MARINA II

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

Executive Summary

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Foreword

The present study, which is called MARINA II, has been undertaken for the Directorate-General for Environment of the European Commission in order to provide information on radionuclide discharges into North European marine waters and on radioactivity concentrations in the environment, and to provide an assessment of their impact. It builds on an earlier MARINA study, which considered data up to the mid-1980s.

The 1992 OSPAR Convention for the Protection of the Marine Environment of the North East Atlantic binds the following Contracting Parties: Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, the United Kingdom of Great Britain and Northern Ireland and the European Community. The Convention replaces and up-dates the 1972 Oslo Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft and the 1974 Paris Convention for the Prevention of Marine Pollution from Land-Based Sources. The definition of the North East Atlantic for the purposes of the OSPAR Convention covers the area north of the latitude of the Straits of Gibraltar (36° N) and east of the longitude of the southern point of Greenland (42° W) as far east as Novaya Zemlya (51° E). The Baltic Sea (other than the Kattegat) and the Mediterranean Sea are excluded. The MARINA II Study is therefore of particular relevance to the work of the OSPAR Commission. In relation to the OSPAR Convention the major activities of The European Commission with regard to radioactive substances relate to activities agreed in discussions within the normal work of the OSPAR Radioactive Substances Committee and to consideration of ways in which the work of the European Commission and the OSPAR Commission may be arranged to assist each other's complementary aims. The OSPAR Commission has specific objectives set out in its Strategy with regard to Radioactive Substances, which provides focus for these activities. The MARINA II report is expected to contribute substantially to the implementation of the OSPAR Strategy by assisting the OSPAR Commission to address, in particular, sections *5.4 a* and *b* of the strategy with regard to Radioactive substances and in the establishment of baselines for discharges and concentrations in the environment against which progress in implementing the Strategy can be judged, informed by an assessment of the environmental impacts.

The present document is the final report of the MARINA II study, which was conducted by NNC (UK) and its subcontractors: NRPB (UK), NRG (Netherlands), CEPN (France), Risø (Denmark), University College Dublin (Ireland), The Netherlands Institute for Fisheries Research, SPA Typhoon (Russia), CEFAS (UK), SSI (Sweden) and STUK (Finland). The progress and outcome of the study were thoroughly discussed by the Steering Committee, which included representatives of the European Commission and non-governmental organisations: the World Nuclear Forum, KIMO (Organisation of Coastal Local Authorities) and Greenpeace.

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1 Scope of work

The primary objective of the MARINA II study is to provide an input from the European Commission into the work of the OSPAR Commission in implementation of the OSPAR strategy with regard to radioactive substances and the work of the European Commission in respect of this strategy. It provides information on radioactive discharges, concentrations of radioactivity within the marine environment and an assessment of their impact on humans and marine biota. It follows an earlier MARINA I study [Commission of the European Communities, 1990], which considered data up to the mid-1980s.

The OSPAR Strategy with regard to Radioactive Substances, including waste, sets the objective of preventing pollution of the maritime area from ionising radiation through progressive and substantial reductions of discharges, emissions and losses of radioactive substances. The ultimate aim is for concentrations in the environment to be near background values for naturally occurring radioactive substances and close to zero for artificial radioactive substances. In achieving this objective, legitimate use of the sea, technical feasibility and radiological impacts on man and biota should be taken into account. As its timeframe, the Strategy further declares that, by the year 2020, the Commission will ensure that discharges, emissions and losses of radioactive substances are reduced to levels where the additional concentrations in the marine environment above historic levels, resulting from such discharges, emissions and losses, are close to zero.

The work of the MARINA II study was carried out by five groups of technical experts:

1. Group A, which collated data and made estimates of the discharges of radioactive substances and other inputs of radioactivity into North East Atlantic.

2. Group B, which analysed environmental concentrations and the radiation doses to members of critical groups of people.

3. Group C, which collated information on fishing and trade in sea products for use by Group D in collective dose assessments.

4. Group D, which modelled radionuclide transport in the North East Atlantic and assessed collective doses to the population of Europe.

5. Subgroup D*, which assessed the impact of radioactivity on marine biota.

2 Conclusions

<u>The overall civil nuclear and other anthropogenic inputs of radioactivity into the North East Atlantic have decreased by several orders of magnitude for α- and β-emitters and for tritium since the maximum levels were reached in the 1960s and early 1970s</u> (Figures 1-6). Over the same time period this resulted in reductions in

radionuclide concentrations in the marine environment and consequently reductions in the individual doses to members of critical groups and in collective doses to the public.

Since the mid-1980s, the main contribution to discharges of β-activity into the OSPAR region is from the nuclear reprocessing plants (Sellafield and Cap de la Hague) while the discharges of α-activity have been dominated by the phosphate industry and, later by oil production in the North Sea. As a result, oil production currently is the major contributor to the collective dose to the population of the European Union from industrial activities as discussed below.

Main findings related to discharges from the nuclear industry:

1. **Nuclear industry discharges** are still dominated by the reprocessing of nuclear fuel. Excluding the Chernobyl fallout in 1986, the input of β activity (excluding tritium, which has a very low radiotoxicity) into the OSPAR region decreased by over a factor of four from 1986 to 1991. By this date, the annual discharge had reached the same level as in the early 1950s (Figures 1 and 2). The reason was the major reduction in discharges from Sellafield and Cap de la Hague nuclear fuel reprocessing plants, which were major contributors over the years 1986-1991. Over the same period, the discharges of α activity into the OSPAR region from Sellafield and Cap de la Hague decreased by a factor of three (Figures 3 and 4). Inputs of tritium have also decreased since the mid-1960s (Figure 5). However they have increased since the mid-1980s, due to the increase in reprocessing at Cap de la Hague. (Figure 6).

2. This lead to comparable reductions in the **concentrations of ^{137}Cs** in the areas of highest concentrations in the Irish Sea near Sellafield (Figures 7 and 8). The increase in ^{137}Cs concentration in the Baltic Sea is due to Chernobyl fallout. Outflow of water from the Baltic Sea means that concentrations of ^{137}Cs in seawater from the Kattegat, the straight between Sweden and Denmark, have not declined significantly in recent years. ^{137}Cs is the most widely measured radionuclide in North European waters because of its significance for radiation exposure and because it is relatively easy to measure.

3. Since 1986, the **radiological impact on the most exposed groups of populations** (effective dose to members of the critical group) in the vicinity of the major nuclear sites, such as Sellafield and Cap de la Hague was consistently and significantly below the ICRP and EU Basic Safety Standard limit of 1 mSv per year to members of the general public. The range of doses to members of the critical groups for these two sites during 1988-1999 was 0.01-0.4 mSv per year for anthropogenic radionuclides. The variation in such doses was primarily due to changes in the consumption rates of marine produce by the most exposed groups of the population.

4. Over the period 1988 to 1999 effective doses to critical groups in the **Sellafield area** show no trends but for the **Cap de la Hague** area there is a decreasing trend. For the **OSPAR region in general** the doses to critical

groups follow the same decreasing trend as the environmental radionuclide concentrations.

5. Human habits naturally play an important role in the assessment of radiation doses to critical groups. Existing assessments of radiation exposure from marine pathways to critical groups in the OSPAR region have used a variety of habit data ranging from cautious conservative assumptions to realistic data from detailed habit studies. Dose assessment is very sensitive to variation in habit data so in order to normalise the data **individual doses** have also been calculated **using normalised consumption rates** (Figure 9). In this estimate all exposure has been assumed to result from consumption of seafood based on the maximum seawater concentration of the isotopes ^{137}Cs, ^{90}Sr, ^{99}Tc and ^{239,240}Pu.

6. Near **Sellafield, critical group doses** were dominated by ^{241}Am, Pu isotopes and ^{99}Tc. Since 1986, the level of ^{241}Am in water and marine organisms remained relatively stable due to its ingrowth from ^{241}Pu and remobilisation from sediments in the Irish Sea. Sediment contamination resulted from peak discharges in the early 70s. The same remobilisation phenomenon was the basis of the relative stability in plutonium concentrations. While marine discharges of other significant radionuclides have declined since 1986, discharges and environmental concentrations of ^{99}Tc increased in 1994 when the treatment of historic liquid wastes started at the Enhanced Actinide Removal Plant in Sellafield.

7. **The overall radiological impact from the nuclear industry** (collective dose rate) on the population of European Union from the OSPAR area has decreased from 280 man Sv/yr in 1978 to 14 man Sv/yr in 2000. This reduction was primarily due to decreases in the discharges of ^{137}Cs and ^{106}Ru (Figure 10). Collective doses are conventionally used as an input into the optimisation of radiation protection. They can also be used to compare the radiological impact of particular industrial practices and this is the main purpose of the estimation of collective doses in this study.

8. In terms of contributing to collective dose, **discharges from nuclear power generation, fuel fabrication and research reactors** were negligible compared with discharges from nuclear fuel reprocessing. The contribution to the total collective dose from marine discharges from these installations was estimated to be just 2% in 2000.

Main findings related to discharges from non- nuclear industries:

9. ‘Natural’ as opposed to ‘man-made’ radionuclides were largely present when the earth was made or result from the natural radioactive decay of such nuclides. Two major sources of the so-called ‘Naturally Occurring Radioactive Materials’ (NORM) were considered in the MARINA II study. NORM can be defined as all naturally occurring radioactive materials where human activities have increased the potential for exposure in comparison to the unaltered situation. Activity concentrations may or may not be increased.

a. **Discharges of phosphogypsum**, which contain significant quantities of such radionuclides as ^{226}Ra, ^{210}Pb and ^{210}Po and smaller quantities of Uranium and Thorium isotopes. Phosphogypsum used to be discharged into the OSPAR area in the Netherlands, UK, France, Belgium/Luxembourg, Spain, Denmark, Former West Germany, Portugal and Ireland during the production of phosphoric acid by the fertiliser manufacturing industry. These discharges were largely stopped by 2000 with the introduction of the dry process, new treatment techniques, the storage of phosphogypsum ashore and the import of phosphoric acid from North Africa and the Middle East. There is no information on phosphogypsum discharges prior to 1981.

b. Pumping **oil and gas** from the continental shelf in the North Sea produces large quantities of contaminated water, known as 'produced water'. This results in releases into the marine environment of ^{226}Ra, ^{228}Ra and ^{210}Pb, which are concentrated, and made available for consumption by biota. Off-shore oil production in the North Sea, which is located mainly in the Norwegian and UK coastal waters, increased significantly from the 1970s until 1995, but has remained relatively constant since then.

10. Except for the phosphate production in Whitehaven in Cumbria, North-West England, there are **very little data on discharges** or environmental concentrations resulting **from non-nuclear industries**. MARINA II made 'best estimates' of the magnitude of such discharges and the resulting radiological impact based on the estimated normalised concentrations of radionuclides and the quantities of discharged effluents.

11. The **overall discharge of α-emitters into the OSPAR region** has remained constant since 1986 due to the discharges from the phosphate industry and the production of oil in the North Sea (Figure 4). By 1999, the estimated discharges of produced water alone contributed 90% of the discharge of α activity into the OSPAR region. Since at least 1981, the discharges of phosphogypsum from the phosphate industry have dominated the **collective dose** to the population of the European Union (Figure 11). This is because of the higher radiotoxicity of the radionuclides discharged by these industries compared to that of the radionuclides that are discharged from the reprocessing plants.

12. The **peak collective dose rate from NORM industries** occurred in 1984 and was just over 600 man Sv y^{-1}. This collective dose was almost entirely due to discharges from the phosphate industry with the important sources being discharges into Cumbrian waters from the UK and into the North Sea from the Netherlands. Discharges from the phosphate industry, particularly in the UK, were reduced in the 1990s but the phosphate industry is still a major contributor to the collective dose rate.

13. **Discharges from the oil and gas industry**, which made a small contribution over much of the period from 1981 to 1999, have become relatively more

important. In 2000, discharges from the oil and gas industry contributed about 39% to the total collective dose rate from the NORM industries.

14. The possible **discharges from the production of phosphoric acid around the Mediterranean Sea** and the consequential impact on the population of the European Union have not been assessed as part of this study. This aspect may need to be addressed if MARINA MED [Commission of the European Communities, 1994] is updated at some point in the future.

15. It was found that discharges and collective doses resulting from the production and application of **radiopharmaceuticals** were negligible in comparison with those from either nuclear reprocessing or oil production. The same applies to discharges from **shipyards** servicing nuclear submarines in the UK, **historic dumping of wastes at sea and submarine accidents**.

16. The **Chernobyl accident** caused an additional input of radioactivity into the OSPAR area since 1986, which resulted in a small increase in collective dose rate (see Figure 11). The impact via marine pathways of earlier fallout due to the open-air testing of nuclear weapons peaked in 1964 at 43 man Sv but now is relatively stable at 7 man Sv y^{-1}.

Overall impact of discharges:

17. The **collective dose rates** to the population of the EU over the period 1981 to 2000 due to discharges from all sources are shown in Figure 11. At its peak, collective dose rate of about 760 man Sv y^{-1} is around a factor of 20 less than the annual collective dose from natural radioactivity in the marine environment.

18. **If all discharges of radioactivity stopped** in 2000, the collective dose rate to the European population in 2020 would be approximately half of what it would be if the nuclear industry and the oil extraction industry continued to discharge at the present rate (Figure 12). However, the dose to individuals in the critical group close to Sellafield would be less affected by reduction in discharges because it is largely due to historic discharges. The collective dose rates can be compared with a collective dose rate to the population of the European Union from natural radionuclides in the marine environment of 17,000 man Sv and an annual collective dose from all sources of natural background radiation of 844,000 man Sv (see Figure 13).

19. The present **model for estimating collective** dose rates has been well validated for current conditions and the physical mechanisms that determine the dose rate are well understood. However, significant changes, such as global warming, would invalidate predictions into the future and there is clearly a need to continue to monitor both discharges into and concentrations of radioactivity in the marine environment throughout the OSPAR region.

Impact of discharges on marine biota:

20. The methodology for determining the **impact of radioactivity on marine biota** is still under development. However, according to the available information, there is no identifiable impact on populations of marine biota from radioactive discharges (Figure 14).

3 References

Commission of the European Communities. 'The radiological exposure of the population of the European Community from radioactivity in North European marine waters Project 'MARINA'. EUR report 12483EN (1990).

Commission of the European Communities *The radiological exposure of the population of the European* Community *to radioactivity in the Mediterranean Sea* Radiation Protection 70 Marina-Med Project Report EUR 15564 EN. (1994).

Figure 1 **Trends in overall input of β activity, excluding tritium, into the OSPAR area**

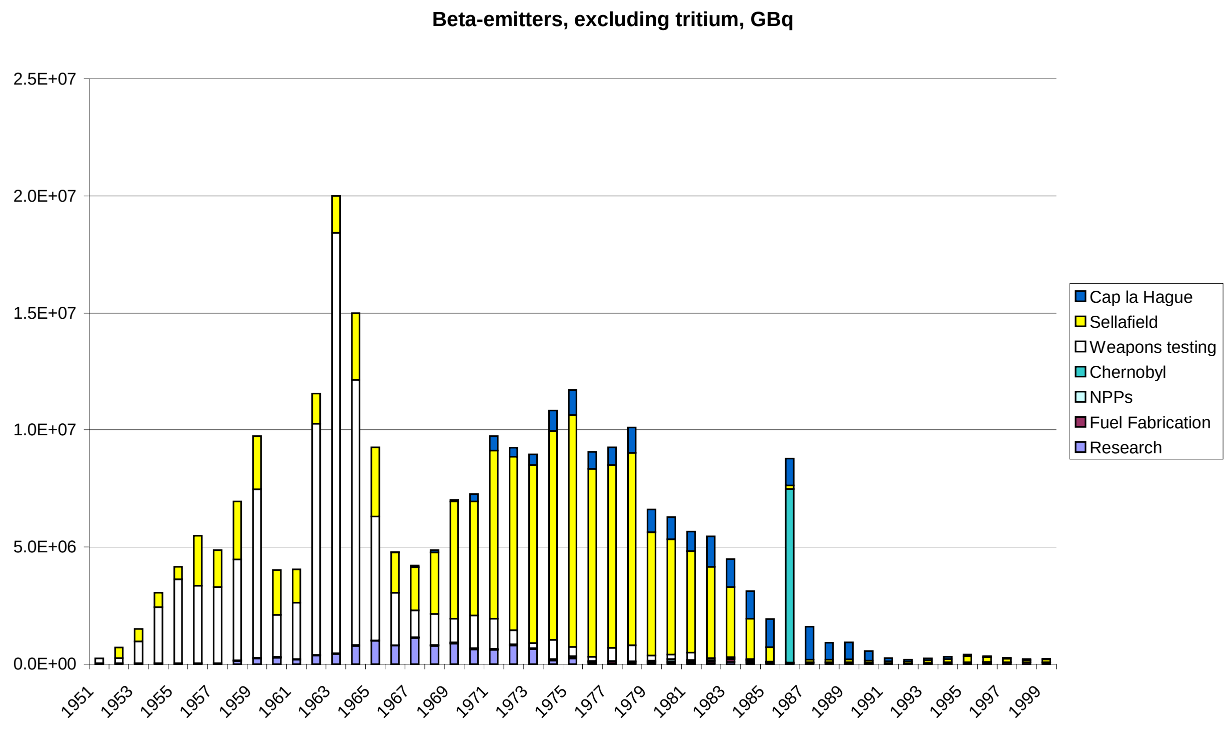


Figure 2 **Recent trends in overall input of β activity (excluding tritium and direct inputs from Chernobyl fallout and Mediterranean Sea) into the OSPAR area**

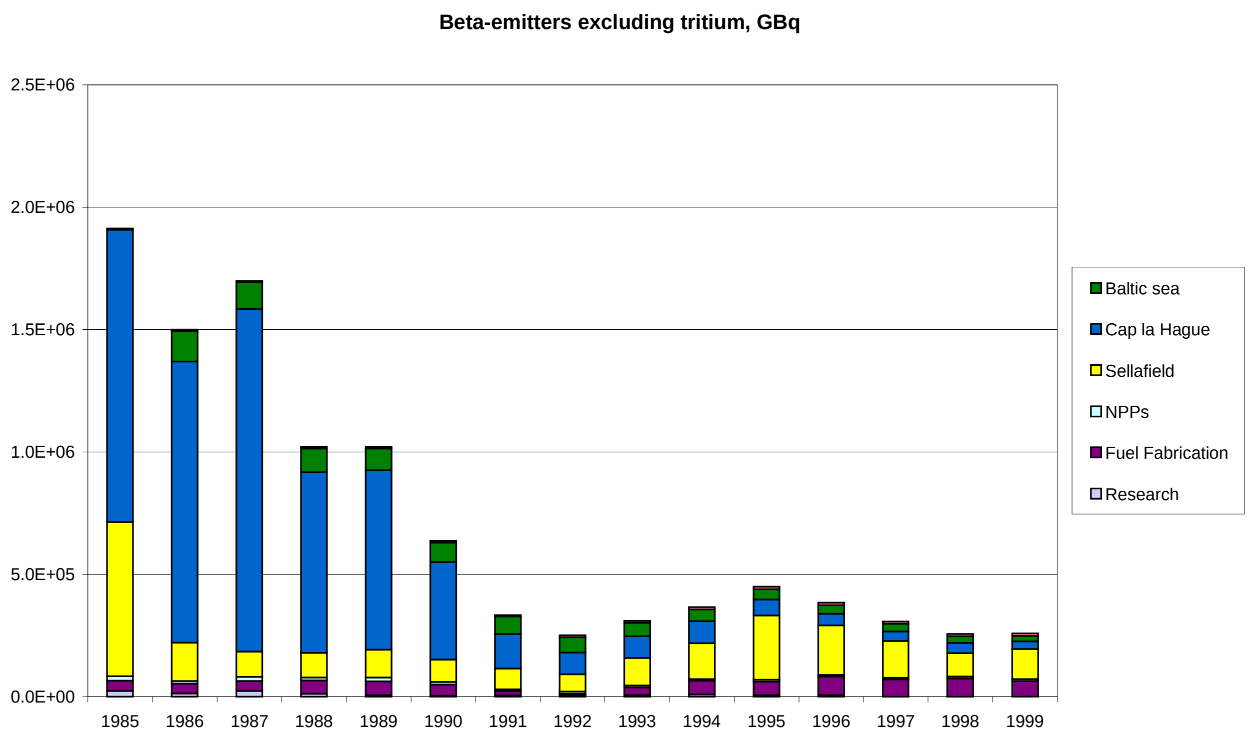


Figure 3 Trends in overall input of α activity into the OSPAR area

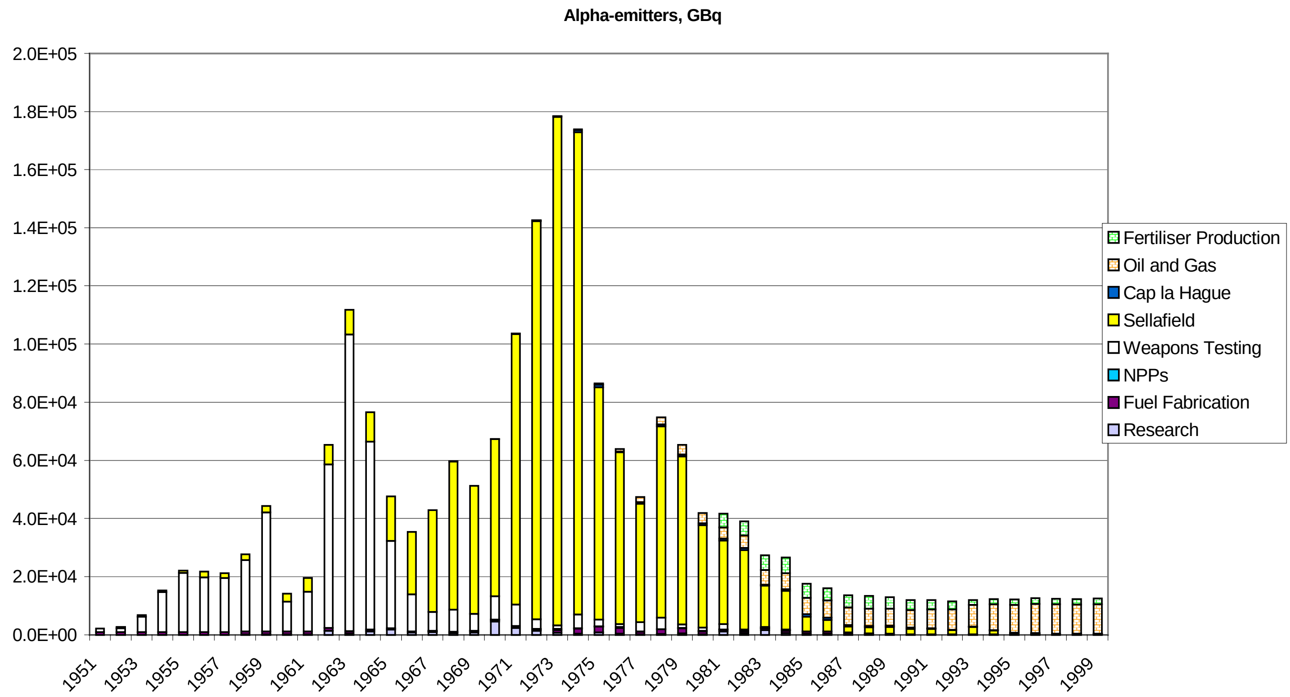


Figure 4 Recent trends in overall input of α activity into the OSPAR area

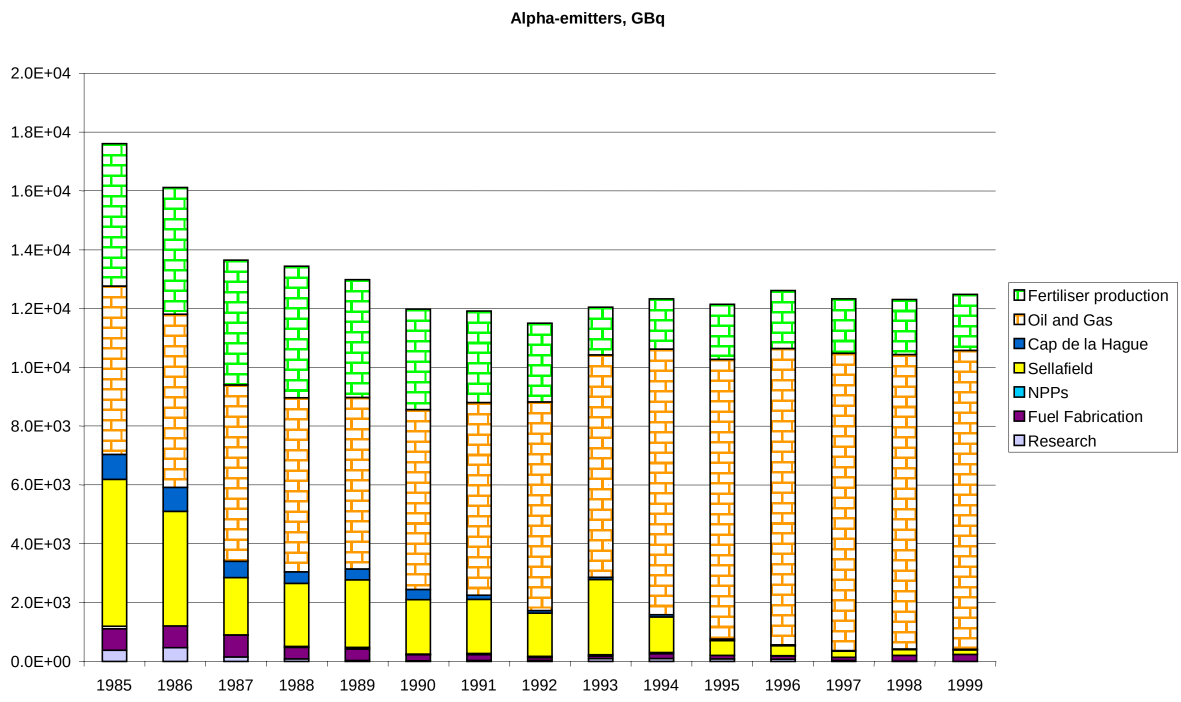


Figure 5 Trends in overall input of tritium into the OSPAR area

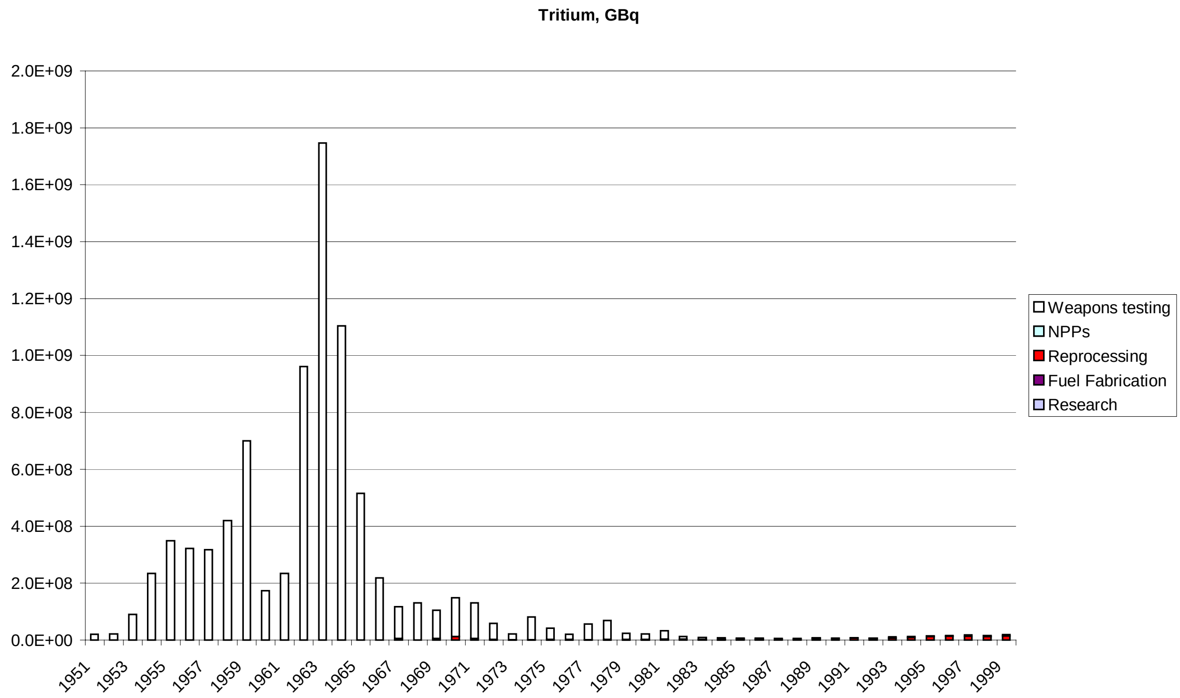


Figure 6 Recent trends in overall input of tritium into the OSPAR area

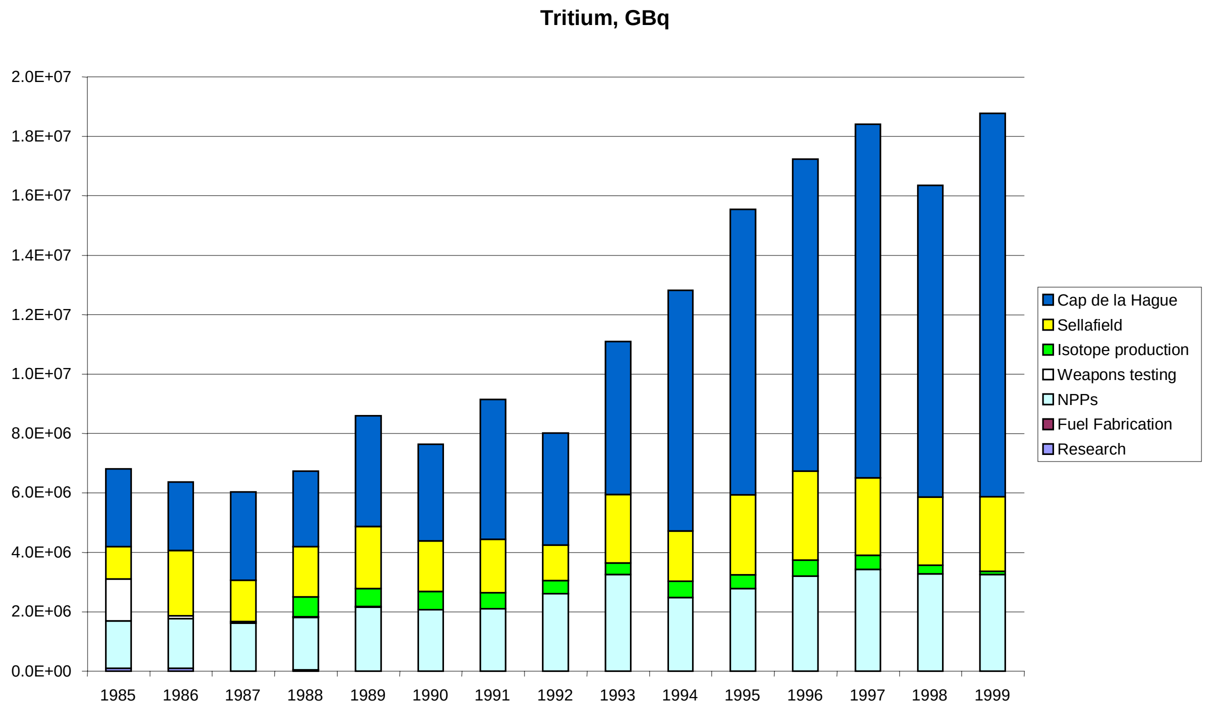


Figure 7 ^{137}Cs **in surface waters of European seas (1981 – 1985)**

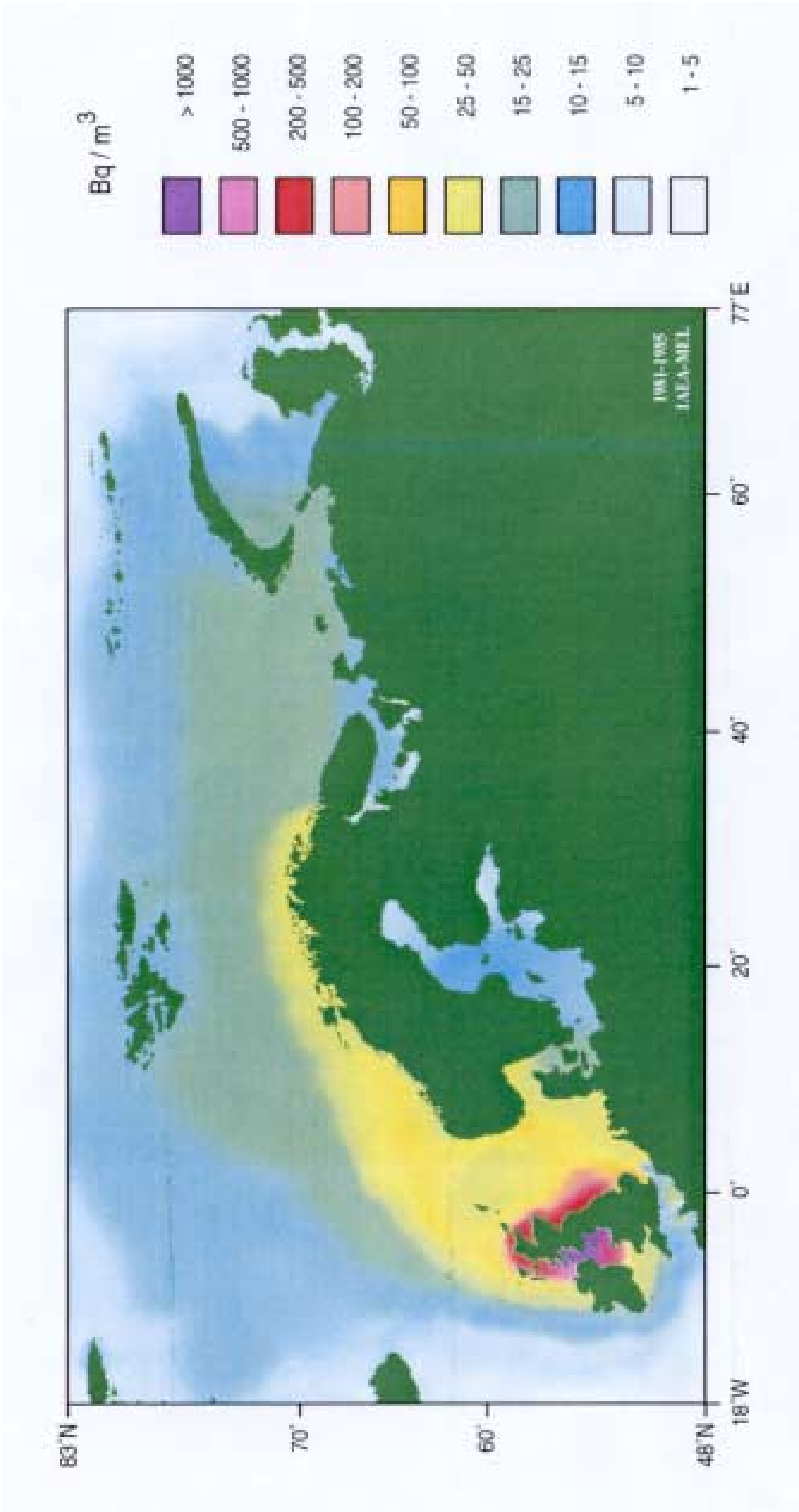


Figure 8 ^{137}Cs **in surface waters of European seas (1991 – 1995)**

Figure 9 Representative maximum annual doses in the OSPAR region from marine pathways calculated from observed concentrations of man-made radionuclides in the water for normalised consumption rates.

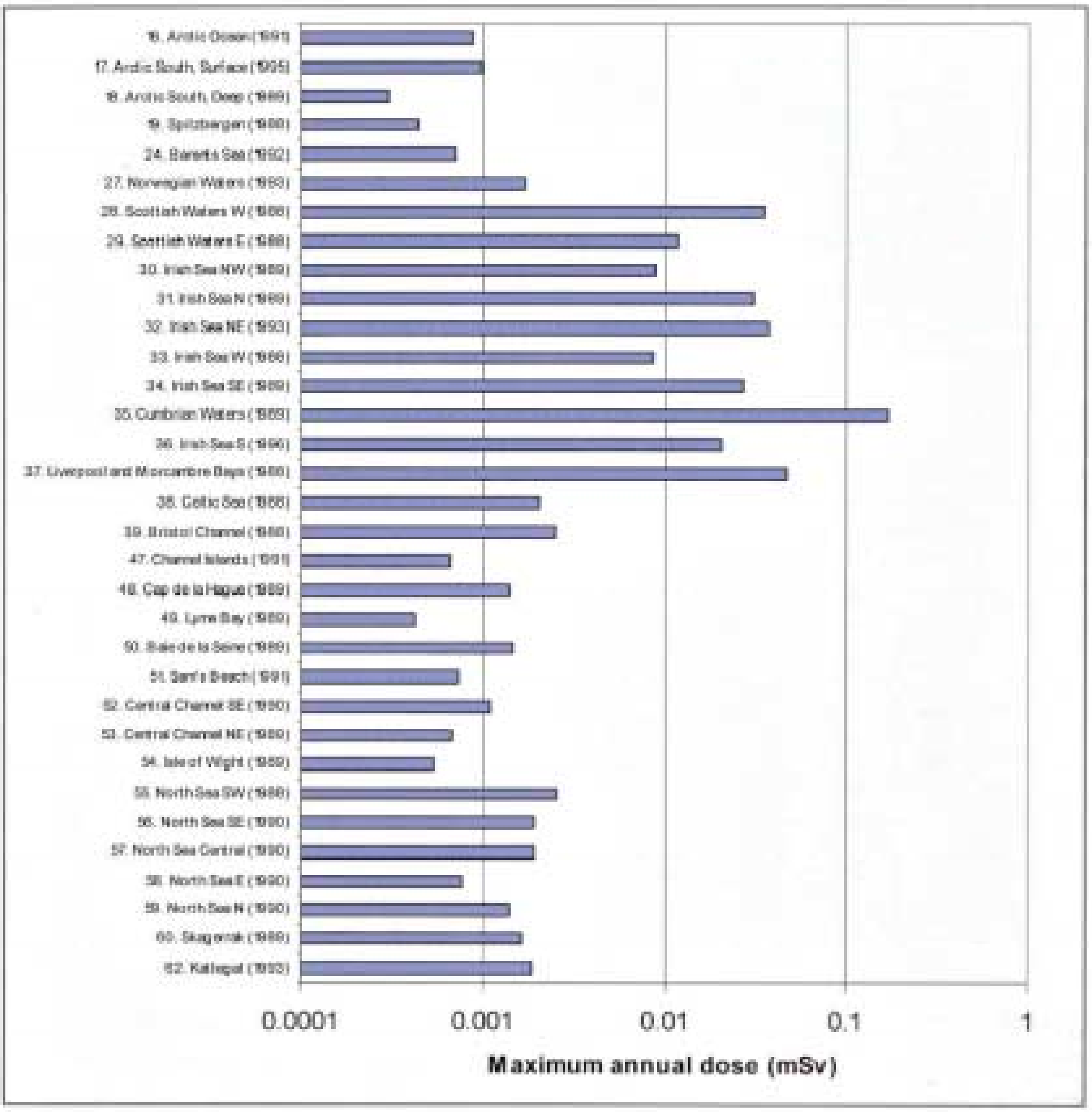


Figure 10 **Collective dose rates to the European Union population by radionuclide for nuclear sites assuming discharges continue to 2000.**

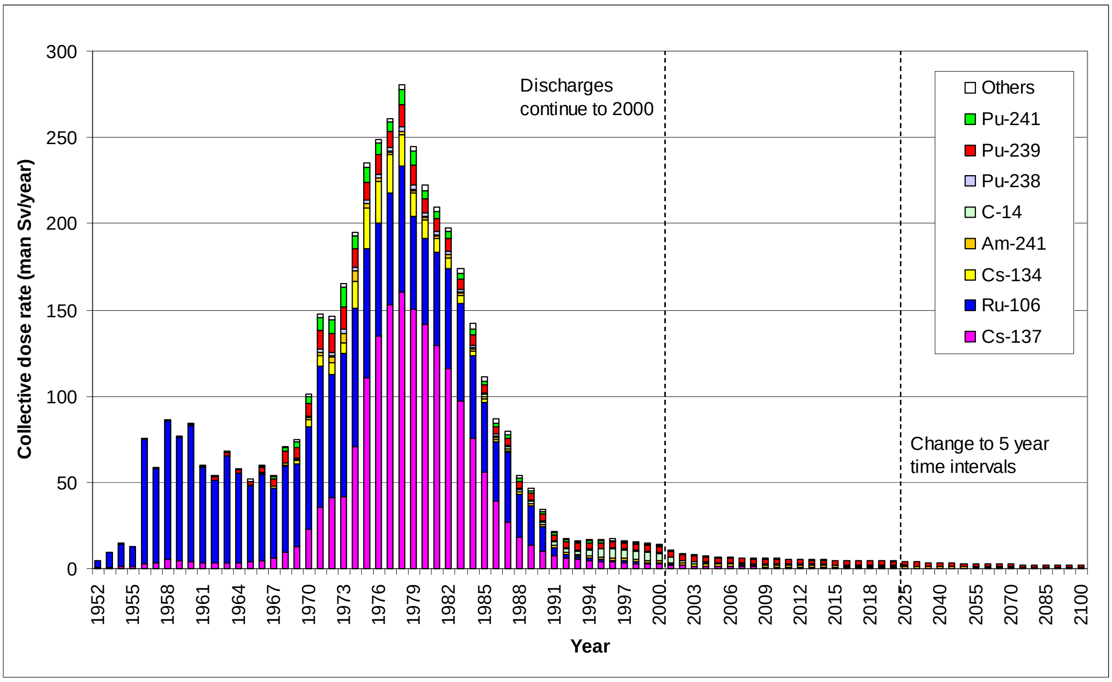


Figure 11 **Collective dose rates by source to the European Union population assuming discharges continue to 2000**

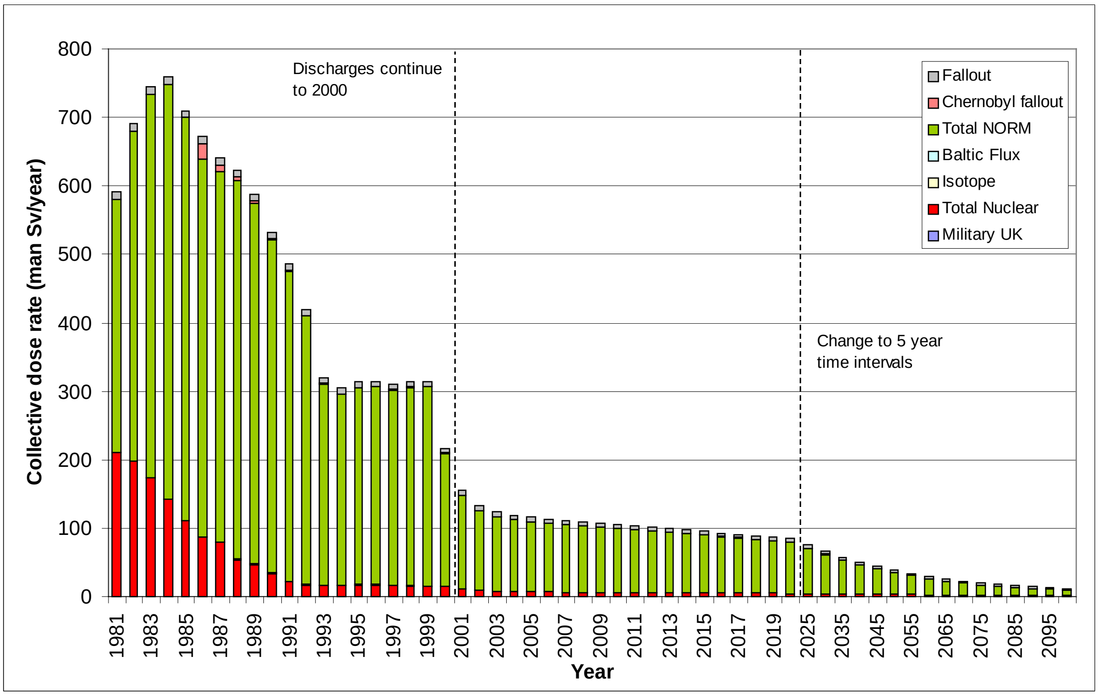


Figure 12 Collective dose rates by major source to the European Union population for discharges/sources continuing to 2000 and 2020

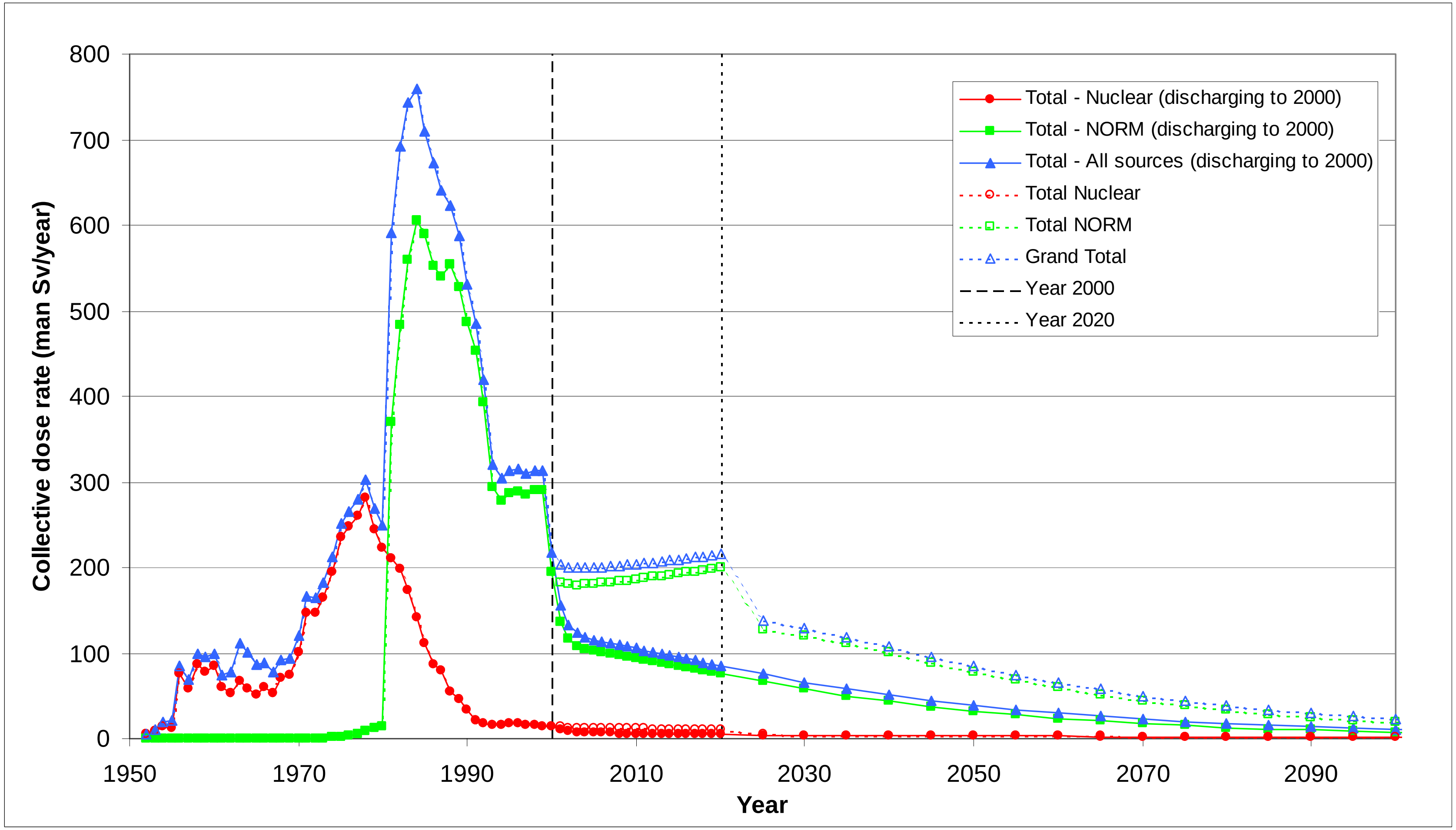


Figure 13 Collective doses rates to the European Union population from major sources compared with naturally occurring radioactivity

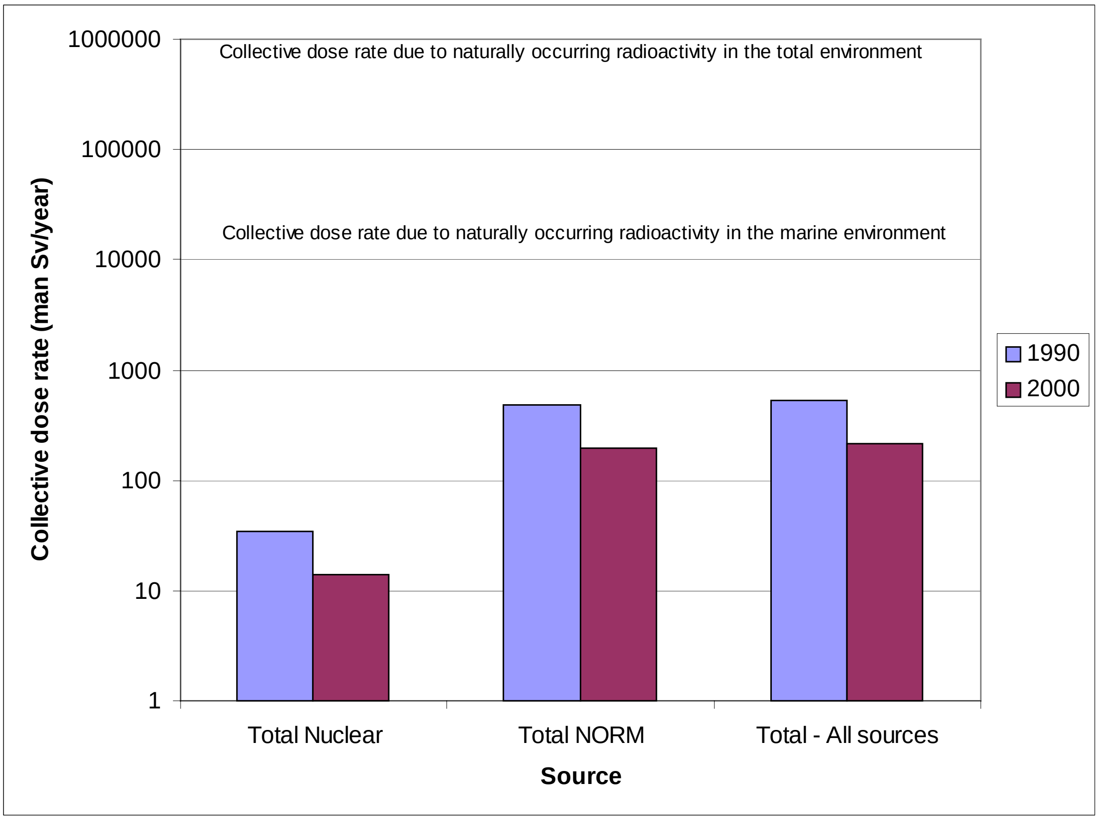
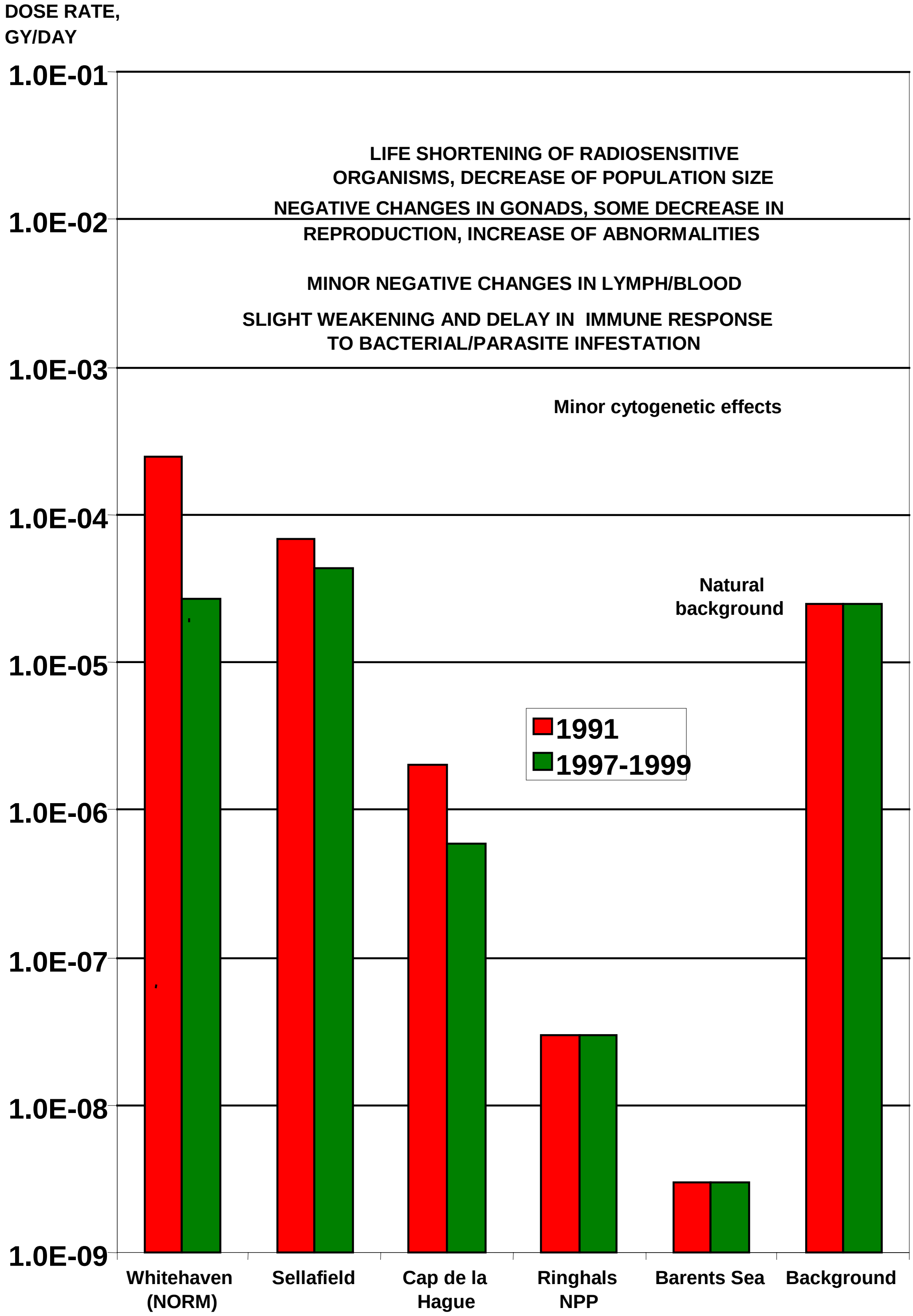


Figure 14 Dose rates to molluscs in the OSPAR region (above natural background) along the scale of radiation effects to aquatic biota



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