 + \frac{1}{n}}\right), m + t_{n-1;97,5\%}s\left(\sqrt{1 + \frac{1}{n}}\right)\right]$, with $t_{n-1;97.5\%}$ being the 97.5 percentile of the Student (*n*-1) distribution. When n=7 for instance we find $[m - 2.4s, m + 2.4s]$.

Finally, another method inspired by approaches used in ecotoxicological problems (see T. Aldenberg and J.S. Jaworska "Uncertainty of the Hazardous Concentration and Fraction Affected for Normal Species Sensitivity Distributions") has been examined[96]. This method would lead to an interval approximately of the form $[m - 4s, m + 4s]$. However we must underline the fact that this interval is suited to situations where

[95] See for instance page 9 of Seymour Geisser's book: "Predictive inference". The page can be consulted for free via Google at this location.

[96] More details on this method can be found in "Some methodological remarks on choosing a baseline interval" by H. Berestycki, J. Berestycki, J.M. Oury, paper presented by France, and of course in the original reference.

our interest is not so much about the prediction interval in itself, but rather about a confidence interval around $[\mu - 1.96\sigma, \mu + 1.96\sigma]$ (i.e. the true prediction interval).

More precisely, our present problem is to find a random interval such that a future random observation will fall inside it with a probability level of 95% ($P(X_0 \in [m - 2.4s, m + 2.4s]) = 95\%$). With the Aldenberg et al. approach on the other hand, the aim is to find a random interval which contains the true prediction interval with a 95% probability (i.e. $P([\mu - 1{,}96\sigma, \mu + 1{,}96\sigma] \subset [m - 4s, m + 4s]) = 95\%$). $P(X_0 \in [m - 4s, m + 4s])$ is generally much larger than 95% so taking this interval is a very conservative approach and yields intervals that are too wide for practical purposes here.

Part 6

The comparison of two samples is best done with the so-called Student t-test[97]. Here for OSPAR the two samples are not paired because even if the two samples have the same size, the first year of sample 1 does not have a special relation with the first year of sample 2, and idem for the second, third, etc. years of the samples. If the two samples have different sizes, it is not possible to pair them. Hence the unpaired version must be applied in any case.

The test works as follows:

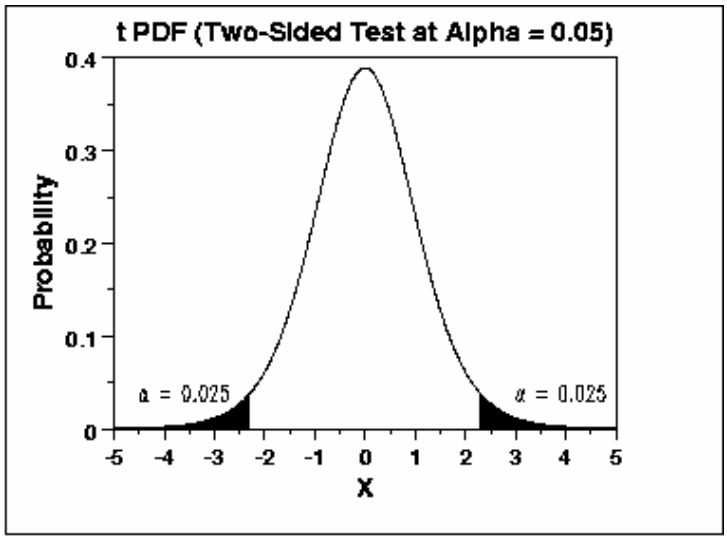
1. we compute the T statistic: $T = \dfrac{m_1 - m_2}{\sqrt{s_1^2 / n_1 + s_2^2 / n_2}}$.

2. we compute the number of degrees of freedom of the test through the formula

$$\nu = \frac{\left(s_1^2 / n_1 + s_2^2 / n_2\right)^2}{\left(s_1^2 / n_1\right)^2 / (n_1 - 1) + \left(s_2^2 / n_2\right)^2 / (n_2 - 1)}$$

3. If α is the confidence level of the test (for instance α =5%) we compute the critical value of the test, denoted by $t_{\alpha/2,\nu}$, as the value such that if the curve in the following figure is the density of a Student variable with ν degrees of freedom, the area below the curve above abscise $t_{\alpha/2,\nu}$ and below - $t_{\alpha/2,\nu}$ (which is shaded in black in the figure) is exactly 5%. This value is easily found in readily available tables or can be computed in any statistic software.

97 See Chapter 3, paragraph 45.



4. We reject the null hypothesis (that is we decide that m_1 and m_2 are significantly different) if and only if $|T| \geq t_{\alpha/2,\nu}$.

Part 7: The Wilcoxon-Mann-Whitney Test

The observations are grouped in two samples of size n_1 and n_2 (with $n_1 \leq n_2$). In the case of the OSPAR discharges, one of the samples is the set of observations of the baseline element reference period from 1995 to 2001 included with a size of 7.

The observations are then ranked from the smallest one to the largest one, irrespective of the sample to which they belong. In case of observations of equal values (ties) each observation in the tie is assigned its average rank (for example, two equal observations coming after rank 2 will be both assigned rank 3.5 instead of 3 and 4 if they had been different, three equal observations coming after rank 5 will be assigned rank 7 instead of 6, 7 and 8 if they had been different, etc.).

The ranks of the observations are summed in the smaller sample to obtain the statistic *S*. For this test, the null hypothesis H_0 is that the two samples come from the same population. Hence under this hypothesis we do not expect to see all the largest observations in one sample and all the smallest ones in the other. If the samples were of equal size we would expect that the sum of the ranks in each sample should be of the same order.

For each possible pair of sizes for the samples, n_1 and n_2, Wilcoxon Rank-Sum Table gives, for a given probability level α (say 5% for instance), two numbers LT and UT (LT stands for lower tail and UT stands for upper tail). LT and UT are computed so that, under the null hypothesis H_0, $P(S<\text{LT})<\alpha/2$ and $P(S>\text{UT})<\alpha/2$ where *S* is the sum of the ranks of the smaller sample.

In other words, if *S* is smaller than the LT or larger than the UT, we are in a case whose probability, under the null hypothesis, is less than α=5%. Thus H_0 is rejected (if $n_1=n_2$ this happens in the case where the sum of the ranks in one sample is very large and the sum of the rank in the other sample is very small).

Annex 7 - Electricity generated by nuclear power plants in the OSPAR Area

Nuclear electricity generation GWh	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Belgium(1)								44987	44921	44899
Spain	21233	21783	21270	21614	23054	24180	24718	24357	23313	24902
Sweden				24910	25 800	18700	25380	25620	25940	28020
UK	88964	94671	98146	99486	95133	85063	90093	87848	88686	79999

(1) Being the net Nuclear Electricity Generation minus Belgium's consummation by indoor services

New Court
48 Carey Street
London WC2A 2JQ
United Kingdom

t: +44 (0)20 7430 5200
f: +44 (0)20 7430 5225
e: secretariat@ospar.org
www.ospar.org

OSPAR's vision is of a clean, healthy and biologically diverse North-East Atlantic used sustainably

ISBN 1-905859-40-6 / 978-1-905859-40-5
Publication Number: 302/2006

© OSPAR Commission, 2006. Permission may be granted by the publishers for the report to be wholly or partly reproduced in publications provided that the source of the extract is clearly indicated.

© Commission OSPAR, 2006. La reproduction de tout ou partie de ce rapport dans une publication peut être autorisée par l'Editeur, sous réserve que l'origine de l'extrait soit clairement mentionnée.