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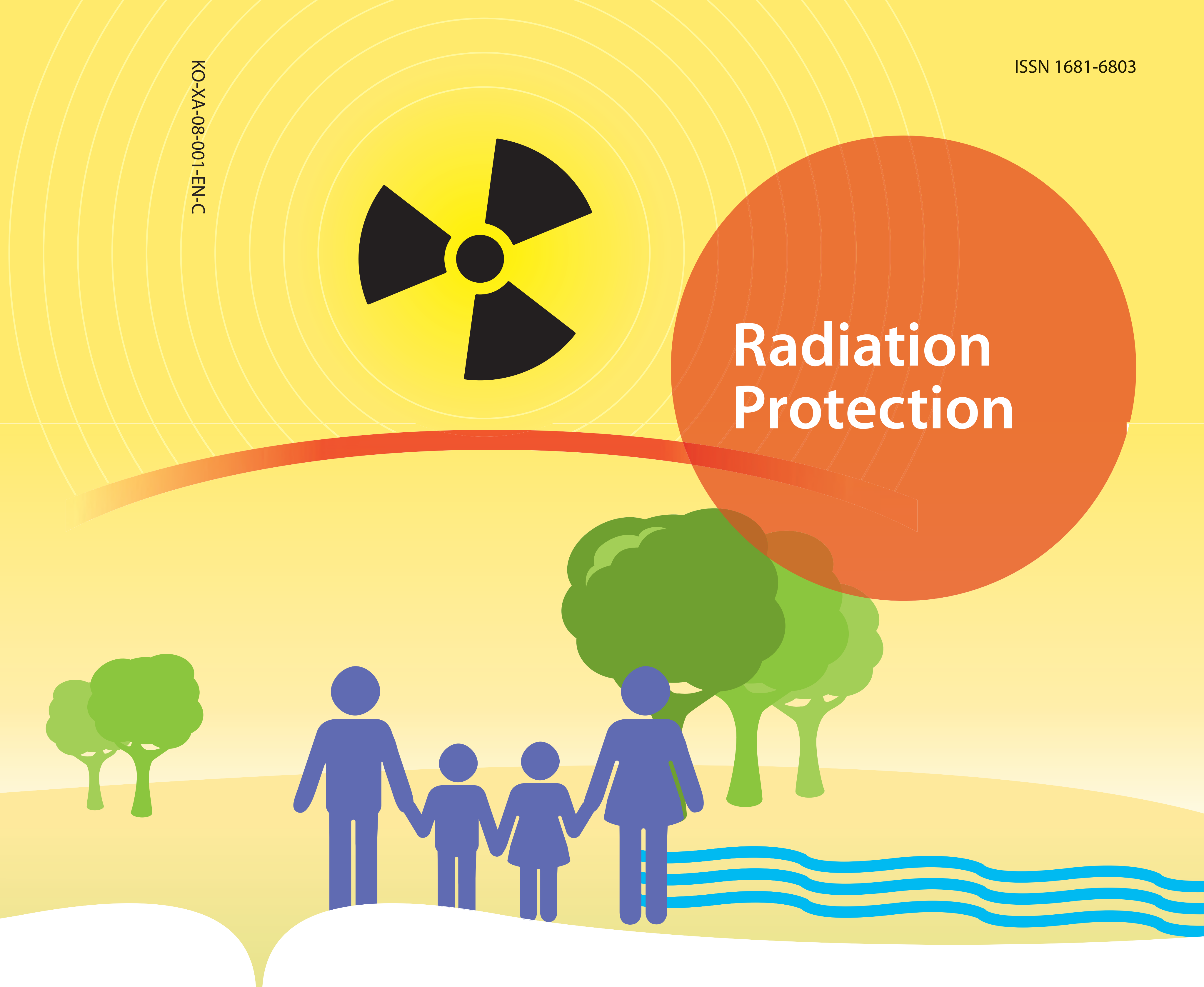

Radiation Protection

NO 153 — IMPLIED DOSES TO THE POPULATION OF THE EU ARISING FROM REPORTED DISCHARGES FROM EU NUCLEAR POWER STATIONS AND REPROCESSING SITES IN THE YEARS 1997 TO 2004

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RADIATION PROTECTION 153

Implied doses to the population of the EU arising from reported discharges from EU nuclear power stations and reprocessing sites in the years 1997 to 2004

Final Report of Contract TREN/06/NUCL/S07.56335

Prepared by M Harvey, W Oatway, J Smith and J Simmonds

Directorate-General for Energy and Transport
Directorate H — Nuclear Energy
Unit H.4 — Radiation Protection
2008

This study was carried out by the Radiation Protection Division of the Health Protection Agency's Centre for Radiation, Chemical and Environmental Hazards, Chilton, Didcot Oxfordshire (UK) for the European Commission and represents that organisation's views on the subject matter. These views have not been adopted or in any way approved by the Commission and should not be relied upon as a statement of the Commission's views.

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Foreword

Luxembourg, April 2008

This report presents information on the radiological impact of routine discharges from nuclear sites located in the European Union.

The Radiation Protection Unit of the European Commission (DG TREN H4) operates a database containing radioactive discharge information from all nuclear power stations and (former) spent fuel reprocessing sites within the European Union. Member States report this information to the European Commission on a yearly basis. The information contained within the European Commission's database was used as the radiological source term for the evaluation of collective and individual doses to the population resulting from routine releases (airborne and liquid) of radioactivity into the environment.

The assessment was performed using a revised and updated European methodology, implemented as a computer program called PC CREAM 98. The CREAM methodology (Consequences of Releases to the Environment Assessment Methodology) allows the calculation of collective doses and doses to critical groups of the population, based on real or default data and models for the transfer of radionuclides in the environment.

Doses were calculated for the years 1997 to 2004 inclusive[1] and extend the period considered in a previous study[2]. Although available guidance was used to ensure an adequate level of realism in the dose assessment it is recognised that the current study only presents an indication of the doses received. In this context it should also be noted that the discharges reported to the EC by Member States reflect the statutory reporting requirements that each Member State places on the operators of a nuclear site. Contrary to the earlier study, the data provided by the Member States have not been complemented with information from other sources. Hence the calculated doses must be interpreted with caution.

This study will be a basis for undertaking further harmonisation of future discharge data submissions by Member States.

Augustin Janssens

Head of Radiation Protection Unit

1 The current report does not include the nuclear sites from the Member States that acceded to the European Union in 2004 (Cyprus, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia) or later.

2 The study, covering the years 1987 to 1996, is available on the European Commission's EUROPA web site: http://ec.europa.eu/energy/nuclear/radioprotection/publication/128_en.htm

Implied doses to the population of the EU arising from reported discharges from EU nuclear power stations and reprocessing sites in the years 1997 to 2004

M Harvey, W Oatway, J Smith and J Simmonds

ABSTRACT

The aim of this study was to assess implied doses to the population of the European Union (EU) based on reported discharges of radioactive material from EU nuclear power stations and reprocessing sites for the period 1997 to 2004. Estimates of both individual and collective doses were made for each site and for selected years and general trends are highlighted. These dose estimates take account of reported discharges to the atmosphere, to rivers and to sea. However, this study goes further than those performed previously in that attempts were made to improve estimates of dose to critical group members that receive exposures from marine and river environments. For these cases the contributions to dose made by all relevant nuclear sites were taken into account. The report gives details of the assessment methodologies and data used and discusses the estimated doses in light of those calculated for previous years.

This study was funded by DG TREN of the European Commission.

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EXECUTIVE SUMMARY

The aim of this study was to assess implied doses to the population of the European Union (EU) based on reported discharges of radioactive material from EU nuclear power stations and reprocessing sites for the period 1997 to 2004. Estimates of both individual and collective doses were made for each site and selected years namely 1997, 1999, 2002 and 2004. By concentrating on these four years it was possible to carry out detailed assessments and still determine the general dose trends within the timeframe of the project. The doses estimated take into account discharges to the atmosphere, to rivers and to sea. However, this study goes further than those performed previously in that attempts were made to improve estimates of dose to critical groups that received exposures from the marine and river environments. For these cases the contributions to dose made by all relevant nuclear sites were taken into account. The report gives details of the assessment methodologies and data used and discusses the estimated doses in light of those calculated for previous years.

The dose calculations were performed using the PC CREAM 98 software with some modifications to include additional radionuclides. Doses arising from atmospheric discharges were calculated entirely within PC CREAM 98. However, for river and marine discharges, PC CREAM 98 output based on unit releases was used as input to an extensive set of spreadsheets that were designed to sum doses where they were the product of discharges from a number of different sites. For example, individual doses to the critical group living along the Rhine took into account discharges from 10 different nuclear sites. Similarly, where a river flows into the sea, the dose to the marine critical group included contributions from all nuclear sites discharging into that river system as well as any nearby coastal sites. The spreadsheets were also used to estimate site specific collective doses for nuclear facilities that discharged either directly or indirectly, via rivers, into the sea.

The dose calculations were based solely on the discharge data that Member States had reported to the European Commission (EC). It was noted that in some cases these reported discharges did not include the full discharge inventory and consequently the doses calculated are those implied by the level of discharge reported and are not necessarily the actual doses received by members of the EU population. With this in mind there seems to have been little change in the total truncated collective dose to the EU population during the period considered in this study. The implied total collective dose (truncated at 500 years) arising from reported discharges in 1997, 1999, 2002 and 2004 was estimated to be approximately 120, 120, 190, and 180 man Sv respectively. In comparison the annual collective dose to the EU population from natural radioactivity, based on UK data [Watson et al, 2005], is estimated to be several hundred thousand man Sieverts. Estimates of implied individual dose vary considerably from one critical group to the next. However, results indicated that while there was a general reduction in doses arising from atmospheric discharges for the period 1997 to 2004, doses from liquid discharges remained fairly constant.

This study has shown that it is necessary to harmonise the reporting of radionuclide discharges among EU Member States if valid conclusions about dose trends are to be

drawn from the assessment. Consistency of reporting by the operators would be needed to show trends in dose as a function of time, while consistency between operators would allow comparisons between sites to be made. To promote such consistency throughout the EU the European Commission issued Commission Recommendation 2004/2/Euratom on standardised information on radioactive airborne and liquid discharges from nuclear power reactors and reprocessing plants in normal operation (OJ L-002 of 06/01/04 P. 0036 - 0046). As an example, the recommendations identify ^{14}C as a radionuclide for which the discharged radioactivity should be assessed for airborne and liquid discharges from fuel reprocessing sites and airborne discharges from nuclear power reactors. Since 2002 there has been more consistent reporting of airborne ^{14}C discharges from power reactors which has enabled better estimates of both individual and collective dose to be made. However, it is noted that liquid discharges of ^{14}C from nuclear power reactors are not required by the recommendations and yet assessments carried out in this study suggest they can make a significant contribution to dose, e.g., from discharges into the Rhone.

A number of facilities were shut down during the period considered in this study and attempts were made to determine the impact of these closures. Unless sites such as Sellafield and Cap de la Hague shut down a single nuclear facility is unlikely to have a significant impact on the total truncated collective dose. However, the impact on individual dose may be more significant even when it is comprised of contributions from a number of sites.

It is important to note that when the next study of this type is carried out it will be necessary to include those Member States that have acceded to the EU since 2004. The inclusion of these new Member States will mean that a significant number of new nuclear sites will have to be added to the dose assessment. These sites are not currently included in the PC CREAM 98 software and have not previously been considered and therefore it will be necessary to collect a significant amount of data as input to the dose assessments.

CONTENTS

1 INTRODUCTION

The assessment of doses to a population is an important part of the system of radiological protection (Council Directive of 13 May 1996 laying down basic safety standards for the health protection of the general public and workers against the dangers of ionising radiation [CEC, 1996]). To ensure public safety the European Commission (EC) periodically initiates a programme of work to assess collective and individual doses to the European Union (EU) population resulting from discharges from EU nuclear facilities. This current report describes such an assessment carried out by the Radiation Protection Division of the UK Health Protection Agency (HPA-RPD), under contract to the EC. The study considered discharges occurring between the years 1997 to 2004 but only included those Member States that were part of the EU prior to 2004 and not those that acceded to the Union in 2004. The previous study [EC, 2002a] considered the years 1986 to 1996. It is important to note that only discharges reported to the EC by Member States were included in this study. Consequently, the doses reported here are those implied by the levels of reported discharges and not necessarily those actually received by members of the EU population. Attempts have been made to identify gaps in the current reporting methodology to aid improvement and to support the need for harmonisation.

2 THE CONCEPT OF DOSE

The term dose used in this report refers to the effective dose and represents the sum of the annual dose from external irradiation and the committed effective dose following the intake of radioactivity in the year. The intake of radioactivity includes the inhalation of radionuclides in the air and the ingestion of radionuclides that have been incorporated into foods. Doses from the intake of radioactivity into the body were determined in accordance with recommendations from the International Commission on Radiological Protection (ICRP) [ICRP, 1991], using the dose coefficients from ICRP Publication 72 [ICRP, 1996].

For each nuclear facility individual doses were calculated for a representative adult member of the critical group, and collective doses were estimated for the population of the European Union. The critical group is representative of those individuals in the population who receive the highest radiation doses and is equivalent to the reference group as defined in the EC Basic Safety Standards [CEC, 1996]. Recently, ICRP has introduced the concept of representative person for the assessment of individual doses [ICRP, 2006]. This concept is broadly similar to that of the critical group and in this study the latter term is used throughout. In this study generic assumptions were made about the location and habits of the critical group for comparison purposes. Individual doses were integrated to 50 years after the time of discharge and represent the dose received in the 50th year assuming the discharge was continuous and constant over

50 years. This dose can be compared with the relevant dose criteria, i.e., the annual dose limit for members of the public (taking account of doses from other controlled sources) or the dose constraint, bearing in mind that dose constraints apply to a single source or site. Collective doses are the sum of doses received by members of the population from all significant pathways and over many generations. To simplify the calculation it was assumed that all members of the population are adults. In this report collective doses were calculated over a period of 500 years, a quantity that is referred to as the collective dose truncated at 500 years.

3 NUCLEAR SITES AND DISCHARGES

3.1 Nuclear sites

The sites included in this study are nuclear power reactors generating more than 50 MW(e) and nuclear fuel reprocessing plants discharging under authorisation within the EU between 1997 and 2004. Since the last study a number of sites are no longer considered separately because they have been shut down and any remaining discharges are now reported as part of the whole site, i.e., Bugey 1, Chinon A, Chooz A and St Laurent A.

It was also noted that Civaux had become operational in 1997/1998 and so had not been considered in the previous study. For this new site appropriate discharge stack height, meteorological data, agricultural production and population distribution data were set up. A full list of the sites considered is given in Appendix A.

In this report Sellafield and Cap de la Hague are referred to as nuclear fuel reprocessing sites but it is important to note that many other processes occur at these sites and reported discharges represent the whole of the site and not just the reprocessing operations.

3.2 Discharge data

The EC recently issued Commission Recommendation 2004/2/Euratom on standardised information on radioactive airborne and liquid discharges from nuclear power reactors and reprocessing plants in normal operation [CEC, 2004]. This recommendation provides guidance with respect to the reporting of radioactive discharges and defines the categories and individual radionuclides that should be reported because of their relevance in terms of radiological protection.

The Radiation Protection Unit of the Directorate-General for Energy and Transport (DG TREN) in the EC maintains a database containing radioactive discharge information for all nuclear power stations and spent fuel reprocessing plants within the EU. Under the Euratom Treaty, Member States are requested to report this information to the EC in line with the recommendations made in 2004/2/Euratom. This study used the information contained within this database to derive the radionuclide releases for each site of interest.

It should be noted that the database held by the EC was made up of the discharges reported by each member state. As part of this study the database was reviewed for consistency but no additional data sources have been used in the dose assessment. However, where additional discharges were thought to have occurred the consequences for the results of the study are discussed. Of particular note are discharges of ^{14}C as these can have a significant impact on both individual and collective doses.

3.3 Analysis of discharge data

DG TREN of the EC provided both atmospheric and aquatic discharge data for each site and for each year between 1997 and 2004. In general, the database included both the radionuclide name and the magnitude of the discharge in terms of radioactivity released per year. This information could be used directly within PC CREAM 98 which was the system used to assess the doses from both atmospheric and liquid discharges [Mayall et al, 1997]. However, there were also a significant number of discharges reported as aggregated totals, such as total alpha and total iodine, which had to be broken down into radionuclide specific discharges. This was achieved in one of two ways. Firstly, if disaggregated discharge data were available in a subsequent year for the same site then these were used to estimate the percentage contribution that various radionuclides made to the aggregated total. This assumed that the amount of each radionuclide discharged relative to the total would not change between years. For example, if the fraction of the total discharge reported as total iodine in one year was made up of 30% ^{131}I and 70% ^{129}I then this was assumed for all years where total iodine was reported. However, if such data were not available then the data originally provided by Gesellschaft für Anlagen-und-Reaktorsicherheit (GRS) for the previous study [EC, 2002a] were used. In this way all of the aggregated discharges were broken down by radionuclide so that they could be used in PC CREAM 98.

Some radionuclides that were reported in the discharge database were not included within the PC CREAM 98 system. If the missing radionuclides were felt to be important in terms of their potential contribution to the total dose then the PC CREAM 98 database was extended to include those radionuclides. However, if the radionuclides were not felt to be significant, for example because they have very short half-lives, then they were omitted from the study. Table 1 provides a list of those radionuclides not included in this study for this reason.

Table 1 Radionuclides discharged but not included in the dose assessment

Discharge to	Radionuclides*
Atmosphere	^{130}Ba, ^{7}Be, ^{109}Cd, ^{143}Ce, ^{64}Cu, ^{203}Hg, ^{142}La, ^{95m}Nb, ^{188}Re, ^{105}Rh, ^{105}Ru, ^{117m}Sn, ^{104}Tc, ^{187}W, ^{90}Y, ^{91m}Y, ^{92}Y, ^{93}Y, ^{69m}Zn, ^{97}Zr
River	^{76}As, ^{141}Ba, ^{7}Be, ^{84}Br, ^{139}Ce, ^{141}Ce, ^{57}Co, ^{138}Cs, ^{132}I, ^{133}I, ^{134}I, ^{135}I, ^{140}La, ^{24}Na, ^{97}Nb, ^{122}Sb, ^{113}Sn, ^{99m}Tc, ^{132}Te, ^{187}W.
Sea	^{108m}Ag, ^{76}As, ^{141}Ba, ^{7}Be, ^{84}Br, ^{139}Ce, ^{141}Ce, ^{143}Ce, ^{57}Co, ^{138}Cs, ^{132}I, ^{133}I, ^{134}I, ^{135}I, ^{42}K, ^{140}La, ^{99}Mo, ^{24}Na, ^{97}Nb, ^{239}Np, ^{83}Rb, ^{106}Rh (included as progeny of ^{106}Ru), ^{46}Sc, ^{128}Sb, ^{113}Sn, ^{117m}Sn, ^{125}Sn, ^{92}Sr, ^{99m}Tc, ^{132}Te, ^{187}W, ^{97}Zr.

* Atmospheric discharges of ^{90}Y are not included independently but only as progeny of ^{90}Sr.

4 METHODOLOGY

4.1 General methodology and assessment data

The release of radioactivity into the environment can lead to the exposure of the local and wider populations via a number of exposure pathways. These pathways depend on the form of the discharge. For example, liquid discharges may result in radionuclides being taken up by fish which are subsequently ingested whilst an atmospheric release may lead to the direct inhalation of radionuclides as the dispersing plume passes over populated areas.

In order to carry out this assessment the software tool PC CREAM 98 was used [Mayall et al, 1997]. PC CREAM 98 was developed by the National Radiological Protection Board (now the Radiation Protection Division of the UK Health Protection Agency) to assess the consequences of radioactive discharges due to normal operations of nuclear installations. The software was developed under contract to the then Directorate-General XI Environment, Nuclear Safety and Civil Protection of the European Commission. With PC CREAM 98 it is possible to calculate collective doses to population groups and individual doses to critical group members. This is achieved using site specific or default data and the results of models that predict the transfer of radionuclides in the environment. Details of the assessment methodology used in PC CREAM 98 are given in an accompanying report [EC, 1995]. Differences between this study and the previous one regarding the application of PC CREAM 98 are discussed in Appendix B.

The individual doses to critical groups presented here are based on an assessment which assumed that the annual discharge for a given year, as reported in the discharge database, continued for a further 50 years. This takes into account the build-up of long lived radionuclides in the environment. For collective doses the assessment considered exposure to the population over a period of 500 years from the year of discharge. Integrating the collective dose to 500 years is considered adequate for comparison purposes given the increasing uncertainties in population size and behaviour with time. For modelling purposes the collective doses from atmospheric and marine discharges have been split into two components: the non-global component which arises only from the 'first pass' of the radioactive material; and the global component which arises only from radionuclides that have become globally dispersed.

All the pathways included in the PC CREAM 98 software were used in this assessment. A review of these pathways in light of the recommendations made concerning realistic dose assessments in reports RP 129 [EC, 2002b] and HPA-RPD-019 [Jones et al, 2006] demonstrated that no significant pathways were being omitted. The pathways included in this assessment are detailed in Table 2.

Input data that supported the dose assessment calculation, such as habit data, meteorological data and population and agricultural production distributions, were also reviewed. Most of the data used in the previous study were considered valid for use in the current study; the few exceptions are considered below.

<table>
<tr><th colspan="4">Table 2 Pathways included in the assessment</th></tr>
<tr><th colspan="2">Atmospheric releases</th><th colspan="2">Liquid releases#</th></tr>
<tr><td colspan="2">Inhalation of radionuclides in the plume</td><td colspan="2">Beta and gamma external irradiation from radionuclides deposited in sediments and also from marine sediments in fishing gear</td></tr>
<tr><td colspan="2">Beta and gamma external irradiation from radionuclides in the plume</td><td colspan="2">Ingestion of drinking water</td></tr>
<tr><td colspan="2">Beta and gamma external irradiation from deposited radionuclides</td><td rowspan="3">Ingestion of radionuclides incorporated into food</td><td>Fish (both freshwater and saltwater)</td></tr>
<tr><td colspan="2">Inhalation from resuspended radionuclides</td><td>Crustaceans</td></tr>
<tr><td rowspan="9">Ingestion of radionuclides incorporated in food *</td><td>Beef</td><td>Molluscs</td></tr>
<tr><td>Milk</td><td colspan="2" rowspan="8">Inhalation of seaspray</td></tr>
<tr><td>Milk products</td></tr>
<tr><td>Offal</td></tr>
<tr><td>Mutton</td></tr>
<tr><td>Green vegetables (includes fruit component for collective dose)</td></tr>
<tr><td>Root vegetables</td></tr>
<tr><td>Fruit</td></tr>
<tr><td>Fruit (individual dose only)</td></tr>
<tr><td colspan="4">* the foods shown in bold were those considered to be ingested at a critical rate for assessing individual doses. All others foods were considered to be ingested at an average rate for that particular country.
the pathways shown in italic apply only to the calculation of individual doses.</td></tr>
</table>

4.2 Atmospheric discharges

The methodology used in this study to assess doses arising from atmospheric discharges was similar to that adopted in the previous study [EC, 2002a]. The methodology used PC CREAM 98, which comprises a series of mathematical models used to represent the transfer of a wide range of radionuclides through various parts of the environment. Of interest in this part of the assessment are the models that deal with atmospheric dispersion and transfer through the terrestrial environment.

As described in Section 3.2 discharge data, as reported by EU Member States, were provided by the EC. Atmospheric discharge data were extracted from this dataset and supplemented with additional data to provide a radionuclide breakdown of all discharges.

A variety of site specific data were also needed to carry out an assessment using PC CREAM 98. These data, which were compiled under the previous study [EC, 2002a], were reviewed and where necessary updated. The meteorological data and grids of population and agricultural production set up under the previous study were again used in the calculation of collective dose. Any changes to these data in the intervening years were not thought to have a significant impact on the dose calculations. However, updates were made to the ingestion rates for terrestrial foods used in the calculation of individual dose. These were recalculated using country specific intake rates based on more recent data from the Food and Agriculture Organization of the United Nations (FAO) for 2003 [FAOSTAT, 2003] (Table 3). In addition, the number of food groups consumed at critical rates was revised from from four to two such that green vegetables and milk were consumed at critical rates while the remaining foods were consumed at average rates. These intake rates were assumed to be representative of the ingestion rates of adults for all the years covered in this study.

Ingestion rates are only needed for those countries where the critical group for a particular release resides. For atmospheric discharges the critical group for ingestion of terrestrial foods was assumed to be located within the country in which the discharge originated. Consequently, no terrestrial ingestion rates were needed for Austria, Luxembourg, Italy or Portugal because none of the nuclear sites considered in this study are located within these Member States.

For the calculation of individual doses to members of the critical group it was assumed that individuals were located at 0.5 km and 5 km from the discharge point and that they obtained all their terrestrial food from these locations. It was also assumed that the wind blew towards them for 20% of the time. Habit data in the form of inhalation rates and occupancy times were reviewed in line with the recommendations made concerning realistic dose assessments in reports RP 129 [EC, 2002b] and HPA-RPD-019 [Jones et al, 2006] and PC CREAM 98 default values were considered fit for purpose. It is worth reiterating that individual doses were calculated for an adult member of a representative critical group and therefore the habit data used were reviewed in this context. Site specific assessments of critical group doses were beyond the scope of this study as they require significant time and effort to implement. However it is noted that this type of detailed assessment is often carried out by operators and national authorities.

Table 3 Adult food ingestion rates* used in the calculation of representative critical group doses arising from atmospheric discharges (kg y^{-1})

Country	Cow Meat	Cow Milk#	Milk Products	Cow Liver
BELGIUM	13.5	253.8	78	0.8
FINLAND	13.1	352.8	62.1	0.6
FRANCE	19	271.9	73.6	3.1
GERMANY	8.4	253.1	81.9	0.9
SPAIN	11.2	172.2	17	1.1
SWEDEN	17.1	374.2	76.1	0.4
THE NETHERLANDS	14.8	325.7	15.4	0.4
UNITED KINGDOM	15	240	20	1

	Sheep Meat	Sheep Liver	Green Vegetables#	Root Vegetables	Fruit
BELGIUM	0.9	0.8	114.3	41.5	15.4
FINLAND	0.2	0.6	61.8	35.7	13.2
FRANCE	1.7	3.1	125	32.2	12
GERMANY	0.4	0.9	79.1	35.8	24
SPAIN	3	1.1	125.3	39.1	15.4
SWEDEN	0.5	0.4	68.6	26.9	15.7
THE NETHERLANDS	0.6	0.4	64.2	43	19.4
UNITED KINGDOM	3	1	80	60	15

* the ingestion rates used in this study were taken directly from the FAO [FAOSTAT, 2003]. They were averaged over the entire population of the named country and a high degree of accuracy of an ingestion rate per person is not implied.

foods consumed at critical rates.

4.3 Aquatic discharges

It is important to note that the methodology for calculating doses from aquatic discharges was revised for this study and, consequently, direct comparisons of dose with the previous study [EC, 2002a] can not be made. The PC CREAM 98 model and the DORIS marine dispersion model (See Figure A7, Appendix A) were again used. However, following a review of the assessment methodology used in the previous study, it was decided that the dynamic river model in PC CREAM 98 would be used rather than the screening model. This was to take account of the adsorption of radionuclides onto river bed sediments and hence to improve the estimation of the amount of radioactive material entering the marine environment via river water. The use of the dynamic river model allowed for the build up of radionuclides in sediments over time and improved estimates of external exposure to long lived radionuclides in sediment.

Data on liquid discharges, as reported by EU Member States, were provided by the EC. Again additional data were used to provide a radionuclide breakdown of any aggregated discharge categories. Other site specific data were also needed to carry out an assessment using PC CREAM 98. These data, which were compiled under the previous study [EC, 2002a], were reviewed and where necessary updated.

Collective doses arising from the ingestion of marine foods were calculated using marine catch data which are supplied with the PC CREAM 98 software. However, critical group ingestion rates for the various aquatic foods were taken from the EC study described in HPA-RPD-019 [Jones et al, 2006] and these are given in Table 4. Ingestion rates are only needed for those countries where the critical group for a particular release reside. For aquatic discharges to rivers doses to members of the critical group were calculated for the countries through which the rivers pass. For discharges into the sea doses to critical groups located within the country, or countries, adjacent to the local marine environment into which the discharge occurred were considered. Therefore, ingestion rates for aquatic foods were only required for selected countries and these did not include Austria, Luxembourg or Italy. The annual consumption of drinking water by adult members of the population was assumed to be 600 litres per year [NRPB, 2003] for all countries and this value was used in both individual and collective dose calculations.

Table 4 Adult food ingestion rates used in the calculation of representative critical group doses arising from aquatic discharges (kg y^{-1})*

Country	Freshwater fish	Sea fish	Crustaceans	Molluscs
BELGIUM	22	68	28	23
FINLAND	76	185	0.2	0.1
FRANCE	33	67	61	31
GERMANY	22	47	10	1.5
PORTUGAL	4	239	39	14
SPAIN	18	125	35	12
SWEDEN	39	150	23	4
THE NETHERLANDS	25	99	57	18
UNITED KINGDOM	23	91	20	3

* from [Jones et al, 2006]

4.3.1 Calculation of doses from discharges to rivers

During the period of the study discharges of radioactive material were made to many rivers within the EU. However, detailed data on the dimensions, sedimentation rates and flow rates of some of these rivers were not readily available and could not be collated on the timescales of this project. Such information was available for different sections of the Loire, the Rhine and the Rhone [EC, 1995]. It was therefore decided that all rivers would adopt the characteristics of one or more sections of these three rivers. In choosing the length of the sections to be included in the river model the effect on predicted activity concentrations in water and sediment had to be considered together with the way in which these concentrations were used in the subsequent dose assessment. In this study the combined effect of all discharges to a particular river system were considered which also had a bearing on the length and number of river sections to be included. A schematic of the model structures used for the

Loire, the Rhine and the Rhone is given in Figure 1 where each river section was modelled as being about 100 km long. Details of the river sections used to model the discharges from each site are presented in Table A2 of Appendix A. When calculating doses to a member of a representative critical group it was assumed that the group was located only in those river sections into which discharges occurred.

Collective doses based on the ingestion of drinking water were calculated for all sites. This contribution to the collective dose was not calculated in the previous study; however, screening calculations performed for this study showed that such population exposures could make a significant contribution to the total truncated collective dose following a liquid release. To estimate the collective dose from the ingestion of drinking water the numbers of people living in the major population centres along each river (see Table A3 in Appendix A) were multiplied by estimated average individual doses at the corresponding locations. The total truncated collective dose for a river was then calculated from the sum of the collective doses from all sites on that river. As large quantities of drinking water were also obtained from boreholes it was assumed that only 50% of drinking water was abstracted from rivers. This assumption was supported by data on typical extraction rates from the Rhine [Dieperink, 1997]. Factors to represent the loss of radioactivity due to water treatment were also included.

The total truncated collective dose for liquid discharges from inland sites included the collective dose from both river and marine pathways, i.e., account was taken of exposures arising after radionuclides in the river water had entered the sea (see Section 4.3.2).

For discharges to rivers the critical group doses were calculated for ingestion of radionuclides in drinking water and fish, and from external exposure to radionuclides in riverbank sediments. In comparison, critical group doses arising from the ingestion of foods from irrigated land were found to be small and therefore were not included in the assessment.

Since Trawsfynydd nuclear power station closed down in 1993 emissions of radionuclides to the atmosphere and to Trawsfynydd Lake have continued during decommissioning, but at a reduced level. The radiological impact of atmospheric discharges was assessed in the same way as for all other sites. However, because of its unique situation, doses arising from discharges into Trawsfynydd Lake were assessed using the model BIOS [Martin et al, 1991]. However, in contrast to previous studies [Carey et al, 1996] and [Bexon, 2000], both individual and collective doses were calculated for the ingestion of fish only, since water from the lake is not consumed by people or used for irrigation in any significant way.

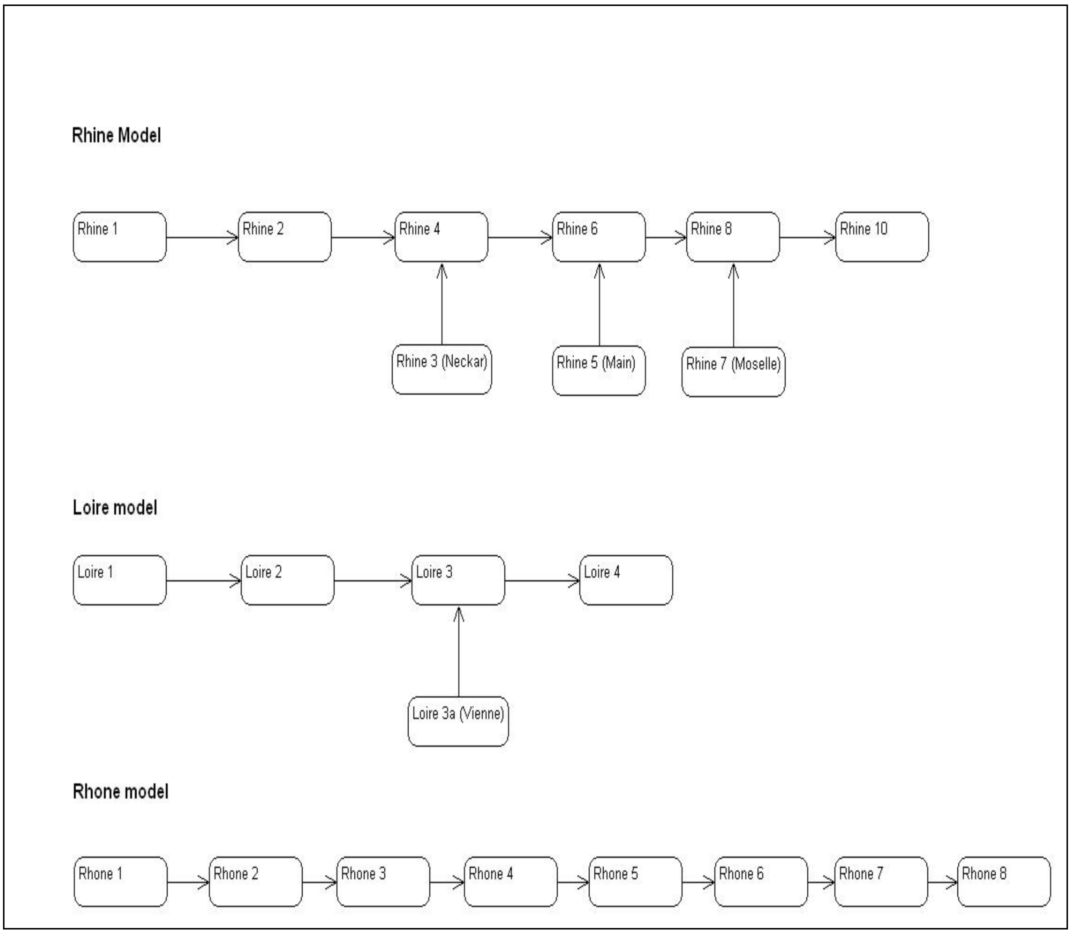

Figure1 Layout of rivers modelled (section 9 of the Rhine river system, i.e., the river Lippe, was not considered as no discharges into this section of the river were reported)

4.3.2 Calculations of doses from discharges to sea

The dynamic river model results used to estimate doses received directly from the river were also used to estimate discharges into the sea from inland sites. This enabled the adsorption of radionuclides onto river bed sediments to be modelled over the whole length of the river. The desorption of radionuclides from river sediments that can occur when they enter an estuary was also modelled. As with the assessment of doses arising directly from the river, doses from the marine environment included contributions from all sites discharging into a particular region of the sea (see Table A4 in Appendix A). Most coastal sites are sufficiently far apart that it was reasonable to assume they have separate critical groups. However, as shown in Figure A4 of Appendix A, in some limited cases more than one nuclear site discharged into the same coastal area. For example, doses to the critical group located in the Rhine and Meuse estuary included contributions from the coastal sites at Borseele and Doel.

The exposure pathways considered included the ingestion of sea fish, crustaceans and molluscs, external exposure to radionuclides in beach sediment, external exposure to contaminated fishing gear (individual only) and inhalation of seaspray (individual only). The percentages of sea fish derived from the local and regional marine compartments were assumed to be 10% and 90% respectively in this study. This is in contrast to the previous assessment which assumed that all of the fish consumed came from the local marine box.

5 RESULTS AND DISCUSSION

5.1 Atmospheric results

5.1.1 Collective doses

The collective doses given in this section can be put in context by considering the annual collective dose to the EU population from natural radioactivity which, based on UK data [Watson et al, 2005], is estimated to be several hundred thousand man Sieverts.

Figure 2 shows the estimated total truncated collective dose truncated at 500 years to the population of the EU from reported atmospheric discharges from nuclear power stations and the reprocessing sites at Sellafield and Cap de la Hague. The collective dose includes contributions from the ‘first pass’ and ‘global’ components (see Section 4.1). Dose estimates for selected years between 1987 and 1996 were taken from the previous study [EC, 2002a] and those between 1997 and 2004 were calculated in the current assessment. By considering only four representative years in the period 1997 to 2004 it was possible to carry out detailed assessments and still determine the general trends in dose within the timeframe of the project.

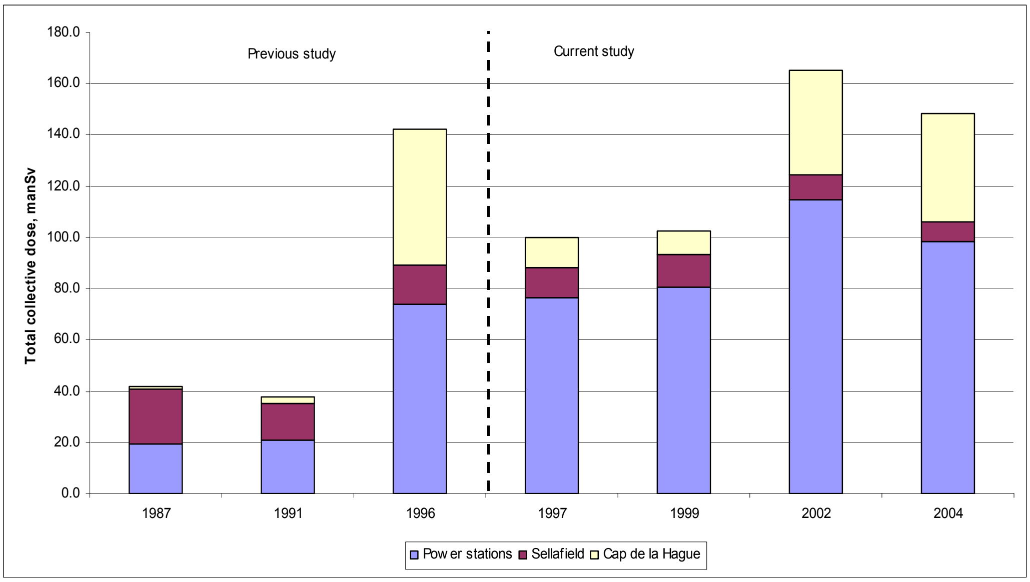

Figure 2 Implied collective doses to the EU population truncated at 500 y arising from reported atmospheric discharges from all nuclear power stations, Sellafield and Cap de la Hague (for Cap de la Hague and some nuclear power stations reported discharges did not include ^{14}C in the years 1987, 1991, 1997 and 1999)

Although Figure 2 seems to indicate that a large increase in the implied collective dose occurred in 1996 it was explained in the previous study [EC, 2002a] that this change was due to the fact that the dose assessment was not based on a complete discharge inventory. This was the case for 1987 and 1991 when discharges of ^{14}C to atmosphere from Cap de la Hague and from gas cooled reactors (GCR) and advanced gas reactors (AGR) in the UK were not available for assessment purposes. It was stated that if all the discharges were reported then the estimated collective doses for years prior to 1996 would be similar to the level of dose estimated for 1996 when ^{14}C was included in the discharge inventory.

Similarly, dose assessments for 1997 and 1999 did not include discharges of ^{14}C to atmosphere from Cap de la Hague and some nuclear power stations in France. For these sites ^{14}C discharges were only reported to the EC from 2002 onwards when it became a regulatory requirement to do so. Figure 2 suggests that the collective dose did not vary greatly from 2002 to 2004, remaining between about 140 and 170 man Sv.

In general, reported atmospheric releases from power production sites were responsible for approximately 75% of the estimated collective dose to the EU population, with the largest contribution coming from the older generation GCRs and AGRs in the UK. Significant implied collective doses also came from the reprocessing sites at Cap de la Hague and Sellafield which contribute approximately 21% and 4% to the total, respectively. Figures 3 and 4 show the reported atmospheric discharges of ^{14}C from Cap de la Hague and Sellafield and the total truncated collective dose from all atmospheric discharges from these sites in the years 1997 to 2004. These figures show how important this radionuclide is when considering the overall trend in collective doses because, for both sites, the change in the reported discharge of this radionuclide is matched by a similar change in the collective dose.

Collective doses resulting from reported atmospheric discharges from each site are presented in Appendix C.

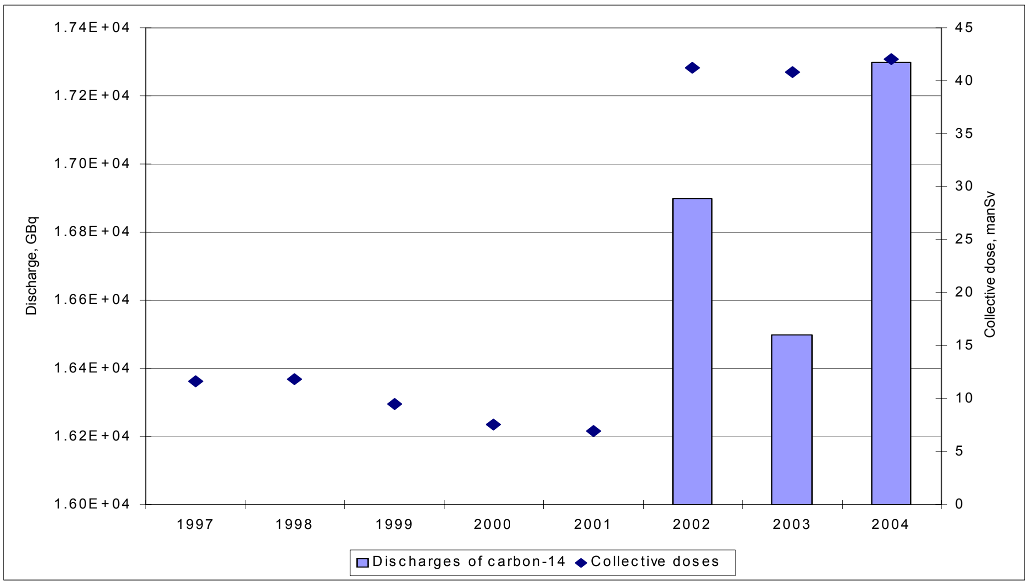

Figure 3 Reported atmospheric discharges of ^{14}C from Cap de la Hague and implied total collective dose to the EU population truncated at 500 y from exposure to all reported atmospheric discharges

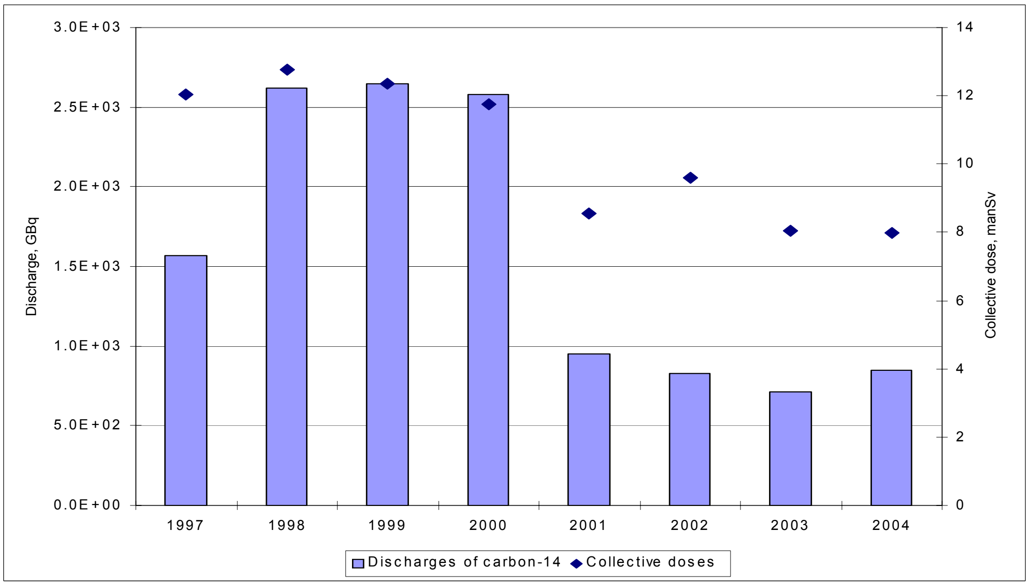

Figure 4 Reported atmospheric discharges of ^{14}C from Sellafield and implied total collective dose to the EU population truncated at 500 y from exposure to all reported atmospheric discharges

5.1.2 Individual doses

The doses calculated in this section can be compared with the annual dose limit to members of the public which is 1 mSv. Tables 5 and 6 show the distribution of representative critical group doses at 500 m and 5000 m respectively, arising from reported discharges from operating nuclear power stations within the EU. As for collective doses, reported discharges of ^{14}C have a significant impact on the doses calculated. It should be noted that doses to the representative critical groups are for comparison purposes and in many cases people will live more than 500 m from the site and hence receive lower doses.

Table 5 Range of doses received by members of representative critical groups living 500 m from operating nuclear power stations (µSv y^{-1}) as a result of reported atmospheric discharges

Percentile	1996	1997	1999	2002	2004
50th	$8.6\ 10^{-2}$	$1.3\ 10^{-1}$	$1.4\ 10^{-1}$	$5.5\ 10^{-1}$	$6.1\ 10^{-1}$
75th	$5.6\ 10^{-1}$	$8.0\ 10^{-1}$	$4.5\ 10^{-1}$	$1.5\ 10^{+0}$	$1.4\ 10^{+0}$
90th	$1.8\ 10^{+1}$	$1.8\ 10^{+1}$	$1.4\ 10^{+1}$	$1.2\ 10^{+1}$	$1.2\ 10^{+1}$
Max	$1.2\ 10^{+2}$	$1.2\ 10^{+2}$	$1.4\ 10^{+2}$	$7.0\ 10^{+1}$	$4.0\ 10^{+1}$

Table 6 Range of doses received by members of representative critical groups living 5000 m from operating nuclear power stations (µSv y^{-1}) as a result of reported atmospheric discharges

Percentile	1996	1997	1999	2002	2004
50th	$2.0\ 10^{-2}$	$2.9\ 10^{-2}$	$3.3\ 10^{-2}$	$1.1\ 10^{-1}$	$1.1\ 10^{-1}$
75th	$1.4\ 10^{-1}$	$1.5\ 10^{-1}$	$1.4\ 10^{-1}$	$2.5\ 10^{-1}$	$2.4\ 10^{-1}$
90th	$1.2\ 10^{+0}$	$1.0\ 10^{+0}$	$6.9\ 10^{-1}$	$6.7\ 10^{-1}$	$6.3\ 10^{-1}$
max	$7.5\ 10^{+0}$	$5.6\ 10^{+0}$	$6.8\ 10^{+0}$	$3.3\ 10^{+0}$	$2.0\ 10^{+0}$

Representative critical group doses were calculated for all nuclear sites for which reported atmospheric discharges were available. Tables showing these doses for each site are presented in Appendix C.

The nuclear fuel reprocessing sites at Sellafield and Cap de la Hague were two of the more important sites in terms of the radiation exposures that arise from their reported discharges. These discharges represent all activities on these sites and not just those related to the reprocessing of nuclear fuels. For these sites representative critical group doses were calculated for every year over the period of the assessment. Doses for discharges occurring in the period 1987 to 1996 were taken from the previous study, RP 128 [EC, 2002a] and doses for discharges occurring in the period 1997 to 2004 were calculated in this study. Figure 5 shows how representative critical group doses at 500 m from each site due to reported atmospheric discharges changed over the years. Again it should be noted that prior to 1992 and from 1997 to 2001 atmospheric discharges of ^{14}C from Cap de la Hague were not part of the discharge inventory reported to the EC. Consequently, actual doses received by members of the public are likely to be underestimated for these years. The extent to which these doses are underestimated can be judged by comparison with those years when ^{14}C was included in the reported discharge inventory.

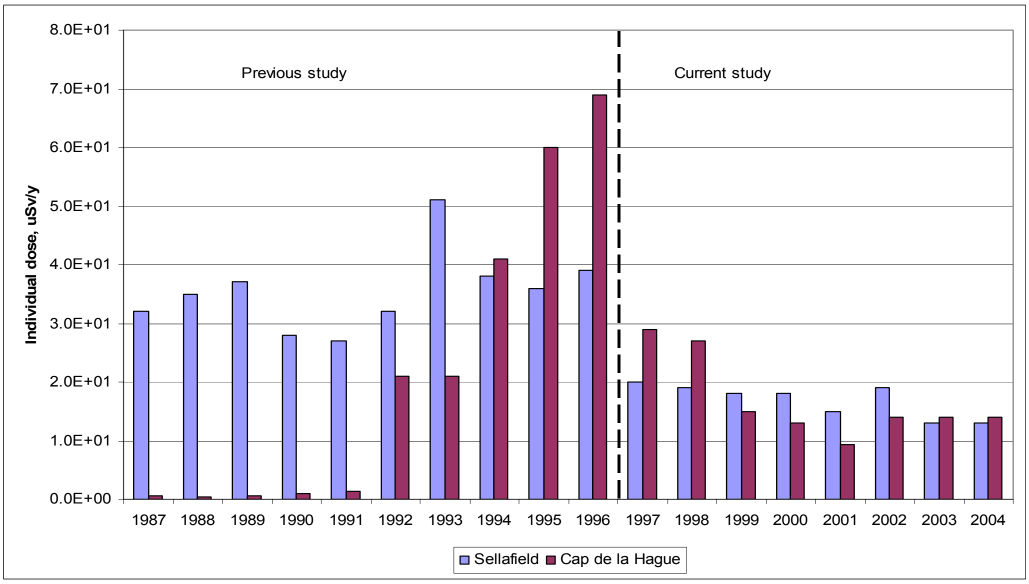

Figure 5 Representative adult critical group doses at the Sellafield and Cap de la Hague sites, based on reported atmospheric discharges, for a member of the critical group living 500 m away from the point of release. For Cap de la Hague reported discharges did not include ^{14}C in the years 1987, 1991, 1997 and 1999

From Figure 5 it is evident that estimates of individual dose in 2002 to 2004 decreased at the Sellafield and Cap de la Hague sites compared to predictions made in 1996. For Sellafield the representative critical group dose at 500 m decreased from about 40 to about 15 μSv per year while for Cap de la Hague it decreased from about 70 to about 15 μSv per year.

It is noticeable that while estimates of adult critical group doses are similar for Sellafield and Cap de la Hague collective doses resulting from discharges from these two sites are significantly different (Figures 3 and 4). This is due to the fact that collective doses are dominated by discharges of ^{14}C and there are significant differences in the atmospheric discharges of this radionuclide from the two sites. Although ^{14}C also makes an important contribution to individual doses it does not dominate in the same way and other radionuclides, such as ^{129}I, are equally as important.

5.2 Liquid releases

5.2.1 Collective doses

As for atmospheric releases the collective doses given in this section can be put into context by considering the annual collective dose to the EU population from natural radioactivity which is estimated to be several hundred thousand man Sieverts, based on UK data [Watson et al, 2005].

5.2.1.1 River doses from discharges from inland sites

Collective doses to populations residing close to rivers into which discharges occurred were not calculated in the previous study. However, a scoping calculation showed that collective doses from drinking contaminated river water may be significant when compared with collective doses arising from subsequent discharges into the marine environment. Therefore, collective doses due to drinking water were estimated for inland sites. The results are given in Figure 6 which shows the estimated collective dose to the EU population arising from the ingestion of drinking water for various European rivers. These collective doses were dominated by discharges of ^{3}H into the river systems. Consequently, the fact that discharges of ^{14}C were only reported after 2001 for some sites had only a small impact on estimates of collective dose.

For the special case of Trawsfynydd which discharges into a lake the collective doses were calculated for the ingestion of fish rather than drinking water, since water from the lake is not consumed by people.

It is worth noting that a level of caution should be attached to these results due to the uncertainty associated with the amount of drinking water that is extracted from each of the rivers considered.

The total truncated collective dose for each inland site also includes a contribution from the marine environment because radionuclides that were discharged into the river eventually enter the sea (see Section 5.2.1.2). These results are presented for each site in Table D1 of Appendix D.

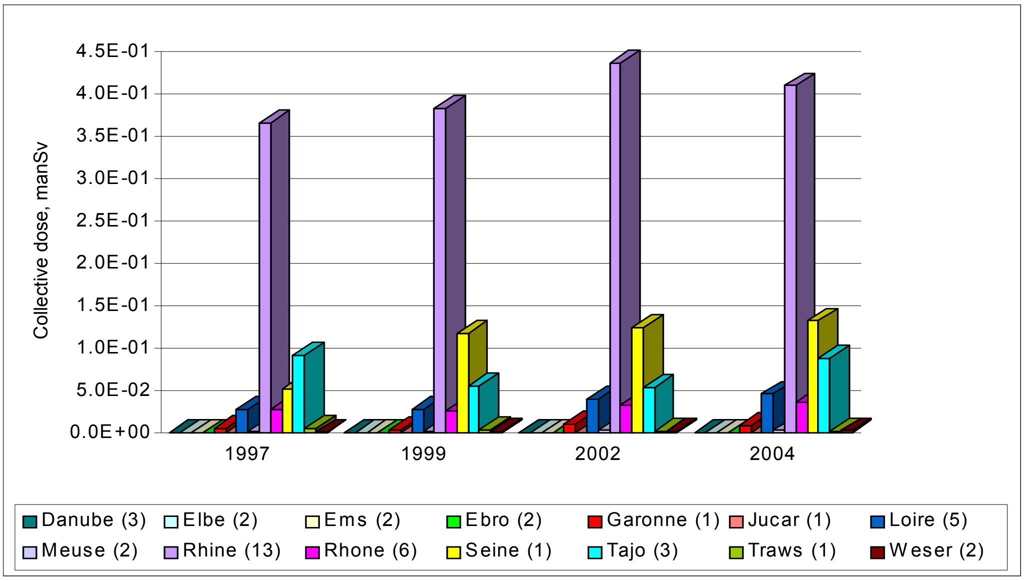

Figure 6 Implied collective doses truncated at 500 y to the EU population from drinking water as a result of reported discharges to rivers from inland sites. Legend includes number of sites in brackets

5.2.1.2 Marine doses from discharges from inland and coastal sites

Collective doses from discharges into the marine environment may arise from both inland sites and coastal sites.

Figure 7 shows total collective doses truncated at 500 years for all sites based on reported discharges into the marine environment and includes both the ‘first pass’ and ‘global’ contributions to dose. It can be seen that discharges from the coastal sites make the greatest contribution to the collective dose. This is due to the importance of liquid discharges from Sellafield and Cap de la Hague which included ^{14}C for the years 1997 to 2004 (see Figure 8). The contribution to marine collective dose from inland sites can only be seen for the years 2002 and 2004 because it is dominated by ^{14}C and this radionuclide was not included in the reported discharge inventory prior to 2002.

For nuclear power stations Figure 9 shows that in 2002 and 2004 discharges from inland sites resulted in collective doses that were greater than those for coastal sites. In particular those sites on the river Loire made a significant contribution to the marine collective dose as can be seen in Figure 10, where the highest collective dose occurred in 2004 from discharges of ^{14}C into this river. As discussed previously discharges of ^{14}C were not reported for all sites before 2002 and this leads to the lower collective doses seen in Figures 9 and 10 for discharges before that time.

Figure 11 shows the ‘global’ contribution from all sites to implied marine collective doses. The global contribution was greater for 2002 and 2004 because of the inclusion of ^{14}C in the discharges reported for those years.

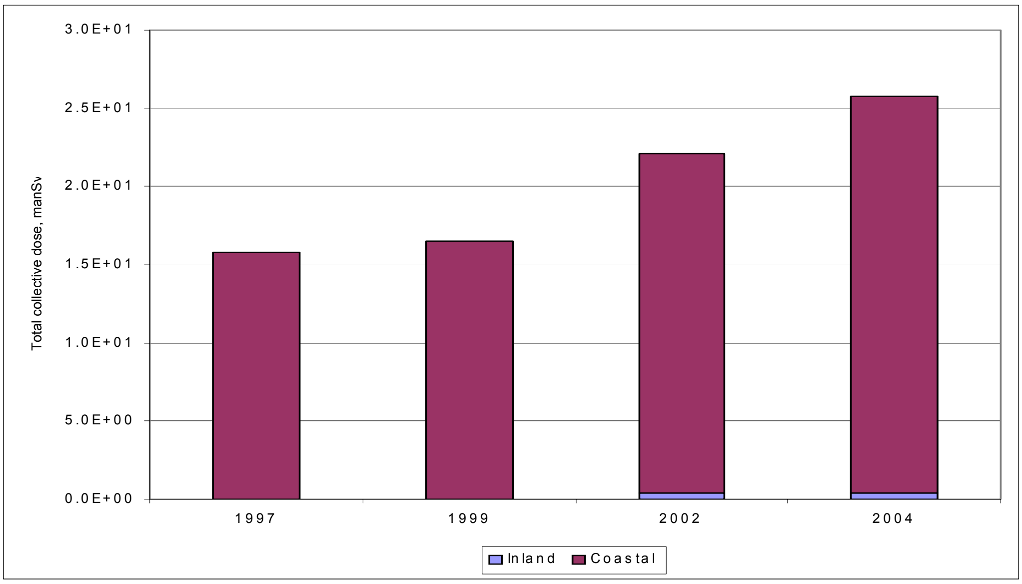

Figure 7 Implied collective doses truncated at 500 y to the EU population arising from reported marine discharges from all sites (for some sites reported discharges did not include ^{14}C prior to 2002)

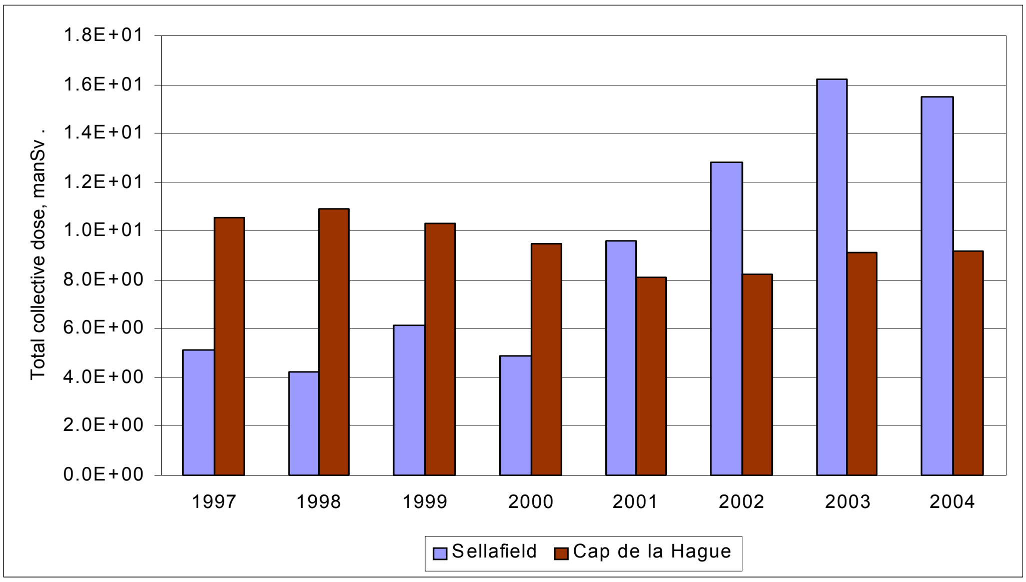

Figure 8 Implied collective doses truncated at 500 y to the EU population arising from reported marine discharges from Sellafield and Cap de la Hague (reported discharges included ^{14}C)

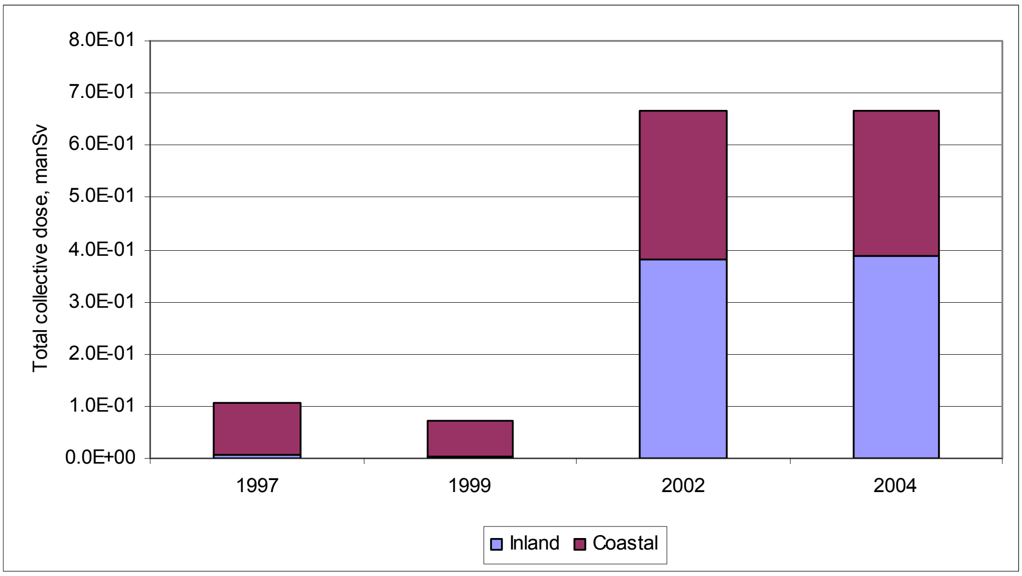

Figure 9 Implied collective doses truncated at 500 y to the EU population arising from reported marine discharges from all nuclear power stations (for some sites reported discharges did not include ^{14}C prior to 2002)

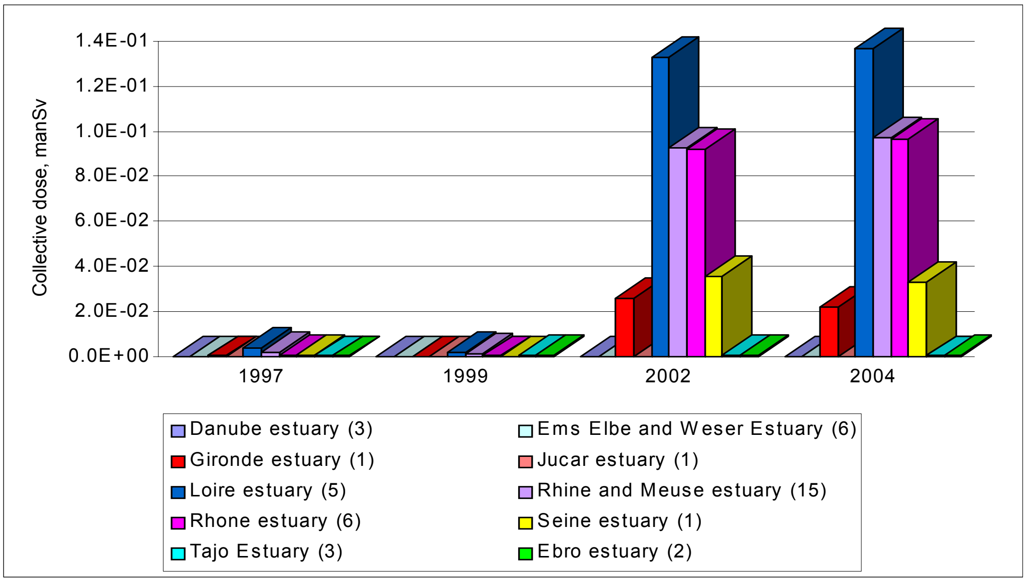

Figure 10 Implied collective doses truncated at 500 y to the EU population arising from reported marine discharges from inland sites (for some sites reported discharges did not include ^{14}C prior to 2002). Legend includes number of sites in brackets

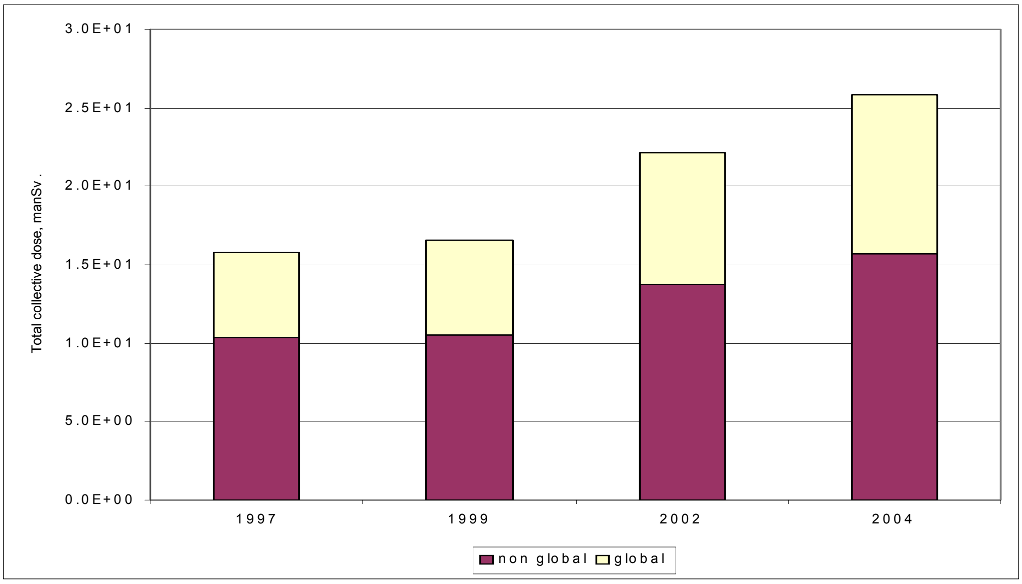

Figure 11 Implied collective doses truncated at 500 y to the EU population arising from reported marine discharges from all sites, showing contributions from 'global' and 'non-global' ('first pass') components (for some sites reported discharges did not include ^{14}C prior to 2002)

The importance of ^{14}C discharges is illustrated in Figures 12 and 13, which show the discharges and total marine collective dose truncated at 500 years for the Cap de la Hague and Sellafield sites.

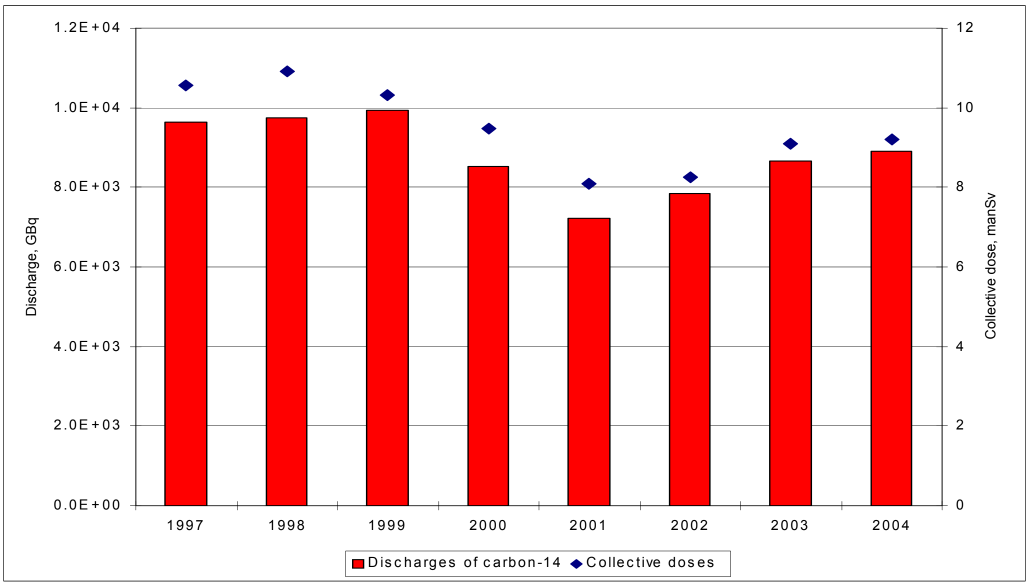

Figure 12 Reported liquid discharges of ^{14}C from Cap de la Hague and implied total collective dose to the EU population truncated at 500 y from exposure to all reported liquid discharges

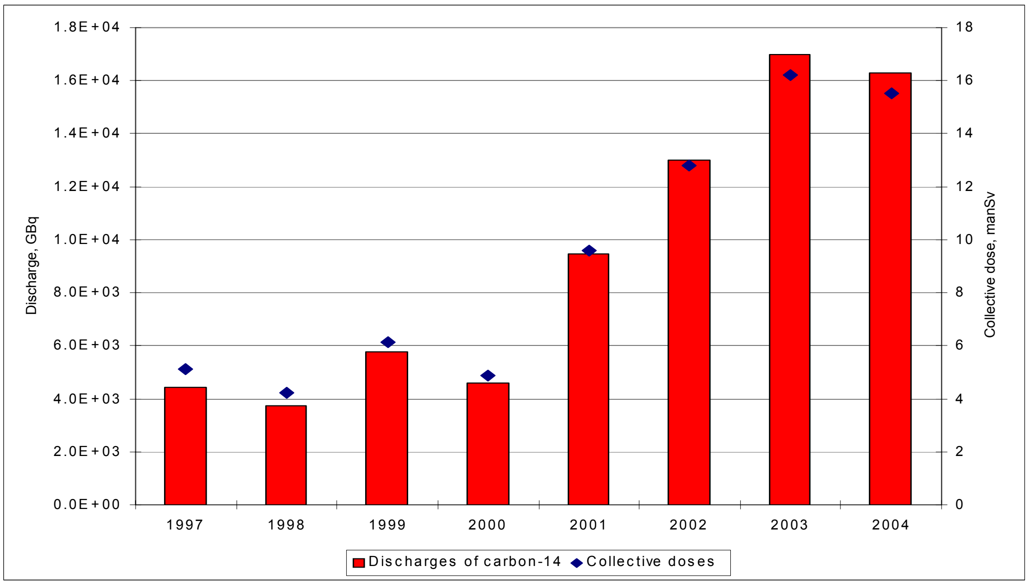

Figure 13 Reported liquid discharges of ^{14}C from Sellafield and implied total collective dose to the EU population truncated at 500 y from exposure to all reported liquid discharges

5.2.1.3 Overall collective doses from liquid discharges

The overall collective dose from liquid discharges will include a contribution from the marine environment, as a result of discharges to sea from both inland and coastal sites, as well as a contribution directly from the river due to discharges from inland sites. Figures 14 and 15 show, respectively, the total collective doses truncated at 500 years for all sites and for nuclear power stations only. The highest total collective dose truncated at 500 years for liquid discharges from all sites occurred for 2004 discharges and was about 27 man Sv, of which almost 97% was from releases to the marine environment and the remainder from drinking water extracted from rivers. This reflects the importance of the discharges from the two coastal sites, Sellafield and Cap de la Hague. If only the discharges from nuclear power stations are considered (Figure 15) then the relative importance of the dose from drinking river water increases significantly.

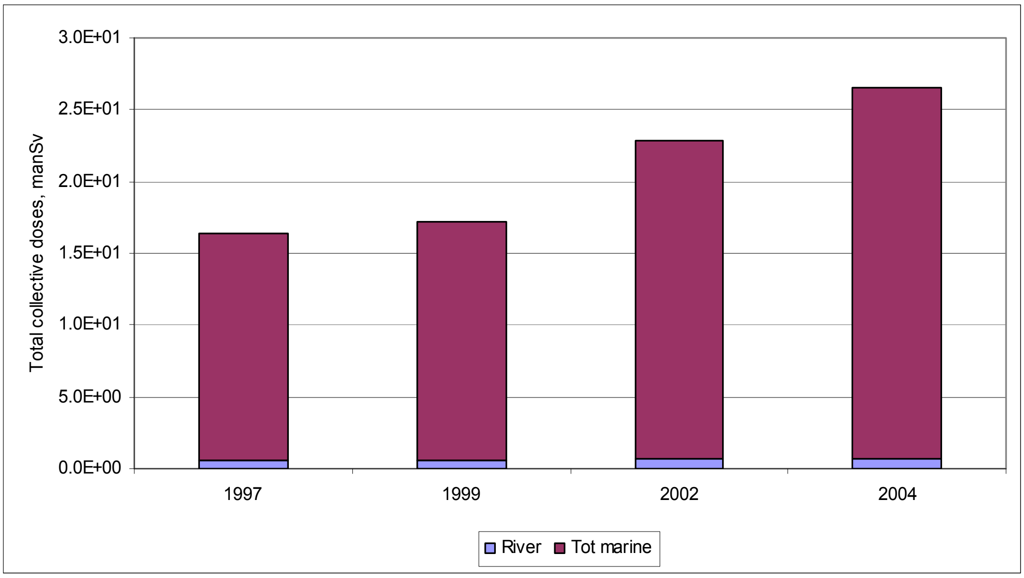

Figure 14 Implied collective doses truncated at 500 y to the EU population arising from reported river and marine discharges for all nuclear sites (for some sites reported discharges did not include ^{14}C prior to 2002)

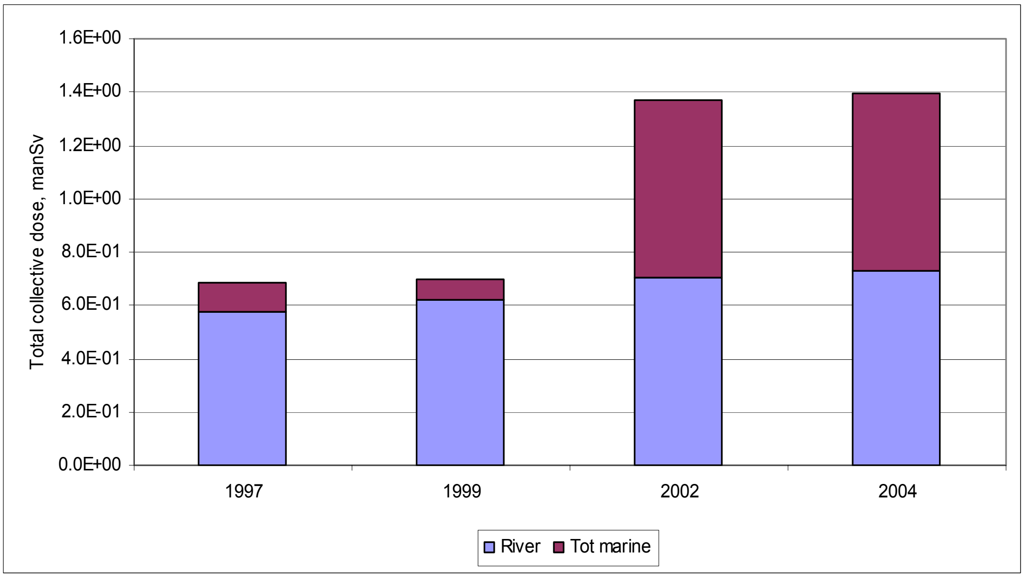

Figure 15 Implied collective doses truncated at 500 y to the EU population arising from reported river and marine discharges for all nuclear power stations (for some sites reported discharges did not include ^{14}C prior to 2002)

5.2.2 Individual doses

The doses calculated in this section can be compared with the annual dose limit to members of the public which is 1 mSv.

5.2.2.1 River doses

Individual doses to representative adult members of critical groups living along 13 European rivers were calculated. For each river the critical group dose was calculated for each section into which a discharge occurred and included contributions from discharges further upstream. These results are presented in Table D2 of Appendix D and the highest estimated individual doses for each river are presented in Figure 16 and Table 7. The individual dose from liquid discharges to Lake Trawsfynydd is also included in Table 7. From Figure 16 it can be seen that the estimated doses were much higher for discharges in 2002 and 2004, due to the inclusion of ^{14}C in the discharges reported to the EC for those years. This is in contrast to Figure 6 which shows no such variation in the collective dose from discharges to river. The reason for this is that the individual dose is dominated by the ingestion of ^{14}C in freshwater fish while the collective dose is dominated by ^{3}H in drinking water and there is considerably less variation in reported discharges of ^{3}H compared to ^{14}C.

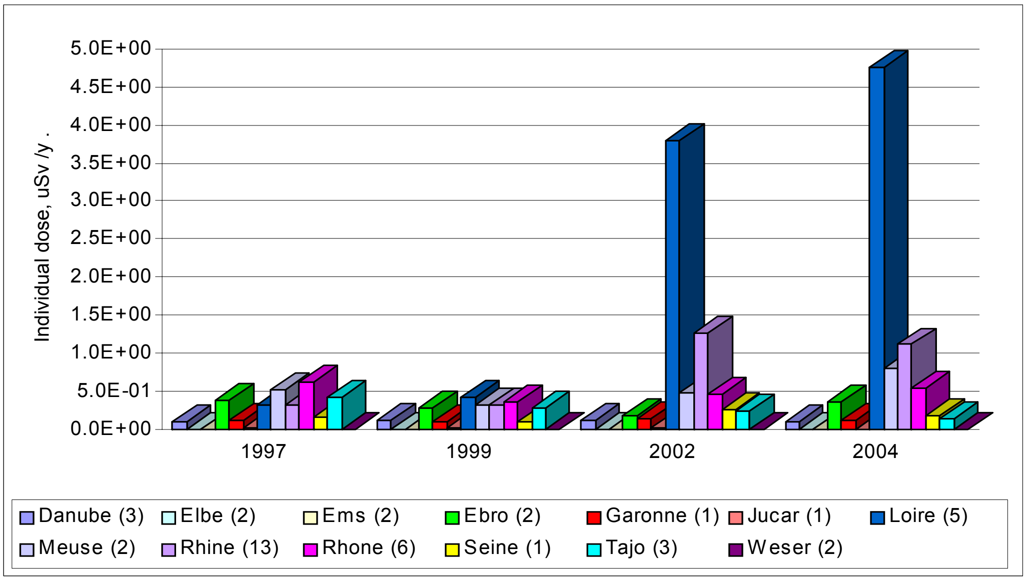

Figure 16 Representative adult critical group doses arising from reported discharges into each river system (for some sites reported discharges did not include ^{14}C prior to 2002). Legend includes number of sites in brackets

Table 7 Estimated adult critical group individual doses for each river ($\mu Sv\ y^{-1}$)

	1997	1999	2002	2004
Danube	$1.0\ 10^{-1}$	$1.2\ 10^{-1}$	$1.2\ 10^{-1}$	$1.1\ 10^{-1}$
Elbe	$6.2\ 10^{-4}$	$6.2\ 10^{-4}$	$9.2\ 10^{-4}$	$3.8\ 10^{-4}$
Ems	$2.4\ 10^{-3}$	$2.7\ 10^{-3}$	$2.4\ 10^{-3}$	$2.9\ 10^{-3}$
Ebro	$3.8\ 10^{-1}$	$2.9\ 10^{-1}$	$1.8\ 10^{-1}$	$3.7\ 10^{-1}$
Gironde	$1.3\ 10^{-1}$	$9.8\ 10^{-2}$	$1.5\ 10^{-1}$	$1.3\ 10^{-1}$
Jucar	$2.0\ 10^{-2}$	$2.2\ 10^{-2}$	$2.0\ 10^{-2}$	$2.2\ 10^{-3}$
Loire	$3.3\ 10^{-1}$	$4.4\ 10^{-1}$	$3.8\ 10^{0}$	$4.8\ 10^{0}$
Meuse	$5.3\ 10^{-1}$	$3.3\ 10^{-1}$	$4.9\ 10^{-1}$	$8.1\ 10^{-1}$
Rhine	$3.3\ 10^{-1}$	$3.3\ 10^{-1}$	$1.3\ 10^{0}$	$1.1\ 10^{0}$
Rhone	$6.3\ 10^{-1}$	$3.6\ 10^{-1}$	$4.7\ 10^{-1}$	$5.4\ 10^{-1}$
Seine	$1.6\ 10^{-1}$	$1.0\ 10^{-1}$	$2.7\ 10^{-1}$	$1.9\ 10^{-1}$
Tajo	$4.2\ 10^{-1}$	$2.9\ 10^{-1}$	$2.4\ 10^{-1}$	$1.4\ 10^{-1}$
Trawsfynydd*	$2.1\ 10^{1}$	$1.7\ 10^{1}$	$6.5\ 10^{0}$	$6.3\ 10^{0}$
Weser	$7.4\ 10^{-3}$	$9.7\ 10^{-3}$	$7.0\ 10^{-3}$	$6.1\ 10^{-3}$

* At this site discharges occur into a lake which has a very low flow rate compared to most rivers and this leads to a significant build-up of radionuclides such as ^{137}Cs in fish.

5.2.2.2 Marine doses

Critical group doses arising from exposure to radionuclides in the marine environment were calculated based on discharges from both inland and coastal sites. Where a coastal site discharged into an estuary that also received river discharges those two components of the dose were summed. For example, doses from the Seine estuary included discharges from one inland site and two coastal sites. The doses for all sites are given in Table D3 in Appendix D. Figure 17 shows the estimated individual doses for each of the critical groups located on a river estuary. For some estuaries these doses were found to be considerably greater than those estimated for individuals living along the river (Figure 16). This was due to the assumptions that more types of marine food were consumed and at greater rates than freshwater fish. In addition, some of these foods, namely crustaceans and molluscs, concentrate important radionuclides such as ^{14}C more effectively. This concentration of radionuclides by aquatic organisms was also the reason why the individual dose from ingestion of drinking water was less significant than the ingestion of marine foods. As noted elsewhere, the higher doses from discharges in 2002 and 2004 were due to ^{14}C being reported in the discharge inventory for these years.

The highest representative critical group doses were found to occur as a consequence of reported discharges from the Sellafield and Cap de la Hague nuclear sites (Figure 18). For comparison, Figure 18 also shows the representative critical group dose for the Rhone estuary as a consequence of discharges into the river Rhone.

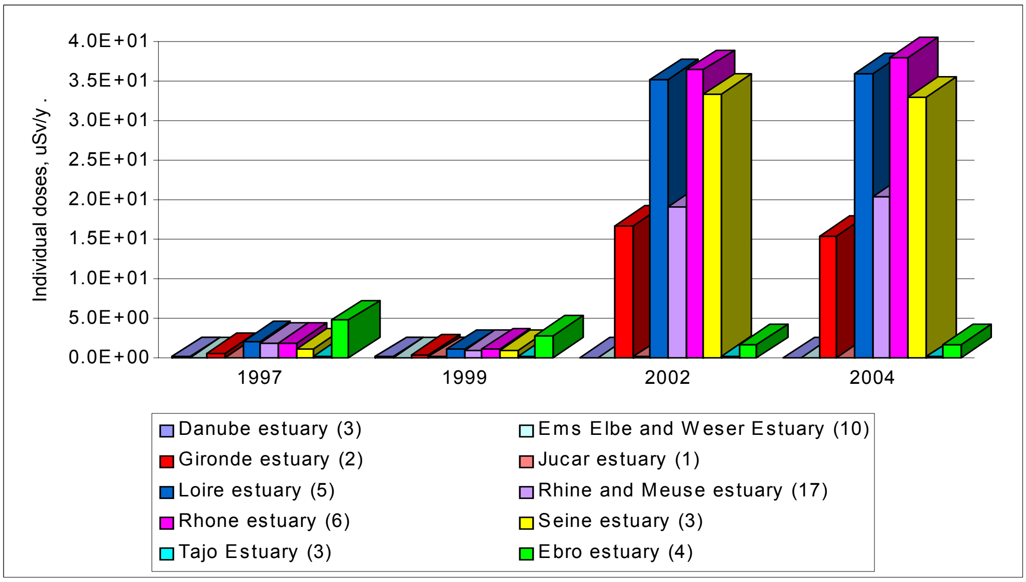

Figure 17 Representative adult critical group doses arising from reported discharges to each river estuary (for some sites reported discharges did not include ^{14}C prior to 2002). Legend includes number of sites in brackets

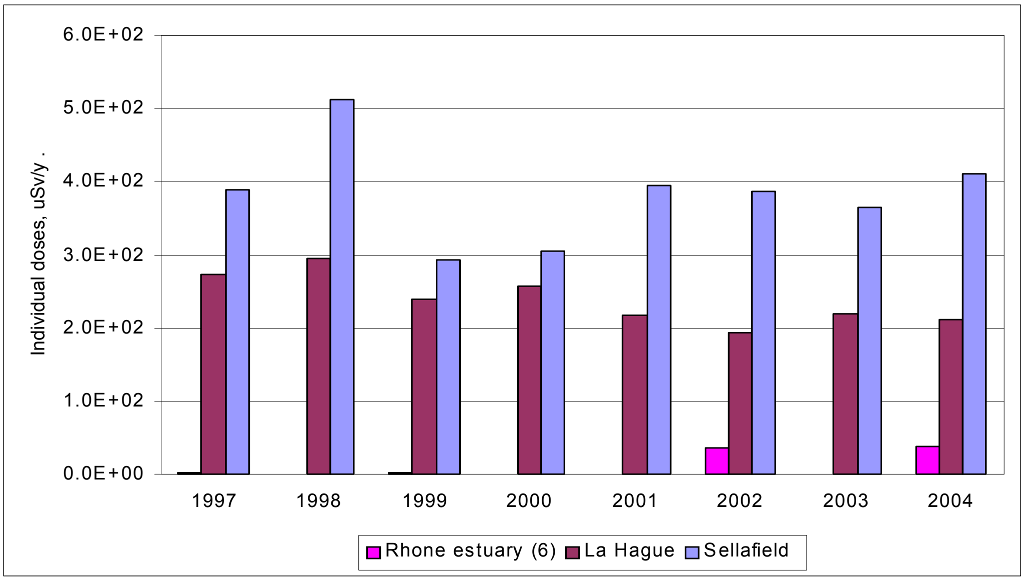

Figure 18 Representative adult critical group doses arising from reported marine discharges for selected sites (for sites on the Rhone reported discharges did not include ^{14}C prior to 2002)

5.2.3 Comparison of marine dispersion models

The calculation of doses arising from exposure to the marine environment was carried out using PC CREAM 98 and the marine dispersion model DORIS. Since the publication of this software an improved dispersion model MARINA II has been developed [EC, 2002c]. The new model has an increased number of compartments and represents the remobilisation of radionuclides from marine sediments more realistically. This is particularly important for radionuclides such as plutonium which readily adsorb onto sediments because these sediments can then act as a long term source for these radionuclides. The model changes made are likely to have most effect on activity concentrations outside the local marine compartments, i.e., away from the discharge point, and therefore they are likely to have a greater impact on the collective dose rather than the individual dose. However, the extent of any differences in model predictions will depend to some extent on the radionuclides discharged. The consequences of using the DORIS model rather than MARINA II were investigated by comparing collective doses estimated in this study with those from EC publication RP 144 [EC, 2007], which gives guidance on the calculation and use of collective doses and used MARINA II to estimate these doses. Collective doses truncated at 500 years estimated in the two studies are shown in Table 8 for discharges from Sellafield and Cap de la Hague. Although these sites do discharge radionuclides that readily adsorb onto sediments differences in the estimated collective doses are small.

Table 8 Comparison of implied collective doses arising from marine discharges estimated using methodologies in PC CREAM 98 (DORIS) and MARINA II

Site	Collective dose arising from marine discharges (man Sv)	
	MARINA II (Average of 1999 to 2003, RP 144)	DORIS (Average of 1997, 1999, 2002 and 2004, this study)
Sellafield	9.9	9.9
Cap de la Hague	9.0	9.5

5.3 Collective doses from all discharges

Figure 19 shows summed collective doses truncated at 500 years to the EU population from reported liquid and atmospheric discharges from all nuclear sites considered in this study. It is evident from this figure that atmospheric discharges made the most significant contribution, i.e., between 80% and 90% of the total truncated collective dose. In general, it can be said that the total truncated collective dose has not changed significantly over the period considered in this study particularly when changes in the reporting methodologies are taken into consideration.

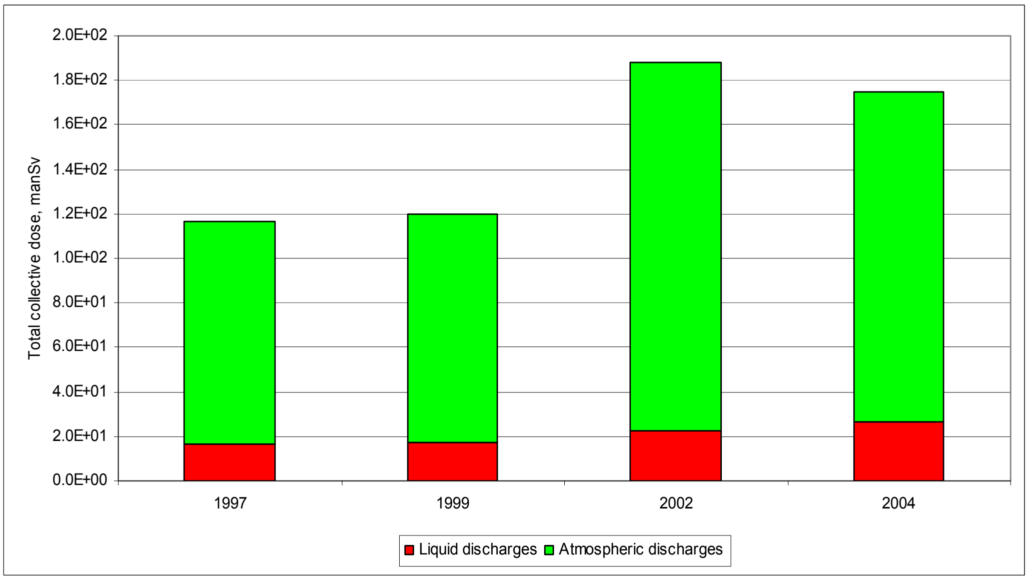

Figure 19 Implied total collective dose truncated at 500 y to the EU population from reported discharges from nuclear sites

Figures 20 and 21 show the contributions that liquid and atmospheric discharges made to the collective dose from Cap de la Hague and Sellafield respectively. For the reprocessing sites at Cap de la Hague and Sellafield doses from liquid discharges form a much more important component of the total truncated collective dose than they do for nuclear power stations (Figure 19). This is particularly true of the Sellafield site where the total collective dose truncated at 500 years varied from about 10 to 30 man Sv per year's discharge between 1987 and 2004. For Cap de la Hague estimates of collective dose reflect the reported levels of discharge of ^{14}C and these were known to be absent from the reported discharge inventory in the years 1987 to 1991 and 1997 to 2001 for atmospheric releases and from 1987 to 1996 for liquid releases. Previously [EC, 2002a], it has been suggested that from 1994 to 1996 the collective dose arising from liquid discharges of ^{14}C from Cap de la Hague was several man Sv per year of discharge. This would account for the step change seen between 1996 and 1997. In this study the most complete estimates of collective dose from Cap de la Hague are for 2002 to 2004 when the contributions from atmospheric and liquid discharges were in a ratio of about 4 to 1 respectively and gave rise to a collective dose of about 50 man Sv.

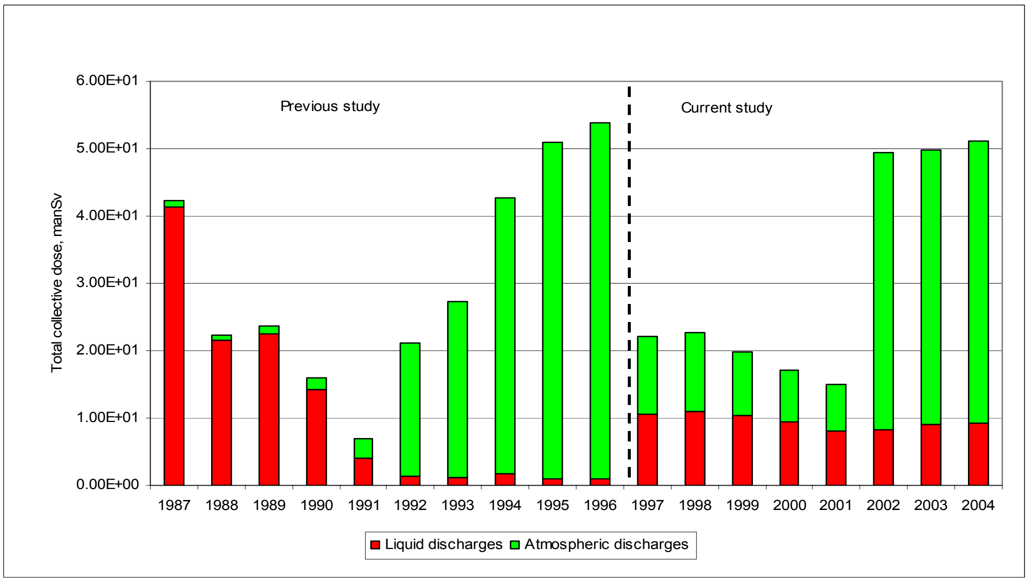

Figure 20 Implied total collective dose truncated at 500 y to the EU population arising from reported discharges from the Cap de la Hague site (reported discharges did not include ^{14}C from 1987 to 1991 and 1997 to 2001 for atmospheric releases and from 1987 to 1996 for liquid releases)

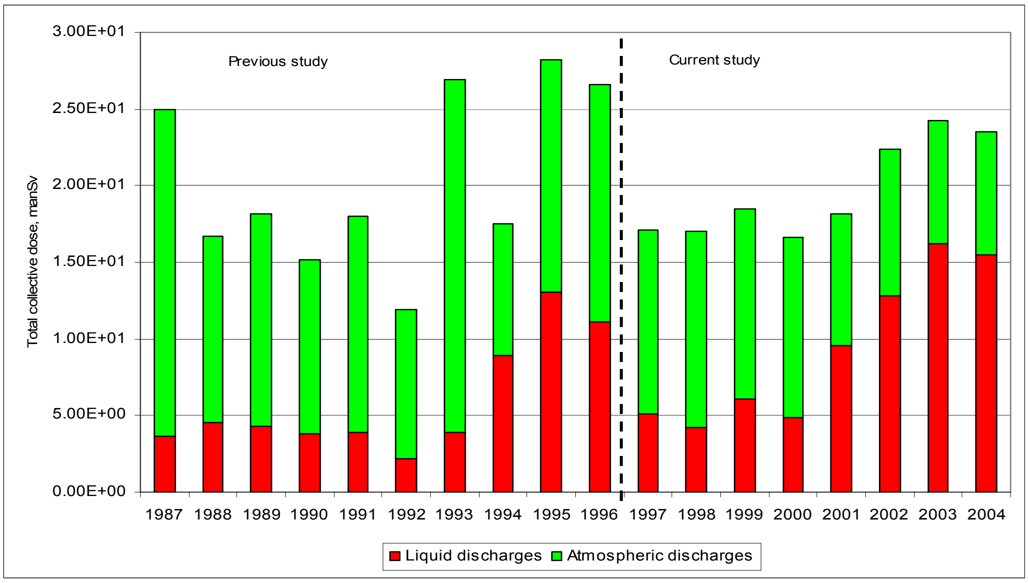

Figure 21 Implied total collective dose truncated at 500 y to the EU population arising from reported discharges from the Sellafield site

6 EFFECT OF DECOMMISSIONING

The reported discharges used in this dose assessment study include contributions from nuclear sites that closed both prior to and during the reporting period, i.e., 1997 to 2004. Tables 9 and 10 list the nuclear sites that are being decommissioned and the dates when they were shut down.

For those stations that have been shut down the reported releases used in this study are as a consequence of decommissioning activities. It is not always possible to assess the impact of these discharges independently because they are often included in the total discharge inventory of a site which may contain other nuclear reactors still in operation. However, discharges from decommissioned reactors are low when compared to the discharges of stations still in operation, and only make a small contribution to the dose.

Table 9 Nuclear reprocessing sites currently being decommissioned and their closure dates

Site	When commissioned	When shut down
Marcoule	1955	Processing of spent fuel largely ceased on 30/09/1997. Other activities continue. Discharges reported to civil authorities are only available for 1996 and 1997.
Dounreay	1975	31/03/1994
Karlsruhe WAK	1971	30/06/1991

Table 10 Closure dates of all EU nuclear power stations that are currently being decommissioned

Site	When commissioned	When shut down
Dungeness AA	21/09/1965	31/12/2006
Dungeness AB	1/11/1965	31/12/2006
Sizewell AA	21/01/1966	31/12/2006
Sizewell AB	9/04/1966	31/12/2006
José Cabrera (Zorita)	14/07/1968	30/04/2006
Barsebäck 2	21/03/1977	11/05/2005
Obrigheim (KWO)	29/10/1968	11/05/2005
Chapelcross A	1/02/1959	29/06/2004
Chapelcross B	1/07/1959	29/06/2004
Chapelcross C	1/11/1959	29/06/2004
Chapelcross D	1/01/1960	29/06/2004
Stade (KKS)	29/01/1972	14/11/2003
Calderhall A	27/08/1956	31/03/2003
Calderhall B	1/02/1957	31/03/2003
Calderhall C	1/03/1958	31/03/2003
Calderhall D	1/04/1959	31/03/2003
Bradwell A	1/07/1962	31/03/2002
Bradwell B	6/07/1962	30/03/2002
Hinkley Point AA	16/02/1965	23/05/2000
Hinkley Point AB	19/03/1965	23/05/2000
Barsebäck 1	15/05/1975	30/11/1999
Creys Malville	14/01/1986	30/12/1998
Dodewaard	18/10/1968	26/03/1997
Würgassen (KWW)	18/12/1971	26/08/1994
Bugey 1	15/04/1972	27/05/1994
St Laurent A2	9/08/1971	27/05/1992
Chooz A	3/04/1967	30/10/1991
Trawsfynydd A	14/01/1965	6/02/1991
Trawsfynydd B	2/02/1965	4/02/1991
Winfrith	1/12/1967	11/09/1990
Vandellos 1	6/05/1972	31/07/1990
Greifswald 4 (KGR-4)	3/09/1979	22/07/1990
Chinon A3	4/08/1966	15/06/1990
Rheinsberg (KKR)	6/05/1966	1/06/1990
St Laurent A1	14/03/1969	18/04/1990
Hunterston AA	5/02/1964	30/03/1990
Greifswald 3 (KGR-3)	24/10/1977	28/02/1990
Greifswald 1 (KGR-1)	17/12/1973	14/02/1990
Greifswald 2 (KGR-2)	23/12/1974	14/02/1990
Hunterston AB	1/06/1964	31/12/1989
Greifswald 5 (KGR-5)	24/04/1989	24/11/1989
Berkeley A	12/06/1962	31/03/1989
Berkeley B	24/06/1962	26/10/1988

Table 10 Cont'd Closure dates of all EU nuclear power stations that are currently being decommissioned

Site	When commissioned	When shut down
Mülheim-Kärlich (KMK)	14/03/1986	9/09/1988
Caorso	23/05/1978	1/08/1988
Trino	22/10/1964	1/08/1988
THTR 300	16/11/1985	20/04/1988
Latina	12/05/1963	1/12/1987
Chinon A2	24/02/1965	14/06/1985
Lingen (KWL)	1/07/1968	5/01/1979
Gundremmingen A (KRB-A)	1/12/1966	31/01/1977
Niederaichbach (KKN)	1/01/1973	21/07/1974
Chinon A1	14/06/1963	16/04/1973

6.1 Effect of decommissioning for atmospheric discharges

The impact of shutting down an individual nuclear facility will obviously vary from one site to the next. Reasons for this include the quantity and type of radionuclides discharged, the discharge routes used, the operating capacity of the site prior to shut down and the decommissioned state of the facility.

Table 11 shows the representative critical group dose and collective dose following shut down of selected nuclear power stations. In some cases doses prior to shut down are also shown and for these results it can be seen that doses arising post closure are at least a factor of ten less than those received during normal operations.

Table 11 Implied doses arising from reported atmospheric discharges from selected sites before and after shut down

Site	Representative critical group dose at 500 m ($\mu Sv\ y^{-1}$)	Collective dose (man Sv)	
		'first pass'	'global'
Hinkley Point A	$3.3\ 10^{1}$ (1999) * $1.9\ 10^{-2}$ (2002)#	$2.9\ 10^{0}$ (1999) $4.4\ 10^{-3}$ (2002)	$2.0\ 10^{0}$ (1999) $3.2\ 10^{-3}$ (2002)
Creys Malville	$6.9\ 10^{-2}$ (1997) * $5.7\ 10^{-3}$ (1999)#	$7.7\ 10^{-3}$ (1997) $5.9\ 10^{-4}$(1999)	$4.2\ 10^{-5}$ (1997) $3.1\ 10^{-6}$ (1999)
Rheinsberg (KKR)	$1.3\ 10^{-4}$ (1997)#	$2.8\ 10^{-5}$ (1997)	$3.9\ 10^{-8}$ (1997)
Bradwell	$5.7\ 10^{0}$ (2002) * $2.2\ 10^{-2}$ (2004)#	$2.6\ 10^{-1}$ (2002) $3.4\ 10^{-3}$ (2004)	$2.0\ 10^{-1}$ (2002) $3.2\ 10^{-3}$ (2004)

* Pre-shut down # Post-shut down

In 2004 the total truncated collective dose due to atmospheric discharges from nuclear sites being decommissioned was about 2 man Sv. This was only a small fraction of the 150 man Sv estimated for nuclear sites in operation during that year.

From Table 10 it can be seen that further site closures have occurred since 2004. These sites are Jose Cabrera, Barsebäck, Dungeness A, Obrigheim and Sizewell A. Using the discharge data for 2004 the impact of shutting down these stations on the collective dose to the EU was estimated to be 13 man Sv. This represents a decrease in the total truncated collective dose, when compared with the 2004 total, of approximately 8-10%.

The impact of plant closure on individual doses arising from reported atmospheric discharges can be seen from the results given in Table C4 of Appendix C and cross referencing these doses with the site information presented in Table 10.

6.2 Effect of decommissioning for liquid discharges

For those nuclear sites that were decommissioned between 1997 and 2004 the impact on the total truncated collective dose arising from reported marine discharges was very small. This was because this discharge route was dominated by discharges from Cap de la Hague and Sellafield, which have not closed down.

Doses, both individual and collective, arising directly from the riverine environment are more sensitive to the closure of sites but this effect will depend on the relative level of discharge of the closed site compared to the total discharge from all sites into the river system.

The impact of plant closure on collective doses arising from reported river discharges can be seen from the results given in Table D1 of Appendix D and cross referencing these doses with the site information presented in Table 10. Similarly, the impact of plant closure on individual doses arising from reported river discharges can be seen by using Tables D2 and D3 of Appendix D and Table 10.

7 SUMMARY

This report gives details of an assessment carried out to determine implied adult individual doses and collective doses received by the population of the EU as a consequence of reported discharges of radionuclides from nuclear sites within the EU. Doses were calculated based on reported discharges in the years 1997 to 2004, and extend the period considered in a previous EC publication [EC, 2002a] which covered 1987 to 1996. In this study the guidance provided in the publications [EC, 2002b] and [Jones et al, 2006] were used to ensure an adequate level of realism in the dose assessment but it was still recognised that this study only presents an indication of the potential doses received. In order to carry out a site specific dose assessment of the discharges from all the sites included in this study significantly greater resources than were available would be required.

The doses calculated in this study were based on discharges reported by Member States to the EC and these data reflect the statutory reporting requirements that each Member State places on its operators of nuclear sites. There may be some radionuclides that operators are not required to report. Of particular importance is the fact that for some sites and years both atmospheric and liquid discharges of ^{14}C were not reported to the EC. This radionuclide is a long lived emitter of beta radiation and is readily transferred throughout the environment both locally and on a global scale. As a consequence it can make a significant contribution to both individual and collective doses in the short and long term. Current EC recommendations, 2004/2/Euratom, identify ^{14}C as a radionuclide for which the discharges should be assessed for most types of release. However, it is noted that liquid discharges of ^{14}C from nuclear power reactors are the exception and yet assessments carried out in this study suggest they can make a significant contribution to dose.

Only those Member States that were part of the EU prior to 2004 were considered in the study. It is important to note that when the next study of this type is carried out it will be necessary to include those Member States that have acceded to the EU since 2004. The inclusion of these new Member States will mean that a significant number of new nuclear sites will have to be added to the dose assessment. These sites are not currently included in the PC CREAM 98 software and have not previously been considered and therefore it will be necessary to collect a significant amount of data as input to the dose calculations.

The implied collective doses estimated in this study, truncated at 500 years, to the EU population from all reported discharges in 1997, 1999, 2002 and 2004, amount to approximately 120, 120, 190, and 180 man Sv respectively. In comparison the annual collective dose to the EC population from natural radioactivity, based on UK data [Watson et al, 2005], is estimated to be several hundred thousand man Sieverts.

Individual doses vary considerably from one critical group to the next. However, results indicate that while there was a general reduction in dose arising from atmospheric discharges for the period 1997 to 2004, the dose from liquid discharges remained fairly constant.

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APPENDIX A Site details

This appendix contains site data used in the assessment. This includes the stack height that was used in the assessment of atmospheric releases and the liquid discharge location, whether it was to a river or to the marine environment. Maps are also presented showing the geographical location of each site included in the assessment.

Note that no discharge data have been presented in this report due to the large amount of data held within the EC database (more than 15000 entries). DG TREN plan to make this database publicly available by placing it on the European Commission's 'Europa' web site during 2008. Information on the logic behind the disaggregation of aggregated discharge totals used in this assessment was presented in the main text (see Section 3.3) and the reader should review that section in conjunction with the database.

Table A1 Site details used in the assessment

Country	Site name	Installation type	Discharge region	Stack height (m)
BELGIUM	Doel	PWR	Inland	60
	Tihange	PWR	Inland	100
FINLAND	Loviisa	PWR	Coastal	100
	Olkiluoto	BWR	Coastal	100
FRANCE	Belleville	PWR	Inland	60
	Blayais	PWR	Inland	60
	Bugey B	PWR	Inland	60
	Cattenom	PWR	Inland	60
	Creys Malville	FBR	Inland	60
	Chinon B	PWR	Inland	60
	Chooz B	PWR	Inland	60
	Cruas	PWR	Inland	60
	Dampierre	PWR	Inland	60
	Fessenheim	PWR	Inland	60
	Flamanville	PWR	Coastal	100
	Golfech	PWR	Inland	60
	Gravelines	PWR	Coastal	60
	Cap de la Hague	NFRP	Coastal	100
	Paluel	PWR	Coastal	60
	Penly	PWR	Coastal	100
	St Alban	PWR	Inland	60
	St Laurent B	PWR	Inland	60
	Marcoule	NFRP	Inland	100
	Nogent	PWR	Inland	60
	Tricastin	PWR	Inland	60
	Civaux	PWR	Inland	60
GERMANY	Biblis A	PWR	Inland	100
	Biblis B	PWR	Inland	100
	Brokdorf	PWR	Inland	60
	Brunsbüttel	BWR	Inland	100
	Emsland	PWR	Inland	100
	Grafenrheinfeld	PWR	Inland	100
	Greifswald	PWR	Inland	100
	Gundremmingen B+C	BWR	Inland	100
	Grohnde	PWR	Inland	100
	Isar 1	BWR	Inland	100
	Isar 2	PWR	Inland	100
	Krümmel	BWR	Inland	100
	Neckarwestheim 1	PWR	Inland	100
	Obrigheim	PWR	Inland	60
	Philippsburg 1	BWR	Inland	100
	Rheinsberg	PWR	Inland	100
	Stade	PWR	Inland	60

Table A1 Cont'd Site details used in the assessment				
Country	Site name	Installation type	Discharge region	Stack height (m)
Germany	Mülheim-Kärlich	PWR	Inland	100
	THTR 300	HTGR	Inland	100
	Philippsburg 2	PWR	Inland	60
	Unterweser	PWR	Inland	100
	Karlsruhe WAK	NFRP	Inland	100
	Würgassen	BWR	Inland	60
	Neckarwestheim 2	PWR	Inland	100
	Gundremmingen A	BWR	Inland	100
	Lingen	BWR	Inland	100
SPAIN	Asco	PWR	Inland	60
	Cofrentes	BWR	Inland	60
	José Cabrera (Zorita)	PWR	Inland	60
	Sta Maria de Garona	BWR	Inland	60
	Almaraz	PWR	Inland	60
	Trillo	PWR	Inland	60
	Vandellos 1	GCR	Coastal	60
	Vandellos 2	PWR	Coastal	60
SWEDEN	Barsebäck	BWR	Coastal	100
	Forsmark	BWR	Inland	100
	Oskarshamn	BWR	Coastal	60
	Ringhals 1	BWR	Coastal	100
	Ringhals 2	PWR	Coastal	60
THE NETHERLANDS	Borssele	PWR	Inland	60
	Dodewaard	BWR	Inland	100
UNITED KINGDOM	Berkeley	GCR	Coastal	30
	Bradwell	GCR	Coastal	30
	Dounreay	NFRP	Coastal	60
	Dungeness A	GCR	Coastal	30
	Dungeness B	AGR	Coastal	30
	Hartlepool	AGR	Coastal	30
	Heysham 1	AGR	Coastal	30
	Heysham 2	AGR	Coastal	30
	Hinkley Point A	GCR	Coastal	30
	Hinkley Point B	AGR	Coastal	30
	Hunterston A	GCR	Coastal	30
	Hunterston B	AGR	Coastal	30
	Chapelcross	GCR	Coastal	30
	Oldbury	GCR	Coastal	30
	Sellafield	NFRP	Coastal	100
	Sizewell A	GCR	Coastal	30
	Sizewell B	PWR	Coastal	30
	Torness	AGR	Coastal	30

	Trawsfynydd	GCR	Inland	30

Table A1 Cont'd Site details used in the assessment

Country	Site name	Installation type	Discharge region	Stack height (m)
UNITED KINGDOM	Winfrith	SGHWR	Coastal	30
	Wylfa	GCR	Coastal	30
	Calder Hall	GCR	Coastal	30

Table A2 River sections and the nuclear sites that discharge into those sections

River	River model (section of discharge)	Discharge station	Country of river section	Country of marine discharge point
Danube	Rhine 1	Gundremmingen	Germany	Greece
	,,	Isar 1	‘’	,,
	,,	Isar 2	‘’	,,
Elbe	Rhine 10	Krummel	Germany	Germany
	,,	Rheinsberg	‘’	,,
Ems	Rhine 10	Emsland	Germany	Germany
	,,	Lingen	,,	,,
Ebro	Rhone 1	Santa Maria de Garona	Spain	Spain
	Rhone 7	Asco	Spain	,,
Garonne	Loire 3	Golfech	France	France
Jucar	Rhone 7	Cofrentes	Spain	Spain
Loire	Loire 1	Belleville	France	France
	,,	Dampierre	,,	,,
	Loire 2	St Luarent B	,,	,,
	Loire 3a (Vienne)	Civaux	,,	,,
	Loire 3	Chinon B	,,	,,
	Loire 4		,,	,,
Meuse	Rhine 8	ChoozB	France	Netherlands
	Rhine 8	Tihange	Belgium	,,
	Rhine 10		Netherlands	,,
Rhine	Rhine 1	Fessenheim	France	Netherlands
	Rhine 2	Karlsruhe Wak	Germany	,,
	,,	Phillipsberg 1	,,	,,
	,,	Phillipsberg 2	,,	,,
	Rhine 3 (Neckar)	Obringheim	,,	,,
	,,	Neckar 1	,,	‘’
	,,	Neckar 2	,,	‘’
	Rhine 4	Biblis A (R4)	,,	‘’
	,,	Biblis B (R4)	,,	‘’
	Rhine 5 (Main)	Grafenrheinfeld	,,	‘’
	Rhine 7 (Mosselle)	Cattenom	France	‘’
	Rhine 8	Mulheim-Karlich	Germany	‘’
	Rhine 10	Dodewaard	Netherlands	‘’
Rhone	Rhone 1	Creys Malville	France	France
	,,	Bugey B	‘’	‘’
	Rhone 4	St Alban (Rh4)	‘’	‘’
	Rhone 5	Cruas (Rh5)	‘’	‘’
	Rhone 6	Tricastin (Rh6)	‘’	‘’
	Rhone 7	Marcoule	‘’	‘’
Seine	Loire 2	Nogent	France	France
Tajo	Loire 1	Jose Cabrera	Spain	Portugal

Table A2 Cont'd River sections and the nuclear sites that discharge into those sections

River	River model (section of discharge)	Discharge station	Country of river section	Country of marine discharge point
	‘’	Trillo	,,	,,
	Loire 3	Almaraz	,,	,,
Trawsfynydd	Lake*	Trawsfynydd	UK	UK
Weser	Rhine 8	Grohnde	Germany	Germany
	,,	Wurgassen	,,	,,

* Modelled using the BIOS dispersion model [Martin et al, 1991]

Table A3 River sections and the population groups in those sections

River	River model (section of discharge and downstream sections assumed)	Discharge station	Country river section	Major towns, cities close to river	Approximate population exposed to drinking river water 2006*
Danube	Rhine 1	Gundremmingen	Germany	Passau Regensburg	$9.02\ 10^{4}$
	,,	Isar 1, Isar 2	‘’	Passau	$2.52\ 10^{4}$
Elbe	Rhine 10	Krummel, Rheinsberg	Germany	Hamburg	$8.77\ 10^{5}$
Ems	Rhine 10	Emsland, Lingen	Germany	Lingen, Meppen	$4.28\ 10^{4}$
Ebro (1)	Rhone 1	Santa Maria de Garona	Spain	Miranda de Ebro	$1.90\ 10^{4}$
	Rhone 2			Logrono	$7.25\ 10^{4}$
	Rhone 3				0
	Rhone 4			Tudela	$2.00\ 10^{4}$
	Rhone 5				0
	Rhone 6				$3.30\ 10^{5}$
(2)	Rhone 7	Asco	Spain		0
	Rhone 8			Tortosa	$1.60\ 10^{4}$
Garonne	Loire 3	Golfech	France	Agen	$1.51\ 10^{4}$
	Loire 4			Marmande, Bordeaux	$5.12\ 10^{5}$
Jucar	Rhone 7	Cofrentes	Spain	Cofrentes	$5.00\ 10^{3}$
	Rhone 8			Alberique, Alzira Cullera	$3.80\ 10^{4}$
Loire	Loire 1	Belleville, Dampierre	France	Orleans	$5.66\ 10^{4}$
	Loire 2	St Laurent B	,,	Tours	$6.85\ 10^{4}$
	Loire 3a (Vienne)	Civaux	,,	Chatellerault	$1.70\ 10^{4}$
	Loire 3	Chinon B	,,	Angers	$7.56\ 10^{4}$
	Loire 4		,,	Nantes	$3.95\ 10^{5}$
Meuse (1)	Rhine 8	ChoozB	France	Charleville, Liege	$1.21\ 10^{5}$
(2)	Rhine 8	Tihange	Belgium	Liege	$9.29\ 10^{4}$
(3)	Rhine 10		Netherlands	Maastricht	$5.95\ 10^{4}$
Rhine	Rhine 1	Fessenheim	France	Strasbourg	$3.53\ 10^{5}$
	Rhine 2	Karlsruhe Wak ,	Germany	Karlsruhe, Mannheim	$2.97\ 10^{5}$
	,,	Phillipsberg 1, Phillipsberg 2	,,	Mannheim	$1.54\ 10^{5}$
	Rhine 3 (Nekar)	Neckar 1, Neckar 2	,,	Heilbronn, Heiderberg	$1.32\ 10^{5}$

	,,	Obringheim	,,	Heiderberg	7.15 10^{4}

Table A3 Cont'd River sections and the population groups in those sections

River	River model (section of discharge and downstream sections assumed)	Discharge station	Country river section	Major towns, cities close to river	Approximate population exposed to drinking river water 2006*
	Rhine 4	Biblis A, Biblis B	,,	‘’	0
	Rhine 5 (Main)	Grafenrheinfeld	,,	Frankfurt	2.90 10^{6}
	Rhine 6			Wiesbaden, Mainz	2.42 10^{5}
	Rhine 7 (Mosslle)	Cattenom	France		0
	Rhine 7		Germany	Trier	5.10 10^{4}
	Rhine 8	Mulheim-Karlich	Germany	Koblenz, Bonn Cologne, Dusseldorf	9.96 10^{5}
	Rhine 10	Dodewaard	Germany / Netherlands	Duisburg,Essen, Krefeld, Arnhem Nijmegen, Rotterdam	6.47 10^{6}
Rhone	Rhone 1	Creys Malville, Bugey B	France	Saint Vulbas Lagnie	3.44 10^{3}
	Rhone 2		,,	Lyon, Villeurbanne	9.57 10^{5}
	Rhone 3		,,	Vienne	1.53 10^{4}
	Rhone 4	St Alban	‘’	St Vallier	3.00 10^{4}
	Rhone 5	Cruas	‘’	Valence	3.21 10^{4}
	Rhone 6	Tricastin	‘’	Montelimar	1.55 10^{4}
	Rhone 7	Marcoule	‘’	Orange,Avignon	5.75 10^{4}
	Rhone 8		,,	Beaucaire, Arles Nimes	1.06 10^{5}
Seine	Loire 2	Nogent	France	Melun Evry	4.49 10^{4}
	Loire 3		,,	Paris	6.00 10^{6}
	Loire 4			Rouen	5.35 10^{4}
Tajo (1)	Loire 1	Jose Cabrera, Trillo	Spain		0
	Loire 2		,,	Toledo Madrid Talavera La Reina	2.86 10^{6}
(2)	Loire 3	Almaraz	Spain/ Portugal	Santorem Abrantes Lisbon	1.40 10^{6}
Trawsfynydd	Lake (BIOS)	Trawsfynydd	UK		Ingestion of fish only

Table A3 Cont'd River sections and the population groups in those sections

River	River model (section of discharge and downstream sections assumed)	Discharge station	Country river section	Major towns, cities close to river	Approximate population exposed to drinking river water 2006*
Weser	Rhine 8	Grohnde, Wurgassen	Germany	Hameln	$2.95\ 10^{4}$
	Rhine 10		Germany	Porta Nienburg Bremen	$7.84\ 10^{5}$

*Accounts for 50% of drinking water being derived from other non river sources.

Table A4 Marine critical group locations with the stations within each location.

Critical group location	Sites discharging to critical group location.	Country of origin	Country of critical group
Mediterranean Sea			
Danube estuary	Gundremmingen (i)	Germany	Greece
(Agean Sea)	Isar 1 (i)	Germany	
	Isar 2 (i)	Germany	
Rhone estuary	Creys Malville (i)	France	France
(Gulf of Lions)	Bugey B (i)	France	
	St Alban (i)	France	
	Cruas (i)	France	
	Tricastin (i)	France	
	Marcoule (i)	France	
Ebro estuary	Asco (i)	Spain	Spain
(Liguro Povencal Basin (1))	Santa Maria de Garona (i)	Spain	
	Vandellos 1 (c)	Spain	
	Vandellos 2 (c)	Spain	
Jucar estuary	Cofrentes (i)	Spain	Spain
(Liguro Povencal Basin (2))			
NE Atlantic (Europe excluding UK)			
Loire estuary	Belleville (i)	France	France
(French Continental Shelf (1))	Chinon B (i)	France	
	Civaux (i)	France	
	Dampierre (i)	France	
	St Laurent B (i)	France	
Gironde estuary (For river Garonne)	Blayais (c)	France	France
(French Continental Shelf (2))	Golfech (i)	France	
English Channel South East (1)	Flamanville	France	France
	Cap de la Hague	France	France
Seine estuary	Paluel (c)	France	France
(English Channel South East (2))	Penly (c)	France	
	Nogent (i)	France	
North Sea South East (1)	Gravelines (c)	France	France
Rhine and Meuse estuary	Biblis A (i)	Germany	Netherlands

North Sea South East (2)	Biblis B (i)	Germany	Netherlands

Table A4 Cont'd Marine critical group locations with the stations within each location.

Critical group location	Sites discharging to critical group location.	Country of origin	Country of critical group
	Borssele (c)	Netherlands	Netherlands
	Cattenom (i)	France	Netherlands
	Chooz B (i)	France	Netherlands
	Dodewaard (i)	Netherlands	Netherlands
	Doel (c)	Belgium	Netherlands
	Fessenheim (i)	France	Netherlands
	Grafenrheinfeld (i)	Germany	Netherlands
	Karlsruhe WAK (i)	Germany	Netherlands
	Mülheim-Kärlich (i)	Germany	Netherlands
	Neckar 1 (i)	Germany	Netherlands
	Neckar 2 (i)	Germany	Netherlands
	Obrigheim (i)	Germany	Netherlands
	Philippsburg 1 (i)	Germany	Netherlands
	Philippsburg 2 (i)	Germany	Netherlands
	Tihange (i)	Belgium	Netherlands
Ems Elbe and Weser Estuary	Brokdorf (c)	Germany	Germany
(North Sea East)	Brunsbüttel (c)	Germany	Germany
	Emsland (i)	Germany	Germany
	Grohnde (i)	Germany	Germany
	Krümmel (i)	Germany	Germany
	Lingen (i)	Germany	Germany
	Rheinsberg (i)	Germany	Germany
	Stade (c)	Germany	Germany
	Unterweser (c)	Germany	Germany
	Würgassen (i)	Germany	Germany
Tajo Estuary	Almaraz (i)	Spain	Portugal
(Portuguese Continental Shelf)	José Cabrera (Zorita) (i)	Spain	Portugal
	Trillo (i)	Spain	Portugal
Baltic region			
Baltic Sea West	Oskarshamn (c)	Sweden	Sweden
Belt Sea (1)	Barseback (c)	Sweden	Sweden
Belt Sea (2)	Greifswald (c)	Germany	Germany
Bothonian Sea (1)	Olkiluoto (c)	Finland	Finland

Bothonian Sea (1)	Forsmark (c)	Sweden	Sweden

Table A4 Cont'd Marine critical group locations with the stations within each location.

Critical group location	Sites discharging to critical group location.	Country of origin	Country of critical group
Gulf of Finland	Loviisa (c)	Finland	Finland
Kategat	Ringhals 1 (c)	Sweden	Sweden
	Ringhals 2 (c)		
UK			
North Sea South West (1)	Bradwell (c)	UK	UK
Bristol Channel (2)	Oldbury (c)	UK	UK
	Berkley (c)		
Irish Sea North East	Chapelcross (c)	UK	UK
Scottish Waters East	Dounreay (c)	UK	UK
English Channel North East	Dungeness A (c)	UK	UK
	Dungeness B (c)		
North Sea Central	Hartlepool (c)	UK	UK
Liverpool and Morcombe Bay	Heysham 1 (c)	UK	UK
	Heysham 2 (c)		
Bristol Channel (1)	Hinkley Point A (c)	UK	UK
	Hinkley Point B (c)		
Scottish Waters West	Hunterston A (c)	UK	UK
	Hunterston B (c)		
Cumbrian Waters	Sellafield (c)	UK	UK
North Sea South West (2)	Sizewell A (c)	UK	UK
	Sizewell B (c)		
Irish Sea South	Trawsfynydd (i)	UK	UK
North Sea Central	Torness (c)	UK	UK
English Channel West	Winfrith (c)	UK	UK

Irish Sea West	Wylfa (c)	UK	UK

i = inland site; c = coastal site. (1) and (2) refer to separate local compartments within a regional compartment.

Figure A1 Location of sites in France with major rivers

Figure A2 Location of sites in Spain with major rivers

Figure A3 Location of sites in Germany with major rivers

Figure A4 Location of sites in the Netherlands and Belgium with major rivers

Figure A5 Location of sites in the Sweden and Finland

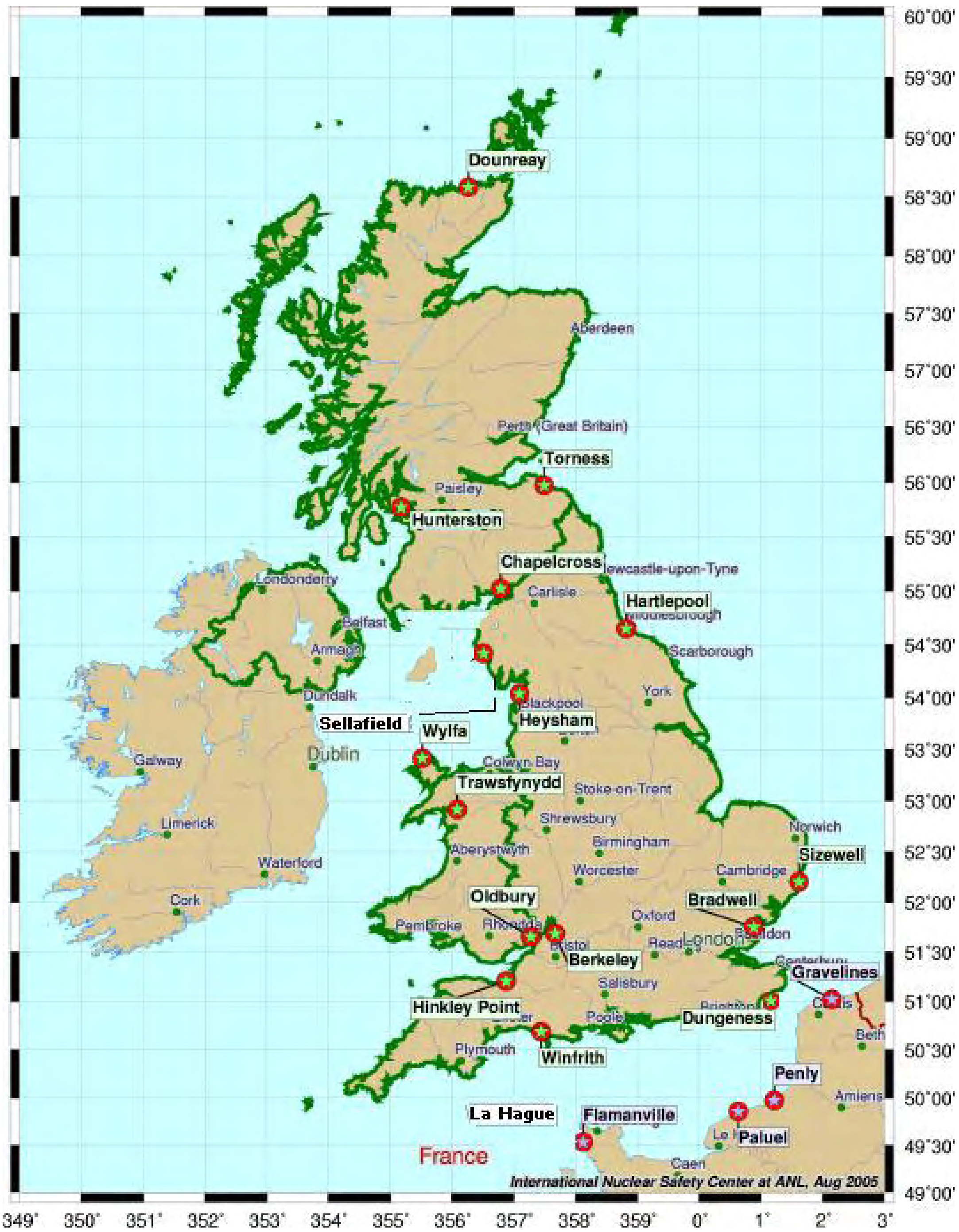
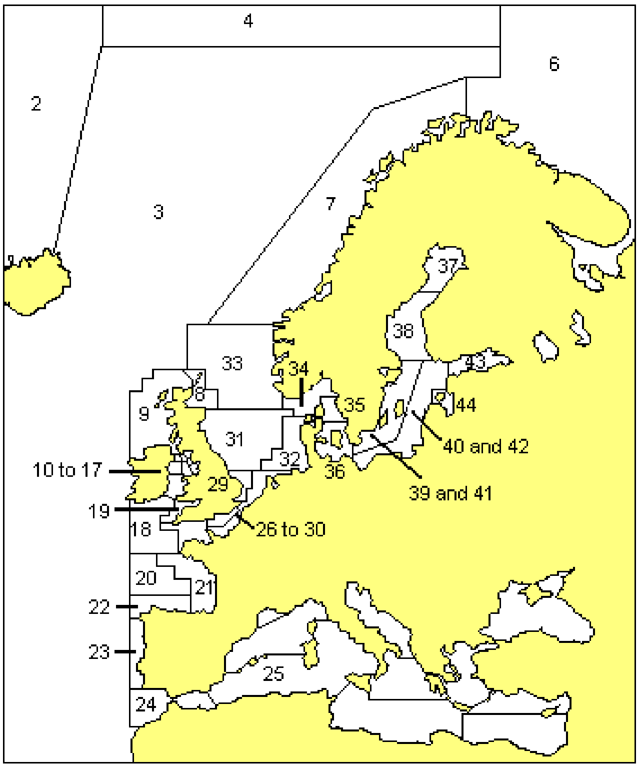


Figure A6 Location of sites in the United Kingdom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44
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40 and 42
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10 to 17
36
29
39 and 41
19
18
26 to 30
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24

Compartment names

1	Other Oceans	23	Portuguese Continental Shelf
2	Atlantic Ocean	**24**	Gulf of Cadiz
3	Atlantic North East	**25**	Mediterranean Sea
4	Arctic Ocean	**26**	English Channel West
5	Spitzbergen (North of Barents Sea)	**27**	English Channel South East
6	Barents Sea	**28**	English Channel North East
7	Norwegian Waters	**29**	North Sea South West
8	Scottish Waters West	**30**	North Sea South East
9	Scottish Waters East	**31**	North Sea Central
10	Irish Sea North West	**32**	North Sea East
11	Irish Sea North	**33**	North Sea North
12	Irish Sea North East	**34**	Skagerrak
13	Irish Sea West	**35**	Kattegat
14	Irish Sea South East	**36**	Belt Sea
15	Cumbrian Waters	**37**	Bothnian Bay
16	Irish Sea South	**38**	Bothnian Sea
17	Liverpool and Morecombe Bays	**39**	Baltic Sea West (Surface Waters)
18	Celtic Sea	**40**	Baltic Sea East (Surface Waters)
19	Bristol Channel	**41**	Baltic Sea West (Deep Waters)
20	Bay of Biscay	**42**	Baltic Sea East (Deep Waters)
21	French Continental Shelf	**43**	Gulf of Finland
22	Cantabrian Sea	**44**	Gulf of Riga

Figure A7 Compartment model of European Waters

APPENDIX B Comparison of dose assessment methodologies

B1 ATMOSPHERIC DISCHARGES

For atmospheric releases differences between the methodology employed in the previous assessment [EC, 2002a] and that used in the current study only affected calculations of individual dose. Ingestion rates of terrestrial foods were modified because the number of foods ingested at critical rates was reduced from four to two. In addition, more recent survey data were used to calculate average ingestion rates for all other terrestrial foods [FAOSTAT, 2003]. For comparison purposes both methodologies were used to calculate doses arising from reported Sellafield discharges for 1996. Table B1 shows the estimated doses from the two studies.

Differences in individual dose estimates were small and lie within expected levels of uncertainty. No changes were made to the methodology for calculating collective doses from atmospheric discharges; the very small differences that can be seen in Table B1 are due to rounding. It can therefore be concluded that the results estimated for the years 1987 to 1996, presented in RP 128 [EC, 2002a], can be considered in series with those estimated for the years 1997 to 2004 as given in this study. Significant differences in the estimated doses with time are therefore due to changes in the levels of reported discharges between the years.

Table B1 Comparison of implied doses from reported atmospheric releases using 1996 discharge data from the Sellafield site

Dose	Previous methodology*	Current methodology$
Representative critical group dose at 500m (μSv y^{-1})	39	35
Representative critical group dose at 5000m (μSv y^{-1})	12	9.9
First pass collective dose to population of EU truncated at 500 y (man Sv)	8.5	8.6
Global collective dose to population of EU truncated at 500 y (man Sv)	7.0	7.1

* Values reported by the previous study RP 128 [EC, 2002a]

$ Calculated using the discharges reported for 1996 but all other parameters are as used in the current study

B2 LIQUID DISCHARGES

This section compares the previous [EC, 2002a] and current methodologies used to calculate doses arising from liquid discharges. Collective doses and individual doses to both river and marine critical groups from inland sites and coastal sites were considered.

B2.1 River doses from discharges from inland sites

The main difference between the two methodologies was that in this study the PC CREAM 98 dynamic river model was used rather than the screening model, critical group doses included contributions from all upstream discharges rather than being calculated for a single site and collective doses from drinking river water were estimated.

A comparison of critical group doses from the two methodologies for a single site gave very similar results. However, greater critical group doses were obtained when they were based on all the reported discharges into the river. For example, for discharges from the Chinon B nuclear site into the Loire in 1996 the estimated critical group dose for that section of the river was 1.9 10^{-1} μSv y^{-1}. If discharges from other sites were included the critical group dose for the same section of the river increased to 3.3 10^{-1} μSv y^{-1}. Figure B1 shows the effect of including all 1996 reported discharges on the estimated critical group doses in each section of the Loire.

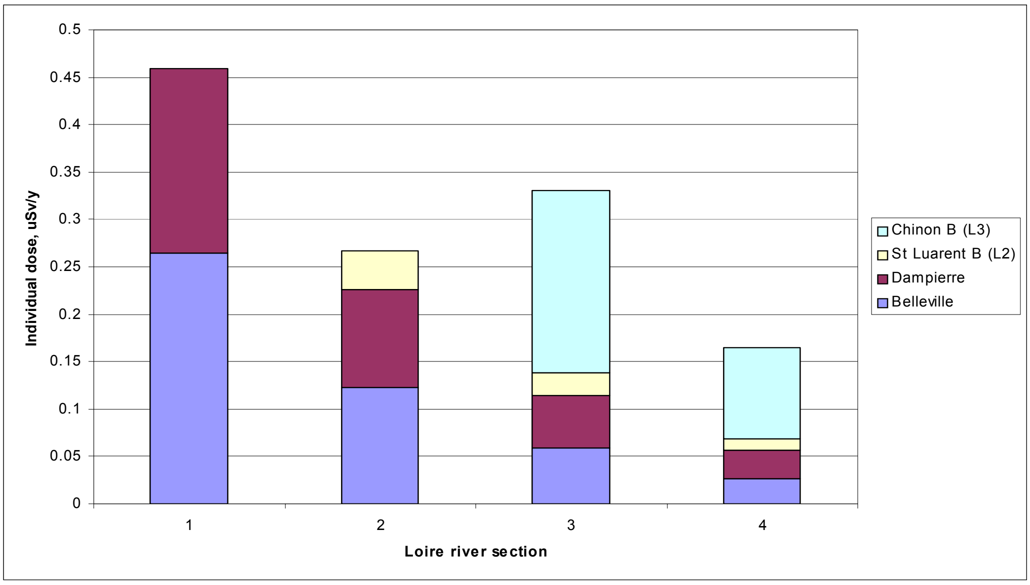

Figure B1 Representative adult critical group doses for different sections of the River Loire showing the contribution of reported discharges from key sites for 1996

Unlike the previous study, which only considered collective doses from exposure to the marine environment, this study also considered collective doses arising directly from discharges to rivers. This was achieved by calculating the collective dose to populations which used the rivers as a source of drinking water. The additional contribution to the overall collective dose, for the example of the Loire considered here, is estimated to be 2.7 10^{-3} man Sv. This is a very low dose but when the discharges to all river systems are considered the implied contribution to the total truncated collective dose from nuclear power stations is significant (Figure 15).

B2.2 Marine doses from discharges from inland sites

As described in Section 4.4 discharges from inland sites were modelled using the PC CREAM 98 dynamic river model. As a result it was possible to calculate losses of activity from river water to sediment for the entire length of the river, ie, from the point of discharge to where the river enters the sea. This was different from the previous study which only considered losses over a 10 km river section. Also in this study individual doses included contributions from different sites, eg, for the Loire estuary 4 different inland sites contributed to the critical group dose. If a coastal site also discharged into or near an estuary then it too contributed to the critical group dose for that area. An example of this is the dose to the critical group in the Rhine and Meuse estuary which included contributions from 14 different sites, both inland and on the coast (see Table A4 in Appendix A).

A comparison of doses from this study and the previous study using 1996 discharge data is given in Table B2. This shows good agreement between the two assessment methodologies.

Table B2 Comparison of implied doses arising from marine pathways using 1996 reported discharges into the river Loire.

Site	Previous methodology	Current methodology
Representative critical group doses for Loire estuary ($\mu Sv\ y^{-1}$)		
	$4.4\ 10^{0}$	$3.9\ 10^{0}$
Collective doses to population of EU truncated at 500 y for coastal discharges (man Sv)		
Coastal discharges only	$3.5\ 10^{-3}$	$3.4\ 10^{-3}$

B2.3 Marine doses from discharges from coastal sites

For this part of the dose assessment the main difference between the current and previous methodologies relates to the source of sea fish consumed by the critical group. In this study it was assumed that 10% of sea fish were taken from the local compartment and 90% from the regional compartment, while in the previous study all fish were assumed to be sourced from the local compartment. Table B3 shows the difference in doses between the two studies for 1996 discharges from Sellafield and Cap de la Hague.

The representative critical group dose from Sellafield was smaller for the current study because the dose was predominantly due to the ingestion of fish and those from the regional compartment included here have lower activity concentrations than those in the local compartment. However, the representative critical group dose from Cap de la Hague was similar for both studies as it was mainly due to ingestion of molluscs and these were assumed to be sourced entirely from the local compartment in both studies. As discussed above the critical group for exposures arising from the marine environment may receive dose contributions from both coastal sites and inland sites. In such cases the estimated dose received may be higher than in the previous study. It should be noted that previously [EC, 2002a] the individual dose calculation for Sellafield and Cap de la Hague was refined using observed to predicted ratios based on measurement data. This was not done in this study and hence comparisons were carried out with individual doses from the previous study that were not modified by the observed to predicted ratios. Results from the previous study [EC, 2002a] for 1996 suggest that the application of these ratios reduces estimates of individual dose arising from Sellafield and Cap de la Hague discharges by a factor of about 4.

For Sellafield and Cap de la Hague collective doses were the same for both studies. This was expected as there are no differences in the collective dose methodologies for these two sites.

Table B3 Comparison of implied doses from marine exposure pathways using 1996 reported discharge data from coastal sites.

Site	Previous methodology	Current methodology
Representative critical group doses (μSv y^{-1})		
Sellafield	$4.7\ 10^{2}$	$3.2\ 10^{2}$
Cap de la Hague	$6.7\ 10^{1}$	$6.2\ 10^{1}$
Collective doses to population of EU truncated at 500 y (including global) (man Sv)		
Sellafield	$1.1\ 10^{1}$	$1.1\ 10^{1}$
Cap de la Hague	$9.3\ 10^{-1}$	$9.3\ 10^{-1}$

APPENDIX C Detailed results for atmospheric discharges

Table C1 Implied collective doses truncated at 500 y to EU population (man Sv) arising from reported annual atmospheric discharges from all nuclear sites

		1997- total	1997 - first pass	1999- total	1999 - first pass	2002- total	2002 - first pass	2004- total	2004 - first pass
Belgium	Doel	$7.9\ 10^{-4}$	$7.8\ 10^{-4}$	$1.9\ 10^{-2}$	$1.9\ 10^{-2}$	$3.5\ 10^{-3}$	$3.5\ 10^{-3}$	$1.5\ 10^{-3}$	$1.5\ 10^{-3}$
Belgium	Tihange	$1.8\ 10^{-2}$	$1.8\ 10^{-2}$	$2.4\ 10^{-2}$	$2.4\ 10^{-2}$	$1.9\ 10^{-2}$	$1.9\ 10^{-2}$	$2.5\ 10^{-2}$	$2.5\ 10^{-2}$
Finland	Loviisa	$4.6\ 10^{-1}$	$1.8\ 10^{-1}$	$6.3\ 10^{-1}$	$2.4\ 10^{-1}$	$7.4\ 10^{-1}$	$2.8\ 10^{-1}$	$6.3\ 10^{-1}$	$2.4\ 10^{-1}$
Finland	Olkiluoto	$1.2\ 10^{0}$	$4.2\ 10^{-1}$	$1.4\ 10^{0}$	$4.8\ 10^{-1}$	$1.8\ 10^{0}$	$6.0\ 10^{-1}$	$1.6\ 10^{0}$	$5.3\ 10^{-1}$
France	St Alban	$2.6\ 10^{-2}$	$2.6\ 10^{-2}$	$3.2\ 10^{-2}$	$3.2\ 10^{-2}$	$9.6\ 10^{-1}$	$4.6\ 10^{-1}$	$1.2\ 10^{0}$	$5.5\ 10^{-1}$
France	Belleville	$4.4\ 10^{-2}$	$4.4\ 10^{-2}$	$3.4\ 10^{-2}$	$3.4\ 10^{-2}$	$1.4\ 10^{0}$	$8.6\ 10^{-1}$	$1.5\ 10^{0}$	$8.8\ 10^{-1}$
France	Blayais	$6.2\ 10^{-3}$	$6.1\ 10^{-3}$	$8.3\ 10^{-3}$	$8.2\ 10^{-3}$	$1.3\ 10^{0}$	$4.9\ 10^{-1}$	$1.2\ 10^{0}$	$4.7\ 10^{-1}$
France	Bugey B	$5.3\ 10^{-3}$	$5.3\ 10^{-3}$	$6.2\ 10^{-3}$	$6.1\ 10^{-3}$	$1.3\ 10^{0}$	$6.7\ 10^{-1}$	$1.5\ 10^{0}$	$7.8\ 10^{-1}$
France	Cap de la Hague	$1.2\ 10^{1}$	$6.2\ 10^{0}$	$9.5\ 10^{0}$	$4.2\ 10^{0}$	$4.1\ 10^{1}$	$1.6\ 10^{1}$	$4.2\ 10^{1}$	$1.6\ 10^{1}$
France	Cattenom	$4.4\ 10^{-2}$	$4.4\ 10^{-2}$	$3.7\ 10^{-2}$	$3.7\ 10^{-2}$	$3.5\ 10^{0}$	$2.4\ 10^{0}$	$3.5\ 10^{0}$	$2.4\ 10^{0}$
France	Chinon B	$2.8\ 10^{-2}$	$2.8\ 10^{-2}$	$3.1\ 10^{-2}$	$3.1\ 10^{-2}$	$1.9\ 10^{0}$	$1.1\ 10^{0}$	$1.7\ 10^{0}$	$9.8\ 10^{-1}$
France	Chooz B	$8.3\ 10^{-3}$	$8.3\ 10^{-3}$	$7.0\ 10^{-3}$	$7.0\ 10^{-3}$	$1.3\ 10^{0}$	$8.1\ 10^{-1}$	$1.5\ 10^{0}$	$9.4\ 10^{-1}$
France	Civaux	$0.0\ 10^{0}$	$0.0\ 10^{0}$	$8.4\ 10^{-3}$	$8.3\ 10^{-3}$	$1.3\ 10^{0}$	$7.3\ 10^{-1}$	$1.6\ 10^{0}$	$8.8\ 10^{-1}$
France	Creys Malville	$7.7\ 10^{-3}$	$7.7\ 10^{-3}$	$5.9\ 10^{-4}$	$5.9\ 10^{-4}$	$3.0\ 10^{-4}$	$3.0\ 10^{-4}$	$3.3\ 10^{-4}$	$3.3\ 10^{-4}$
France	Cruas	$1.4\ 10^{-3}$	$1.4\ 10^{-3}$	$1.3\ 10^{-3}$	$1.3\ 10^{-3}$	$1.2\ 10^{0}$	$4.8\ 10^{-1}$	$1.2\ 10^{0}$	$4.5\ 10^{-1}$
France	Dampierre	$6.4\ 10^{-3}$	$6.4\ 10^{-3}$	$6.8\ 10^{-3}$	$6.8\ 10^{-3}$	$1.7\ 10^{0}$	$1.0\ 10^{0}$	$1.8\ 10^{0}$	$1.1\ 10^{0}$
France	Fessenheim	$2.8\ 10^{-2}$	$2.8\ 10^{-2}$	$3.1\ 10^{-2}$	$3.1\ 10^{-2}$	$9.8\ 10^{-1}$	$7.0\ 10^{-1}$	$1.1\ 10^{0}$	$7.8\ 10^{-1}$
France	Flamanville	$2.9\ 10^{-2}$	$2.9\ 10^{-2}$	$1.4\ 10^{-2}$	$1.4\ 10^{-2}$	$8.1\ 10^{-1}$	$3.5\ 10^{-1}$	$9.3\ 10^{-1}$	$4.0\ 10^{-1}$
France	Golfech	$3.3\ 10^{-2}$	$3.3\ 10^{-2}$	$2.8\ 10^{-2}$	$2.8\ 10^{-2}$	$1.0\ 10^{0}$	$4.8\ 10^{-1}$	$8.9\ 10^{-1}$	$4.1\ 10^{-1}$
France	Gravelines	$3.0\ 10^{-2}$	$3.0\ 10^{-2}$	$2.9\ 10^{-2}$	$2.9\ 10^{-2}$	$2.0\ 10^{0}$	$1.0\ 10^{0}$	$2.2\ 10^{0}$	$1.1\ 10^{0}$
France	St Laurent	$2.0\ 10^{-2}$	$2.0\ 10^{-2}$	$1.8\ 10^{-2}$	$1.8\ 10^{-2}$	$9.7\ 10^{-1}$	$5.9\ 10^{-1}$	$9.7\ 10^{-1}$	$5.9\ 10^{-1}$
France	Marcoule	$1.1\ 10^{0}$	$9.4\ 10^{-1}$	$0.0\ 10^{0}$	$0.0\ 10^{0}$	$0.0\ 10^{0}$	$0.0\ 10^{0}$	$0.0\ 10^{0}$	$0.0\ 10^{0}$

Table C1 Cont'd Implied collective doses truncated at 500 y to EU population (man Sv) arising from reported annual atmospheric discharges from all nuclear sites

		1997- total	1997 - first pass	1999- total	1999 - first pass	2002- total	2002 - first pass	2004- total	2004 - first pass
France	Nogent	$1.2\ 10^{-2}$	$1.2\ 10^{-2}$	$1.0\ 10^{-2}$	$9.9\ 10^{-3}$	$1.3\ 10^{0}$	$8.2\ 10^{-1}$	$1.2\ 10^{0}$	$7.6\ 10^{-1}$
France	Paluel	$3.0\ 10^{-2}$	$3.0\ 10^{-2}$	$2.9\ 10^{-2}$	$2.9\ 10^{-2}$	$1.9\ 10^{0}$	$9.4\ 10^{-1}$	$1.8\ 10^{0}$	$9.0\ 10^{-1}$
France	Penly	$1.0\ 10^{-2}$	$1.0\ 10^{-2}$	$1.0\ 10^{-2}$	$1.0\ 10^{-2}$	$8.8\ 10^{-1}$	$4.2\ 10^{-1}$	$1.0\ 10^{0}$	$4.8\ 10^{-1}$
France	Tricastin	$7.3\ 10^{-3}$	$7.2\ 10^{-3}$	$6.5\ 10^{-3}$	$6.4\ 10^{-3}$	$1.3\ 10^{0}$	$5.8\ 10^{-1}$	$1.2\ 10^{0}$	$5.4\ 10^{-1}$
Germany	Biblis A	$1.3\ 10^{0}$	$9.4\ 10^{-1}$	$1.3\ 10^{0}$	$9.4\ 10^{-1}$	$1.4\ 10^{0}$	$9.7\ 10^{-1}$	$5.7\ 10^{-1}$	$4.1\ 10^{-1}$
Germany	Biblis B	$1.4\ 10^{0}$	$1.0\ 10^{0}$	$4.3\ 10^{-1}$	$3.1\ 10^{-1}$	$8.8\ 10^{-1}$	$6.3\ 10^{-1}$	$1.3\ 10^{0}$	$9.4\ 10^{-1}$
Germany	Brokdorf	$1.0\ 10^{0}$	$5.8\ 10^{-1}$	$8.7\ 10^{-1}$	$5.0\ 10^{-1}$	$9.6\ 10^{-1}$	$5.5\ 10^{-1}$	$8.4\ 10^{-1}$	$4.8\ 10^{-1}$
Germany	Brunsbuttel	$3.5\ 10^{-1}$	$1.8\ 10^{-1}$	$6.9\ 10^{-1}$	$3.6\ 10^{-1}$	$4.3\ 10^{-1}$	$2.2\ 10^{-1}$	$6.6\ 10^{-1}$	$3.4\ 10^{-1}$
Germany	Emsland	$7.2\ 10^{-1}$	$4.1\ 10^{-1}$	$2.1\ 10^{0}$	$1.2\ 10^{0}$	$1.2\ 10^{0}$	$6.6\ 10^{-1}$	$7.5\ 10^{-1}$	$4.3\ 10^{-1}$
Germany	Grafenrheinfeld	$3.4\ 10^{-1}$	$2.2\ 10^{-1}$	$1.8\ 10^{-1}$	$1.2\ 10^{-1}$	$9.4\ 10^{-1}$	$6.2\ 10^{-1}$	$1.2\ 10^{0}$	$7.6\ 10^{-1}$
Germany	Greifswald	$3.3\ 10^{-2}$	$1.7\ 10^{-2}$	$1.6\ 10^{-4}$	$1.6\ 10^{-4}$	$2.6\ 10^{-4}$	$2.6\ 10^{-4}$	$5.5\ 10^{-5}$	$5.5\ 10^{-5}$
Germany	Grohnde	$1.5\ 10^{-2}$	$9.0\ 10^{-3}$	$9.9\ 10^{-1}$	$5.8\ 10^{-1}$	$1.1\ 10^{0}$	$6.3\ 10^{-1}$	$9.3\ 10^{-1}$	$5.5\ 10^{-1}$
Germany	Gundremmingen A	$8.2\ 10^{-4}$	$8.2\ 10^{-4}$	$1.5\ 10^{-4}$	$1.5\ 10^{-4}$	$2.3\ 10^{-5}$	$2.3\ 10^{-5}$	$9.8\ 10^{-5}$	$9.8\ 10^{-5}$
Germany	Gundremmingen B+C	$4.6\ 10^{0}$	$3.1\ 10^{0}$	$3.4\ 10^{0}$	$2.3\ 10^{0}$	$3.7\ 10^{0}$	$2.5\ 10^{0}$	$3.1\ 10^{0}$	$2.1\ 10^{0}$
Germany	Isar 1	$5.8\ 10^{-1}$	$3.7\ 10^{-1}$	$9.9\ 10^{-1}$	$6.3\ 10^{-1}$	$1.1\ 10^{0}$	$6.7\ 10^{-1}$	$1.2\ 10^{0}$	$7.4\ 10^{-1}$
Germany	Isar 2	$1.7\ 10^{0}$	$1.1\ 10^{0}$	$1.9\ 10^{0}$	$1.2\ 10^{0}$	$1.5\ 10^{0}$	$9.8\ 10^{-1}$	$9.2\ 10^{-1}$	$5.9\ 10^{-1}$
Germany	Krummel	$9.0\ 10^{-1}$	$4.8\ 10^{-1}$	$1.3\ 10^{0}$	$6.7\ 10^{-1}$	$2.6\ 10^{-1}$	$1.4\ 10^{-1}$	$4.5\ 10^{-1}$	$2.4\ 10^{-1}$
Germany	Lingen	$1.4\ 10^{-3}$	$8.2\ 10^{-4}$	$2.3\ 10^{-3}$	$1.3\ 10^{-3}$	$1.9\ 10^{-3}$	$1.1\ 10^{-3}$	$1.9\ 10^{-3}$	$1.1\ 10^{-3}$
Germany	Mulheim-Karlich	$1.0\ 10^{-2}$	$7.4\ 10^{-3}$	$2.4\ 10^{-3}$	$1.8\ 10^{-3}$	$1.3\ 10^{-1}$	$9.4\ 10^{-2}$	$3.2\ 10^{-3}$	$2.3\ 10^{-3}$
Germany	Neckarwestheim 1	$4.5\ 10^{-2}$	$3.3\ 10^{-2}$	$1.1\ 10^{0}$	$7.7\ 10^{-1}$	$1.0\ 10^{0}$	$7.4\ 10^{-1}$	$1.2\ 10^{0}$	$9.0\ 10^{-1}$
Germany	Neckarwestheim 2	$9.4\ 10^{-1}$	$6.8\ 10^{-1}$	$1.2\ 10^{0}$	$8.7\ 10^{-1}$	$9.8\ 10^{-1}$	$7.1\ 10^{-1}$	$1.9\ 10^{0}$	$1.4\ 10^{0}$
Germany	Obrigheim	$1.6\ 10^{-1}$	$1.2\ 10^{-1}$	$2.3\ 10^{-1}$	$1.7\ 10^{-1}$	$3.0\ 10^{-1}$	$2.2\ 10^{-1}$	$2.3\ 10^{-1}$	$1.7\ 10^{-1}$
Germany	Philippsburg 1	$1.6\ 10^{0}$	$1.0\ 10^{0}$	$2.1\ 10^{0}$	$1.3\ 10^{0}$	$1.9\ 10^{0}$	$1.2\ 10^{0}$	$1.4\ 10^{0}$	$8.6\ 10^{-1}$
Germany	Philippsburg 2	$9.2\ 10^{-1}$	$6.1\ 10^{-1}$	$6.6\ 10^{-1}$	$4.4\ 10^{-1}$	$8.0\ 10^{-1}$	$5.3\ 10^{-1}$	$6.2\ 10^{-1}$	$4.1\ 10^{-1}$

Germany	Rhiensberg	$2.8\ 10^{-5}$	$2.8\ 10^{-5}$	$5.8\ 10^{-6}$	$5.8\ 10^{-6}$	$2.8\ 10^{-5}$	$2.8\ 10^{-5}$	$1.9\ 10^{-7}$	$1.9\ 10^{-7}$

Table C1 Cont'd Implied collective doses truncated at 500 y to EU population (man Sv) arising from reported annual atmospheric discharges from all nuclear sites

		1997- total	1997 - first pass	1999- total	1999 - first pass	2002- total	2002 - first pass	2004- total	2004 - first pass
Germany	Stade	$2.8\ 10^{-1}$	$1.6\ 10^{-1}$	$5.3\ 10^{-1}$	$3.0\ 10^{-1}$	$2.7\ 10^{-1}$	$1.5\ 10^{-1}$	$5.7\ 10^{-1}$	$3.2\ 10^{-1}$
Germany	THTR 300	$1.6\ 10^{-5}$	$1.6\ 10^{-5}$	$2.8\ 10^{-6}$	$2.8\ 10^{-6}$	$7.1\ 10^{-7}$	$7.1\ 10^{-7}$	$7.1\ 10^{-7}$	$7.1\ 10^{-7}$
Germany	Unterweser	$1.0\ 10^{-1}$	$5.2\ 10^{-2}$	$9.5\ 10^{-2}$	$4.9\ 10^{-2}$	$1.8\ 10^{-1}$	$9.1\ 10^{-2}$	$9.7\ 10^{-2}$	$5.0\ 10^{-2}$
Germany	Karlsuhe WAK	$1.1\ 10^{-1}$	$8.6\ 10^{-2}$	$3.2\ 10^{-1}$	$2.3\ 10^{-1}$	$1.3\ 10^{-1}$	$9.2\ 10^{-2}$	$1.1\ 10^{-1}$	$7.7\ 10^{-2}$
Germany	Wurgassen	$3.5\ 10^{-3}$	$2.3\ 10^{-3}$	$1.1\ 10^{-3}$	$7.9\ 10^{-4}$	$6.0\ 10^{-3}$	$3.7\ 10^{-3}$	$2.7\ 10^{-3}$	$1.7\ 10^{-3}$
Netherlands	Borssele	$1.6\ 10^{-1}$	$9.5\ 10^{-2}$	$2.1\ 10^{-1}$	$1.2\ 10^{-1}$	$3.6\ 10^{-1}$	$2.1\ 10^{-1}$	$2.8\ 10^{-1}$	$1.6\ 10^{-1}$
Netherlands	Dodewaard	$3.6\ 10^{-2}$	$2.2\ 10^{-2}$	$1.9\ 10^{-3}$	$1.2\ 10^{-3}$	$9.1\ 10^{-4}$	$4.9\ 10^{-4}$	$2.4\ 10^{-4}$	$1.3\ 10^{-4}$
Spain	Almaraz	$1.4\ 10^{-2}$	$1.4\ 10^{-2}$	$1.4\ 10^{-2}$	$1.4\ 10^{-2}$	$1.6\ 10^{-2}$	$1.6\ 10^{-2}$	$8.3\ 10^{-3}$	$8.2\ 10^{-3}$
Spain	Asco	$8.9\ 10^{-3}$	$8.8\ 10^{-3}$	$1.4\ 10^{-2}$	$1.4\ 10^{-2}$	$1.1\ 10^{-2}$	$1.1\ 10^{-2}$	$7.5\ 10^{-3}$	$7.5\ 10^{-3}$
Spain	Cofrentes	$5.3\ 10^{-3}$	$5.3\ 10^{-3}$	$3.7\ 10^{-3}$	$3.7\ 10^{-3}$	$1.5\ 10^{-2}$	$1.5\ 10^{-2}$	$1.5\ 10^{-2}$	$1.5\ 10^{-2}$
Spain	Jose Cabrera	$1.7\ 10^{-3}$	$1.7\ 10^{-3}$	$1.0\ 10^{-3}$	$1.0\ 10^{-3}$	$1.1\ 10^{-3}$	$1.1\ 10^{-3}$	$1.0\ 10^{-3}$	$1.0\ 10^{-3}$
Spain	Sta Maria de Garona	$7.3\ 10^{-4}$	$7.2\ 10^{-4}$	$1.0\ 10^{-3}$	$1.0\ 10^{-3}$	$7.9\ 10^{-4}$	$7.8\ 10^{-4}$	$1.1\ 10^{-3}$	$1.1\ 10^{-3}$
Spain	Trillo	$1.9\ 10^{-1}$	$9.5\ 10^{-2}$	$2.4\ 10^{-1}$	$1.2\ 10^{-1}$	$1.1\ 10^{-1}$	$5.4\ 10^{-2}$	$8.0\ 10^{-2}$	$4.1\ 10^{-2}$
Spain	Vandellos 1	$8.6\ 10^{-6}$	$7.4\ 10^{-6}$	$2.2\ 10^{-6}$	$1.8\ 10^{-6}$	$0.0\ 10^{0}$	$0.0\ 10^{0}$	$0.0\ 10^{0}$	$0.0\ 10^{0}$
Spain	Vandellos 2	$4.7\ 10^{-4}$	$4.7\ 10^{-4}$	$6.5\ 10^{-4}$	$6.4\ 10^{-4}$	$6.5\ 10^{-4}$	$6.4\ 10^{-4}$	$3.2\ 10^{-4}$	$3.2\ 10^{-4}$
Sweden	Barseback	$1.8\ 10^{-3}$	$1.8\ 10^{-3}$	$5.5\ 10^{-3}$	$5.5\ 10^{-3}$	$9.6\ 10^{-1}$	$4.2\ 10^{-1}$	$9.2\ 10^{-1}$	$4.1\ 10^{-1}$
Sweden	Fosmark	$3.8\ 10^{-3}$	$3.8\ 10^{-3}$	$3.7\ 10^{-4}$	$3.7\ 10^{-4}$	$5.1\ 10^{0}$	$1.8\ 10^{0}$	$4.2\ 10^{0}$	$1.5\ 10^{0}$
Sweden	Oskarshamn	$5.5\ 10^{-2}$	$5.5\ 10^{-2}$	$2.2\ 10^{-3}$	$2.2\ 10^{-3}$	$1.9\ 10^{0}$	$8.2\ 10^{-1}$	$1.8\ 10^{0}$	$7.3\ 10^{-1}$
Sweden	Ringhals 1	$9.5\ 10^{-2}$	$9.5\ 10^{-2}$	$3.8\ 10^{-2}$	$3.8\ 10^{-2}$	$1.0\ 10^{0}$	$4.2\ 10^{-1}$	$1.0\ 10^{0}$	$4.2\ 10^{-1}$
Sweden	Ringhals 2	$8.5\ 10^{-5}$	$8.5\ 10^{-5}$	$1.9\ 10^{-4}$	$1.9\ 10^{-4}$	$1.7\ 10^{0}$	$7.5\ 10^{-1}$	$1.6\ 10^{0}$	$7.2\ 10^{-1}$
UK	Berkeley	$1.0\ 10^{-3}$	$6.6\ 10^{-4}$	$5.6\ 10^{-4}$	$4.1\ 10^{-4}$	$8.8\ 10^{-4}$	$5.5\ 10^{-4}$	$7.2\ 10^{-4}$	$4.6\ 10^{-4}$
UK	Bradwell	$8.6\ 10^{-1}$	$5.2\ 10^{-1}$	$5.9\ 10^{-1}$	$3.4\ 10^{-1}$	$4.6\ 10^{-1}$	$2.6\ 10^{-1}$	$6.6\ 10^{-3}$	$3.4\ 10^{-3}$
UK	Calder Hall	$9.1\ 10^{-1}$	$5.2\ 10^{-1}$	$9.8\ 10^{-1}$	$5.5\ 10^{-1}$	$1.4\ 10^{-1}$	$7.4\ 10^{-2}$	$8.8\ 10^{-4}$	$3.9\ 10^{-4}$

UK	Chapelcross	2.5 10^{0}	2.5 10^{0}	3.4 10^{0}	3.4 10^{0}	1.8 10^{0}	1.8 10^{0}	1.3 10^{0}	1.3 10^{0}
UK	Dungeness A	8.6 10^{0}	4.7 10^{0}	9.6 10^{0}	5.2 10^{0}	9.4 10^{0}	5.1 10^{0}	8.3 10^{0}	4.5 10^{0}

Table C1 Cont'd Implied collective doses truncated at 500 y to EU population (man Sv) arising from reported annual atmospheric discharges from all nuclear sites

		1997- total	1997 - first pass	1999- total	1999 - first pass	2002- total	2002 - first pass	2004- total	2004 - first pass
UK	Dungeness B	1.3 10^{0}	7.0 10^{-1}	1.3 10^{0}	6.8 10^{-1}	1.7 10^{0}	9.6 10^{-1}	1.8 10^{0}	1.0 10^{0}
UK	Dounreay	1.4 10^{-2}	1.4 10^{-2}	8.3 10^{-3}	7.9 10^{-3}	7.2 10^{-3}	6.7 10^{-3}	5.1 10^{-3}	4.5 10^{-3}
UK	Hartlepool	4.2 10^{0}	2.2 10^{0}	4.4 10^{0}	2.3 10^{0}	4.6 10^{0}	2.4 10^{0}	3.7 10^{0}	1.9 10^{0}
UK	Hinkley Point A	6.2 10^{0}	3.8 10^{0}	4.9 10^{0}	2.9 10^{0}	7.6 10^{-3}	4.4 10^{-3}	4.6 10^{-3}	2.7 10^{-3}
UK	Hinkley Point B	4.2 10^{0}	2.5 10^{0}	3.6 10^{0}	2.1 10^{0}	3.3 10^{0}	2.0 10^{0}	4.1 10^{0}	2.5 10^{0}
UK	Hunterston A	4.3 10^{-4}	2.1 10^{-4}	5.5 10^{-6}	5.5 10^{-6}	4.3 10^{-4}	2.1 10^{-4}	3.3 10^{-4}	1.6 10^{-4}
UK	Hunterston B	4.1 10^{0}	2.0 10^{0}	4.7 10^{0}	2.2 10^{0}	5.4 10^{0}	2.6 10^{0}	4.6 10^{0}	2.2 10^{0}
UK	Heysham 1	2.6 10^{0}	9.8 10^{-1}	1.4 10^{0}	5.3 10^{-1}	2.6 10^{0}	1.0 10^{0}	1.4 10^{0}	5.2 10^{-1}
UK	Heysham 2	1.6 10^{0}	6.3 10^{-1}	2.2 10^{0}	9.0 10^{-1}	2.6 10^{0}	9.7 10^{-1}	2.8 10^{0}	1.1 10^{0}
UK	Oldbury	1.3 10^{1}	8.3 10^{0}	1.3 10^{1}	8.6 10^{0}	1.5 10^{1}	9.8 10^{0}	5.2 10^{0}	3.3 10^{0}
UK	Selafield	1.2 10^{1}	8.2 10^{0}	1.2 10^{1}	7.3 10^{0}	9.6 10^{0}	6.6 10^{0}	8.0 10^{0}	4.7 10^{0}
UK	Sizewell A	1.4 10^{0}	7.4 10^{-1}	2.8 10^{0}	1.5 10^{0}	3.0 10^{0}	1.6 10^{0}	2.7 10^{0}	1.4 10^{0}
UK	Sizewell B	1.8 10^{-1}	8.9 10^{-2}	5.8 10^{-2}	2.9 10^{-2}	4.6 10^{-1}	2.2 10^{-1}	4.8 10^{-1}	2.3 10^{-1}
UK	Trawsfynydd	2.0 10^{-3}	9.6 10^{-4}	1.8 10^{-3}	7.4 10^{-4}	1.8 10^{-3}	6.8 10^{-4}	2.3 10^{-3}	8.6 10^{-4}
UK	Torness	1.1 10^{0}	4.9 10^{-1}	1.1 10^{0}	4.4 10^{-1}	1.0 10^{0}	3.9 10^{-1}	1.2 10^{0}	4.4 10^{-1}
UK	Winfrith	3.7 10^{-3}	2.8 10^{-3}	3.8 10^{-3}	2.6 10^{-3}	1.7 10^{-3}	1.2 10^{-3}	1.8 10^{-2}	1.7 10^{-2}
UK	Wylfa	2.6 10^{0}	1.0 10^{0}	3.0 10^{0}	1.2 10^{0}	3.0 10^{0}	1.1 10^{0}	2.7 10^{0}	1.0 10^{0}
Total		1.0 10^{2}	6.0 10^{1}	1.0 10^{2}	5.9 10^{1}	1.7 10^{2}	8.6 10^{1}	1.5 10^{2}	7.4 10^{1}

Table C2 Implied collective doses truncated at 500 y to EU population (man Sv) from reported annual atmospheric discharges from Sellafield and Cap de la Hague between the years 1997 and 2004

		1997	1998	1999	2000	2001	2002	2003	2004
Sellafield	Total	12.0	12.8	12.4	11.8	8.6	9.6	8.0	8.0
	First pass	8.2	7.6	7.3	7.1	5.4	6.6	4.9	4.7
Cap de la Hague	Total	11.6	11.9	9.5	7.6	7.0	41.2	40.8	42.0
	First pass	6.2	6.1	4.2	3.4	2.9	16.0	16.0	16.0

Table C3 Implied doses to adult member of representative critical group (μSv y^{-1}) from reported atmospheric discharges from Sellafield and Cap de la Hague between the years of 1997 and 2004

	Sellafield		Cap de la Hague	
	500m	5000m	500m	5000m
1997	$2.0\ 10^{1}$	$9.4\ 10^{0}$	$2.9\ 10^{1}$	$1.2\ 10^{1}$
1998	$1.9\ 10^{1}$	$8.1\ 10^{0}$	$2.7\ 10^{1}$	$1.1\ 10^{1}$
1999	$1.8\ 10^{1}$	$7.7\ 10^{0}$	$1.5\ 10^{1}$	$6.1\ 10^{0}$
2000	$1.8\ 10^{1}$	$7.5\ 10^{0}$	$1.3\ 10^{1}$	$5.1\ 10^{0}$
2001	$1.5\ 10^{1}$	$6.2\ 10^{0}$	$9.4\ 10^{0}$	$3.7\ 10^{0}$
2002	$1.9\ 10^{1}$	$7.7\ 10^{0}$	$1.4\ 10^{1}$	$7.7\ 10^{0}$
2003	$1.3\ 10^{1}$	$5.7\ 10^{0}$	$1.4\ 10^{1}$	$7.5\ 10^{0}$
2004	$1.3\ 10^{1}$	$5.3\ 10^{0}$	$1.4\ 10^{1}$	$7.7\ 10^{0}$

Table C4 Implied doses to adult member of representative critical group (μSv y^{-1}) from reported atmospheric discharges from nuclear sites between the years 1997 and 2004

		Individual doses at 500m from the release point, μSv per year				Individual doses at 5000m from the release point, μSv per year			
		1997	1999	2002	2004	1997	1999	2002	2004
Belgium	Doel	$5.5\ 10^{-3}$	$1.1\ 10^{-1}$	$2.1\ 10^{-2}$	$8.9\ 10^{-3}$	$7.5\ 10^{-4}$	$1.4\ 10^{-2}$	$2.9\ 10^{-3}$	$1.2\ 10^{-3}$
Belgium	Tihange	$3.3\ 10^{-2}$	$3.0\ 10^{-2}$	$3.3\ 10^{-2}$	$5.5\ 10^{-2}$	$9.2\ 10^{-3}$	$1.1\ 10^{-2}$	$9.3\ 10^{-3}$	$1.4\ 10^{-2}$
Finland	Loviisa	$4.8\ 10^{-2}$	$6.3\ 10^{-2}$	$6.4\ 10^{-2}$	$6.6\ 10^{-2}$	$5.3\ 10^{-2}$	$7.4\ 10^{-2}$	$8.4\ 10^{-2}$	$7.4\ 10^{-2}$
Finland	Olkiluooto	$2.2\ 10^{-1}$	$2.5\ 10^{-1}$	$3.1\ 10^{-1}$	$2.7\ 10^{-1}$	$1.5\ 10^{-1}$	$1.7\ 10^{-1}$	$2.1\ 10^{-1}$	$1.8\ 10^{-1}$
France	St Alban	$2.3\ 10^{-1}$	$2.9\ 10^{-1}$	$1.0\ 10^{0}$	$1.2\ 10^{0}$	$3.3\ 10^{-2}$	$4.0\ 10^{-2}$	$1.4\ 10^{-1}$	$1.7\ 10^{-1}$
France	Belleville	$2.7\ 10^{-1}$	$2.1\ 10^{-1}$	$1.1\ 10^{0}$	$1.1\ 10^{0}$	$3.8\ 10^{-2}$	$3.0\ 10^{-2}$	$1.6\ 10^{-1}$	$1.6\ 10^{-1}$
France	Blayais	$8.8\ 10^{-2}$	$3.2\ 10^{-1}$	$1.1\ 10^{0}$	$1.1\ 10^{0}$	$1.3\ 10^{-2}$	$4.7\ 10^{-2}$	$1.9\ 10^{-1}$	$1.8\ 10^{-1}$
France	Bugey B	$8.9\ 10^{-2}$	$9.3\ 10^{-2}$	$1.2\ 10^{0}$	$1.4\ 10^{0}$	$1.1\ 10^{-2}$	$1.1\ 10^{-2}$	$1.7\ 10^{-1}$	$2.1\ 10^{-1}$
France	Cap de la Hague	$2.9\ 10^{1}$	$1.5\ 10^{1}$	$1.4\ 10^{1}$	$1.4\ 10^{1}$	$1.2\ 10^{1}$	$6.1\ 10^{0}$	$7.7\ 10^{0}$	$7.7\ 10^{0}$
France	Cattenom	$1.9\ 10^{-1}$	$1.6\ 10^{-1}$	$2.2\ 10^{0}$	$2.2\ 10^{0}$	$2.6\ 10^{-2}$	$2.1\ 10^{-2}$	$3.1\ 10^{-1}$	$3.1\ 10^{-1}$
France	Chinon B	$2.0\ 10^{-1}$	$2.4\ 10^{-1}$	$1.5\ 10^{0}$	$1.4\ 10^{0}$	$2.7\ 10^{-2}$	$3.2\ 10^{-2}$	$2.1\ 10^{-1}$	$1.9\ 10^{-1}$
France	Chooz B	$1.4\ 10^{-1}$	$6.5\ 10^{-2}$	$1.0\ 10^{0}$	$1.2\ 10^{0}$	$1.8\ 10^{-2}$	$8.0\ 10^{-3}$	$1.5\ 10^{-1}$	$1.7\ 10^{-1}$
France	Civaux	$0.0\ 10^{0}$	$7.6\ 10^{-2}$	$1.1\ 10^{0}$	$1.3\ 10^{0}$	$0.0\ 10^{0}$	$9.3\ 10^{-3}$	$1.5\ 10^{-1}$	$1.9\ 10^{-1}$
France	Creys Malville	$6.9\ 10^{-2}$	$5.7\ 10^{-3}$	$3.0\ 10^{-3}$	$3.1\ 10^{-3}$	$7.4\ 10^{-3}$	$6.2\ 10^{-4}$	$3.3\ 10^{-4}$	$4.1\ 10^{-4}$
France	Cruas	$2.6\ 10^{-2}$	$2.5\ 10^{-2}$	$1.5\ 10^{0}$	$1.4\ 10^{0}$	$2.7\ 10^{-3}$	$2.7\ 10^{-3}$	$2.1\ 10^{-1}$	$1.9\ 10^{-1}$
France	Dampierre	$5.5\ 10^{-2}$	$6.4\ 10^{-2}$	$1.3\ 10^{0}$	$1.3\ 10^{0}$	$7.3\ 10^{-3}$	$8.5\ 10^{-3}$	$1.9\ 10^{-1}$	$1.9\ 10^{-1}$
France	Fessenheim	$8.1\ 10^{-2}$	$9.1\ 10^{-2}$	$5.5\ 10^{-1}$	$6.1\ 10^{-1}$	$1.1\ 10^{-2}$	$1.3\ 10^{-2}$	$7.8\ 10^{-2}$	$8.7\ 10^{-2}$
France	Flamanville	$3.7\ 10^{-2}$	$2.5\ 10^{-2}$	$8.1\ 10^{-2}$	$8.8\ 10^{-2}$	$2.7\ 10^{-2}$	$1.5\ 10^{-2}$	$7.8\ 10^{-2}$	$8.7\ 10^{-2}$
France	Golfech	$4.0\ 10^{-1}$	$3.4\ 10^{-1}$	$1.1\ 10^{0}$	$9.4\ 10^{-1}$	$5.6\ 10^{-2}$	$4.7\ 10^{-2}$	$1.6\ 10^{-1}$	$1.3\ 10^{-1}$
France	Gravelines	$1.9\ 10^{-1}$	$1.9\ 10^{-1}$	$1.5\ 10^{0}$	$1.7\ 10^{0}$	$2.9\ 10^{-2}$	$3.0\ 10^{-2}$	$2.5\ 10^{-1}$	$2.8\ 10^{-1}$
France	St Laurent	$1.3\ 10^{-1}$	$1.2\ 10^{-1}$	$7.3\ 10^{-1}$	$7.2\ 10^{-1}$	$1.8\ 10^{-2}$	$1.6\ 10^{-2}$	$1.0\ 10^{-1}$	$1.0\ 10^{-1}$
France	Marcoule	$3.6\ 10^{0}$	$0.0\ 10^{0}$	$0.0\ 10^{0}$	$0.0\ 10^{0}$	$1.5\ 10^{0}$	$0.0\ 10^{0}$	$0.0\ 10^{0}$	$0.0\ 10^{0}$
France	Nogent	$9.7\ 10^{-2}$	$9.7\ 10^{-2}$	$1.1\ 10^{0}$	$1.2\ 10^{0}$	$1.3\ 10^{-2}$	$1.3\ 10^{-2}$	$1.5\ 10^{-1}$	$1.6\ 10^{-1}$
France	Paluel	$2.1\ 10^{-1}$	$2.0\ 10^{-1}$	$1.5\ 10^{0}$	$1.4\ 10^{0}$	$3.5\ 10^{-2}$	$3.3\ 10^{-2}$	$2.5\ 10^{-1}$	$2.4\ 10^{-1}$
France	Penly	$1.2\ 10^{-2}$	$9.4\ 10^{-3}$	$8.1\ 10^{-2}$	$9.1\ 10^{-2}$	$8.7\ 10^{-3}$	$7.7\ 10^{-3}$	$7.8\ 10^{-2}$	$8.9\ 10^{-2}$

Table C4 Cont'd Implied doses to adult member of representative critical group (µSv y^{-1}) from reported atmospheric discharges from nuclear sites between the years 1997 and 2004

		Individual doses at 500m from the release point, µSv per year				Individual doses at 5000m from the release point, µSv per year			
		1997	1999	2002	2004	1997	1999	2002	2004
France	Tricastin	$1.1\ 10^{-1}$	$8.3\ 10^{-2}$	$1.4\ 10^{0}$	$1.3\ 10^{0}$	$1.3\ 10^{-2}$	$1.0\ 10^{-2}$	$2.0\ 10^{-1}$	$1.9\ 10^{-1}$
Germany	Biblis A	$1.3\ 10^{-1}$	$1.3\ 10^{-1}$	$1.3\ 10^{-1}$	$5.5\ 10^{-2}$	$5.9\ 10^{-2}$	$5.9\ 10^{-2}$	$6.1\ 10^{-2}$	$2.5\ 10^{-2}$
Germany	Biblis B	$1.3\ 10^{-1}$	$4.3\ 10^{-2}$	$8.4\ 10^{-2}$	$1.3\ 10^{-1}$	$6.3\ 10^{-2}$	$2.0\ 10^{-2}$	$3.9\ 10^{-2}$	$5.9\ 10^{-2}$
Germany	Brokdorf	$8.0\ 10^{-1}$	$6.9\ 10^{-1}$	$7.5\ 10^{-1}$	$6.6\ 10^{-1}$	$1.1\ 10^{-1}$	$9.8\ 10^{-2}$	$1.1\ 10^{-1}$	$9.5\ 10^{-2}$
Germany	Brunsbuttel	$6.5\ 10^{-2}$	$1.2\ 10^{-1}$	$7.2\ 10^{-2}$	$1.2\ 10^{-1}$	$2.8\ 10^{-2}$	$5.4\ 10^{-2}$	$3.3\ 10^{-2}$	$5.2\ 10^{-2}$
Germany	Emsland	$1.1\ 10^{-1}$	$3.0\ 10^{-1}$	$1.7\ 10^{-1}$	$1.1\ 10^{-1}$	$5.1\ 10^{-2}$	$1.4\ 10^{-1}$	$8.0\ 10^{-2}$	$5.2\ 10^{-2}$
Germany	Grafenrheinfeld	$4.0\ 10^{-2}$	$2.2\ 10^{-2}$	$1.1\ 10^{-1}$	$1.3\ 10^{-1}$	$1.9\ 10^{-2}$	$1.0\ 10^{-2}$	$5.1\ 10^{-2}$	$6.3\ 10^{-2}$
Germany	Greifswald	$9.2\ 10^{-3}$	$1.0\ 10^{-3}$	$1.9\ 10^{-3}$	$3.5\ 10^{-4}$	$3.1\ 10^{-3}$	$1.4\ 10^{-4}$	$2.7\ 10^{-4}$	$4.9\ 10^{-5}$
Germany	Grohnde	$2.7\ 10^{-3}$	$1.4\ 10^{-1}$	$1.5\ 10^{-1}$	$1.3\ 10^{-1}$	$1.2\ 10^{-3}$	$6.5\ 10^{-2}$	$7.1\ 10^{-2}$	$6.1\ 10^{-2}$
Germany	Gundremmingen A	$7.4\ 10^{-4}$	$1.1\ 10^{-4}$	$3.6\ 10^{-5}$	$5.9\ 10^{-5}$	$2.6\ 10^{-4}$	$5.1\ 10^{-5}$	$8.1\ 10^{-6}$	$2.8\ 10^{-5}$
Germany	Gundremmingen B+C	$5.0\ 10^{-1}$	$3.8\ 10^{-1}$	$4.2\ 10^{-1}$	$3.4\ 10^{-1}$	$2.3\ 10^{-1}$	$1.8\ 10^{-1}$	$1.9\ 10^{-1}$	$1.6\ 10^{-1}$
Germany	Isar 1	$7.5\ 10^{-2}$	$1.2\ 10^{-1}$	$1.3\ 10^{-1}$	$1.4\ 10^{-1}$	$3.4\ 10^{-2}$	$5.7\ 10^{-2}$	$6.1\ 10^{-2}$	$6.7\ 10^{-2}$
Germany	Isar 2	$2.2\ 10^{-1}$	$2.3\ 10^{-1}$	$1.9\ 10^{-1}$	$1.1\ 10^{-1}$	$1.0\ 10^{-1}$	$1.1\ 10^{-1}$	$8.8\ 10^{-2}$	$5.3\ 10^{-2}$
Germany	Krummel	$1.8\ 10^{-1}$	$2.1\ 10^{-1}$	$5.8\ 10^{-2}$	$7.6\ 10^{-2}$	$7.1\ 10^{-2}$	$9.7\ 10^{-2}$	$2.4\ 10^{-2}$	$3.5\ 10^{-2}$
Germany	Lingen	$2.1\ 10^{-4}$	$3.3\ 10^{-4}$	$2.8\ 10^{-4}$	$2.7\ 10^{-4}$	$9.7\ 10^{-5}$	$1.5\ 10^{-4}$	$1.3\ 10^{-4}$	$1.3\ 10^{-4}$
Germany	Mulheim-Karlich	$1.1\ 10^{-3}$	$3.0\ 10^{-4}$	$1.2\ 10^{-2}$	$3.3\ 10^{-4}$	$5.0\ 10^{-4}$	$1.4\ 10^{-4}$	$5.8\ 10^{-3}$	$1.5\ 10^{-4}$
Germany	Neckarwestheim 1	$9.8\ 10^{-3}$	$1.0\ 10^{-1}$	$9.9\ 10^{-2}$	$1.2\ 10^{-1}$	$2.7\ 10^{-3}$	$4.7\ 10^{-2}$	$4.5\ 10^{-2}$	$5.5\ 10^{-2}$
Germany	Neckarwestheim 2	$8.8\ 10^{-2}$	$1.1\ 10^{-1}$	$9.2\ 10^{-2}$	$1.8\ 10^{-1}$	$4.1\ 10^{-2}$	$5.3\ 10^{-2}$	$4.3\ 10^{-2}$	$8.2\ 10^{-2}$
Germany	Obrigheim	$8.0\ 10^{-2}$	$1.1\ 10^{-1}$	$1.4\ 10^{-1}$	$1.1\ 10^{-1}$	$1.1\ 10^{-2}$	$1.6\ 10^{-2}$	$2.0\ 10^{-2}$	$1.6\ 10^{-2}$
Germany	Philippsburg 1	$2.1\ 10^{-1}$	$2.6\ 10^{-1}$	$2.3\ 10^{-1}$	$1.8\ 10^{-1}$	$9.9\ 10^{-2}$	$1.2\ 10^{-1}$	$1.1\ 10^{-1}$	$8.3\ 10^{-2}$
Germany	Philippsburg 2	$5.9\ 10^{-1}$	$4.3\ 10^{-1}$	$5.1\ 10^{-1}$	$4.0\ 10^{-1}$	$8.4\ 10^{-2}$	$6.1\ 10^{-2}$	$7.2\ 10^{-2}$	$5.6\ 10^{-2}$
Germany	Rhiensberg	$1.3\ 10^{-4}$	$2.9\ 10^{-5}$	$1.0\ 10^{-4}$	$1.8\ 10^{-4}$	$2.0\ 10^{-5}$	$4.1\ 10^{-6}$	$3.3\ 10^{-5}$	$4.7\ 10^{-5}$
Germany	Stade	$2.6\ 10^{-1}$	$4.5\ 10^{-1}$	$2.4\ 10^{-1}$	$4.7\ 10^{-1}$	$3.7\ 10^{-2}$	$6.4\ 10^{-2}$	$3.4\ 10^{-2}$	$6.7\ 10^{-2}$
Germany	THTR 300	$1.3\ 10^{-5}$	$2.3\ 10^{-6}$	$5.9\ 10^{-7}$	$5.9\ 10^{-7}$	$6.2\ 10^{-6}$	$1.1\ 10^{-6}$	$2.7\ 10^{-7}$	$2.7\ 10^{-7}$
Germany	Unterweser	$2.1\ 10^{-2}$	$1.9\ 10^{-2}$	$3.2\ 10^{-2}$	$1.9\ 10^{-2}$	$8.4\ 10^{-3}$	$8.0\ 10^{-3}$	$1.4\ 10^{-2}$	$8.1\ 10^{-3}$

Table C4 Cont'd Implied doses to adult member of representative critical group (μSv y^{-1}) from reported atmospheric discharges from nuclear sites between the years 1997 and 2004

		Individual doses at 500m from the release point, μSv per year				Individual doses at 5000m from the release point, μSv per year			
		1997	1999	2002	2004	1997	1999	2002	2004
Germany	Karlsuhe WAK	$2.4\ 10^{-2}$	$4.3\ 10^{-2}$	$2.0\ 10^{-2}$	$1.8\ 10^{-2}$	$1.1\ 10^{-2}$	$1.9\ 10^{-2}$	$8.3\ 10^{-3}$	$7.5\ 10^{-3}$
Germany	Wurgassen	$6.4\ 10^{-3}$	$2.7\ 10^{-3}$	$5.6\ 10^{-3}$	$3.0\ 10^{-3}$	$7.9\ 10^{-4}$	$3.2\ 10^{-4}$	$7.9\ 10^{-4}$	$4.2\ 10^{-4}$
Netherlands	Borssele	$1.1\ 10^{-1}$	$1.3\ 10^{-1}$	$2.3\ 10^{-1}$	$1.7\ 10^{-1}$	$1.5\ 10^{-2}$	$1.7\ 10^{-2}$	$3.1\ 10^{-2}$	$2.3\ 10^{-2}$
Netherlands	Dodewaard	$3.7\ 10^{-2}$	$1.3\ 10^{-3}$	$1.5\ 10^{-4}$	$3.4\ 10^{-5}$	$4.4\ 10^{-3}$	$2.2\ 10^{-4}$	$5.8\ 10^{-5}$	$1.4\ 10^{-5}$
Spain	Almaraz	$1.2\ 10^{-1}$	$1.2\ 10^{-1}$	$1.2\ 10^{-1}$	$6.4\ 10^{-2}$	$2.1\ 10^{-2}$	$2.2\ 10^{-2}$	$2.5\ 10^{-2}$	$1.3\ 10^{-2}$
Spain	Asco	$3.4\ 10^{-2}$	$5.9\ 10^{-2}$	$4.3\ 10^{-2}$	$5.6\ 10^{-2}$	$6.6\ 10^{-3}$	$1.0\ 10^{-2}$	$8.4\ 10^{-3}$	$1.0\ 10^{-2}$
Spain	Cofrentes	$7.6\ 10^{-2}$	$3.4\ 10^{-2}$	$1.8\ 10^{-1}$	$2.9\ 10^{-1}$	$1.1\ 10^{-2}$	$4.9\ 10^{-3}$	$3.0\ 10^{-2}$	$4.4\ 10^{-2}$
Spain	Jose Cabrera	$3.7\ 10^{-2}$	$1.1\ 10^{-2}$	$1.4\ 10^{-2}$	$5.1\ 10^{-2}$	$4.9\ 10^{-3}$	$1.0\ 10^{-3}$	$1.2\ 10^{-3}$	$3.9\ 10^{-3}$
spain	Sta Maria de Garona	$5.5\ 10^{-3}$	$8.0\ 10^{-3}$	$6.1\ 10^{-3}$	$8.8\ 10^{-3}$	$1.0\ 10^{-3}$	$1.5\ 10^{-3}$	$1.2\ 10^{-3}$	$1.7\ 10^{-3}$
Spain	Trillo	$1.4\ 10^{-1}$	$1.5\ 10^{-1}$	$6.9\ 10^{-2}$	$6.0\ 10^{-2}$	$2.8\ 10^{-2}$	$2.9\ 10^{-2}$	$1.4\ 10^{-2}$	$1.2\ 10^{-2}$
Spain	Vandellos 1	$1.5\ 10^{-4}$	$1.7\ 10^{-5}$	$0.0\ 10^{0}$	$0.0\ 10^{0}$	$3.0\ 10^{-5}$	$2.6\ 10^{-6}$	$0.0\ 10^{0}$	$0.0\ 10^{0}$
Spain	Vandellos 2	$7.6\ 10^{-3}$	$1.5\ 10^{-2}$	$8.1\ 10^{-3}$	$2.3\ 10^{-3}$	$1.4\ 10^{-3}$	$2.7\ 10^{-3}$	$1.5\ 10^{-3}$	$4.5\ 10^{-4}$
Sweden	Barseback	$1.7\ 10^{-2}$	$3.8\ 10^{-2}$	$1.8\ 10^{-1}$	$2.5\ 10^{-1}$	$1.8\ 10^{-3}$	$4.2\ 10^{-3}$	$1.1\ 10^{-1}$	$1.1\ 10^{-1}$
Sweden	Fosmark	$7.9\ 10^{-2}$	$6.8\ 10^{-3}$	$1.0\ 10^{0}$	$8.2\ 10^{-1}$	$1.5\ 10^{-2}$	$1.8\ 10^{-3}$	$6.5\ 10^{-1}$	$5.4\ 10^{-1}$
Sweden	Oskarshamn	$1.3\ 10^{0}$	$1.1\ 10^{-1}$	$2.1\ 10^{0}$	$1.8\ 10^{0}$	$1.2\ 10^{-1}$	$1.3\ 10^{-2}$	$4.0\ 10^{-1}$	$3.5\ 10^{-1}$
Sweden	Ringhals 1	$3.2\ 10^{0}$	$7.0\ 10^{-1}$	$2.7\ 10^{-1}$	$2.0\ 10^{-1}$	$3.3\ 10^{-1}$	$7.8\ 10^{-2}$	$1.3\ 10^{-1}$	$1.2\ 10^{-1}$
Sweden	Ringhals 2	$9.3\ 10^{-3}$	$1.3\ 10^{-2}$	$1.4\ 10^{0}$	$1.5\ 10^{0}$	$1.2\ 10^{-3}$	$1.7\ 10^{-3}$	$3.1\ 10^{-1}$	$3.4\ 10^{-1}$
UK	Berkeley	$2.6\ 10^{-3}$	$3.2\ 10^{-3}$	$1.9\ 10^{-3}$	$1.8\ 10^{-3}$	$1.2\ 10^{-4}$	$1.5\ 10^{-4}$	$9.2\ 10^{-5}$	$8.6\ 10^{-5}$
UK	Bradwell	$1.5\ 10^{1}$	$8.2\ 10^{0}$	$5.7\ 10^{0}$	$2.2\ 10^{-2}$	$7.4\ 10^{-1}$	$4.1\ 10^{-1}$	$3.0\ 10^{-1}$	$1.1\ 10^{-3}$
UK	Calder Hall	$5.5\ 10^{1}$	$5.6\ 10^{1}$	$7.1\ 10^{0}$	$7.4\ 10^{-3}$	$2.7\ 10^{0}$	$2.7\ 10^{0}$	$3.4\ 10^{-1}$	$3.7\ 10^{-4}$
UK	Chapelcross	$1.2\ 10^{2}$	$1.4\ 10^{2}$	$7.0\ 10^{1}$	$3.8\ 10^{1}$	$5.6\ 10^{0}$	$6.8\ 10^{0}$	$3.3\ 10^{0}$	$1.8\ 10^{0}$
UK	Dungeness A	$4.2\ 10^{1}$	$4.8\ 10^{1}$	$4.6\ 10^{1}$	$4.0\ 10^{1}$	$2.0\ 10^{0}$	$2.3\ 10^{0}$	$2.2\ 10^{0}$	$2.0\ 10^{0}$
UK	Dungeness B	$4.1\ 10^{0}$	$3.4\ 10^{0}$	$6.7\ 10^{0}$	$6.7\ 10^{0}$	$2.1\ 10^{-1}$	$1.7\ 10^{-1}$	$3.5\ 10^{-1}$	$3.5\ 10^{-1}$
UK	Dounreay	$5.7\ 10^{-1}$	$3.7\ 10^{-1}$	$3.5\ 10^{-1}$	$2.6\ 10^{-1}$	$8.7\ 10^{-2}$	$5.5\ 10^{-2}$	$5.3\ 10^{-2}$	$3.8\ 10^{-2}$
UK	Hartlepool	$1.2\ 10^{1}$	$1.2\ 10^{1}$	$1.6\ 10^{1}$	$1.2\ 10^{1}$	$6.1\ 10^{-1}$	$5.8\ 10^{-1}$	$8.4\ 10^{-1}$	$6.3\ 10^{-1}$

Table C4 Cont'd Implied doses to adult member of representative critical group (μSv y^{-1}) from reported atmospheric discharges from nuclear sites between the years 1997 and 2004

		Individual doses at 500m from the release point, μSv per year				Individual doses at 5000m from the release point, μSv per year			
		1997	1999	2002	2004	1997	1999	2002	2004
UK	Hinkley Point A	$7.3\ 10^{1}$	$3.3\ 10^{1}$	$1.9\ 10^{-2}$	$1.4\ 10^{-2}$	$3.5\ 10^{0}$	$1.6\ 10^{0}$	$9.2\ 10^{-4}$	$6.7\ 10^{-4}$
UK	Hinkley Point B	$1.2\ 10^{1}$	$9.2\ 10^{0}$	$1.2\ 10^{1}$	$1.5\ 10^{1}$	$6.4\ 10^{-1}$	$4.6\ 10^{-1}$	$6.7\ 10^{-1}$	$8.3\ 10^{-1}$
UK	Hunterston A	$1.5\ 10^{-3}$	$9.3\ 10^{-5}$	$1.3\ 10^{-3}$	$9.8\ 10^{-4}$	$7.1\ 10^{-5}$	$5.8\ 10^{-6}$	$6.2\ 10^{-5}$	$4.8\ 10^{-5}$
UK	Hunterston B	$1.7\ 10^{1}$	$1.4\ 10^{1}$	$1.8\ 10^{1}$	$1.3\ 10^{1}$	$9.1\ 10^{-1}$	$6.9\ 10^{-1}$	$9.1\ 10^{-1}$	$6.5\ 10^{-1}$
UK	Heysham 1	$9.4\ 10^{0}$	$5.3\ 10^{0}$	$9.6\ 10^{0}$	$5.1\ 10^{0}$	$4.6\ 10^{-1}$	$2.7\ 10^{-1}$	$4.8\ 10^{-1}$	$2.5\ 10^{-1}$
UK	Heysham 2	$6.4\ 10^{0}$	$1.0\ 10^{1}$	$9.1\ 10^{0}$	$1.0\ 10^{1}$	$3.1\ 10^{-1}$	$5.4\ 10^{-1}$	$4.5\ 10^{-1}$	$4.9\ 10^{-1}$
UK	Oldbury	$3.8\ 10^{1}$	$4.2\ 10^{1}$	$4.8\ 10^{1}$	$1.5\ 10^{1}$	$2.0\ 10^{0}$	$2.2\ 10^{0}$	$2.5\ 10^{0}$	$7.8\ 10^{-1}$
UK	Selafield	$2.0\ 10^{1}$	$1.8\ 10^{1}$	$1.9\ 10^{1}$	$1.3\ 10^{1}$	$9.4\ 10^{0}$	$7.7\ 10^{0}$	$7.7\ 10^{0}$	$5.3\ 10^{0}$
UK	Sizewell A	$2.8\ 10^{1}$	$4.4\ 10^{1}$	$4.8\ 10^{1}$	$3.8\ 10^{1}$	$1.4\ 10^{0}$	$2.2\ 10^{0}$	$2.4\ 10^{0}$	$1.9\ 10^{0}$
UK	Sizewell B	$5.3\ 10^{-1}$	$3.2\ 10^{-1}$	$1.3\ 10^{0}$	$1.4\ 10^{0}$	$2.5\ 10^{-2}$	$1.5\ 10^{-2}$	$6.5\ 10^{-2}$	$6.5\ 10^{-2}$
UK	Trawsfynydd	$2.3\ 10^{-2}$	$1.2\ 10^{-2}$	$8.7\ 10^{-3}$	$1.1\ 10^{-2}$	$1.1\ 10^{-3}$	$5.6\ 10^{-4}$	$4.2\ 10^{-4}$	$5.1\ 10^{-4}$
UK	Torness	$2.0\ 10^{1}$	$4.8\ 10^{0}$	$4.4\ 10^{0}$	$4.6\ 10^{0}$	$1.2\ 10^{0}$	$2.4\ 10^{-1}$	$2.2\ 10^{-1}$	$2.4\ 10^{-1}$
UK	Winfrith	$2.7\ 10^{-2}$	$1.5\ 10^{-2}$	$8.2\ 10^{-3}$	$2.6\ 10^{-1}$	$1.3\ 10^{-3}$	$7.4\ 10^{-4}$	$3.9\ 10^{-4}$	$1.3\ 10^{-2}$
UK	Wylfa	$1.8\ 10^{1}$	$2.3\ 10^{1}$	$1.9\ 10^{1}$	$1.7\ 10^{1}$	$1.0\ 10^{0}$	$1.3\ 10^{0}$	$1.0\ 10^{0}$	$9.5\ 10^{-1}$

APPENDIX D Detailed results for liquid discharges

Table D1 Implied collective doses truncated at 500 y to EU population (man Sv) from reported annual liquid releases

Point of discharge	Site name	1997		1999		2002		2004	
		Total Marine	Total dose*	Total Marine	Total dose*	Total Marine	Total dose*	Total Marine	Total dose*
Mediterranean Sea									
Danube estuary	Gundremmingen (i)	$4.3\ 10^{-5}$	$6.2\ 10^{-4}$	$3.1\ 10^{-5}$	$3.2\ 10^{-4}$	$2.1\ 10^{-5}$	$2.9\ 10^{-4}$	$2.7\ 10^{-5}$	$4.3\ 10^{-4}$
(Agean sea)	Isar 1 (i)	$4.8\ 10^{-6}$	$2.0\ 10^{-5}$	$8.4\ 10^{-7}$	$5.2\ 10^{-6}$	$9.8\ 10^{-7}$	$5.4\ 10^{-6}$	$1.4\ 10^{-6}$	$8.1\ 10^{-6}$
	Isar 2 (i)	$3.9\ 10^{-5}$	$2.5\ 10^{-4}$	$5.4\ 10^{-5}$	$3.5\ 10^{-4}$	$4.3\ 10^{-5}$	$2.8\ 10^{-4}$	$4.1\ 10^{-5}$	$2.6\ 10^{-4}$
Rhone estuary	Creys Malville (i)	$6.9\ 10^{-9}$	$1.8\ 10^{-6}$	$3.3\ 10^{-9}$	$1.1\ 10^{-6}$	$1.8\ 10^{-7}$	$1.3\ 10^{-5}$	$1.3\ 10^{-7}$	$1.7\ 10^{-6}$
(Golf Of Lions)	Bugey B (i)	$1.9\ 10^{-4}$	$2.4\ 10^{-2}$	$9.2\ 10^{-5}$	$2.1\ 10^{-2}$	$2.2\ 10^{-2}$	$4.7\ 10^{-2}$	$2.6\ 10^{-2}$	$5.5\ 10^{-2}$
	St Alban (i)	$5.4\ 10^{-5}$	$1.3\ 10^{-3}$	$7.7\ 10^{-5}$	$2.5\ 10^{-3}$	$1.8\ 10^{-2}$	$2.1\ 10^{-2}$	$2.1\ 10^{-2}$	$2.4\ 10^{-2}$
	Cruas (i)	$1.4\ 10^{-4}$	$1.8\ 10^{-3}$	$7.7\ 10^{-5}$	$2.1\ 10^{-3}$	$2.6\ 10^{-2}$	$2.9\ 10^{-2}$	$2.5\ 10^{-2}$	$2.7\ 10^{-2}$
	Tricastin (i)	$1.3\ 10^{-4}$	$1.4\ 10^{-3}$	$1.4\ 10^{-4}$	$1.2\ 10^{-3}$	$2.6\ 10^{-2}$	$2.8\ 10^{-2}$	$2.5\ 10^{-2}$	$2.6\ 10^{-2}$
	Marcoule (i)	$4.6\ 10^{-6}$	$1.4\ 10^{-5}$	$3.1\ 10^{-5}$	$4.5\ 10^{-5}$	$3.7\ 10^{-6}$	$2.3\ 10^{-5}$	$2.0\ 10^{-6}$	$1.2\ 10^{-5}$
Ebro estuary	Santa Maria de Garona (i)	$2.9\ 10^{-6}$	$4.1\ 10^{-5}$	$4.9\ 10^{-5}$	$1.0\ 10^{-4}$	$5.3\ 10^{-6}$	$8.3\ 10^{-5}$	$5.9\ 10^{-6}$	$4.6\ 10^{-5}$
(Liguro Povencal Basin (1))	Asco (i)	$3.1\ 10^{-4}$	$5.0\ 10^{-4}$	$4.3\ 10^{-4}$	$7.2\ 10^{-4}$	$4.1\ 10^{-4}$	$7.2\ 10^{-4}$	$8.2\ 10^{-4}$	$1.0\ 10^{-3}$
	Vandellos 1 (c)	$3.8\ 10^{-3}$	$3.8\ 10^{-3}$	$1.3\ 10^{-3}$	$1.3\ 10^{-3}$	$2.1\ 10^{-4}$	$2.1\ 10^{-4}$	$0.0\ 10^{0}$	$0.0\ 10^{0}$
	Vandellos 2 (c)	$7.2\ 10^{-4}$	$7.2\ 10^{-4}$	$6.6\ 10^{-4}$	$6.6\ 10^{-4}$	$5.8\ 10^{-4}$	$5.8\ 10^{-4}$	$3.0\ 10^{-4}$	$3.0\ 10^{-4}$
Jucar estuary	Cofrentes (i)	$9.2\ 10^{-6}$	$1.6\ 10^{-5}$	$1.5\ 10^{-5}$	$1.7\ 10^{-5}$	$1.9\ 10^{-5}$	$4.6\ 10^{-5}$	$4.1\ 10^{-7}$	$1.0\ 10^{-6}$
(Liguro Povencal Basin (2))									

Table D1 Cont'd Implied collective doses truncated at 500 y to EU population (man Sv) from reported annual liquid releases

Point of discharge	Site name	1997		1999		2002		2004	
		Total Marine	Total dose*	Total Marine	Total dose*	Total Marine	Total dose*	Total Marine	Total dose*
NE Atlantic (Europe excluding UK)									
Loire estuary	Belleville (i)	$5.1\ 10^{-4}$	$8.1\ 10^{-3}$	$5.4\ 10^{-4}$	$7.9\ 10^{-3}$	$2.5\ 10^{-2}$	$3.6\ 10^{-2}$	$2.5\ 10^{-2}$	$3.8\ 10^{-2}$
(French Continental Shelf (1))	Dampierre (i)	$1.4\ 10^{-3}$	$1.0\ 10^{-2}$	$6.9\ 10^{-4}$	$9.9\ 10^{-3}$	$3.0\ 10^{-2}$	$4.0\ 10^{-2}$	$3.1\ 10^{-2}$	$4.2\ 10^{-2}$
	St Luarent B (i)	$4.9\ 10^{-4}$	$3.6\ 10^{-3}$	$2.5\ 10^{-4}$	$4.6\ 10^{-3}$	$1.7\ 10^{-2}$	$2.2\ 10^{-2}$	$1.7\ 10^{-2}$	$2.2\ 10^{-2}$
	Civaux (i)	$0.0\ 10^{0}$	$0.0\ 10^{0}$	$8.2\ 10^{-5}$	$1.4\ 10^{-3}$	$2.5\ 10^{-2}$	$3.2\ 10^{-2}$	$3.0\ 10^{-2}$	$4.2\ 10^{-2}$
	Chinon B (i)	$1.2\ 10^{-3}$	$9.3\ 10^{-3}$	$2.4\ 10^{-4}$	$5.8\ 10^{-3}$	$3.5\ 10^{-2}$	$4.1\ 10^{-2}$	$3.3\ 10^{-2}$	$3.8\ 10^{-2}$
Gironde estuary	Blayais (c)	$5.9\ 10^{-4}$	$5.9\ 10^{-4}$	$4.4\ 10^{-4}$	$4.4\ 10^{-4}$	$3.8\ 10^{-2}$	$3.8\ 10^{-2}$	$3.6\ 10^{-2}$	$3.6\ 10^{-2}$
(French Continental shelf (2))	Golfech (i)	$2.5\ 10^{-4}$	$5.0\ 10^{-3}$	$1.3\ 10^{-4}$	$3.4\ 10^{-3}$	$2.6\ 10^{-2}$	$3.6\ 10^{-2}$	$2.2\ 10^{-2}$	$3.1\ 10^{-2}$
English Channel South East (1)	Flamanville (c)	$2.1\ 10^{-4}$	$2.1\ 10^{-4}$	$1.6\ 10^{-4}$	$1.6\ 10^{-4}$	$1.6\ 10^{-2}$	$1.6\ 10^{-2}$	$1.7\ 10^{-2}$	$1.7\ 10^{-2}$
English Channel South East (1)	Cap de la Hague (c)	$1.1\ 10^{1}$	$1.1\ 10^{1}$	$1.0\ 10^{1}$	$1.0\ 10^{1}$	$8.2\ 10^{0}$	$8.2\ 10^{0}$	$9.2\ 10^{0}$	$9.2\ 10^{0}$
Seine estuary	Paluel (c)	$1.2\ 10^{-3}$	$1.2\ 10^{-3}$	$1.3\ 10^{-3}$	$1.3\ 10^{-3}$	$7.4\ 10^{-2}$	$7.4\ 10^{-2}$	$7.0\ 10^{-2}$	$7.0\ 10^{-2}$
(English Channel South East (2))	Penly (c)	$6.4\ 10^{-4}$	$6.4\ 10^{-4}$	$2.5\ 10^{-4}$	$2.5\ 10^{-4}$	$3.4\ 10^{-2}$	$3.4\ 10^{-2}$	$3.9\ 10^{-2}$	$3.9\ 10^{-2}$
	Nogent (i)	$4.3\ 10^{-4}$	$5.2\ 10^{-2}$	$2.3\ 10^{-4}$	$1.2\ 10^{-1}$	$3.6\ 10^{-2}$	$1.6\ 10^{-1}$	$3.3\ 10^{-2}$	$1.6\ 10^{-1}$
North Sea South East (1)	Gravelines (c)	$8.9\ 10^{-4}$	$8.9\ 10^{-4}$	$9.2\ 10^{-4}$	$9.2\ 10^{-4}$	$6.0\ 10^{-2}$	$6.0\ 10^{-2}$	$6.8\ 10^{-2}$	$6.8\ 10^{-2}$

Table D1 Cont'd Implied collective doses truncated at 500 y to EU population (man Sv) from reported annual liquid releases

Point of discharge	Site name	1997		1999		2002		2004	
		Total Marine	Total dose*	Total Marine	Total dose*	Total Marine	Total dose*	Total Marine	Total dose*
Rhine and Meuse estuary	BiblisA (i)	$3.3\ 10^{-6}$	$1.6\ 10^{-3}$	$3.3\ 10^{-5}$	$2.0\ 10^{-2}$	$3.8\ 10^{-5}$	$2.1\ 10^{-2}$	$3.5\ 10^{-5}$	$2.1\ 10^{-2}$
North Sea South East (2)	BiblisB (i)	$2.6\ 10^{-5}$	$1.5\ 10^{-2}$	$3.4\ 10^{-5}$	$2.0\ 10^{-2}$	$3.2\ 10^{-5}$	$1.8\ 10^{-2}$	$2.3\ 10^{-5}$	$1.3\ 10^{-2}$
	Grafenrheinfeld (i)	$3.3\ 10^{-5}$	$1.3\ 10^{-1}$	$2.9\ 10^{-5}$	$1.1\ 10^{-1}$	$4.3\ 10^{-5}$	$1.7\ 10^{-1}$	$3.5\ 10^{-5}$	$1.4\ 10^{-1}$
	KarlsruheWAK (i)	$1.2\ 10^{-5}$	$7.7\ 10^{-3}$	$2.5\ 10^{-5}$	$1.6\ 10^{-2}$	$2.5\ 10^{-6}$	$1.6\ 10^{-3}$	$1.9\ 10^{-6}$	$1.2\ 10^{-3}$
	Mulheim-Karlich (i)	$3.8\ 10^{-7}$	$2.1\ 10^{-4}$	$2.6\ 10^{-8}$	$1.1\ 10^{-5}$	$6.9\ 10^{-8}$	$1.7\ 10^{-5}$	$4.0\ 10^{-8}$	$8.8\ 10^{-6}$
	Neckar1 (i)	$2.8\ 10^{-5}$	$2.4\ 10^{-2}$	$1.4\ 10^{-5}$	$1.1\ 10^{-2}$	$2.4\ 10^{-5}$	$2.0\ 10^{-2}$	$1.5\ 10^{-5}$	$1.3\ 10^{-2}$
	Neckar2 (i)	$3.9\ 10^{-5}$	$3.2\ 10^{-2}$	$3.4\ 10^{-5}$	$2.9\ 10^{-2}$	$3.5\ 10^{-5}$	$2.9\ 10^{-2}$	$3.6\ 10^{-5}$	$3.0\ 10^{-2}$
	Obrigheim (i)	$1.7\ 10^{-5}$	$7.6\ 10^{-3}$	$2.9\ 10^{-5}$	$9.1\ 10^{-3}$	$1.4\ 10^{-5}$	$8.7\ 10^{-3}$	$1.4\ 10^{-5}$	$9.3\ 10^{-3}$
	Philippsburg1 (i)	$5.5\ 10^{-5}$	$7.5\ 10^{-4}$	$1.8\ 10^{-5}$	$7.9\ 10^{-4}$	$1.7\ 10^{-5}$	$6.1\ 10^{-4}$	$1.4\ 10^{-5}$	$6.1\ 10^{-4}$
	Philippsburg2 (i)	$4.2\ 10^{-5}$	$2.0\ 10^{-2}$	$3.8\ 10^{-5}$	$2.3\ 10^{-2}$	$3.4\ 10^{-5}$	$2.0\ 10^{-2}$	$3.1\ 10^{-5}$	$1.9\ 10^{-2}$
	Cattenom (i)	$2.0\ 10^{-4}$	$9.3\ 10^{-2}$	$2.3\ 10^{-4}$	$1.1\ 10^{-1}$	$5.2\ 10^{-2}$	$1.7\ 10^{-1}$	$5.1\ 10^{-2}$	$1.8\ 10^{-1}$
	ChoozB (i)	$7.9\ 10^{-5}$	$4.8\ 10^{-4}$	$1.5\ 10^{-4}$	$7.6\ 10^{-4}$	$2.7\ 10^{-2}$	$2.8\ 10^{-2}$	$3.1\ 10^{-2}$	$3.2\ 10^{-2}$
	Fessenheim (i)	$1.5\ 10^{-4}$	$3.3\ 10^{-2}$	$2.0\ 10^{-4}$	$3.1\ 10^{-2}$	$1.3\ 10^{-2}$	$3.8\ 10^{-2}$	$1.5\ 10^{-2}$	$5.0\ 10^{-2}$
	Dodewaard (i)	$1.5\ 10^{-4}$	$4.3\ 10^{-4}$	$1.1\ 10^{-4}$	$3.0\ 10^{-4}$	$2.1\ 10^{-5}$	$6.0\ 10^{-5}$	$1.3\ 10^{-4}$	$3.7\ 10^{-4}$
	Doel (c)	$9.2\ 10^{-4}$	$9.2\ 10^{-4}$	$7.1\ 10^{-4}$	$7.1\ 10^{-4}$	$3.0\ 10^{-4}$	$3.0\ 10^{-4}$	$4.9\ 10^{-4}$	$4.9\ 10^{-4}$
	Tihange (i)	$8.8\ 10^{-4}$	$2.1\ 10^{-3}$	$2.3\ 10^{-4}$	$1.9\ 10^{-3}$	$3.5\ 10^{-4}$	$1.9\ 10^{-3}$	$4.8\ 10^{-4}$	$1.7\ 10^{-3}$
	Borssele(c)	$5.8\ 10^{-5}$	$5.8\ 10^{-5}$	$2.3\ 10^{-5}$	$2.3\ 10^{-5}$	$2.4\ 10^{-5}$	$2.4\ 10^{-5}$	$2.5\ 10^{-5}$	$2.5\ 10^{-5}$
Ems Elbe and Weser Estuary	Brokdorf (c)	$3.7\ 10^{-5}$	$3.7\ 10^{-5}$	$4.0\ 10^{-5}$	$4.0\ 10^{-5}$	$3.9\ 10^{-5}$	$3.9\ 10^{-5}$	$3.5\ 10^{-5}$	$3.5\ 10^{-5}$
(North Sea East)	Brunsbüttel (c)	$3.0\ 10^{-6}$	$3.0\ 10^{-6}$	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$	$1.7\ 10^{-5}$	$1.7\ 10^{-5}$	$2.4\ 10^{-5}$	$2.4\ 10^{-5}$
	Emsland (i)	$3.3\ 10^{-5}$	$1.3\ 10^{-4}$	$3.7\ 10^{-5}$	$1.5\ 10^{-4}$	$3.3\ 10^{-5}$	$1.3\ 10^{-4}$	$3.9\ 10^{-5}$	$1.6\ 10^{-4}$
	Grohnde (i)	$1.6\ 10^{-5}$	$9.5\ 10^{-4}$	$4.1\ 10^{-5}$	$2.4\ 10^{-3}$	$3.9\ 10^{-5}$	$2.2\ 10^{-3}$	$4.8\ 10^{-5}$	$2.8\ 10^{-3}$
	Krümmel (i)	$1.0\ 10^{-6}$	$6.5\ 10^{-5}$	$7.7\ 10^{-7}$	$4.8\ 10^{-5}$	$1.6\ 10^{-6}$	$8.5\ 10^{-5}$	$1.2\ 10^{-6}$	$7.7\ 10^{-5}$
	Lingen (i)	$6.3\ 10^{-10}$	$1.2\ 10^{-9}$	$0.0\ 10^{0}$	$0.0\ 10^{0}$	$6.2\ 10^{-9}$	$7.6\ 10^{-9}$	$3.2\ 10^{-9}$	$3.6\ 10^{-9}$
	Rheinsberg (i)	$1.1\ 10^{-7}$	$2.6\ 10^{-7}$	$1.1\ 10^{-7}$	$2.7\ 10^{-7}$	$5.1\ 10^{-8}$	$1.4\ 10^{-6}$	$4.6\ 10^{-8}$	$7.1\ 10^{-7}$

Table D1 Cont'd Implied collective doses truncated at 500 y to EU population (man Sv) from reported annual liquid releases

Point of discharge	Site name	1997		1999		2002		2004	
		Total Marine	Total dose*	Total Marine	Total dose*	Total Marine	Total dose*	Total Marine	Total dose*
	Stade (c)	$1.4\ 10^{-5}$	$1.4\ 10^{-5}$	$9.5\ 10^{-6}$	$9.5\ 10^{-6}$	$8.4\ 10^{-6}$	$8.4\ 10^{-6}$	$3.4\ 10^{-5}$	$3.4\ 10^{-5}$
	Unterweser (c)	$3.7\ 10^{-5}$	$3.7\ 10^{-5}$	$1.9\ 10^{-5}$	$1.9\ 10^{-5}$	$3.7\ 10^{-5}$	$3.7\ 10^{-5}$	$3.6\ 10^{-5}$	$3.6\ 10^{-5}$
	Würgassen (i)	$2.3\ 10^{-7}$	$3.7\ 10^{-6}$	$6.2\ 10^{-7}$	$3.2\ 10^{-6}$	$1.1\ 10^{-7}$	$2.6\ 10^{-6}$	$1.4\ 10^{-7}$	$4.0\ 10^{-6}$
Tajo Estuary	Almaraz (i)	$2.4\ 10^{-4}$	$2.1\ 10^{-2}$	$3.1\ 10^{-4}$	$1.9\ 10^{-2}$	$2.9\ 10^{-4}$	$1.1\ 10^{-2}$	$1.6\ 10^{-4}$	$1.7\ 10^{-2}$
(Portuguese Continental Shelf)	José Cabrera (Zorita) (i)	$4.5\ 10^{-6}$	$4.9\ 10^{-3}$	$1.2\ 10^{-5}$	$1.3\ 10^{-2}$	$4.9\ 10^{-6}$	$5.4\ 10^{-3}$	$6.0\ 10^{-6}$	$6.8\ 10^{-3}$
(Assumed model French Continental Shelf)	Trillo (i)	$7.3\ 10^{-5}$	$6.4\ 10^{-2}$	$4.4\ 10^{-5}$	$2.4\ 10^{-2}$	$7.6\ 10^{-5}$	$3.8\ 10^{-2}$	$8.3\ 10^{-5}$	$6.4\ 10^{-2}$
Baltic region									
Baltic Sea West	Oskarshamn (c)	$1.2\ 10^{-3}$		$6.2\ 10^{-4}$		$4.4\ 10^{-4}$		$1.5\ 10^{-4}$	
Belt Sea (1)	Barseback (c)	$1.1\ 10^{-3}$	$1.1\ 10^{-3}$	$7.9\ 10^{-4}$	$7.9\ 10^{-4}$	$1.1\ 10^{-3}$	$1.1\ 10^{-3}$	$2.7\ 10^{-4}$	$2.7\ 10^{-4}$
Belt Sea (2)	Greifswald (c)	$1.4\ 10^{-5}$	$1.4\ 10^{-5}$	$1.2\ 10^{-5}$	$1.2\ 10^{-5}$	$1.7\ 10^{-6}$	$1.7\ 10^{-6}$	$5.4\ 10^{-6}$	$5.4\ 10^{-6}$
Bothonian Sea (1)	Olkiluoto (c)	$8.5\ 10^{-4}$	$8.5\ 10^{-4}$	$1.1\ 10^{-4}$	$1.1\ 10^{-4}$	$4.6\ 10^{-5}$	$4.6\ 10^{-5}$	$2.9\ 10^{-5}$	$2.9\ 10^{-5}$
Bothonian Sea (1)	Forsmark (c)	$6.2\ 10^{-3}$	$6.2\ 10^{-3}$	$2.0\ 10^{-3}$	$2.0\ 10^{-3}$	$4.1\ 10^{-4}$	$4.1\ 10^{-4}$	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$
Gulf of Finland	Loviisa (c)	$4.7\ 10^{-5}$	$4.7\ 10^{-5}$	$6.3\ 10^{-5}$	$6.3\ 10^{-5}$	$8.3\ 10^{-5}$	$8.3\ 10^{-5}$	$1.1\ 10^{-4}$	$1.1\ 10^{-4}$
Kategat	Ringhals 1 (c)	$2.6\ 10^{-3}$	$2.6\ 10^{-3}$	$4.1\ 10^{-4}$	$4.1\ 10^{-4}$	$1.1\ 10^{-4}$	$1.1\ 10^{-4}$	$1.2\ 10^{-4}$	$1.2\ 10^{-4}$

	Ringhals 2 (c)	$3.7\ 10^{-4}$	$3.7\ 10^{-4}$	$3.0\ 10^{-4}$	$3.0\ 10^{-4}$	$1.5\ 10^{-4}$	$1.5\ 10^{-4}$	$1.3\ 10^{-4}$	$1.3\ 10^{-4}$

Table D1 Cont'd Implied collective doses truncated at 500 y to EU population (man Sv) from reported annual liquid releases

Point of discharge	Site name	1997		1999		2002		2004	
		Total Marine	Total dose*	Total Marine	Total dose*	Total Marine	Total dose*	Total Marine	Total dose*
UK									
North Sea South West (1)	Bradwell (c)	$3.1\ 10^{-2}$	$3.1\ 10^{-2}$	$2.3\ 10^{-2}$	$2.3\ 10^{-2}$	$2.0\ 10^{-2}$	$2.0\ 10^{-2}$	$2.0\ 10^{-2}$	$2.0\ 10^{-2}$
Bristol Channel (2)	Oldbury	$8.0\ 10^{-4}$	$8.0\ 10^{-4}$	$1.1\ 10^{-3}$	$1.1\ 10^{-3}$	$8.5\ 10^{-3}$	$8.5\ 10^{-3}$	$5.4\ 10^{-3}$	$5.4\ 10^{-3}$
Bristol Channel (2)	Berkley (c)	$3.1\ 10^{-4}$	$3.1\ 10^{-4}$	$1.4\ 10^{-4}$	$1.4\ 10^{-4}$	$6.4\ 10^{-6}$	$6.4\ 10^{-6}$	$3.8\ 10^{-6}$	$3.8\ 10^{-6}$
Irish Sea North East	Chapelcross (c)	$3.1\ 10^{-4}$	$3.1\ 10^{-4}$	$2.5\ 10^{-4}$	$2.5\ 10^{-4}$	$9.4\ 10^{-4}$	$9.4\ 10^{-4}$	$3.3\ 10^{-4}$	$3.3\ 10^{-4}$
Scottish Waters East	Dounreay (c)	$2.1\ 10^{-2}$	$2.1\ 10^{-2}$	$5.5\ 10^{-3}$	$5.5\ 10^{-3}$	$1.3\ 10^{-3}$	$1.3\ 10^{-3}$	$9.8\ 10^{-4}$	$9.8\ 10^{-4}$
English Channel NE	Dungeness A (c)	$2.3\ 10^{-2}$	$2.3\ 10^{-2}$	$1.9\ 10^{-2}$	$1.9\ 10^{-2}$	$1.5\ 10^{-2}$	$1.5\ 10^{-2}$	$7.6\ 10^{-3}$	$7.6\ 10^{-3}$
	Dungeness B (c)	$1.4\ 10^{-3}$	$1.4\ 10^{-3}$	$1.2\ 10^{-3}$	$1.2\ 10^{-3}$	$1.6\ 10^{-3}$	$1.6\ 10^{-3}$	$3.1\ 10^{-3}$	$3.1\ 10^{-3}$
North Sea Central	Hartlepool (c)	$9.8\ 10^{-4}$	$9.8\ 10^{-4}$	$9.4\ 10^{-4}$	$9.4\ 10^{-4}$	$1.3\ 10^{-3}$	$1.3\ 10^{-3}$	$6.8\ 10^{-4}$	$6.8\ 10^{-4}$
Liverpool and Morcombe Bay	Heysham 1 (c)	$1.3\ 10^{-3}$	$1.3\ 10^{-3}$	$1.3\ 10^{-3}$	$1.3\ 10^{-3}$	$1.7\ 10^{-3}$	$1.7\ 10^{-3}$	$1.4\ 10^{-3}$	$1.4\ 10^{-3}$
	Heysham 2 (c)	$1.0\ 10^{-3}$	$1.0\ 10^{-3}$	$1.0\ 10^{-3}$	$1.0\ 10^{-3}$	$1.3\ 10^{-3}$	$1.3\ 10^{-3}$	$7.7\ 10^{-4}$	$7.7\ 10^{-4}$
Bristol Channel (1)	Hinkley Point A (c)	$8.3\ 10^{-3}$	$8.3\ 10^{-3}$	$8.3\ 10^{-3}$	$8.3\ 10^{-3}$	$6.1\ 10^{-3}$	$6.1\ 10^{-3}$	$4.1\ 10^{-3}$	$4.1\ 10^{-3}$
	Hinkley Point B (c)	$8.4\ 10^{-4}$	$8.4\ 10^{-4}$	$8.3\ 10^{-4}$	$8.3\ 10^{-4}$	$8.0\ 10^{-4}$	$8.0\ 10^{-4}$	$7.0\ 10^{-4}$	$7.0\ 10^{-4}$
Scottish Waters West	Hunterston A (c)	$4.9\ 10^{-3}$	$4.9\ 10^{-3}$	$6.8\ 10^{-3}$	$6.8\ 10^{-3}$	$7.1\ 10^{-4}$	$7.1\ 10^{-4}$	$1.2\ 10^{-3}$	$1.2\ 10^{-3}$
	Hunterston B (c)	$9.9\ 10^{-4}$	$9.9\ 10^{-4}$	$1.2\ 10^{-3}$	$1.2\ 10^{-3}$	$1.1\ 10^{-3}$	$1.1\ 10^{-3}$	$1.4\ 10^{-3}$	$1.4\ 10^{-3}$

Table D1 Cont'd Implied collective doses truncated at 500 y to EU population (man Sv) from reported annual liquid releases

Point of discharge	Site name	1997		1999		2002		2004	
		Total Marine	Total dose*	Total Marine	Total dose*	Total Marine	Total dose*	Total Marine	Total dose*
Cumbrian waters	Sellafield (c)	$5.1\ 10^{0}$	$5.1\ 10^{0}$	$6.1\ 10^{0}$	$6.1\ 10^{0}$	$1.3\ 10^{1}$	$1.3\ 10^{1}$	$1.6\ 10^{1}$	$1.6\ 10^{1}$
North Sea South West (2)	Sizewell A (c)	$5.5\ 10^{-3}$	$5.5\ 10^{-3}$	$3.8\ 10^{-3}$	$3.8\ 10^{-3}$	$3.1\ 10^{-2}$	$3.1\ 10^{-2}$	$3.5\ 10^{-2}$	$3.5\ 10^{-2}$
	Sizewell B (c)	$1.1\ 10^{-3}$	$1.1\ 10^{-3}$	$2.3\ 10^{-3}$	$2.3\ 10^{-3}$	$2.5\ 10^{-3}$	$2.5\ 10^{-3}$	$1.2\ 10^{-3}$	$1.2\ 10^{-3}$
Irish Sea South	Trawsfynydd (i)	$4.6\ 10^{-4}$	$5.5\ 10^{-3}$	$3.0\ 10^{-4}$	$4.3\ 10^{-3}$	$1.3\ 10^{-4}$	$1.7\ 10^{-3}$	$1.2\ 10^{-4}$	$1.6\ 10^{-3}$
North Sea Central	Torness (c)	$7.0\ 10^{-4}$	$7.0\ 10^{-4}$	$6.9\ 10^{-4}$	$6.9\ 10^{-4}$	$5.6\ 10^{-4}$	$5.6\ 10^{-4}$	$7.0\ 10^{-4}$	$7.0\ 10^{-4}$
English Channel West	Winfrith (c)	$5.6\ 10^{-3}$	$5.6\ 10^{-3}$	$4.8\ 10^{-3}$	$4.8\ 10^{-3}$	$1.7\ 10^{-3}$	$1.7\ 10^{-3}$	$2.1\ 10^{-3}$	$2.1\ 10^{-3}$
Irish Sea West	Wylfa (c)	$1.7\ 10^{-4}$	$1.7\ 10^{-4}$	$9.3\ 10^{-5}$	$9.3\ 10^{-5}$	$1.4\ 10^{-3}$	$1.4\ 10^{-3}$	$4.5\ 10^{-4}$	$4.5\ 10^{-4}$

i = inland site; c = coastal site. (1) and (2) refer to separate local compartments within a regional compartment.

* The total dose presented in this column is the sum of the dose from the marine and river environments

Table D2 Implied doses to adult member of representative critical group ($\mu Sv\ y^{-1}$) living near rivers (includes upstream contributions and based on reported discharges to rivers)

River	River section of critical group	Sites discharging	Country of critical group	Total Doses integrated to 50 years, µSv			
				1997	1999	2002	2004
Danube	1	Gundremmingen	Germany	$1.0\ 10^{-1}$	$1.2\ 10^{-1}$	$1.2\ 10^{-1}$	$1.1\ 10^{-1}$
		Isar 1					
		Isar 2					
Elbe		Krummel	Germany	$6.2\ 10^{-4}$	$6.2\ 10^{-4}$	$9.2\ 10^{-4}$	$3.8\ 10^{-4}$
		Rheinsberg					
Ems		Emsland	Germany	$2.4\ 10^{-3}$	$2.7\ 10^{-3}$	$2.4\ 10^{-3}$	$2.9\ 10^{-3}$
		Lingen					
Ebro	1	Santa Maria de Garona	Spain	$5.0\ 10^{-2}$	$8.9\ 10^{-2}$	$3.6\ 10^{-2}$	$2.2\ 10^{-2}$
	2	Asco	Spain	$3.8\ 10^{-1}$	$2.9\ 10^{-1}$	$1.8\ 10^{-1}$	$3.7\ 10^{-1}$
Garonne		Golfech	France	$1.3\ 10^{-1}$	$9.8\ 10^{-2}$	$1.5\ 10^{-1}$	$1.3\ 10^{-1}$
Jucar		Cofrentes	Spain	$2.0\ 10^{-2}$	$2.2\ 10^{-2}$	$2.0\ 10^{-2}$	$2.2\ 10^{-3}$
Loire	1	Belleville	France	$3.3\ 10^{-1}$	$4.4\ 10^{-1}$	$6.9\ 10^{-1}$	$6.5\ 10^{-1}$
		Dampierre					
	2	St Luarent B	France	$2.2\ 10^{-1}$	$2.6\ 10^{-1}$	$6.3\ 10^{-1}$	$6.1\ 10^{-1}$
	3a (Vienne)	Civaux	France	$0.0\ 10^{0}$	$8.3\ 10^{-2}$	$3.8\ 10^{0}$	$4.8\ 10^{0}$
	3	Chinon B	France	$1.9\ 10^{-1}$	$1.7\ 10^{-1}$	$6.3\ 10^{-1}$	$6.5\ 10^{-1}$
	4		France	$9.4\ 10^{-2}$	$8.6\ 10^{-2}$	$4.1\ 10^{-1}$	$4.3\ 10^{-1}$
Meuse	1	ChoozB	France	$9.9\ 10^{-3}$	$1.5\ 10^{-2}$	$5.5\ 10^{-2}$	$6.8\ 10^{-2}$
	2	Tihange	Belgium	$5.3\ 10^{-1}$	$3.3\ 10^{-1}$	$4.9\ 10^{-1}$	$8.1\ 10^{-1}$
	3		Netherlands	$1.7\ 10^{-1}$	$1.1\ 10^{-1}$	$1.8\ 10^{-1}$	$3.0\ 10^{-1}$
Rhine	1	Fessenheim	Germany	$1.3\ 10^{-1}$	$4.9\ 10^{-2}$	$9.7\ 10^{-2}$	$9.6\ 10^{-2}$
	2	Karlksruhe Wak	Germany	$1.2\ 10^{-1}$	$7.5\ 10^{-2}$	$7.8\ 10^{-2}$	$5.2\ 10^{-2}$
		Phillipsberg 1					
		Phillipsberg 2					
	3	Obringheim	Germany	$1.8\ 10^{-1}$	$1.7\ 10^{-1}$	$1.5\ 10^{-1}$	$1.2\ 10^{-1}$
		Neckar 1					
		Neckar 2					
	4	Biblis A	Germany	$1.2\ 10^{-1}$	$9.3\ 10^{-2}$	$1.1\ 10^{-1}$	$6.6\ 10^{-2}$
		Biblis B					
	5	Grafenrheinfeld	Germany	$4.4\ 10^{-2}$	$4.4\ 10^{-2}$	$6.1\ 10^{-2}$	$5.6\ 10^{-2}$
	7	Cattenom	Germany	$3.3\ 10^{-1}$	$3.3\ 10^{-1}$	$1.3\ 10^{0}$	$1.1\ 10^{0}$
	8	Mulheim-Karlich	Germany	$6.4\ 10^{-2}$	$6.7\ 10^{-2}$	$1.4\ 10^{-1}$	$1.2\ 10^{-1}$
	10	Dodewaard	Netherlands	$2.5\ 10^{-1}$	$2.0\ 10^{-1}$	$1.4\ 10^{-1}$	$2.9\ 10^{-1}$

Table D2 Cont'd Implied doses to adult member of representative critical group (µSv y^{-1}) living near rivers (includes upstream contributions and based on reported discharges to rivers)

River	River section of critical group	Sites discharging	Country of critical group	Total Doses integrated to 50 years, µSv			
				1997	1999	2002	2004
Rhone	1	Creys Malville	France	$4.9\ 10^{-1}$	$1.9\ 10^{-1}$	$3.2\ 10^{-1}$	$3.4\ 10^{-1}$
		Bugey B					
	4	St Alban (Rh4)	France	$5.4\ 10^{-1}$	$1.7\ 10^{-1}$	$3.1\ 10^{-1}$	$4.3\ 10^{-1}$
	5	Cruas (Rh5)	France	$5.3\ 10^{-1}$	$1.9\ 10^{-1}$	$3.6\ 10^{-1}$	$4.7\ 10^{-1}$
	6	Tricastin (Rh6)	France	$6.3\ 10^{-1}$	$3.0\ 10^{-1}$	$4.7\ 10^{-1}$	$5.4\ 10^{-1}$
	7	Marcoule	France	$5.7\ 10^{-1}$	$3.6\ 10^{-1}$	$4.7\ 10^{-1}$	$5.1\ 10^{-1}$
Seine		Nogent	France	$1.6\ 10^{-1}$	$1.0\ 10^{-1}$	$2.7\ 10^{-1}$	$1.9\ 10^{-1}$
Tajo	1	Jose Cabrera	Spain	$8.9\ 10^{-2}$	$8.0\ 10^{-2}$	$5.8\ 10^{-2}$	$4.7\ 10^{-2}$
		Trillo					
	2	Almaraz	Spain	$4.2\ 10^{-1}$	$2.9\ 10^{-1}$	$2.4\ 10^{-1}$	$1.4\ 10^{-1}$
Traws		Trawsfynydd	UK	$2.1\ 10^{1}$	$1.7\ 10^{1}$	$6.5\ 10^{0}$	$6.3\ 10^{0}$
Weser		Grohnde	Germany	$7.4\ 10^{-3}$	$9.7\ 10^{-3}$	$7.0\ 10^{-3}$	$6.1\ 10^{-3}$
		Wurgassen					

Table D3 Implied doses to adult member of representative critical group (µSv y^{-1}) living near the coast (includes contributions from inland and coastal sites and based on reported discharges)

Point of discharge	Site name	1997	1999	2002	2004
Mediterranean Sea					
Danube estuary	Gundremmingen (i)	$3.8\ 10^{-2}$	$4.4\ 10^{-2}$	$1.6\ 10^{-2}$	$1.3\ 10^{-2}$
(Agean sea)	Isar 1 (i)				
	Isar 2 (i)				
Rhone estuary	Creys Malville (i)	$1.8\ 10^{0}$	$1.1\ 10^{0}$	$3.6\ 10^{1}$	$3.8\ 10^{1}$
(Golf Of Lions)	Bugey B (i)				
	St Alban (i)				
	Cruas (i)				
	Tricastin (i)				
	Marcoule (i)				
Ebro estuary	Asco (i)	$4.7\ 10^{0}$	$2.7\ 10^{0}$	$1.6\ 10^{0}$	$1.7\ 10^{0}$
(Liguro Povencal Basin (1))	Santa Maria de Garona (i)				
	Vandellos 1 (c)				
	Vandellos 2 (c)				
Jucar estuary	Cofrentes (i)	$2.2\ 10^{-2}$	$3.8\ 10^{-2}$	$3.7\ 10^{-2}$	$9.0\ 10^{-4}$
(Liguro Povencal Basin (2))					
NE Atlantic (Europe excluding UK)					
Loire estuary	Belleville (i)	$2.1\ 10^{0}$	$9.6\ 10^{-1}$	$3.5\ 10^{1}$	$3.6\ 10^{1}$
(French Continental shelf (1))	Chinon B (i)				
	Civaux (i)				
	Dampierre (i)				
	St Laurent B (i)				
Gironde estuary	Blayais (c)	$4.5\ 10^{-1}$	$2.9\ 10^{-1}$	$1.7\ 10^{1}$	$1.5\ 10^{1}$
(French Continental shelf (2))	Golfech (i)				
English Channel SE 1	Flamanville	$2.2\ 10^{-2}$	$1.2\ 10^{-2}$	$4.5\ 10^{-1}$	$4.7\ 10^{-1}$
English Channel SE 1	Cap de la Hague	$2.7\ 10^{2}$	$2.4\ 10^{2}$	$1.9\ 10^{2}$	$2.1\ 10^{2}$
Seine estuary	Paluel (c)	$1.1\ 10^{0}$	$8.4\ 10^{-1}$	$3.3\ 10^{1}$	$3.3\ 10^{1}$
(English Channel SE 2)	Penly (c)				
	Nogent (i)				
North Sea SE (1)	Gravelines (c)	$5.0\ 10^{-2}$	$5.0\ 10^{-2}$	$9.2\ 10^{-1}$	$1.0\ 10^{0}$
Rhine and Meuse estuary	Biblis A (i)	$1.8\ 10^{0}$	$9.0\ 10^{-1}$	$1.9\ 10^{1}$	$2.0\ 10^{1}$
North Sea SE (2)	Biblis B (i)				
	Borssele (c)				

	Cattenom (i)				

Table D3 Cont'd Implied doses to adult member of representative critical group (µSv y^{-1}) living near the coast (includes contributions from inland and coastal sites and based on reported discharges)

Point of discharge	Site name	1997	1999	2002	2004
	Chooz B (i)				
	Dodewaard (i)				
	Doel (c)				
	Fessenheim (i)				
	Grafenrheinfeld (i)				
	Karlsruhe WAK (i)				
	Mülheim-Kärlich (i)				
	Neckar 1 (i)				
	Neckar 2 (i)				
	Obrigheim (i)				
	Philippsburg 1 (i)				
	Philippsburg 2 (i)				
	Tihange (i)				
Ems Elbe and Weser Estuary	Brokdorf (c)	$6.1\ 10^{-3}$	$6.8\ 10^{-3}$	$7.5\ 10^{-3}$	$8.0\ 10^{-3}$
(North sea (E))	Brunsbüttel (c)				
	Emsland (i)				
	Grohnde (i)				
	Krümmel (i)				
	Lingen (i)				
	Rheinsberg (i)				
	Stade (c)				
	Unterweser (c)				
	Würgassen (i)				
Tajo Estuary	Almaraz (i)	$9.3\ 10^{-2}$	$1.1\ 10^{-1}$	$1.2\ 10^{-1}$	$5.9\ 10^{-2}$
(French continental shelf used as surrogate for Portuguese Continental Shelf)	José Cabrera (Zorita) (i)				
	Trillo (i)				
Baltic region					
(Baltic sea west)	Oskarshamn (c)	$8.3\ 10^{-1}$	$5.7\ 10^{-1}$	$4.1\ 10^{-1}$	$1.8\ 10^{-1}$
(Belt sea (1))	Barseback (c)	$8.1\ 10^{-1}$	$6.1\ 10^{-1}$	$7.6\ 10^{-1}$	$2.1\ 10^{-1}$
(Belt sea (2))	Greifswald (c)	$1.3\ 10^{-3}$	$1.4\ 10^{-3}$	$4.1\ 10^{-5}$	$1.4\ 10^{-4}$
(Bothonian sea (1))	Olkiluoto (c)	$1.4\ 10^{-1}$	$2.9\ 10^{-2}$	$1.7\ 10^{-2}$	$1.0\ 10^{-2}$
(Bothonian sea (1))	Forsmark (c)	$3.1\ 10^{0}$	$5.1\ 10^{-1}$	$1.4\ 10^{-1}$	$4.8\ 10^{-2}$

(Gulf of finland)	Loviisa (c)	$2.4\ 10^{-4}$	$6.8\ 10^{-4}$	$3.4\ 10^{-2}$	$1.4\ 10^{-2}$

Table D3 Cont'd Implied doses to adult member of representative critical group (µSv y^{-1}) living near the coast (includes contributions from inland and coastal sites and based on reported discharges)

Point of discharge	Site name	1997	1999	2002	2004
(Kategat)	Ringhals 1	$4.7\ 10^{0}$	$7.7\ 10^{-1}$	$2.4\ 10^{-1}$	$1.8\ 10^{-1}$
(Kategat)	Ringhals 2				
UK					
(North Sea SW (1))	Bradwell (c)	$3.3\ 10^{0}$	$2.3\ 10^{0}$	$1.8\ 10^{0}$	$2.0\ 10^{0}$
Bristol Channel (2)	Oldbury	$4.4\ 10^{-1}$	$5.0\ 10^{-1}$	$3.4\ 10^{0}$	$2.2\ 10^{0}$
	Berkley				
(Irish sea NE)	Chapelcross (c)	$9.5\ 10^{-2}$	$4.4\ 10^{-2}$	$9.8\ 10^{-2}$	$3.2\ 10^{-2}$
(Scottish waters East)	Dounreay (c)	$1.1\ 10^{0}$	$1.1\ 10^{-1}$	$6.4\ 10^{-2}$	$2.6\ 10^{-2}$
(English Channel NE)	Dungeness A (c)	$3.2\ 10^{-1}$	$2.8\ 10^{-1}$	$2.1\ 10^{-1}$	$1.3\ 10^{-1}$
	Dungeness B (c)				
(North sea central)	Hartlepool (c)	$1.3\ 10^{-1}$	$1.1\ 10^{-1}$	$1.9\ 10^{-1}$	$8.7\ 10^{-2}$
(Liverpool and Morcombe Bay)	Heysham 1 (c)	$1.7\ 10^{0}$	$2.1\ 10^{0}$	$2.5\ 10^{0}$	$1.6\ 10^{0}$
(Liverpool and Morcombe Bay)	Heysham 2 (c)				
Bristol Channel (1)	Hinkley Point A (c)	$1.6\ 10^{-1}$	$1.6\ 10^{-1}$	$1.1\ 10^{-1}$	$7.7\ 10^{-2}$
Bristol Channel (1)	Hinkley Point B (c)				
(Scottish waters West)	Hunterston A (c)	$6.1\ 10^{-2}$	$7.3\ 10^{-2}$	$1.7\ 10^{-2}$	$3.4\ 10^{-2}$
(Scottish waters West)	Hunterston B (c)				
(Cumbrian waters)		$3.9\ 10^{2}$	$2.9\ 10^{2}$	$3.9\ 10^{2}$	$4.1\ 10^{2}$
(Cumbrian waters)					
(North Sea SW (2))	Sizewell A (c)	$3.3\ 10^{-1}$	$3.3\ 10^{-1}$	$1.7\ 10^{0}$	$1.8\ 10^{0}$
(North Sea SW (2))	Sizewell B (c)				
(Irish Sea South)	Trawsfynydd (i)	$4.9\ 10^{-2}$	$3.5\ 10^{-2}$	$1.4\ 10^{-2}$	$1.3\ 10^{-2}$
(North sea central)	Torness (c)	$6.3\ 10^{-2}$	$5.9\ 10^{-2}$	$5.2\ 10^{-2}$	$6.0\ 10^{-2}$
(English channel W)	Winfrith (c)	$1.4\ 10^{-1}$	$2.5\ 10^{-1}$	$6.3\ 10^{-2}$	$6.6\ 10^{-2}$
(Irish Sea West)	Wylfa (c)	$4.4\ 10^{-1}$	$2.1\ 10^{-1}$	$5.0\ 10^{-1}$	$4.0\ 10^{-1}$

i = inland site; c = coastal site