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Assessment of the radiological impact on the population of the European Union from European Union nuclear sites between 1987 and 1996

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Assessment of the Radiological Impact on the Population of the European Union of Discharges from European Union Nuclear Sites between 1987 and 1996

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Abstract

This report presents information on the radiological impact of routine discharges from nuclear sites located in the European Union (EU). The assessment was performed using a revised and updated methodology, implemented as a computer program called PC CREAM. Calculations of collective doses truncated at 500 years and individual doses indicative of those received by members of the critical group have been performed for discharges occurring in the period 1987 to 1996. Exposures are broken down by site and form of discharge ie liquid and atmospheric. More detailed results including radionuclide and pathway breakdowns of individual and collective doses are available on an accompanying CD.

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1 Introduction

In 1995 a report was published by the European Commission entitled 'Radioactive effluents from nuclear power stations and nuclear fuel reprocessing plants in the European Community, 1977-86'. The report was in two parts. The first part included records of discharge data[1]. The second part[2] included the results of an assessment carried out to determine collective and individual doses to the population of the European Community (EC). The dose assessment was carried out in 1990 using the methodology described by NRPB/CEA[3].

Since 1990, a revised and updated methodology for assessing the radiological consequences of routine discharges to the environment has been published[4] and implemented as a computer program called PC CREAM[5]. PC CREAM includes revisions to dosimetry and also calculates effective dose, as defined by ICRP in the 1990 Recommendations (ICRP 60)[6], using dose coefficients from ICRP 72[7].

In 1999 NRPB began, on behalf of the European Commission's Directorate General Environment, a revised radiological impact assessment of routine discharges from EC nuclear sites. The aim of this assessment was to estimate collective and individual doses received by members of the EC as a result of routine radiological discharges from nuclear power plants and nuclear fuel reprocessing plants in the EC Member States occurring between 1987 and 1996. It was a contract requirement that the assessment should be carried out using PC CREAM and the discharge database Bilcom97.mdb (referred to as the Bilcom97 database in the remainder of this report) compiled by the European Commission[8]. NRPB took responsibility for co-ordinating the project and carrying out the assessment of doses arising from atmospheric discharges. However, two sub-contractors made significant input to the project, the Nuclear Research and Consultancy Group of KEMA ECN (NRG) in the Netherlands and Gesellschaft für Anlagen-und-Reaktorsicherheit (GRS) in Germany. NRG had responsibility for the assessment of doses from exposure to aquatic discharges and GRS provided supplementary discharge data.

This report describes this assessment. The collective exposures of the population of the EC from discharges occurring in selected years (1987, 1991 and 1996) are presented together with exposures of individuals living near to the nuclear sites. Exposures are broken down by site and form of discharge ie liquid and atmospheric. More detailed results including radionuclide and pathway breakdowns of individual and collective doses are available on an accompanying CD.

2 Nuclear Installations

This study includes all nuclear power stations of capacity greater than 50 MW(e) and fuel reprocessing plants operational in the member states of the EC between 1987 and 1996. For each year the exposed population was taken to be that of the EU as it stood in 1996. Also discharges from the nuclear facilities of countries that joined the EU after 1986 are included throughout the entire study period. A wide range of nuclear power stations exist including: Advanced Gas-cooled Reactors (AGRs), Boiling Water Reactors (BWRs), Fast Breeder Reactors (FBRs), Gas Cooled Reactors (GCRs), High Temperature Gas Reactors (HTGRs), Pressurised Water Reactors (PWRs) and a Heavy Water Moderated Reactor (SGHWR).

In the previous study[1,2] the EC countries operating nuclear facilities were Belgium, the Federal Republic of Germany, France, Italy, the Netherlands, Spain and the United Kingdom. The current assessment includes additional sites located in countries with significant nuclear installations that have joined the EC since 1986 ie Finland, Sweden and the former East Germany. A full list of the nuclear facilities included in this assessment is given in Tables 1 and 2 and their location shown in Figure 1. Because of the large number of sites the assessment was in general carried out for three specific years within the period 1987 to 1996. The selected years were 1987, 1991 and 1996. For some sites discharge data for these years were unavailable, usually because they were not in operation (for years of site

operation, see Tables 1 and 2). For those sites that are of greatest radiological significance, namely Sellafield and Cap de la Hague, doses were calculated for each year from 1987 to 1996. Doses were calculated for each of the sites held on the Bilcom97 database. For each site, reactors of the same type were grouped together. In 1987 nuclear power accounted for approximately 30% of the Community's total electric production with 118 power reactors in operation. Despite the expansion of the EC, the decommissioning of old sites and the completion of new sites, this percentage changed little during the period up to 1996 by which time 164 individual reactors were in operation.

3 Concepts and Quantities

The term dose in this report refers to the effective dose and is the sum of the annual external effective dose and the committed effective dose to adults for intakes over one year. Doses were determined in accordance with the most recent recommendations of the International Commission on Radiological Protection (ICRP)[6] using dose coefficients from ICRP Publication 72[7].

For each nuclear facility, individual doses have been calculated that are indicative of doses received by the most exposed members of the population ie the critical group. It is assumed that equilibrium conditions apply between the release and the concentrations in environmental materials. This is modelled by calculating the annual dose received in the 50^{th} year assuming the discharge is continuous and constant over 50 years. This dose can be compared with the relevant dose criteria ie the annual dose limit for members of the public (taking account of doses from other controlled sources) or the dose constraint.

In addition, the dose to the exposed population of the EC, the collective dose, has been estimated as a consequence of discharges from each facility. The collective dose is the sum of doses received by the members of the exposed population from all significant pathways. It can be related to the number of serious health effects which might occur in the exposed population as a result of the additional exposure. Long-lived radionuclides can give rise to doses over extended periods of time, long after a release has stopped. To account for this the annual individual doses in an exposed population are summed over various time periods following the year of release. If doses are summed over all time the resulting quantity is known as the collective dose to infinity. In this report doses have been summed to a specified time of 500 years and the quantity is referred to as the collective dose truncated at 500 years.

4 Data and Methods

4.1 Discharge Data

The quantities of radionuclides discharged in airborne and liquid effluents from each site are taken from the Bilcom97 database compiled by the European Commission[8]. Discharge data are available as annual totals for years 1987 to 1996 and include the name and type of facility, the country of operation and the form of the release. The database is based on discharge reports produced by site operators. Methods of reporting vary from site to site and as a result some inconsistencies occur within the database. Consequently, careful interpretation of the data was needed. In particular, assumptions had to be made regarding the radionuclide composition of aggregated discharges where breakdowns were missing or incomplete. These assumptions were based on data provided by GRS which gave typical radionuclide spectra based on the type of power station and the country of origin. These data are presented in Table 3.1.1.1 to 3.9.2.3 of the GRS report which can be found on the accompanying CD. In addition the database was known to be incomplete at the time the assessment began. Consequently, supplementary data were obtained from additional sources (Tables A1 and A2). It is important to note that the doses calculated in this study are based on the reported discharges held in the Bilcom97 database and will reflect any inaccuracies or omissions in the data.

The reprocessing plants at Sellafield and Marcoule have other nuclear facilities on the site which share the same liquid effluent treatment plants. Therefore, liquid discharges as recorded on the Bilcom97 database are attributed to the site as a whole. Although airborne discharges are generally reported for each facility on a site they have been combined to obtain a total airborne discharge consistent with the liquid effluent data.

4.1.1 Airborne Effluents

Airborne effluents from nuclear power stations generally consist of ^{3}H, ^{14}C, noble gases, and an aerosol component containing a wide spectrum of activation and fission products sometimes including small quantities of actinides. Gaseous halogens are also normally included in the aerosol component. In general, noble gases are the largest component of the discharge in terms of activity, ^{3}H and ^{14}C contribute less and aerosol discharges are very small. However, there is considerable variation in the quantities and types of radionuclides discharged, even between stations of similar design.

A wide spectrum of radionuclides is also present in airborne discharges from nuclear fuel reprocessing plants, with ^{85}Kr and ^{3}H discharges generally being the highest in terms of activity. Bilcom97 does not hold atmospheric discharge data for Cap de la Hague for the years 1992 to 1995. Data for these years have been taken from the Nord-Cotentin study[9], and are contained in Table A2.

4.1.2 Liquid Effluents

In general, ^{3}H discharges are one or two orders of magnitude greater than discharges of other radionuclides in terms of activity, although this is not so significant in terms of environmental impact since ^{3}H is a radionuclide of comparatively low radiotoxicity. The mix of radionuclides other than tritium varies considerably from reactor to reactor and the principal components are identified in the GRS report. The reporting of liquid effluents from nuclear power stations is more detailed than for airborne effluents. Nevertheless, there are cases where Bilcom97 gives insufficient information and again the radionuclide spectra provided by GRS were used (see GRS report on CD for details). However, it should be noted that, for liquid discharges, radionuclides from these spectra were only considered if they also appeared on the Bilcom97 database for the site under consideration.

The liquid effluents from fuel reprocessing plants are dominated by fission products such as ^{137}Cs, ^{106}Ru, ^{60}Co and ^{90}Sr, and generally contain relatively significant quantities of actinides.

4.2 Other Site Specific Data

In addition to discharge data, an extensive set of site-specific data is needed as input to the dose calculations. Site-specific data include details about the nuclear facility, meteorological conditions around the site and information about the individuals who live nearby.

4.2.1 Discharge points

To estimate doses from atmospheric discharges using PC CREAM the following information is required on the point of discharge: stack heights, number of stacks and stack locations. In this assessment a single stack was used when modelling atmospheric discharges from a site. The co-ordinates of the site defined the assumed location of the stack. For aquatic effluents discharges take place into the local marine compartment that surrounds the site, or the appropriate river section, and details of the assumptions made are given in the NRG report on the accompanying CD.

4.2.2 Meteorological data

Meteorological data are also needed when assessing doses from airborne discharges. Where possible the meteorological data from the previous study[2] have been used again in this assessment. However, data for new sites not previously considered have been obtained. Meteorological data

directly applicable to the Finnish reactor sites of Loviisa and Olkiluoto were available but for other nuclear plants it was necessary to use meteorological data from a nearby site. These data have been used in the calculation of collective doses. Separate files have been used for individual dose calculations to represent the unique assumptions that have been made regarding the location of the critical group, see section 4.3.2.

4.2.3 Population and food production data

Grids of population and agricultural production data in polar co-ordinates around each site have been created for all sites in the Bilcom97 database. These grids provide input to the collective dose calculation from atmospheric discharges. For liquid discharges collective doses are based on seafood catches and these data are held within PC CREAM for various sea regions surrounding Europe.

4.2.4 Habit data

The habits of individuals are needed as input to the individual dose calculations. The data required to assess dose from atmospheric discharges are ingestion rates of terrestrial foods, the fraction of ingested food that is locally produced, inhalation rates, occupancy factors at receptor sites, the fraction of time spent indoors at receptor sites, and shielding factors at receptor sites. For some of these parameters the generic PC CREAM default values were applicable and were used but for others country specific data were used. Further details are given in section 4.3.2.

The required habit data of members of the critical group for aquatic discharges include tidal and river bank occupancy rates, inhalation rates, ingestion rates of aquatic foods, and the fraction of ingested food caught locally. Data for these parameters are given in the NRG report.

4.3 Methodology

The release of radioactive material into the environment can lead to the exposure of individuals by a variety of pathways. In an assessment of doses received by individuals and population groups all of the important exposure pathways must be considered. However, in most situations involving the routine release of radionuclides, activity concentrations in environmental media are below detection limits and hence measurements cannot be used for calculating exposures. It is for this reason that mathematical models are often used to predict the transfer of radionuclides in the environment. The doses presented in this report have been calculated using the NRPB radiological impact assessment software PC CREAM[5] which was developed under contract to the European Commission and is a personal computer (PC) implementation of the assessment methodology RP 72[4]. At present, PC CREAM does not have the capability of calculating doses from liquid discharges to lakes. Therefore, estimated doses arising from liquid discharges from the Trawsfynydd nuclear power plant were modelled using the NRPB biosphere transport model BIOS[12].

The dispersion of radionuclides discharged to atmosphere was modelled using a Gaussian plume model[11]. Allowance is made for the range of meteorological conditions that might prevail during the discharge. To this end, representative meteorological data have been obtained for each site (see section 4.2.2). An effective release height of 30 m, 60 m or 100 m has been allocated based on the value nearest to the release height quoted for each site (Table 3). The atmospheric dispersion model also calculates the rate of deposition onto the ground of radionuclides. A dry deposition velocity of 10^{-3} ms^{-1} and a washout coefficient of 10^{-4} s^{-1} were used for all radionuclides except those of the noble gases, ^{3}H, ^{14}C and the halogens. It was assumed that deposition of noble gases does not occur. Tritium and ^{14}C are assumed to reach equilibrium rapidly with the ground and its vegetative cover, so that the net deposition of these radionuclides was taken to be zero. Radioisotopes of iodine were assumed to be discharged in an elemental form and a dry deposition velocity of 10^{-2} ms^{-1} was used.

Radioactive materials released into the atmosphere may lead to the radiological exposure of humans via a number of potential pathways. While in the air, radionuclides may give exposures by:

- external irradiation by photons and electrons emitted as a result of the radioactive decay process, and
- internal irradiation following their inhalation.

Radionuclides in the air will gradually be removed by the processes of deposition onto underlying surfaces and radioactive decay. The deposition of radionuclides onto the ground, and onto other surfaces, leads to their further transfer in the terrestrial environment where they can continue to expose humans. A number of exposure routes may occur here:

- deposited radionuclides may still be available for inhalation as a result of resuspension, caused by wind-driven or man-made disturbance,
- radioactive decay of deposited radionuclides will also lead to external exposure from photons and electrons,
- deposition onto vegetation and soils leads to the transfer of radionuclides into human foodstuffs, the consumption of which will lead to internal exposure, and
- there may be inadvertent ingestion of contaminated soils.

Full details of the models and methods used to assess transfer and exposures relating to atmospheric releases are given in reference 4.

To calculate doses arising from liquid discharges the sites have been grouped into two categories; “coastal” sites which are located along the coast and discharge directly into the marine environment and “inland” sites which are located inland and discharge into freshwater systems before ultimately reaching the sea.

Radionuclides discharged to the marine environment are dispersed by the action of currents and by diffusion. Some radionuclides interact with sediments suspended in the water and may therefore be transported to and from the seabed. Interaction with the sediments can also lead to the presence of radionuclides in the beach material. Radionuclides in water or attached to sediments can enter the aquatic foodchain, giving rise to contamination of foodstuffs consumed by man. Radionuclides in the sea can also be returned to the terrestrial environment in seaspray. The model used to represent the dispersion of radionuclides is based on the compartmental marine dispersion model described in reference 4. The model comprises two components, a generic regional model and a site-specific local model. The local model simulates the dispersion near the site and therefore is more important in assessing individual doses in the local population, whereas the regional model is more important for collective doses. The local compartments typically extend for 5 km along the coastline either side of the site. The regional marine compartments surrounding Europe are shown in Figure 2. Further details of the assessment carried out by NRG to calculate doses arising from liquid discharges are given in the NRG report.

Radionuclides discharged to rivers have been modelled using the extended screening model with complete mixing as described in reference 5. Three river systems were explicitly modelled, these being the Loire, the Rhine and the Rhone. The characteristics of these rivers have been taken from data used in the previous dose assessment[2] and are given in the NRG report. Each inland nuclear site was allocated to one of these rivers for the purposes of calculating doses from terrestrial pathways (see Table 3). Rivers are commonly used as a source of water for drinking and irrigating crops and, as a consequence, ingestion doses can be important. External exposure to riverbed sediments is also considered. Details of the assessment carried out by NRG can be found on the CD.

All the exposure pathways arising from airborne and liquid discharges that have been considered in this assessment are given in Table 4.

4.3.1 Collective dose

Collective doses truncated at 500 years have been calculated for the population of the European Union which at the end of the study period in 1996 included the member states Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the United Kingdom. The total population of the EC is about 377 million people.

For atmospheric discharges, activity concentrations in environmental media were calculated using the models described above. The area around each site is divided into annular segments on a polar grid. It is assumed that the activity concentrations, population and agricultural production are uniformly distributed within each segment. These quantities are combined to calculate the collective doses in each segment and the collective dose to the population is obtained by summing over all segments. It is assumed that all the food produced in an annular segment is consumed within that segment; this assumption is likely to result in a small overestimate of collective dose as some food will be exported out of the EC. For discharges to the marine environment the model described previously is used to calculate concentrations in environmental media. These values are combined with seafood catch data and coastline lengths to estimate collective doses[4].

It is not possible to calculate collective doses arising from discharges to rivers in PC CREAM, although output from the model could be used as the basis of a collective dose calculation. However, in this study collective doses from river water were only considered in terms of the exposures arising from the marine environment into which the river ultimately discharges. To achieve this a simple link was set up between the river and marine dispersion models. Possible limitations of this approach are discussed further in section 5.3 below.

4.3.2 Individual dose

For both atmospheric and aquatic discharges, doses indicative of those received by the critical group residing near each site have been calculated by selecting appropriate habit data and food consumption data and using calculated activity concentrations in environmental media near the site. In some cases the habit and consumption data used may be conservative, leading to some overestimation of doses, however this will not affect the conclusions that can be drawn from dose trends. The activity concentrations in environmental materials are calculated assuming that equilibrium conditions have been reached.

For atmospheric discharges, exposures indicative of those received by members of the critical group have been estimated for two separate locations. Individuals were assumed to live within a 30° sector into which the wind blows for 20% of the time, and at distances of 0.5 km and 5 km from the discharge point. The first distance point corresponds approximately to the site boundary and the second one to the nearest point at which habitation and food production may reasonably be considered to occur. The dose at each location was estimated assuming that the individuals remained there throughout the year and spent 90% of this time indoors. It was also assumed that the individuals obtained 100% of their annual food intake from the same location. Terrestrial food ingestion rates have been derived under a separate study[12] and are presented in Table 5.

To calculate doses from marine discharges it was assumed that individuals obtained all their seafood from the local compartment and that beach occupancy occurred entirely within this compartment. Ingestion rates for aquatic foods have been derived under a separate study[12] and are presented in the NRG report. However, for selected sites where data are available the critical group dose has been refined taking into account measured activity concentrations in media from the local environment and site specific habit data. Two sites were selected, namely Sellafield and Cap de la Hague, because of their importance in terms of their radiological impact and also because measured activity concentrations in environmental media are readily available. Further details are presented in the NRG report.

Individual doses arising from discharges to rivers were estimated using PC CREAM. Doses arising directly from the river were calculated along with doses from exposures to radionuclides dispersed in the marine environment into which the river discharges. This was achieved by linking the river and marine models. Possible limitations of this approach are discussed further in section 5.3 and details of the calculation are given in the NRG report.

5 Results and discussion

Over the reporting period of 1987 to 1996 significant changes have taken place affecting discharges from EC nuclear sites. Some 23 power reactors on 17 sites have been shut down while an additional 23 reactors situated at 13 sites have begun operation. For some decommissioned sites discharge data continue to be reported in the Bilcom97 database and these clearly relate to the process of decommissioning rather than routine operation. The operations conducted at reprocessing sites such as Sellafield and Cap de la Hague have changed and these are reflected in the release profiles from these sites.

The collective exposures of the population of the EC from reported discharges in three selected years (1987, 1991 and 1996) have been calculated along with exposures of individuals living near to the nuclear sites. Exposures are broken down by site and form of discharge ie liquid and atmospheric. More detailed results including radionuclide and pathway breakdowns of individual and collective doses are available on an accompanying CD.

5.1 Collective dose

Collective doses truncated at 500 years to the EC population from all EC civil nuclear sites in 1987, 1991 and 1996 are given in Tables 6, 7, 8, the NRG report and Figure 3. In most cases the collective exposures from routine releases of radioactivity will be delivered within 500 years. Exceptions are the mobile, very long-lived radionuclides ^{129}I and ^{14}C, which may continue to cause exposures beyond 500 years. Although actinides are long-lived they generally bind to sediments, are therefore less mobile and give rise to insignificant exposures beyond 500 years.

5.1.1 Atmospheric discharges

Collective doses from releases to the atmosphere from nuclear power stations are given in Table 6 and Figure 4. The collective dose has been split into two components: the non-global component which arises only from the ‘first pass’ of the radioactive plume; and the global component which arises only from radionuclides that have become globally dispersed. The estimated non-global component of collective dose, summed over all power plants, has increased in the latter stages of the study period from 14 man Sv in 1987 to 43 man Sv in 1996. The estimate of the global component also increased between 1987 (5.4 man Sv) and 1996 (27 man Sv). Both components of the estimated collective dose have increased because discharges of ^{14}C from UK Nuclear Electric GCRs and AGRs were only reported after 1991 when a revised discharge authorisation came into effect. The ^{14}C discharges from these sites make a significant contribution to the non-global component, e.g. Oldbury (8.1 man Sv in 1996), Dungeness A (3.8 man Sv in 1996) and Hinkley Point A and B (2.1 and 3.3 man Sv respectively in 1996), and account for almost 100% of the global component at each site. Consequently the increase in collective dose will, to some extent, be an artefact of the Bilcom97 database. Other contributions to the total collective dose of note came from the German stations Gundremmingen and Isar 2 (nearly 100% ^{14}C) and Chapelcross in the UK (90% ^{3}H).

Collective doses arising from atmospheric releases from reprocessing plants are given in Table 7. For Cap de la Hague and Sellafield, doses were calculated for each year between 1987 and 1996 (see Figures 5 and 6). For Sellafield it can be seen that there was little change in the estimate of collective dose over the study period (22 man Sv in 1987 to 16 man Sv in 1996). The global component

makes a significant contribution in most years. Important radionuclides are ^{129}I and ^{14}C. For Cap de la Hague there has been a consistent increase in the estimate of collective dose over this ten-year period (0.95 to 53 man Sv). This rise is due primarily to an increase in reported discharges of ^{14}C, ^{129}I and ^{85}Kr. Again the global component, which is dominated by ^{14}C, is the same order of magnitude as the non-global component. From 1992 to 1996 significant contributions to the non-global component arise from ^{14}C (~ 60%) and ^{129}I (20% to 30%) but these radionuclides are not included in the Bilcom97 database prior to 1992. Hence, doses from discharges prior to 1992 may have been higher than those predicted and the apparent increase in dose at Cap de la Hague may not have occurred as the doses may have been at post 1992 levels in the years before 1992. Collective doses from Dounreay have decreased over the study period from 5.8E-2 man Sv in 1987 to 6.8E-3 man Sv in 1996, while for WAK, which is currently being decommissioned, the dose has dropped from 1.9E-1 man Sv in 1987 to 1.3E-2 man Sv in 1991 with no data for 1996. For Marcoule discharge data only exist in the Bilcom97 database for 1996 and doses have been estimated at 4.9 man Sv.

5.1.2 Liquid discharges

Section 6 of the NRG report shows collective doses from discharges into the marine environment. The actual dose calculation performed depends on the location of the site ie “coastal” or “inland” (see section 2 of the NRG report). For coastal sites the discharge occurs directly into the marine environment but for inland sites discharges are initially into a freshwater system before ultimately being dispersed in the sea.

Collective doses from liquid discharges summed over all power plants are presented in Table 8 and Figure 4. The estimated dose has decreased from 0.74 man Sv in 1987 to 0.13 man Sv in 1996 with a very small contribution from the global component. In 1987 and 1991 significant contributions (0.23 and 0.31 man Sv respectively) are predicted to come from the Magnox GCR at Trawsfynydd in the UK. The unique nature of this site, which is situated on a lake, means that it cannot at present be modelled using PC CREAM. It has previously been modelled at NRPB using the BIOS code[10] and this approach was repeated in this study for the assessment of dose from liquid discharges. It should be noted that liquid discharges of ^{137}Cs from Trawsfynydd have been estimated using the generic radionuclide breakdown data derived by GRS. The radionuclide composition of discharges published by the Trawsfynydd site operators suggests that the contribution from ^{137}Cs is overestimated by this approach, by a factor of 4 or 5. Even though discharges of some other radionuclides will have been correspondingly underestimated it is expected that the collective doses presented here are conservative because of the radiological importance of ^{137}Cs. In 1987 a significant contribution to the collective dose from liquid discharges (0.12 man Sv) also comes from Paluel in France and is attributable to exposure from ^{110m}Ag via the ingestion of seafood, particularly crustaceans and molluscs. This radionuclide is also an important contributor to dose for discharges from Cattenom, Chinon B, Chooz A, Fessenheim and Le Blayais. Other important sites include Bradwell and Sizewell A for which ^{137}Cs in crustaceans contributes most to the collective dose.

For some sites doses may be somewhat underestimated in this assessment because in many cases only a subset of the actual site discharges was available on the Bilcom97 database. Evidence to support this comes from the UK sites, for which the collective doses estimated in this study are in general less than those reported in a previous study[13] which was able to draw on more detailed discharge data. Nevertheless liquid discharges from power stations have tended to decrease, as a consequence of which exposures from airborne releases have become relatively more important, and hence the possible underestimate of the doses from liquid discharges is not thought to be of overall significance.

Collective doses from liquid discharges from reprocessing plants are summarised in Table 8 and given in more detail in the NRG report. For Cap de la Hague and Sellafield, doses were calculated for

each year between 1987 and 1996 (Figures 5 and 6). Total collective doses arising from liquid discharges from Sellafield remained fairly steady at around 4 man Sv until 1994 when it more than doubled to around 10 man Sv. This increase was due to an increase in the level of reported discharges of ^{14}C. Consequently, the global component of the collective dose makes a significant contribution in these later years. The total collective dose from liquid discharges from Cap de la Hague has steadily declined from 1989 (23 man Sv) to 1996 (0.9 man Sv) and this is mainly due to reductions in the discharge of ^{106}Ru. In 1991 ^{241}Pu was the dominant radionuclide but the associated discharge data from Bilcom97 is higher than that reported in reference 9. It should also be noted that liquid discharges of ^{14}C from Cap de la Hague are only reported in the Bilcom97 database for 1996. For consistency, no liquid discharges of ^{14}C have been included in the dose calculations for any years for this site. However, the contribution of ^{14}C is expected to be several man Sv in the years 1994 to 1996 when discharges increased to almost 10 TBq per year from an initial value of 2 TBq per year in 1987[9]. Collective doses from liquid discharges from Dounreay have also decreased from 0.41 man Sv in 1987 to 0.14 man Sv in 1996. Liquid discharge data for Marcoule are only available for 1996 when the collective dose from liquid discharges was estimated to be 0.24 man Sv. Karlsruhe in Germany was previously the site of the reprocessing plant WAK and also two power reactors, MZFR and KNK. All these facilities have been shut down and are presently being decommissioned (Table 2). As a result, reported discharges from WAK are at least an order of magnitude, and in many cases several orders of magnitude, less than those for other reprocessing plants.

5.1.3 Summary

The general decrease in discharges to the aquatic environment means that atmospheric discharges are relatively more important in 1996 than in 1987 (Table 8). Reported atmospheric discharges in 1987 accounted for about 48% (43 man Sv) of the total collective dose truncated at 500 years from all discharges in that year. For discharges in 1996 the corresponding contribution from atmospheric discharges had risen to 88% (140 man Sv). Nuclear power stations accounted for 47% (20 man Sv) of the collective dose from atmospheric discharges in 1987 and 50% (70 man Sv) of the collective dose from atmospheric discharges in 1996. As discussed earlier, it seems very likely that doses for 1987 would be much closer to those predicted for 1996 if atmospheric discharges of ^{14}C from UK GCRs and AGRs and Cap de la Hague were considered.

5.2 Individual dose

As explained in section 4.3.2 these doses are indicative of those received by the most exposed members of the population ie the critical group. The doses are calculated for discharges in 1987, 1991 and 1996 and the calculations assume that equilibrium conditions apply between the release and concentrations in environmental materials.

5.2.1 Atmospheric discharges

Calculated annual doses to adults in the vicinity of nuclear power stations, from atmospheric releases from those sites are given in Table 9. These doses are generally higher for discharges from UK sites. In the UK, doses are dominated by discharges of ^{14}C, ^{35}S, ^{41}Ar and to a lesser extent ^{3}H from GCRs and AGRs. It is again important to note that at GCRs and AGRs operated by Nuclear Electric discharges of ^{14}C were only reported after 1991 when a revised discharge authorisation came into effect. Consequently the estimates of individual dose for these sites, based on the Bilcom97 database, will be underestimated for years prior to 1992. The highest annual dose from a UK site comes from Chapelcross where the dose at the site boundary (0.5 km) is approximately 0.14 and 0.12 mSv for annual releases in 1987 and 1996 respectively. At this site ^{3}H and ^{41}Ar are the main contributors to individual dose. The majority of the tritium discharges from this site result from activities other than those related to power generation.

Annual doses from atmospheric discharges indicative of those received by members of the critical groups residing near reprocessing plants are given in Table 10. At Sellafield and Cap de la Hague doses only amount to a few tens of μSv throughout the period of interest. The most important radionuclide (contributing 47% and 55% of the dose at 0.5 and 5 km from the site) in 1987 at Sellafield is ^{129}I in milk, milk products and to a lesser extent in fruit. In 1996 ^{129}I was still important, contributing 49% and 66% of the dose at 0.5 and 5 km from the site. In addition external exposure to gamma rays from ^{41}Ar in the plume makes a significant contribution to individual dose at the Sellafield site particularly at the 0.5 km distance (44% in 1987 and 38% in 1996). For Cap de la Hague ^{129}I is also an important radionuclide in 1996 (87% and 75% of the dose at 0.5 and 5 km from the site) but was not recorded in the discharge database Bilcom97 prior to 1992. This is also true of ^{14}C which contributed 8% and 19% of the dose at 0.5 and 5 km from the site in 1996. Before 1992 ^{85}Kr dominates the exposure (over 90% of the dose at 0.5 and 5 km from the site) of individuals from atmospheric releases. At Marcoule the annual dose received from discharges in 1996 was estimated at 100 μSv and 30 μSv at 0.5 and 5 km from the site respectively. This was dominated by discharges of ^{129}I. For Marcoule, the Bilcom97 database actually records halogens as the discharge category and in the absence of better information it was assumed that this was made up entirely of ^{129}I. This assumption is likely to contribute to the elevated dose that has been estimated.

5.2.2 Liquid discharges

Individual exposures from discharges into the aquatic environment are given in section 6 of the NRG report and summarised, for selected sites, in Tables 11 and 12 of this report. Exposures to discharges from coastal sites generally give rise to doses of a few μSv for the majority of power stations. Exceptions include: Bradwell, for which a dose of 10 μSv was calculated for 1996 discharges and is dominated by ^{137}Cs in fish; Heysham 1, for which a dose of 10 μSv was calculated for discharges in 1991, and is dominated by external gamma exposure to ^{60}Co; and 70 μSv for Paluel from 1987 discharges for which ^{110m}Ag in crustaceans and molluscs is the largest contributor.

However, the more significant exposures arise as a result of discharges from reprocessing plants. Because of the radiological importance of Sellafield and Cap de la Hague the individual dose calculation was refined using observed to predicted ratios based on data from references 9 and 14 to calibrate the marine dispersion model. The results presented here are the refined calculations. Details of the original calculations performed, and also additional calculations that used more realistic habit data are given in the NRG report. At Cap de la Hague the refined dose calculation was based on measurement data for the Les Huquets region of the Normandy coast. It shows that doses have dropped steadily from 170 μSv in 1987 to 19 μSv in 1996 and are dominated throughout this period by the consumption of molluscs contaminated with ^{106}Ru and ^{241}Pu and external exposure to gamma rays from ^{60}Co in sediments. As mentioned in section 5.1.2, liquid discharges of ^{14}C are only recorded in the Bilcom97 database for 1996 and for consistency have been excluded from the dose assessment for Cap de la Hague for all years. However, the contribution from this radionuclide is expected to be of the order of 10 μSv in the years 1994 to 1996 when discharges increased to almost 10 TBq per year from an initial value of 2 TBq per year in 1987[9]. Doses to individuals residing near the Sellafield site have also decreased from 187 μSv in 1987 to 114 μSv in 1996. The contribution to dose from various radionuclides and exposure pathways varies considerably over the study period. However, important radionuclides include ^{99}Tc in crustaceans, ^{14}C and ^{137}Cs in fish, ^{106}Ru and ^{241}Pu in molluscs and external exposure to ^{60}Co, ^{65}Zn ^{95}Zr, ^{95}Nb, and ^{152}Eu. Exposures from discharges at Dounreay are considerably less than the previous two sites and were estimated at 15 μSv in 1987 decreasing to about 5 μSv in 1996, and dominated by ^{137}Cs in fish.

The method for modelling exposures from inland sites is described in the NRG report and results are given in section 6 of the report. Briefly, three groups of individuals were considered:

X: those residing close to the river,

Y: consumers of seafood, and

Z: individuals inhabiting the area around the river estuary.

Doses to group X have been calculated assuming that these individuals live 10 km downstream of the discharge point and are exposed only to external gamma and beta from river bed sediments, consumption of freshwater fish and drinking water. These doses are generally only a few μSv with the most notable exposure arising from 1987 discharges from Dampierre (28 μSv), dominated by external gamma exposure to ^{60}Co. Doses to groups Y and Z have been calculated using activity concentrations derived from the river model as a source term for the marine dispersion model. Group Y individuals are seafood consumers and group Z individuals are exposed to external gamma and beta in marine sediments, external gamma and beta from handling fishing gear, and inhalation of seaspray. Group Y individuals always belong to the country in which the discharging site operates while individuals in group Z will only differ from those in group Y if the river discharges into the sea from a country in which the site does not operate. The highest doses to group Y individuals were calculated for Bugey (1987) at 20 μSv, Chinon (1987) at 12 μSv, Dampierre (1987) at 39 μSv, Le Blayais (1987) at 16 μSv and Marcoule (1996) at 300 μSv. Where group Z individuals differed from group Y the doses to the former were, in general, at least a factor of 5 lower and in most cases a factor of 10. Discharges from the Karlsruhe site have decreased since decommissioning of WAK and the KNK reactor began in 1990/91. No total alpha was reported after this time and the major component of the discharge was ^{3}H which remained at a few tens of TBq per year over this period. Consequently, the critical group dose, based on the aquatic discharges reported in the Bilcom97 database, is unlikely to be greater than a few tens of micro Sieverts. The assessment of doses from liquid discharges from the Trawsfynydd nuclear reactor was carried out by NRPB using BIOS[10]. Discharges from Trawsfynydd initially enter a lake before being transported to the sea. Therefore, two critical groups were considered, those exposed to terrestrial pathways and those exposed to marine pathways. Dose estimates for 1987 and 1991 to the marine critical group were 5.4 μSv and 7.8 μSv respectively, while those to the terrestrial critical group were 370 μSv and 520 μSv respectively. The dominant exposure pathway for the terrestrial critical group was ^{137}Cs in freshwater fish, which accounted for 90% of the dose. However, as discussed in section 5.1.2, it is likely that liquid discharges of ^{137}Cs from Trawsfynydd have been overestimated by a factor of 4 or 5 in this study. Nevertheless, assessed doses to the terrestrial critical group in excess of 100 μSv are likely as a result of liquid discharges in 1987 and 1991. Additional evidence to support this is given in reference 15 in which the critical group dose, based on monitoring data, was estimated to be 110 μSv in 1991.

5.3 Identification of weaknesses and uncertainties in the assessment

The EC discharge database Bilcom97 is a very valuable tool for dose assessments but has a weakness in that there is some inconsistency in the data entries across sites. To overcome this problem a consistent method of reporting discharges needs to be adopted by operators throughout the EC. This would remove some of the ambiguity in the database and ensure that aggregated discharges were always accompanied by radionuclide breakdowns. In this study there were many cases where assumptions had to be made regarding the radionuclide composition of aggregated discharges because breakdowns were missing or incomplete. These assumptions were based on data provided by GRS which gave typical radionuclide spectra for each aggregated discharge category as a function of country and type of facility. However, for liquid discharges the radionuclides in these spectra were only included in the doses assessments if they already existed on the discharge database Bilcom97 for the

site under consideration. It is important to note that the doses calculated in this study are based on the reported discharges held in the Bilcom97 database and will reflect any inaccuracies or omissions in the data.

This study was carried out for more than 90 nuclear facilities throughout the EC. Consequently, it was not possible, given the limitations of time and resources, to carry out detailed site-specific assessments for each nuclear facility. Instead assumptions were made regarding many of the input parameters and generic values used. These assumptions were generally conservative and in the case of individual exposures lead to a probable overestimate of the dose. This was particularly true of individual doses calculated for Sellafield and La Hague. For this reason it was felt that the individual dose assessment for these two sites should be refined to include site specific data that are readily available. The results from these site specific dose assessments have been compared with other published data[9,13,16,17] and are in good agreement. This demonstrates that the use of conservative generic data may have limitations and that refinement using site specific data will under some circumstances be necessary to obtain an appropriate degree of accuracy.

The calculation of collective dose from liquid discharges to rivers did not consider the following pathways: irrigation of agricultural land, consumption of drinking water, consumption of freshwater fish and external irradiation from river sediments. However, collective doses from the marine environment arising as a consequence of discharges to rivers were considered. The river screening model in PC CREAM was used to predict activity concentrations in river water and suspended sediments at the mouth of the river due to discharges upstream. These concentrations were used as the source of activity and treated as a liquid discharge in the local marine compartment. This is likely to overestimate collective doses in the marine environment because, in reality, activity associated with suspended sediments is less available for dispersion. It is likely that this overestimate will compensate for the omission of collective doses received directly from riverbed sediments or the use of river water. Exceptions may arise where the release is dominated by short-lived radionuclides.

PC CREAM is an extremely useful tool for carrying out radiological impact assessments. However, there are limitations to its use. In particular atmospheric dispersion from stacks that are greater than 100m in height cannot be modelled. Consequently, for sites such as Isar 2 in Germany, which has a 160m stack, it is possible that exposures in the vicinity of the site will be overestimated. Although more recent atmospheric dispersion models than the Gaussian model used in PC CREAM exist, this model has been shown to be fit for purpose and it has been demonstrated that the predictions of this model are comparable with those from more complex models for particular release scenarios[18]. In many regions of Europe the irrigation of crops with river water is common practice and may lead to exposures from the ingestion of terrestrial foods. Such pathways are not currently considered in PC CREAM. These and other issues have been discussed by the PC CREAM user group[18].

The assessment includes a number of uncertainties and variabilities that inevitably affect the doses that have been estimated. Uncertainties are defined as arising from limitations in current knowledge while variability reflects a genuine difference in parameter values such as the ingestion rates of individuals. A recent study has estimated that doses received by the critical groups at Sellafield and Sizewell cover a range of typically 3 to 4 between the ratio of the 5^{th} to 95^{th} percentiles of dose[12]. Collective doses truncated at 500 years tend to be much less sensitive to changes in parameter values as the dose is delivered to a population and spatial and temporal averaging occurs.

6 Summary

This report gives details of an assessment carried out to determine individual and collective doses received by members of the EC as a consequence of discharges of radionuclides from nuclear sites within the EC. Doses have been calculated based on discharges in the years 1987 to 1996 and

extend the period considered in a previous EC publication[2] which covered 1977 to 1986. The present assessment uses updated dose coefficients[7] and a revised methodology[4].

It is important to note that the doses calculated in this study are based on the reported discharges held in the Bilcom97 database and will reflect any inaccuracies or omissions in that data set. In addition the generic values used for habit data and consumption rates may, in some cases, be conservative leading to some overestimation of the exposures.

The collective doses estimated in this study, truncated at 500 years to the EC population from all of the discharges in 1987, 1991 and 1996, amount to approximately 90, 47 and 160 man Sv respectively. However, some significant discharges are omitted from these dose estimates. These include atmospheric discharges of ^{14}C from UK GCRs and AGRs prior to 1992, atmospheric discharges of ^{14}C and ^{129}I from Cap de la Hague prior to 1992 and liquid discharges of ^{14}C from Cap de la Hague for all years. Atmospheric discharges of ^{14}C from UK GCRs and AGRs have remained fairly constant over the study period and are expected to increase the collective dose in the late 80s and early 90s by a few man Sv per site. Atmospheric discharges of ^{14}C and ^{129}I from Cap de la Hague are thought to have increased by factors of 4 and 3 respectively from 1987 to 1996[9] and collectively are expected to increase doses prior to 1992 by about 10 to 20 man Sv. Finally, liquid discharges of ^{14}C from Cap de la Hague[9] have increased by a factor of 4 and are expected to increase doses in all years by between 2 and 8 man Sv. In comparison the annual collective dose to the EC population from natural radioactivity, based on UK data[19], is approximately 844,000 man Sv.

In overall terms the estimated collective exposure of the EC population, based on discharge data held in Bilcom97, has increased by about 76% between the years of 1987 and 1996. This rise is likely to be less significant if pre-1992 atmospheric discharges of ^{14}C from UK GCRs and AGRs and Cap de la Hague are taken into consideration. However, an increase is still likely to be seen primarily because of the increase in atmospheric discharges of ^{14}C from Cap de la Hague.

The reduction in the contribution from liquid discharges from 1987 to 1996 means that atmospheric discharges have become relatively more important in the later years. Liquid discharges have decreased mainly as a result of decreases in the levels of discharges reported from the Cap de la Hague reprocessing plant.

The two most important sources over this time period in terms of contributions made to the collective dose were the reprocessing plants at Cap de la Hague and Sellafield.

Individual doses around the nuclear sites are also reported. In all cases they are below the relevant dose limit.

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TABLE 1 European Community nuclear power stations

				Years of Operation	
Country	Facility	Reactor Type	Output Capacity (MW(e))	First Year	Last Year
Belgium	Doel 1	PWR	392	1974	
	Doel 2	"	392	1975	
	Doel 3	"	1006	1982	
	Doel 4	"	1001	1985	
	Tihange 1	PWR	962	1975	
	Tihange 2	"	960	1982	
	Tihange 3	"	1015	1985	
Finland	Loviisa 1	PWR	510	1977	
	Loviisa 2	"	510	1980	
	TVO 1 (Olkiluoto)	BWR	870	1978	
	TVO 2 (Olkiluoto)	"	870	1980	
France	Belleville 1	PWR	1310	1987	
	Belleville 2	"	1310	1988	
	Blayais 1	PWR	910	1981	
	Blayais 2	"	910	1982	
	Blayais 3	"	910	1983	
	Blayais 4	"	910	1983	
	Bugey 1	GCR	540	1972	1994
	Bugey 2	PWR	910	1978	
	Bugey 3	"	910	1978	
	Bugey 4	"	880	1979	
	Bugey 5	"	880	1979	
	Cattenom 1	PWR	1300	1986	
	Cattenom 2	"	1300	1987	
	Cattenom 3	"	1300	1990	
	Cattenom 4	"	1300	1991	
	Chinon A3	GCR	360	1966	1990
	Chinon B1	PWR	905	1982	
	Chinon B2	"	905	1983	
	Chinon B3	"	905	1986	
	Chinon B4	"	905	1987	
	Chooz A	PWR	305	1967	1991
	Chooz B1	PWR	1455	1996	
	Chooz B2	"	1455	1997	
	Civaux 1[1]	PWR	1400	1997	
	Civaux 2	"	1400	1998	
	Creys Malville	FBR	1200	1986	
	Cruas 1	PWR	915	1983	
	Cruas 2	"	915	1984	
	Cruas 3	"	915	1984	
	Cruas 4	"	880	1984	
	Dampierre 1	PWR	890	1980	
	Dampierre 2	"	890	1980	
	Dampierre 3	"	890	1981	
	Dampierre 4	"	890	1981	
	Fessenheim 1	PWR	880	1977	
	Fessenheim 2	"	880	1977	
	Flamanville 1	PWR	1330	1985	
	Flamanville 2	"	1330	1986	
	Golfech 1	PWR	1310	1990	
	Golfech 2	"	1310	1993	
	Gravelines 1	PWR	910	1980	
	Gravelines 2	"	910	1980	

Country	Facility	Reactor Type	Output Capacity (MW(e))	Years of Operation	
				First Year	Last Year
	Gravelines 3	"	910	1980	
	Gravelines 4	"	910	1981	
	Gravelines 5	"	910	1984	
	Gravelines 6	"	910	1985	
	Nogent 1	PWR	1310	1987	
	Nogent 2	"	1310	1988	
	Paluel 1	PWR	1330	1984	
	Paluel 2	"	1330	1984	
	Paluel 3	"	1330	1985	
	Paluel 4	"	1330	1986	
	Penly 1	PWR	1330	1990	
	Penly 2	"	1330	1992	
	St Alban 1	PWR	1335	1985	
	St Alban 2	"	1335	1986	
	St Laurent A1	GCR	390	1969	1990
	St Laurent A2	"	450	1971	1992
	St Laurent B1	PWR	915	1981	
	St Laurent B2	"	915	1981	
	Tricastin 1	PWR	915	1980	
	Tricastin 2	"	915	1980	
	Tricastin 3	"	915	1981	
	Tricastin 4	"	915	1981	
Germany	Biblis A (KWB-A)	PWR	1167	1974	
	Biblis B (KWB-B)	PWR	1240	1976	
	Brokdorf (KBR)	PWR	1326	1986	
	Brunsbuettel (KBR)	BWR	771	1976	
	Emsland (KKE)	PWR	1290	1988	
	Grafenrheinfeld (KKG)	PWR	1275	1981	
	Greifswald 1	PWR	440	1973	1990
	Greifswald 2	"	440	1974	1990
	Greifswald 3	"	440	1977	1990
	Greifswald 4	"	440	1979	1990
	Grohnde (KWG)	PWR	1360	1984	
	Gundremmingen B (KRB)	BWR	1284	1984	
	Gundremmingen C (KRB)	"	1288	1984	
	Isar 1 (KKI-1)	BWR	870	1977	
	Isar 2 (KKI-2)	PWR	1365	1988	
	Kruemmel (KKK)	BWR	1260	1983	
	Meulheim-Karlich (KMK)	PWR	1165	1986	1988
	Neckarwestheim 1 (GKN-1)	PWR	785	1976	
	Neckarwestheim 2 (GKN-2)	PWR	1269	1989	
	Obrigheim (KWO)	PWR	340	1968	
	Philipsburg 1 (KKP-1)	BWR	890	1979	
	Philipsburg 2 (KKP-2)	PWR	1358	1984	
	Rheinsberg	PWR	70	1966	1990
	Stade (KKS)	PWR	640	1972	
	THTR 300	HTGR	296	1985	1989

				Years of Operation	
Country	Facility	Reactor Type	Output Capacity (MW(e))	First Year	Last Year
	Unterweser (KKU)	PWR	1285	1978	
	Wuergassen	BWR	640	1971	1994
Italy	Caorso	BWR	860	1978	1988
	Latina	GCR	153	1963	1987
	Trino	PWR	260	1964	1988
Spain	Almaraz 1	PWR	973	1981	
	Almaraz 2	"	895	1983	
	Asco 1	PWR	973	1983	
	Asco 2	"	966	1985	
	Cofrentes	BWR	953	1984	
	Jose Cabrera (Zorita)	PWR	153	1968	
	Sta Maria de Garona	BWR	440	1971	
	Trillo	PWR	1001	1988	
	Vandellos 1	GCR	480	1972	1990
	Vandellos 2	PWR	961	1987	
Sweden	Barsebaeck 1	BWR	600	1975	
	Barsebaeck 2	"	600	1977	
	Forsmark 1	BWR	968	1980	
	Forsmark 2	"	968	1981	
	Forsmark 3	"	1155	1985	
	Oskarshamn 1	BWR	445	1970	
	Oskarshamn 2	"	605	1974	
	Oskarshamn 3	"	1160	1985	
	Ringhals 1	BWR	835	1974	
	Ringhals 2	PWR	872	1974	
	Ringhals 3	"	915	1980	
	Ringhals 4	"	915	1982	
The Netherlands	Borssele	PWR	452	1973	
	Dodewaard	BWR	55	1968	1997
United Kingdom	Berkeley A	GCR	138	1962	1989
	Berkeley B	"	138	1962	1988
	Bradwell A	GCR	123	1962	
	Bradwell B	"	123	1962	
	Chapelcross A	GCR	48	1959	
	Chapelcross B	"	48	1959	
	Chapelcross C	"	48	1959	
	Chapelcross D	"	48	1960	
	Dungeness A1	GCR	212	1965	
	Dungeness A2	"	212	1965	
	Dungeness B1	AGR	450	1983	
	Dungeness B2	"	450	1985	
	Hartlepool A1	AGR	625	1983	
	Hartlepool A2	"	625	1984	
	Heysham 1A	AGR	621	1983	
	Heysham 1B	"	622	1984	
	Heysham 2A	AGR	615	1988	
	Heysham 2B	"	615	1988	
	Hinkley Point AA	GCR	235	1965	
	Hinkley Point AB	"	235	1965	
	Hinkley Point BA	AGR	560	1976	
	Hinkley Point BB	"	560	1976	
	Hunterston AA	GCR	150	1964	1990
	Hunterston AB	"	150	1964	1989

Country	Facility	Reactor Type	Output Capacity (MW(e))	Years of Operation	
				First Year	Last Year
	Hunterston B1	AGR	575	1976	
	Hunterston B2	"	575	1977	
	Oldbury AA	GCR	217	1967	
	Oldbury AB	"	217	1968	
	Sizewell AA	GCR	210	1966	
	Sizewell AB	"	210	1966	
	Sizewell B	PWR	1188	1995	
	Torness 1	AGR	625	1988	
	Torness 2	"	625	1989	
	Trawsfynydd A	GCR	195	1965	1993
	Trawsfynydd B	"	195	1965	1993
	Winfrith	SGHWR	92	1967	1990
	Wylfa A	GCR	420	1971	
	Wylfa B	"	420	1971	

Note
(1) This site only became operational in 1997/1998 and so is outside the scope of this assessment.

TABLE 2 European Community reprocessing plants

Country	Facility	Processed fuel	Capacity (t HM/a)	1st start up	Shut down
France	Marcoule (APM)[1]	GCR	600	1958	
	Marcoule (UP1)[1]	FBR	5	1974	
	Cap de la Hague (UP2)[2]	LWR	400	1976	
	Cap de la Hague (UP3)	LWR	800	1990	
Germany	WAK (Karlsruhe)[3]	LWR	35	1971	1990
United Kingdom	Dounreay	FBR	1	1980	
	Sellafield[4]	GCR	1500	1952	

Notes
(1) The dose assessment was carried out for the Marcoule site as a whole. This included the Phenix FBR.
(2) The dose assessment was carried out for the Cap de la Hague site as a whole.
(3) The dose assessment was carried out for the Karlsruhe site as a whole. Liquid discharges for this site include the Karlsruhe reactor KNK up until 1991 when it was shut down. Decommissioning of the reactors KNK II and MZFR and the reprocessing plant is now taking place and is expected to be completed by 2006 and 2009 respectively.
(4) The dose assessment for the Sellafield site includes discharges from Calder Hall nuclear power plant.

TABLE 3 Site specific modelling data for nuclear installations in the European Community[1]

Country	Facility	Site Location		Effective release height (metres)[2]	Meteorological data[3]	Sea/River/Lake[9]		Sea Region[10]
		Latitude	Longitude			Actual	Assumed	
(A) NUCLEAR POWER PLANTS								
Belgium	Doel 1 + 2 + 3 + 4	51.3170	4.2670	60	(4)	Scheldt	Rhine 10	North Sea South East
	Tihange 1 + 2 + 3	50.5330	5.2500	100	(4)	Meuse	Rhine 8	North Sea South East
Finland	Loviisa 1 + 2	60.4923	26.2592	100	(7)		Baltic Sea	Gulf of Finland
	TVO 1 + 2 (Olkiluoto)	61.1400	21.2600	100	(8)		Baltic Sea	Bothnian Sea
France	Belleville 1 + 2	47.5523	2.7667	60	Dampierre	Loire 1	*	French Continental Shelf
	Blayais 1 + 2 + 3 +4	45.1670	-1.6670	60	(4)	Not considered in assessment of liquid discharges		
	Bugey 1	45.7830	5.2000	100	(4)	Rhone 1	*	Liguro Provencal Basin
	Bugey 2 + 3 + 4 + 5			60				
	Cattenom 1 + 2 + 3 + 4	49.8000	6.2500	60	(4)	Mosselle	Rhine 7	North Sea South East
	Chinon A3	47.1670	0.2500	60	(4)	Loire 3	*	French Continental Shelf
	Chinon B1 + B2 + B3 + B4			60				
	Chooz A	50.1330	4.8170	30	Tihange	Meuse	Rhine 8	North Sea South East
	Chooz B1 + B2			60				
	Creys Malville	45.7122	5.5439	60	(4)	Rhone 1	*	Liguro Provencal Basin
	Cruas 1 + 2 + 3 + 4	44.6670	4.7670	60	(4)	Rhone 5	Rhone 1	Liguro Provencal Basin
	Dampierre 1 + 2 + 3 + 4	47.7330	2.5000	60	(4)	Loire 1	*	French Continental Shelf
	Fessenheim 1 + 2	47.9330	7.5500	60	(4)	Rhine 1	*	North Sea South East
	Flamanville 1 + 2	49.5330	-1.8830	100	(4)		English Channel	English channel south east
	Golfech 1 + 2	44.0694	0.9634	60	Cruas	Gironde	Loire 3	French Continental Shelf
	Gravelines 1 + 2 + 3 + 4 + 5 + 6	50.9830	2.1330	60	(4)		North Sea	North Sea South East
	Nogent 1 + 2	48.5225	3.6140	60	Dampierre	Seine	Loire 2	English channel south east
	Paluel 1 + 2 + 3 + 4	49.7500	0.3830	60	(4)		English Channel	English channel south east
	Penly 1 + 2	49.9670	1.2757	100	Paluel		English Channel	English channel south east
	St Alban 1 + 2	45.5170	4.8170	60	(4)	Rhone 4	*	Liguro Provencal Basin

Country	Facility	Site Location		Effective release height (metres)[2]	Meteorological data[3]	Sea/River/Lake[9]		Sea Region[10]
		Latitude	Longitude			Actual	Assumed	
	St Laurent A1 + A2	47.7170	1.6000	60	(4)	Loire 2	*	French Continental Shelf
	St Laurent B1 + B2			60				
	Tricastin 1 + 2 + 3 + 4	44.3670	4.6830	60	(4)	Rhone 6	*	Liguro Provencal Basin
Germany	Biblis A (KWB-A)	49.6830	8.4500	100	(4)	Rhine 4	*	North Sea East
	Biblis B (KWB-B)			100				
	Brokdorf (KBR)	53.8670	9.3330	60	(4)	Elbe	Rhine 10	North Sea East
	Brunsbuettel (KBR)	53.9000	9.1330	100	(4)	Elbe	Rhine 10	North Sea East Coastal Water
	Emsland (KKE)	52.5330	7.3170	100	THTR 300	Ems	Rhine 9	North Sea South East
	Grafenrheinfeld (KKG)	50.0000	10.2000	100	(4)	Main	Rhine 5	North Sea South East
	Greifswald 1 + 2 + 3 + 4	54.1330	13.6600	100	Brunsbuettel	Not considered in assessment of liquid discharges		
	Grohnde (KWG)	52.0170	9.4170	100	(4)	Weser	Rhine 8	North Sea East
	Gundremmingen B + C (KRB)	48.4500	10.3000	100	(4)	Danube	Rhine 1	Aegean Sea
	Isar 1 (KKI-1)	48.6000	12.3500	100	(4)	Isar	Rhine 1	Aegean Sea
	Isar 2 (KKI-2)			100				
	Kruemmel (KKK)	53.4330	10.4000	100	(4)	Elbe	Rhine 10	North Sea East
	Meulheim-Karlich (KMK)	50.3889	7.5336	100	(4)	Rhine 8	*	North Sea South East
	Neckarwestheim 1 (GKN-1)	49.0330	9.1670	100	(4)	Neckar	Rhine 3	North Sea South East
	Neckarwestheim 2 (GKN-2)			100				
	Obrigheim (KWO)	49.3500	8.4670	60	(4)	Neckar	Rhine 3	North Sea South East
	Philipsburg 1 (KKP-1)	49.2500	8.4670	100	(4)	Rhine 1	*	North Sea South East
	Philipsburg 2 (KKP-2)			60				
	Rheinsberg	53.1330	12.9800	100	Kruemmel	Not considered in assessment of liquid discharges		
	Stade (KKS)	53.6000	9.4670	60	Brunsbuettel	Elbe	Rhine 10	North Sea East
	THTR 300	51.6800	7.9600	100	(4)	Not considered in assessment of liquid discharges		
	Unterweser (KKU)	53.5000	8.5670	100	(4)	Weser	Rhine 10	North Sea East

Country	Facility	Site Location		Effective release height (metres)[2]	Meteorological data[3]	Sea/River/Lake[9]		Sea Region[10]
		Latitude	Longitude			Actual	Assumed	
	Wuergassen	51.6330	9.4330	60	Unterweser	Weser	Rhine 8	North Sea East
Italy	Caorso	45.0500	9.8600	60	(4)	Not considered in assessment of liquid discharges		
	Latina	41.4600	12.8800	60	(4)	Not considered in assessment of liquid discharges		
	Trino	45.2000	8.3000	100	(4)	Not considered in assessment of liquid discharges		
Spain	Almaraz 1 + 2	39.8330	5.6670	60	(6)	Tagus	Loire 3	Portuguese Continental Shelf
	Asco 1 + 2	41.0170	0.5670	60	(6)	Ebro	Rhone 7	Gulf of Lions
	Cofrentes	39.2330	-1.0670	60	(6)	Jucar	Rhone 7	Gulf of Lions
	Jose Cabrera (Zorita)	40.3330	-2.9000	60	Trillo	Tagus	Loire 1	Portuguese Continental Shelf
	Sta Maria de Garona	42.1330	-3.9830	60	(6)	Ebro	Rhone 1	Gulf of Lions
	Trillo	40.6971	-2.6220	60	(4)	Tagus	Loire 1	Portuguese Continental Shelf
	Vandellos 1	41.0170	0.8170	60	(4)		Mediterranean Sea	Gulf of Lions
	Vandellos 2			60				
Sweden	Barsebaeck 1 + 2	55.7728	12.9468	100	Olkiluoto		Baltic Sea	Belt Sea
	Forsmark 1 + 2 + 3	60.3776	18.2540	100	Olkiluoto	Ekoln	Rhine 10	Bothnian Sea
	Oskarshamn 1 + 2 + 3	57.4159	16.6321	60	Olkiluoto		Baltic Sea	Baltic Sea West
	Ringhals 1	57.2417	12.2813	100	Olkiluoto		Baltic Sea	Kattegat
	Ringhals 2 + 3 + 4			60				
The Netherlands	Borssele	51.4167	3.7500	60	(4)	Scheldt	Rhine 10	North Sea South East
	Dodewaard	51.9000	5.6500	100	Doel	Rhine 10	*	North Sea South East
United Kingdom	Berkeley A + B	51.6930	-2.4920	30	(5)	Not considered in assessment of liquid discharges		
	Bradwell A + B	51.7420	0.9000	30	(5)	Blackwater estuary	North Sea	North Sea South West
	Chapelcross A + B + C + D	53.0160	-3.2260	30	(5)	Solway Firth	Irish Sea	Irish Sea North East
	Dungeness AA + AB	50.9120	0.9650	30	(5)	English Channel	*	English Channel North East
	Dungeness B1 + B2			30				
	Hartlepool A1 + A2	54.6350	-1.1790	30	(5)	North Sea	*	North Sea Central
	Heysham 1A + 1B	54.0310	-2.9160	30	(5)	Irish Sea	*	Liverpool and Morecambe Bays

Country	Facility	Site Location		Effective release height (metres)[2]	Meteorological data[3]	Sea/River/Lake[9]		Sea Region[10]
		Latitude	Longitude			Actual	Assumed	
	Heysham 2A + 2B			30				
	Hinkley Point AA + AB	51.2080	-3.1270	30	(5)	Bridgewater Bay	Bristol Channel	Bristol Channel
	Hinkley Point BA + BB			30				
	Hunterston AA + AB	55.7230	-4.8900	30	(5)	Firth of Clyde	Scottish Waters	Scottish Waters West
	Hunterston B1 + B2			30				
	Oldbury AA +AB	51.6470	-2.5710	30	(5)	Severn Estuary	Bristol Channel	Bristol Channel
	Sizewell AA + AB	52.2110	1.6220	30	(5)	North Sea	*	North Sea South West
	Sizewell B			30				
	Torness 1 + 2	55.9690	-2.4050	30	(5)		North Sea	North Sea Central
	Trawsfynydd A + B	52.9300	-3.9490	30	(5)	Lake Trawsynydd	*	South Irish Sea
	Winfrith	50.6820	-2.2550	30	(5)	Not considered in assessment of liquid discharges		
	Wylfa A + B	53.4150	-4.4780	30	(5)	Irish sea	*	Irish Sea West
(B) REPROCESSING PLANTS								
France	Cap de la Hague	49.6830	-1.8830	100	(4)		English Channel	English Channel South East
	Marcoule	44.1330	4.7170	100	(4)	Rhone 7	*	Liguro Provencal Basin
Germany	WAK (Karlsruhe)	49.0000	8.4000	100	Biblis	Not considered in assessment of liquid discharges		
United Kingdom	Dounreay	58.5780	-3.7530	60	(5)		Scottish Waters	Scottish Waters East
	Sellafield	54.4150	-3.4980	100	(5)		Irish Sea	Cumbrian Waters

Notes

(1) The data in this table are intended to indicate certain basic features of the assessment of collective dose.
(2) The choice is made on the basis of the nearest value to the release heights quoted. CEC private communication and GRS, Germany private communication.
(3) Where site specific data are not available, data for the nearest appropriate site are taken. Otherwise the reference is indicated.
(4) CEC private communication.
(5) Meteorological Office, Bracknell, private communication.
(6) No data were available for this site. A uniform windrose and appropriate Pasquill stability category distribution were adopted.
(7) Fortum, Finland, Private communication.
(8) Olkiluoto TVO, Finland, Private communication.
(9) The river section is identified by a number which is defined in the NRG report. For some sites it was not possible to explicitly model the rivers upon which they stand, and in these cases a representative value of collective dose is calculated on the basis of data from another location. The assumed locations are clearly marked in the table. An asterisk indicates that the actual location is taken.
(10) The sea region given is the initial marine environment into which liquid effluents are assumed to be dispersed. The regions are shown in Figure 2.

TABLE 4 Exposure pathways included for each discharge mode

Atmospheric	Marine	River [1]
Inhalation of radionuclides in the plume	Consumption of seafish	External gamma from radionuclides in sediments
External gamma dose from airborne radionuclides	Consumption of crustaceans	External beta from radionuclides in sediments
External beta dose from airborne radionuclides	Consumption of molluscs	Consumption of fish
External beta from deposited radionuclides	Inhalation of radionuclides in seaspray	Consumption of radionuclides in drinking water
External gamma from deposited radionuclides	External gamma from radionuclides in sediments	
Inhalation of resuspended radionuclides	External beta from radionuclides in sediments	
Consumption of cow and sheep meat	External beta from radionuclides in fishing gear	
Consumption of cow and sheep liver		
Consumption of cow's milk		
Consumption of cow's milk products		
Consumption of green vegetables		
Consumption of root vegetables		
Consumption of fruit [1]		
Consumption of grain		

Note
(1) Not available in PC CREAM for collective dose assessments.

TABLE 5 Critical group ingestion rates (kg y^{-1}) of terrestrial foods

	Austria	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	UK
Cereals	50	54	47	57	50	75	68	80	39	59	51	50	50
Root Vegetables	**69**	**81**	**81**	**79**	**95**	**76**	**150**	**44**	**102**	**161**	**104**	**74**	**130**
Fruit	**91**	**80**	**64**	**81**	**106**	**123**	**81**	**117**	**127**	**103**	**92**	**82**	**75**
Green Vegetables	**53**	**47**	**36**	**67**	**46**	**96**	**42**	**75**	**47**	**82**	**67**	**35**	**45**
Eggs	11	11	8	12	10	8	7	10	12	7	11	10	8
Milk	**268**	**241**	**354**	**264**	**246**	**245**	**236**	**264**	**348**	**192**	**171**	**372**	**240**
Milk Products	67	65	85	86	90	17	81	33	14	17	8	94	20
Beef	21	19	19	27	16	20	13	24	18	14	13	18	15
Mutton	0.5	0.4	0.2	2	0.5	6	4	0.	0.6	2	3	0.3	3
Poultry	4	5	3	7	4	5	7	5	6	6	7	3	8
Pork	41	41	20	22	33	15	20	22	32	24	33	22	15
Offal	2	1.0	2	7	3	3	15	3	2	4	3	1.3	2

Note
Foods in bold font are assumed to be consumed at critical rates

TABLE 6 Collective dose truncated at 500 years from discharges to atmosphere from European Community nuclear power stations (man Sv)

Year of Discharge	1987		1991		1996	
	Non-global[(1)]	Global[(2)]	Non-global[(1)]	Global[(2)]	Non-global[(1)]	Global[(2)]
Belgium						
Doel 1 + 2 + 3 + 4	$5.3\ 10^{-3}$	$2.4\ 10^{-5}$	$9.0\ 10^{-3}$	$5.2\ 10^{-5}$	$1.4\ 10^{-3}$	$9.2\ 10^{-6}$
Tihange 1 + 2 + 3	$5.5\ 10^{-3}$	$3.8\ 10^{-5}$	$3.4\ 10^{-3}$	$2.1\ 10^{-5}$	$1.7\ 10^{-2}$	$1.2\ 10^{-4}$
Finland						
Loviisa 1 + 2	$2.8\ 10^{-1}$	$3.9\ 10^{-1}$	$2.7\ 10^{-1}$	$3.9\ 10^{-1}$	$8.5\ 10^{-2}$	$1.2\ 10^{-1}$
TVO 1 + 2 (Olkiluoto)	$4.8\ 10^{-1}$	$7.6\ 10^{-1}$	$4.8\ 10^{-1}$	$7.7\ 10^{-1}$	$4.9\ 10^{-1}$	$7.8\ 10^{-1}$
France						
Belleville 1 + 2	$2.2\ 10^{-3}$	$3.5\ 10^{-5}$	$5.6\ 10^{-3}$	$5.6\ 10^{-5}$	$3.2\ 10^{-3}$	$2.9\ 10^{-5}$
Blayais 1 + 2 + 3 +4	$4.0\ 10^{-3}$	$1.4\ 10^{-4}$	$5.2\ 10^{-3}$	$1.9\ 10^{-4}$	$1.3\ 10^{-3}$	$2.3\ 10^{-5}$
Bugey 1	$9.3\ 10^{-3}$		$1.5\ 10^{-2}$			
Bugey 2 + 3 + 4 + 5	$9.7\ 10^{-3}$	$6.6\ 10^{-5}$	$1.0\ 10^{-2}$	$5.8\ 10^{-5}$	$3.3\ 10^{-3}$	$1.6\ 10^{05}$
Cattenom 1 + 2 + 3 + 4	$1.0\ 10^{-2}$	$5.0\ 10^{-5}$	$2.0\ 10^{-2}$	$1.3\ 10^{-4}$	$5.9\ 10^{-3}$	$2.9\ 10^{-5}$
Chinon A3	$1.6\ 10^{-2}$		$1.1\ 10^{-3}$			
Chinon B1 + B2 + B3 + B4	$4.6\ 10^{-3}$	$6.1\ 10^{-5}$	$2.0\ 10^{-2}$	$2.1\ 10^{-4}$	$3.1\ 10^{-3}$	$4.4\ 10^{-5}$
Chooz A	$2.7\ 10^{-3}$	$1.9\ 10^{-5}$	$2.4\ 10^{-2}$	$1.6\ 10^{-4}$		
Chooz B1 + B2					$2.3\ 10^{-3}$	$2.1\ 10^{-5}$
Creys Malville			$8.2\ 10^{-4}$	$8.3\ 10^{-4}$	$8.1\ 10^{-4}$	$8.0\ 10^{-4}$
Cruas 1 + 2 + 3 + 4	$1.6\ 10^{-3}$	$2.3\ 10^{-5}$	$2.6\ 10^{-3}$	$3.5\ 10^{-5}$	$2.4\ 10^{-3}$	$3.3\ 10^{-5}$
Dampierre 1 + 2 + 3 + 4	$1.6\ 10^{-2}$	$2.0\ 10^{-4}$	$8.1\ 10^{-3}$	$9.5\ 10^{-5}$	$2.1\ 10^{-3}$	$2.4\ 10^{-5}$
Fessenheim 1 + 2	$1.2\ 10^{-2}$	$5.5\ 10^{-5}$	$3.8\ 10^{-3}$	$1.8\ 10^{-5}$	$2.7\ 10^{-3}$	$1.2\ 10^{-5}$
Flamanville 1 + 2	$1.6\ 10^{-3}$	$3.0\ 10^{-5}$	$1.1\ 10^{-3}$	$8.3\ 10^{-6}$	$1.1\ 10^{-3}$	$1.5\ 10^{-5}$
Golfech 1 + 2			$5.6\ 10^{-4}$	$1.4\ 10^{-5}$	$1.3\ 10^{-3}$	$1.9\ 10^{-5}$
Gravelines 1 + 2 + 3 + 4 + 5 + 6	$2.3\ 10^{-2}$	$1.3\ 10^{-4}$	$1.3\ 10^{-2}$	$5.5\ 10^{-5}$	$6.6\ 10^{-3}$	$3.3\ 10^{-5}$
Nogent 1 + 2	$3.3\ 10^{-4}$	$3.8\ 10^{-6}$	$3.2\ 10^{-3}$	$3.6\ 10^{-5}$	$2.8\ 10^{-3}$	$1.6\ 10^{-5}$
Paluel 1 + 2 + 3 + 4	$2.0\ 10^{-2}$	$2.8\ 10^{-4}$	$1.2\ 10^{-2}$	$1.6\ 10^{-4}$	$4.0\ 10^{-3}$	$3.6\ 10^{-5}$
Penly 1 + 2			$9.2\ 10^{-4}$	$1.5\ 10^{-5}$	$1.5\ 10^{-3}$	$1.8\ 10^{-5}$
St Alban 1 + 2	$2.8\ 10^{-3}$	$1.9\ 10^{-5}$	$4.1\ 10^{-3}$	$2.0\ 10^{-5}$	$2.4\ 10^{-3}$	$1.4\ 10^{-5}$
St Laurent A1 + A2	$2.3\ 10^{-2}$		$7.7\ 10^{-3}$			
St Laurent B1 + B2	$2.0\ 10^{-3}$	$1.4\ 10^{-5}$	$3.7\ 10^{-4}$	$2.5\ 10^{-6}$	$1.5\ 10^{-3}$	$1.4\ 10^{-5}$
Tricastin 1 + 2 + 3 + 4	$2.9\ 10^{-3}$	$3.5\ 10^{-5}$	$4.4\ 10^{-3}$	$4.4\ 10^{-5}$	$2.6\ 10^{-3}$	$3.4\ 10^{-5}$
Germany						
Biblis A (KWB-A)	$1.2\ 10^{-1}$	$3.9\ 10^{-2}$	$3.3\ 10^{-2}$	$1.1\ 10^{-2}$	$1.4\ 10^{-1}$	$5.4\ 10^{-2}$

Year of Discharge	1987		1991		1996	
	Non-global[(1)]	Global[(2)]	Non-global[(1)]	Global[(2)]	Non-global[(1)]	Global[(2)]
Biblis B (KWB-B)	$5.1\ 10^{-2}$	$1.5\ 10^{-2}$	$7.8\ 10^{-2}$	$2.9\ 10^{-2}$	$8.5\ 10^{-1}$	$3.3\ 10^{-1}$
Brokdorf (KBR)	$2.1\ 10^{-2}$	$1.5\ 10^{-2}$	$2.8\ 10^{-1}$	$1.9\ 10^{-1}$	$3.7\ 10^{-1}$	$2.5\ 10^{-1}$
Brunsbuettel (KBR)	$2.6\ 10^{-1}$	$2.4\ 10^{-1}$	$3.4\ 10^{-1}$	$3.1\ 10^{-1}$	$9.2\ 10^{-2}$	$8.4\ 10^{-2}$
Emsland (KKE)			$3.5\ 10^{-1}$	$2.5\ 10^{-1}$	$3.1\ 10^{-1}$	$2.2\ 10^{-1}$
Grafenrheinfeld (KKG)	$1.9\ 10^{-1}$	$9.0\ 10^{-2}$	$3.7\ 10^{-1}$	$1.8\ 10^{-1}$	$2.5\ 10^{-1}$	$1.2\ 10^{-1}$
Greifswald 1 + 2 + 3 + 4	$1.7\ 10^{-2}$	$7.9\ 10^{-4}$	$6.4\ 10^{-4}$	$1.6\ 10^{-6}$		
Grohnde (KWG)	$1.1\ 10^{-1}$	$7.4\ 10^{-2}$	$1.7\ 10^{-1}$	$1.2\ 10^{-1}$	$9.3\ 10^{-2}$	$6.3\ 10^{-2}$
Gundremmingen B + C (KRB)	2.2	$9.8\ 10^{-1}$	3.0	1.3	4.3	1.9
Isar 1 (KKl-1)	$7.4\ 10^{-1}$	$4.0\ 10^{-1}$	$6.5\ 10^{-1}$	$3.5\ 10^{-1}$	$4.5\ 10^{-1}$	$2.4\ 10^{-1}$
Isar 2 (KKl-2)			1.0	$5.5\ 10^{-1}$	1.1	$5.7\ 10^{-1}$
Kruemmel (KKK)	$6.3\ 10^{-1}$	$5.3\ 10^{-1}$	$3.3\ 10^{-1}$	$2.8\ 10^{-1}$	$1.2\ 10^{-1}$	$9.9\ 10^{-2}$
Meulheim-Karlich (KMK)	$6.4\ 10^{-2}$	$2.4\ 10^{-2}$	$8.7\ 10^{-3}$	$2.9\ 10^{-3}$		
Neckarwestheim 1 (GKN-1)	$1.7\ 10^{-1}$	$5.9\ 10^{-2}$	$2.5\ 10^{-2}$	$6.9\ 10^{-3}$	$2.6\ 10^{-2}$	$8.9\ 10^{-3}$
Neckarwestheim 2 (GKN-2)			$1.6\ 10^{-1}$	$5.9\ 10^{-2}$	$5.9\ 10^{-1}$	$2.2\ 10^{-1}$
Obrigheim (KWO)	$5.0\ 10^{-2}$	$1.6\ 10^{-2}$	$1.1\ 10^{-2}$	$3.4\ 10^{-3}$	$2.3\ 10^{-1}$	$7.3\ 10^{-2}$
Philipsburg 1 (KKP-1)	$7.0\ 10^{-1}$	$3.9\ 10^{-1}$	$9.6\ 10^{-1}$	$5.3\ 10^{-1}$	1.3	$7.0\ 10^{-1}$
Philipsburg 2 (KKP-2)	$1.5\ 10^{-1}$	$6.5\ 10^{-2}$	$1.4\ 10^{-1}$	$6.3\ 10^{-2}$	$5.0\ 10^{-1}$	$2.3\ 10^{-1}$
Rheinsberg	$3.0\ 10^{-2}$	$6.5\ 10^{-6}$	$3.3\ 10^{-7}$			
Stade (KKS)	$3.6\ 10^{-2}$	$1.5\ 10^{-2}$	$4.0\ 10^{-2}$	$2.9\ 10^{-2}$	$2.6\ 10^{-1}$	$1.9\ 10^{-1}$
THTR 300	$9.8\ 10^{-2}$	$5.6\ 10^{-2}$	$8.6\ 10^{-4}$	$1.6\ 10^{-4}$		
Unterweser (KKU)	$4.0\ 10^{-2}$	$3.4\ 10^{-2}$	$9.8\ 10^{-2}$	$8.9\ 10^{-2}$	$6.7\ 10^{-2}$	$6.1\ 10^{-2}$
Wuergassen	$3.3\ 10^{-1}$	$2.2\ 10^{-1}$	$4.2\ 10^{-1}$	$2.8\ 10^{-1}$		
Italy						
Caorso	$1.4\ 10^{-3}$	$9.1\ 10^{-6}$				
Trino	$1.4\ 10^{-3}$	$6.2\ 10^{-6}$				
Spain						
Almaraz 1 + 2	$2.6\ 10^{-3}$	$2.5\ 10^{-5}$	$9.4\ 10^{-3}$	$9.7\ 10^{-5}$	$1.4\ 10^{-2}$	$1.2\ 10^{-4}$
Asco 1 + 2	$5.0\ 10^{-3}$	$2.1\ 10^{-5}$	$9.6\ 10^{-3}$	$3.8\ 10^{-5}$	$5.5\ 10^{-3}$	$3.1\ 10^{-5}$
Cofrentes	$7.1\ 10^{-3}$	$3.6\ 10^{-5}$	$1.1\ 10^{-2}$	$3.4\ 10^{-5}$	$1.8\ 10^{-3}$	$1.3\ 10^{-5}$
Jose Cabrera (Zorita)	$1.5\ 10^{-2}$	$3.8\ 10^{-5}$	$5.6\ 10^{-3}$	$1.2\ 10^{-5}$	$2.1\ 10^{-3}$	$6.1\ 10^{-7}$
Sta Maria de Garona	$3.4\ 10^{-3}$	$2.1\ 10^{-5}$	$5.2\ 10^{-3}$	$4.1\ 10^{-5}$	$1.6\ 10^{-3}$	$8.5\ 10^{-6}$
Trillo			$7.5\ 10^{-5}$	$3.0\ 10^{-9}$	$2.1\ 10^{-1}$	$1.8\ 10^{-1}$
Vandellos 1	$7.8\ 10^{-4}$	$5.2\ 10^{-4}$				
Vandellos 2			$1.4\ 10^{-3}$	$6.1\ 10^{-6}$	$1.5\ 10^{-4}$	$1.3\ 10^{-6}$
Sweden						
Barsebaeck 1 + 2	$1.3\ 10^{-3}$	$2.4\ 10^{-6}$	$3.7\ 10^{-2}$	$6.0\ 10^{-4}$	$5.6\ 10^{-3}$	
Forsmark 1 + 2 + 3	$8.5\ 10^{-3}$	$3.0\ 10^{-4}$	$1.1\ 10^{-1}$	$9.7\ 10^{-3}$	$3.9\ 10^{-3}$	
Oskarshamn 1 + 2 + 3	$1.8\ 10^{-2}$	$5.4\ 10^{-4}$	$2.3\ 10^{-1}$	$1.9\ 10^{-2}$	$3.5\ 10^{-3}$	$1.6\ 10^{-8}$
Ringhals 1	$1.9\ 10^{-2}$	$7.1\ 10^{-4}$	$3.2\ 10^{-3}$	$1.1\ 10^{-4}$	$1.9\ 10^{-1}$	
Ringhals 2 + 3 + 4	$7.6\ 10^{-3}$	$2.0\ 10^{-5}$	$4.4\ 10^{-3}$	$1.1\ 10^{-5}$	$1.2\ 10^{-3}$	$5.1\ 10^{-6}$
The Netherlands						
Borssele	$1.4\ 10^{-3}$	$9.2\ 10^{-6}$	$1.4\ 10^{-3}$	$1.0\ 10^{-5}$	$6.0\ 10^{-2}$	$4.0\ 10^{-2}$
Dodewaard	$1.1\ 10^{-3}$	$1.1\ 10^{-5}$	$1.7\ 10^{-3}$	$1.9\ 10^{-5}$	$4.2\ 10^{-2}$	$3.5\ 10^{-2}$
United Kingdom						
Berkeley A + B	$8.8\ 10^{-2}$					
Bradwell A + B	$1.9\ 10^{-1}$		$1.6\ 10^{-1}$		$6.8\ 10^{-1}$	$4.3\ 10^{-1}$
Chapelcross A + B + C + D	4.0	$3.7\ 10^{-2}$	3.5	$3.2\ 10^{-2}$	2.9	$2.6\ 10^{-2}$
Dungeness AA + AB	$1.0\ 10^{-1}$		$1.1\ 10^{-1}$		4.0	3.0
Dungeness B1 + B2	$1.1\ 10^{-2}$		$1.2\ 10^{-2}$		$7.7\ 10^{-1}$	$5.9\ 10^{-1}$
Hartlepool A1 + A2	$1.7\ 10^{-2}$		$1.3\ 10^{-2}$		2.2	1.8
Heysham 1A + 1B	$6.6\ 10^{-1}$	$9.8\ 10^{-1}$	$2.7\ 10^{-2}$		$8.1\ 10^{-1}$	1.2
Heysham 2A + 2B			$1.0\ 10^{-2}$		$6.9\ 10^{-1}$	1.0
Hinkley Point AA + AB	$7.3\ 10^{-1}$		$4.5\ 10^{-1}$		2.7	1.4

Year of Discharge	1987		1991		1996	
	Non-global[1]	Global[2]	Non-global[1]	Global[2]	Non-global[1]	Global[2]
Hinkley Point BA + BB	$1.6\ 10^{-1}$		$2.7\ 10^{-1}$		3.5	2.3
Hunterston AA + AB	$9.1\ 10^{-2}$	$4.6\ 10^{-5}$				
Hunterston B1 + B2	$2.5\ 10^{-1}$	$1.4\ 10^{-4}$	$6.7\ 10^{-2}$	$6.6\ 10^{-5}$	1.7	1.6
Oldbury AA +AB	$1.1\ 10^{-1}$		$2.9\ 10^{-2}$		8.7	4.6
Sizewell AA + AB	$2.9\ 10^{-1}$		$2.9\ 10^{-1}$		$1.7\ 10^{-1}$	$1.3\ 10^{-1}$
Sizewell B					$6.9\ 10^{-2}$	$6.5\ 10^{-2}$
Torness 1 + 2	$2.3\ 10^{-10}$	$2.1\ 10^{-2}$	$2.3\ 10^{-3}$	$3.0\ 10^{-5}$	$5.4\ 10^{-1}$	$6.9\ 10^{-1}$
Trawsfynydd A + B	$3.3\ 10^{-1}$		$1.4\ 10^{-2}$			
Winfrith	$7.9\ 10^{-2}$	$4.4\ 10^{-4}$				
Wylfa A + B	$6.6\ 10^{-2}$		$2.6\ 10^{-1}$		$9.9\ 10^{-1}$	1.5
Sum	$1.4\ 10^{1}$	5.4	$1.5\ 10^{1}$	5.9	$4.3\ 10^{1}$	$2.7\ 10^{1}$

Notes
(1) Non-global only includes doses arising from the 'first pass' of the plume, before radionuclides become globally dispersed.
(2) Global only includes doses arising from the global dispersion of radionuclides and not from the 'first pass' of the plume.

TABLE 7 Collective dose truncated at 500 years from discharges to atmosphere from European Community reprocessing plants (man Sv)

	Sellafield		Cap de la Hague		Dounreay		Karlsruhe (WAK)		Marcoule (APM)	
	Non-global[1]	Global[2]	Non-global[1]	Global[2]	Non-global[1]	Global[2]	Non-global[1]	Global[2]	Non-global[1]	Global[2]
1987	9.3	$1.2\ 10^{1}$	$3.3\ 10^{-1}$	$6.2\ 10^{-1}$	$4.5\ 10^{-2}$	$1.3\ 10^{-2}$	$1.4\ 10^{-1}$	$4.8\ 10^{-2}$		
1988	7.2	4.9	$2.7\ 10^{-1}$	$4.8\ 10^{-1}$						
1989	8.1	5.8	$4.0\ 10^{-1}$	$7.4\ 10^{-1}$						
1990	5.9	5.4	$5.8\ 10^{-1}$	1.1						
1991	6.5	7.6	$9.1\ 10^{-1}$	1.8	$1.8\ 10^{-2}$	$1.0\ 10^{-2}$	$1.3\ 10^{-2}$	$2.3\ 10^{-4}$		
1992	6.0	3.7	8.7	$1.1\ 10^{1}$						
1993	$1.3\ 10^{1}$	$1.0\ 10^{1}$	$1.1\ 10^{1}$	$1.5\ 10^{1}$						
1994	6.6	2.0	$1.8\ 10^{1}$	$2.3\ 10^{1}$						
1995	7.8	7.4	$2.3\ 10^{1}$	$2.7\ 10^{1}$						
1996	8.5	7.0	$2.5\ 10^{1}$	$2.8\ 10^{1}$	$6.6\ 10^{-3}$	$1.9\ 10^{-4}$			4.3	$6.4\ 10^{-1}$

Notes
(1) Non-global only includes doses arising from the 'first pass' of the plume, before radionuclides become globally dispersed.
(2) Global only includes doses arising from the global dispersion of radionuclides and not from the 'first pass' of the plume.

TABLE 8 Collective dose truncated at 500 years from all sites (man Sv)

	Collective Dose Truncated at 500 years								
	1987			1991			1996		
Site	Airborne	Liquid	Total	Airborne	Liquid	Total	Airborne	Liquid	Total
All Nuclear Power Stations	$2.0\ 10^{1}$ (1)	$7.4\ 10^{-1}$	$2.1\ 10^{1}$	$2.1\ 10^{1}$ (1)	$5.2\ 10^{-1}$	$2.2\ 10^{1}$	$7.0\ 10^{1}$	$1.3\ 10^{-1}$	$7.0\ 10^{1}$
Cap de la Hague	$9.5\ 10^{-1}$ (2)	$4.1\ 10^{1}$ (2)	$4.2\ 10^{1}$	$2.7\ 10^{0}$ (2)	$4.1\ 10^{0}$ (2)	$6.8\ 10^{0}$	$5.3\ 10^{1}$	$9.3\ 10^{-1}$ (2)	$5.4\ 10^{1}$
Dounreay	$5.8\ 10^{-2}$	$4.1\ 10^{-1}$	$4.7\ 10^{-1}$	$2.8\ 10^{-2}$	$1.1\ 10^{-1}$	$1.4\ 10^{-1}$	$6.8\ 10^{-3}$	$1.4\ 10^{-1}$	$1.5\ 10^{-1}$
Marcoule							$4.9\ 10^{0}$	$2.4\ 10^{-1}$	$5.2\ 10^{0}$
Sellafield	$2.2\ 10^{1}$	$3.7\ 10^{0}$	$2.6\ 10^{1}$	$1.4\ 10^{1}$	$3.9\ 10^{0}$	$1.8\ 10^{1}$	$1.6\ 10^{1}$	$1.1\ 10^{1}$	$2.7\ 10^{1}$
WAK	$1.9\ 10^{-1}$		$1.9\ 10^{-1}$	$1.3\ 10^{-2}$		$1.3\ 10^{-2}$			
Total	$4.3\ 10^{1}$	$4.6\ 10^{1}$	$9.0\ 10^{1}$	$3.8\ 10^{1}$	$8.6\ 10^{0}$	$4.7\ 10^{1}$	$1.4\ 10^{2}$	$1.2\ 10^{1}$	$1.6\ 10^{2}$

Notes
(1) Doses do not include contribution from ^{14}C from UK GCRs and AGRs.
(2) Doses do not include contribution from ^{14}C.

TABLE 9 Critical group dose to adults in the 50th year from discharges to atmosphere from European Community nuclear power stations (μSv)

Year of Discharge	1987		1991		1996	
Distance from site (km)	0.5	5.0	0.5	5.0	0.5	5.0
Belgium						
Doel 1 + 2 + 3 + 4	$4.8\ 10^{-2}$	$5.9\ 10^{-3}$	$2.2\ 10^{-1}$	$2.9\ 10^{-2}$	$1.1\ 10^{-2}$	$1.4\ 10^{-3}$
Tihange 1 + 2 + 3	$6.2\ 10^{-2}$	$7.4\ 10^{-3}$	$3.6\ 10^{-2}$	$4.4\ 10^{-3}$	$4.3\ 10^{-2}$	$9.4\ 10^{-3}$
Finland						
Loviisa 1 + 2	$6.9\ 10^{-2}$	$1.1\ 10^{-1}$	$6.7\ 10^{-2}$	$1.1\ 10^{-1}$	$2.6\ 10^{-2}$	$3.3\ 10^{-2}$
TVO 1 + 2 (Olkiluoto)	$3.3\ 10^{-1}$	$2.0\ 10^{-1}$	$4.3\ 10^{-1}$	$2.2\ 10^{-1}$	$3.8\ 10^{-1}$	$2.1\ 10^{-1}$
France						
Belleville 1 + 2	$7.8\ 10^{-2}$	$5.7\ 10^{-3}$	$1.5\ 10^{-1}$	$1.2\ 10^{-2}$	$7.9\ 10^{-2}$	$6.5\ 10^{-3}$
Blayais 1 + 2 + 3 + 4	$2.8\ 10^{-1}$	$2.3\ 10^{-2}$	$3.7\ 10^{-1}$	$3.0\ 10^{-2}$	$6.1\ 10^{-2}$	$6.0\ 10^{-3}$
Bugey 1	$2.6\ 10^{-1}$	$2.3\ 10^{-2}$	$3.9\ 10^{-1}$	$3.5\ 10^{-2}$		
Bugey 2 + 3 + 4 + 5	$1.9\ 10^{-1}$	$1.6\ 10^{-2}$	$1.8\ 10^{-1}$	$1.6\ 10^{-2}$	$5.5\ 10^{-2}$	$5.1\ 10^{-3}$
Cattenom 1 + 2 + 3 + 4	$1.3\ 10^{-1}$	$1.0\ 10^{-2}$	$2.9\ 10^{-1}$	$2.1\ 10^{-2}$	$7.5\ 10^{-2}$	$6.0\ 10^{-3}$
Chinon A3	$2.2\ 10^{-1}$	$2.6\ 10^{-2}$	$1.0\ 10^{-1}$	$7.5\ 10^{-3}$		
Chinon B1 + B2 + B3 + B4	$1.5\ 10^{-1}$	$1.1\ 10^{-2}$	$5.6\ 10^{-1}$	$4.5\ 10^{-2}$	$1.0\ 10^{-1}$	$7.8\ 10^{-3}$
Chooz A	$9.7\ 10^{-2}$	$5.3\ 10^{-3}$	$8.4\ 10^{-1}$	$4.6\ 10^{-2}$		
Chooz B1 + B2					$4.9\ 10^{-2}$	$3.7\ 10^{-3}$
Creys Malville			$3.4\ 10^{-3}$	$5.2\ 10^{-4}$	$3.4\ 10^{-3}$	$5.1\ 10^{-4}$
Cruas 1 + 2 + 3 + 4	$5.5\ 10^{-2}$	$4.3\ 10^{-3}$	$8.6\ 10^{-2}$	$6.7\ 10^{-3}$	$8.1\ 10^{-2}$	$6.3\ 10^{-3}$
Dampierre 1 + 2 + 3 + 4	$4.9\ 10^{-1}$	$3.7\ 10^{-2}$	$2.3\ 10^{-1}$	$1.8\ 10^{-2}$	$5.8\ 10^{-2}$	$4.5\ 10^{-3}$
Fessenheim 1 + 2	$1.3\ 10^{-1}$	$9.6\ 10^{-3}$	$4.1\ 10^{-2}$	$3.1\ 10^{-3}$	$2.8\ 10^{-2}$	$2.2\ 10^{-3}$
Flamanville 1 + 2	$3.8\ 10^{-2}$	$3.9\ 10^{-3}$	$1.8\ 10^{-2}$	$2.1\ 10^{-3}$	$2.2\ 10^{-2}$	$2.4\ 10^{-3}$
Golfech 1 + 2			$3.2\ 10^{-2}$	$2.4\ 10^{-3}$	$5.3\ 10^{-2}$	$4.5\ 10^{-3}$
Gravelines 1 + 2 + 3 + 4 + 5 + 6	$3.4\ 10^{-1}$	$3.3\ 10^{-2}$	$1.7\ 10^{-1}$	$1.8\ 10^{-2}$	$9.1\ 10^{-2}$	$9.2\ 10^{-3}$
Nogent 1 + 2	$8.9\ 10^{-3}$	$6.7\ 10^{-4}$	$8.6\ 10^{-2}$	$6.6\ 10^{-3}$	$5.1\ 10^{-2}$	$4.5\ 10^{-3}$
Paluel 1 + 2 + 3 + 4	$5.5\ 10^{-1}$	$4.6\ 10^{-2}$	$3.2\ 10^{-1}$	$2.7\ 10^{-2}$	$8.6\ 10^{-2}$	$8.0\ 10^{-3}$
Penly 1 + 2			$1.8\ 10^{-2}$	$1.8\ 10^{-3}$	$2.4\ 10^{-2}$	$2.5\ 10^{-3}$
St Alban 1 + 2	$4.7\ 10^{-2}$	$3.7\ 10^{-3}$	$6.2\ 10^{-2}$	$5.4\ 10^{-3}$	$3.9\ 10^{-2}$	$3.2\ 10^{-3}$
St Laurent A1 + A2	1.4	$1.0\ 10^{-1}$	$4.9\ 10^{-1}$	$3.6\ 10^{-2}$		
St Laurent B1 + B2	$3.9\ 10^{-2}$	$3.3\ 10^{-3}$	$7.3\ 10^{-3}$	$6.2\ 10^{-4}$	$3.5\ 10^{-2}$	$2.8\ 10^{-3}$
Tricastin 1 + 2 + 3 + 4	$8.9\ 10^{-2}$	$7.1\ 10^{-3}$	$1.2\ 10^{-1}$	$1.0\ 10^{-2}$	$8.2\ 10^{-2}$	$6.3\ 10^{-3}$
Germany						
Biblis A (KWB-A)	$1.1\ 10^{-1}$	$1.8\ 10^{-2}$	$1.8\ 10^{-2}$	$4.1\ 10^{-3}$	$3.1\ 10^{-2}$	$1.3\ 10^{-2}$

Year of Discharge	1987		1991		1996	
Distance from site (km)	0.5	5.0	0.5	5.0	0.5	5.0
Biblis B (KWB-B)	$8.6\ 10^{-2}$	$1.1\ 10^{-2}$	$2.2\ 10^{-2}$	$7.9\ 10^{-3}$	$1.8\ 10^{-1}$	$7.9\ 10^{-2}$
Brokdorf (KBR)	$3.3\ 10^{-2}$	$6.8\ 10^{-3}$	$4.3\ 10^{-1}$	$8.8\ 10^{-2}$	$5.6\ 10^{-1}$	$1.2\ 10^{-1}$
Brunsbuettel (KBR)	$1.4\ 10^{-1}$	$6.0\ 10^{-2}$	$1.7\ 10^{-1}$	$7.6\ 10^{-2}$	$5.7\ 10^{-2}$	$2.2\ 10^{-2}$
Emsland (KKE)			$1.4\ 10^{-1}$	$6.2\ 10^{-2}$	$1.2\ 10^{-1}$	$5.5\ 10^{-2}$
Grafenrheinfeld (KKG)	$5.1\ 10^{-2}$	$2.3\ 10^{-2}$	$9.9\ 10^{-2}$	$4.4\ 10^{-2}$	$6.7\ 10^{-2}$	$3.0\ 10^{-2}$
Greifswald 1 + 2 + 3 + 4	1.1	$2.0\ 10^{-1}$	$4.2\ 10^{-3}$	$6.2\ 10^{-4}$		
Grohnde (KWG)	$5.0\ 10^{-2}$	$1.9\ 10^{-2}$	$6.8\ 10^{-2}$	$3.0\ 10^{-2}$	$3.9\ 10^{-2}$	$1.7\ 10^{-2}$
Gundremmingen B + C (KRB)	$5.6\ 10^{-1}$	$2.4\ 10^{-1}$	$7.2\ 10^{-1}$	$3.2\ 10^{-1}$	1.0	$4.7\ 10^{-1}$
Isar 1 (KKI-1)	$2.2\ 10^{-1}$	$9.8\ 10^{-2}$	$1.9\ 10^{-1}$	$8.5\ 10^{-2}$	$1.3\ 10^{-1}$	$5.9\ 10^{-2}$
Isar 2 (KKI-2)			$3.0\ 10^{-1}$	$1.3\ 10^{-1}$	$3.1\ 10^{-1}$	$1.4\ 10^{-1}$
Kruemmel (KKK)	$3.2\ 10^{-1}$	$1.3\ 10^{-1}$	$1.6\ 10^{-1}$	$6.9\ 10^{-2}$	$9.4\ 10^{-2}$	$3.0\ 10^{-2}$
Meulheim-Karlich (KMK)	$1.3\ 10^{-2}$	$5.9\ 10^{-3}$	$2.1\ 10^{-3}$	$9.5\ 10^{-4}$		
Neckarwestheim 1 (GKN-1)	$6.1\ 10^{-2}$	$1.8\ 10^{-2}$	$3.0\ 10^{-2}$	$4.6\ 10^{-3}$	$1.0\ 10^{-2}$	$2.9\ 10^{-3}$
Neckarwestheim 2 (GKN-2)			$4.0\ 10^{-2}$	$1.6\ 10^{-2}$	$1.2\ 10^{-1}$	$5.3\ 10^{-2}$
Obrigheim (KWO)	$3.9\ 10^{-2}$	$7.7\ 10^{-3}$	$9.3\ 10^{-3}$	$1.9\ 10^{-3}$	$1.7\ 10^{-1}$	$3.4\ 10^{-2}$
Philipsburg 1 (KKP-1)	$2.1\ 10^{-1}$	$9.4\ 10^{-2}$	$2.9\ 10^{-1}$	$1.3\ 10^{-1}$	$3.8\ 10^{-1}$	$1.7\ 10^{-1}$
Philipsburg 2 (KKP-2)	$1.6\ 10^{-1}$	$3.2\ 10^{-2}$	$1.6\ 10^{-1}$	$3.2\ 10^{-2}$	$5.2\ 10^{-1}$	$1.1\ 10^{-1}$
Rheinsberg	$1.8\ 10^{-1}$	$2.4\ 10^{-2}$	$1.9\ 10^{-6}$	$2.6\ 10^{-7}$		
Stade (KKS)	$3.7\ 10^{-1}$	$3.5\ 10^{-2}$	$8.8\ 10^{-2}$	$1.7\ 10^{-2}$	$4.5\ 10^{-1}$	$9.0\ 10^{-2}$
THTR 300	$4.7\ 10^{-2}$	$2.1\ 10^{-2}$	$6.8\ 10^{-4}$	$2.8\ 10^{-4}$		
Unterweser (KKU)	$3.3\ 10^{-2}$	$1.1\ 10^{-2}$	$5.8\ 10^{-2}$	$2.4\ 10^{-2}$	$3.8\ 10^{-2}$	$1.6\ 10^{-2}$
Wuergassen	$5.5\ 10^{-1}$	$1.1\ 10^{-1}$	$6.6\ 10^{-1}$	$1.3\ 10^{-1}$		
Italy						
Caorso	$2.2\ 10^{-2}$	$1.9\ 10^{-3}$				
Trino	$4.5\ 10^{-3}$	$5.3\ 10^{-4}$				
Spain						
Almaraz 1 + 2	$3.3\ 10^{-2}$	$5.1\ 10^{-3}$	$7.8\ 10^{-2}$	$1.7\ 10^{-2}$	$1.1\ 10^{-1}$	$2.2\ 10^{-2}$
Asco 1 + 2	$9.0\ 10^{-2}$	$9.1\ 10^{-3}$	$2.3\ 10^{-1}$	$2.1\ 10^{-2}$	$1.8\ 10^{-2}$	$4.7\ 10^{-3}$
Cofrentes	$6.9\ 10^{-1}$	$6.5\ 10^{-2}$	1.4	$2.3\ 10^{-1}$	$2.9\ 10^{-2}$	$3.2\ 10^{-3}$
Jose Cabrera (Zorita)	$4.9\ 10^{-1}$	$4.4\ 10^{-2}$	$2.0\ 10^{-1}$	$3.1\ 10^{-2}$	$1.9\ 10^{-2}$	$1.9\ 10^{-3}$
Sta Maria de Garona	$3.0\ 10^{-1}$	$2.0\ 10^{-2}$	$4.0\ 10^{-1}$	$3.1\ 10^{-2}$	$1.3\ 10^{-2}$	$2.6\ 10^{-3}$
Trillo			$4.4\ 10^{-4}$	$7.5\ 10^{-5}$	$2.8\ 10^{-1}$	$8.2\ 10^{-2}$
Vandellos 1	$2.2\ 10^{-2}$	$5.3\ 10^{-3}$				
Vandellos 2			$7.9\ 10^{-2}$	$6.6\ 10^{-3}$	$2.2\ 10^{-3}$	$5.5\ 10^{-4}$
Sweden						
Barsebaeck 1 + 2	$1.4\ 10^{-2}$	$2.1\ 10^{-3}$	1.2	$1.3\ 10^{-1}$	$8.3\ 10^{-2}$	$8.4\ 10^{-3}$
Forsmark 1 + 2 + 3	1.1	$2.2\ 10^{-1}$	$2.1\ 10^{1}$	2.5	$1.2\ 10^{-1}$	$2.0\ 10^{-2}$
Oskarshamn 1 + 2 + 3	1.9	$2.1\ 10^{-1}$	$5.6\ 10^{1}$	4.3	$7.6\ 10^{-1}$	$6.8\ 10^{-2}$
Ringhals 1	1.5	$1.6\ 10^{-1}$	$2.0\ 10^{-1}$	$1.9\ 10^{-2}$	$2.8\ 10^{1}$	2.2
Ringhals 2 + 3 + 4	$5.3\ 10^{-1}$	$1.3\ 10^{-1}$	$3.0\ 10^{-1}$	$6.9\ 10^{-2}$	$2.7\ 10^{-2}$	$4.4\ 10^{-3}$
The Netherlands						
Borssele	$6.5\ 10^{-3}$	$1.2\ 10^{-3}$	$1.9\ 10^{-2}$	$2.2\ 10^{-3}$	$7.9\ 10^{-2}$	$1.6\ 10^{-2}$
Dodewaard	$1.1\ 10^{-2}$	$1.1\ 10^{-3}$	$1.6\ 10^{-2}$	$1.3\ 10^{-3}$	$2.4\ 10^{-2}$	$7.3\ 10^{-3}$
United Kingdom						
Berkeley A + B	5.5	$2.8\ 10^{-1}$				
Bradwell A + B	$1.4\ 10^{1}$	$7.0\ 10^{-1}$	$1.2\ 10^{1}$	$6.2\ 10^{-1}$	$1.8\ 10^{1}$	1.1
Chapelcross A + B + C + D	$1.4\ 10^{2}$	9.2	$1.3\ 10^{2}$	8.3	$1.2\ 10^{2}$	7.5
Dungeness AA + AB	$2.1\ 10^{1}$	1.1	$2.2\ 10^{1}$	1.1	$4.7\ 10^{1}$	2.9
Dungeness B1 + B2	1.1	$7.8\ 10^{-2}$	1.5	$9.6\ 10^{-2}$	5.5	$3.9\ 10^{-1}$
Hartlepool A1 + A2	1.2	$9.3\ 10^{-2}$	$8.5\ 10^{-1}$	$6.0\ 10^{-2}$	$1.6\ 10^{1}$	1.2
Heysham 1A + 1B	8.6	$6.2\ 10^{-1}$	1.2	$8.7\ 10^{-2}$	$1.0\ 10^{1}$	$7.5\ 10^{-1}$
Heysham 2A + 2B			$4.5\ 10^{-1}$	$3.1\ 10^{-2}$	8.6	$6.3\ 10^{-1}$
Hinkley Point AA + AB	$7.3\ 10^{1}$	3.7	$4.9\ 10^{1}$	2.5	$6.5\ 10^{1}$	3.6
Hinkley Point BA + BB	4.6	$3.0\ 10^{-1}$	6.2	$4.4\ 10^{-1}$	$2.0\ 10^{1}$	1.5

Year of Discharge	1987		1991		1996	
Distance from site (km)	0.5	5.0	0.5	5.0	0.5	5.0
Hunterston AA + AB	3.7	$3.0\ 10^{-1}$				
Hunterston B1 + B2	$1.0\ 10^{1}$	$8.2\ 10^{-1}$	2.9	$2.1\ 10^{-1}$	$1.6\ 10^{1}$	1.2
Oldbury AA +AB	3.9	$2.2\ 10^{-1}$	1.6	$7.8\ 10^{-2}$	$4.5\ 10^{1}$	3.4
Sizewell AA + AB	$4.2\ 10^{1}$	2.3	$4.0\ 10^{1}$	2.2	7.0	$3.8\ 10^{-1}$
Sizewell B					$5.6\ 10^{-1}$	$4.0\ 10^{-2}$
Torness 1 + 2	$4.7\ 10^{-8}$	$2.4\ 10^{-9}$	$1.7\ 10^{-1}$	$1.0\ 10^{-2}$	$1.4\ 10^{1}$	1.1
Trawsfynydd A + B	$9.5\ 10^{1}$	4.8	4.2	$2.1\ 10^{-1}$		
Winfrith	1.1	$8.3\ 10^{-2}$				
Wylfa A + B	4.3	$3.2\ 10^{-1}$	$1.4\ 10^{1}$	1.1	$1.9\ 10^{1}$	1.5

TABLE 10 Critical group dose to adults in the 50th year from discharges to atmosphere from European Community reprocessing plants (μSv)

	Sellafield		Cap de la Hague		Dounreay		Karlsruhe (WAK)		Marcoule (APM) [1]	
Distance from site (km)	0.5	5.0	0.5	5.0	0.5	5.0	0.5	5.0	0.5	5.0
1987	$3.2\ 10^{1}$	$1.1\ 10^{1}$	$4.9\ 10^{-1}$	$2.1\ 10^{-1}$	2.0	$5.3\ 10^{-1}$	$8.7\ 10^{-2}$	$2.6\ 10^{-2}$		
1988	$3.5\ 10^{1}$	$1.1\ 10^{1}$	$3.9\ 10^{-1}$	$1.8\ 10^{-1}$						
1989	$3.7\ 10^{1}$	$1.2\ 10^{1}$	$6.0\ 10^{-1}$	$2.6\ 10^{-1}$						
1990	$2.8\ 10^{1}$	8.2	$8.9\ 10^{-1}$	$3.8\ 10^{-1}$						
1991	$2.7\ 10^{1}$	8.1	1.4	$5.8\ 10^{-1}$	$5.4\ 10^{-1}$	$1.3\ 10^{-1}$	$7.5\ 10^{-2}$	$2.1\ 10^{-2}$		
1992	$3.2\ 10^{1}$	9.2	$2.1\ 10^{1}$	$1.0\ 10^{1}$						
1993	$5.1\ 10^{1}$	$1.8\ 10^{1}$	$2.1\ 10^{1}$	$1.1\ 10^{1}$						
1994	$3.8\ 10^{1}$	$1.1\ 10^{1}$	$4.1\ 10^{1}$	$2.0\ 10^{1}$						
1995	$3.6\ 10^{1}$	$1.1\ 10^{1}$	$6.0\ 10^{1}$	$2.8\ 10^{1}$						
1996	$3.9\ 10^{1}$	$1.2\ 10^{1}$	$6.9\ 10^{1}$	$3.2\ 10^{1}$	$1.9\ 10^{-1}$	$4.6\ 10^{-2}$			$1.0\ 10^{2}$	$3.0\ 10^{1}$

Notes

(1) No atmospheric discharges reported on Bilcom97 database from 1987 to 1995.

TABLE 11 Critical group dose to adults in the 50th year from liquid discharges from selected European Community 'coastal' nuclear sites (μSv)

Year of discharge	Sellafield	Cap de la Hague	Bradwell A+B	Heysham 1A+1B	Paluel 1+2+3+4
1987	$1.87\ 10^{2}$	$1.73\ 10^{2}$	$9.55\ 10^{0}$	$9.24\ 10^{0}$	$6.97\ 10^{1}$
1988	$1.50\ 10^{2}$	$1.36\ 10^{2}$			
1989	$1.80\ 10^{2}$	$1.27\ 10^{2}$			
1990	$1.35\ 10^{2}$	$1.37\ 10^{2}$			
1991	$1.46\ 10^{2}$	$1.16\ 10^{2}$	$6.09\ 10^{0}$	$1.01\ 10^{1}$	$9.42\ 10^{0}$
1992	$1.14\ 10^{2}$	$3.22\ 10^{1}$			
1993	$1.44\ 10^{2}$	$3.89\ 10^{1}$			
1994	$1.42\ 10^{2}$	$3.46\ 10^{1}$			
1995	$1.55\ 10^{2}$	$2.32\ 10^{1}$			
1996	$1.14\ 10^{2}$	$1.87\ 10^{1}$	$1.01\ 10^{1}$	$3.09\ 10^{0}$	$5.56\ 10^{-1}$

TABLE 12 Critical group dose to adults in the 50th year from liquid discharges from selected European Community 'inland' nuclear sites (μSv)

	Group X(1)	Group Y(2)					
Year of discharge	Dampierre 1+2+3+4	Dampierre 1+2+3+4	Bugey 2+3+4+5	Chinon B1+B2+B3+B4	Le Blayais 1+2+3+4	Trawsfynydd A+B(3)	Marcoule (APM)
1987	$2.77\ 10^{1}$	$3.90\ 10^{1}$	$1.98\ 10^{1}$	$1.19\ 10^{1}$	$1.58\ 10^{1}$	$3.65\ 10^{2}$ *$5.44\ 10^{0}$*	(4)
1991	$1.26\ 10^{0}$	$1.79\ 10^{0}$	$7.60\ 10^{0}$	$8.41\ 10^{0}$	$3.54\ 10^{0}$	$5.21\ 10^{2}$ *$7.82\ 10^{0}$*	(4)
1996	$3.16\ 10^{-1}$	$1.00\ 10^{0}$	$4.55\ 10^{-1}$	$2.19\ 10^{0}$	$9.61\ 10^{-1}$	(4)	$3.07\ 10^{2}$

Notes

(1) Individuals residing close to the river who are exposed via the following pathways: external gamma and beta from the river bed sediments, consumption of freshwater fish and drinking water.

(2) Individuals residing on the coast near the river mouth who are exposed via the following pathways: consumption of sea fish, molluscs and crustaceans; external gamma and beta from marine sediments and fishing gear; and inhalation of seaspray.

(3) Two critical groups were considered for Trawsfynydd, those exposed to terrestrial pathways and those exposed to marine pathways. Doses to the latter are given in italics. Doses to the terrestrial critical group have probably been overestimated and are more likely to be in the region of 100 μSv (see section 5.2.2).

(4) No liquid discharges reported on Bilcom97 database. Trawsfynydd A+B ceased to operate in 1993.

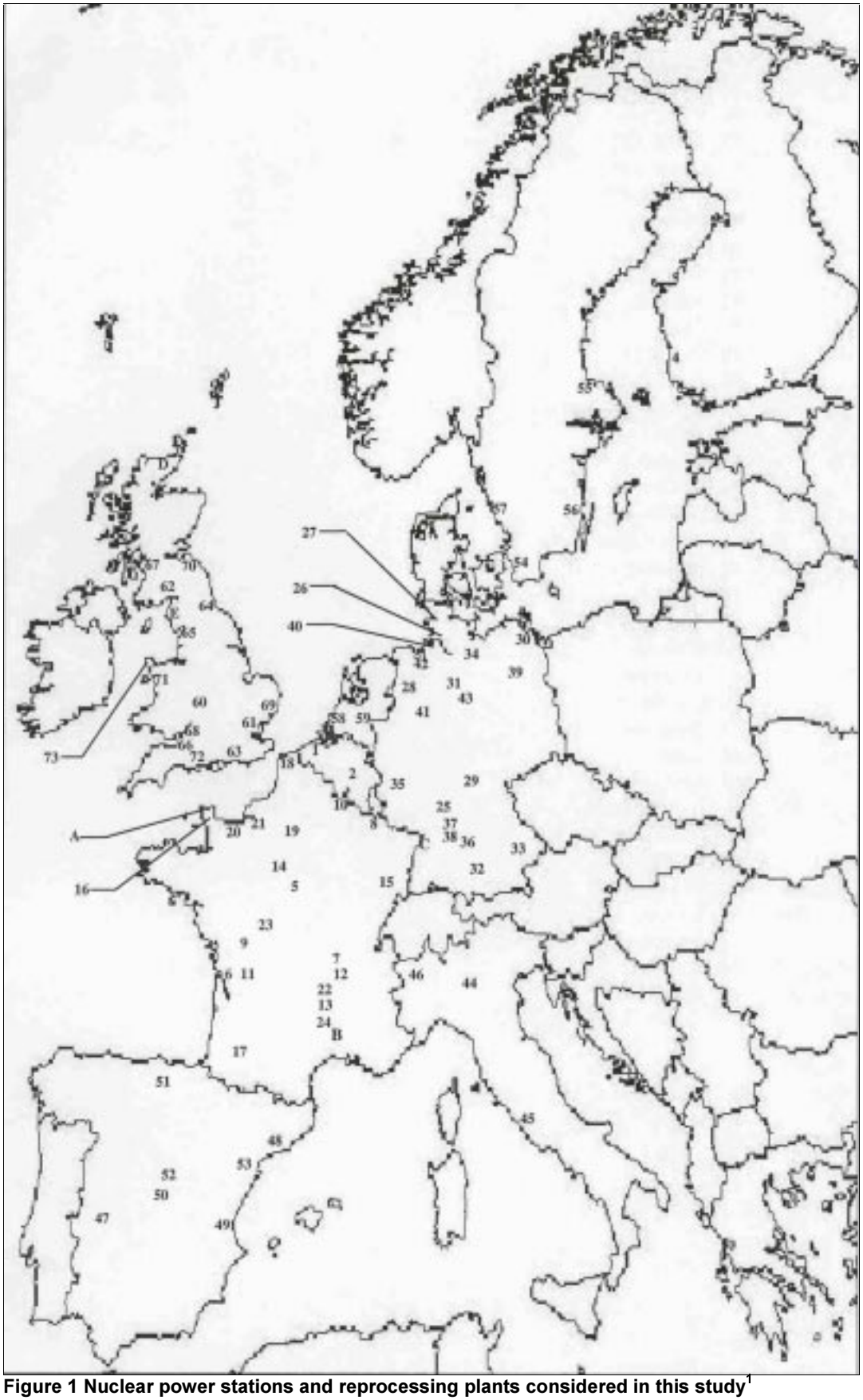


Figure 1 Nuclear power stations and reprocessing plants considered in this study[1]

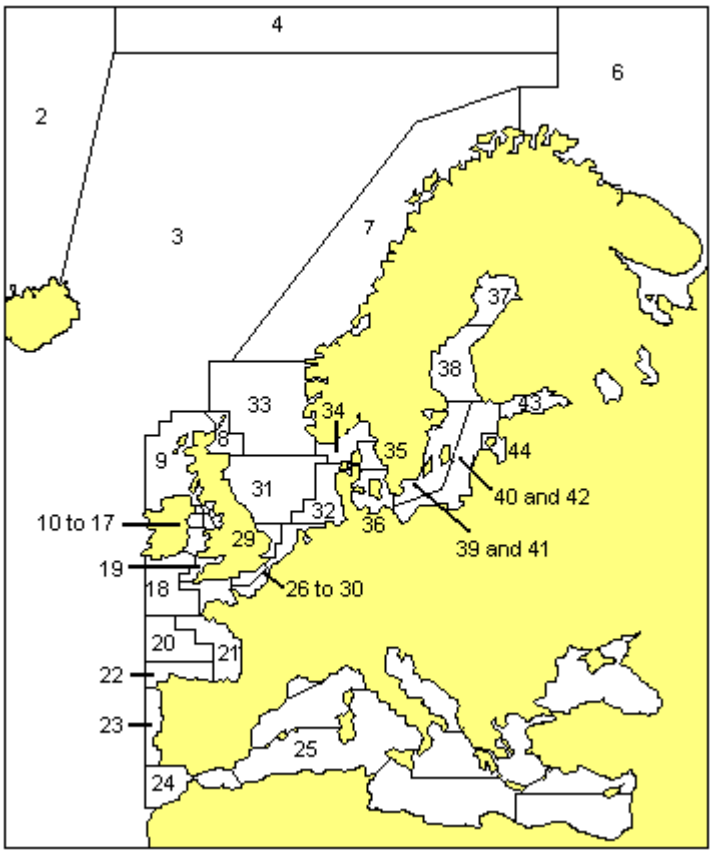
[1] For key see next page

Nuclear Power Stations

1 Doel
2 Tihange
3 Loviisa
4 TVO (Olkiluoto)
5 Belleville
6 Blayais
7 Bugey
8 Cattenom
9 Chinon
10 Chooz
11 Civaux
12 Creys Malville
13 Cruas
14 Dampierre
15 Fessenheim
16 Flamanville
17 Golfech
18 Gravelines
19 Nogent
20 Paluel
21 Penly
22 St Alban
23 St Laurent
24 Tricastin
25 Biblis
26 Brokdorf
27 Brunsbuettel
28 Emsland
29 Grafenrheinfeld
30 Greifswald
31 Grohnde
32 Gundremmingen
33 Isar
35 Kruemmel
35 Meulheim-Karlich
36 Neckarwestheim
37 Obrigheim
38 Philipsburg
39 Rheinsberg
40 Stade
41 THTR 300
42 Unterweser
43 Wuergassen
44 Caorso
45 Latina
46 Trino
47 Almaraz
48 Asco
49 Cofrentes
50 Jose Cabrera
51 Sta Maria de Garona
52 Trillo
53 Vandellos
54 Barsebaeck
55 Forsmark
56 Oskarshamn
57 Ringhals
58 Borssele
59 Dodewaard
60 Berkeley
61 Bradwell
62 Chapelcross
63 Dungeness
64 Hartlepool
65 Heysham
66 Hinkley Point
67 Hunterston
68 Oldbury
69 Sizewell
70 Torness
71 Trawsfynydd
72 Winfrith
73 Wylfa

Reprocessing Plants

A Marcoule
B Cap de la Hague
C WAK (Karlsruhe)
D Dounreay
E Sellafield



Compartment names

1	All Oceans outside this figure	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 2 Compartment model of European Waters

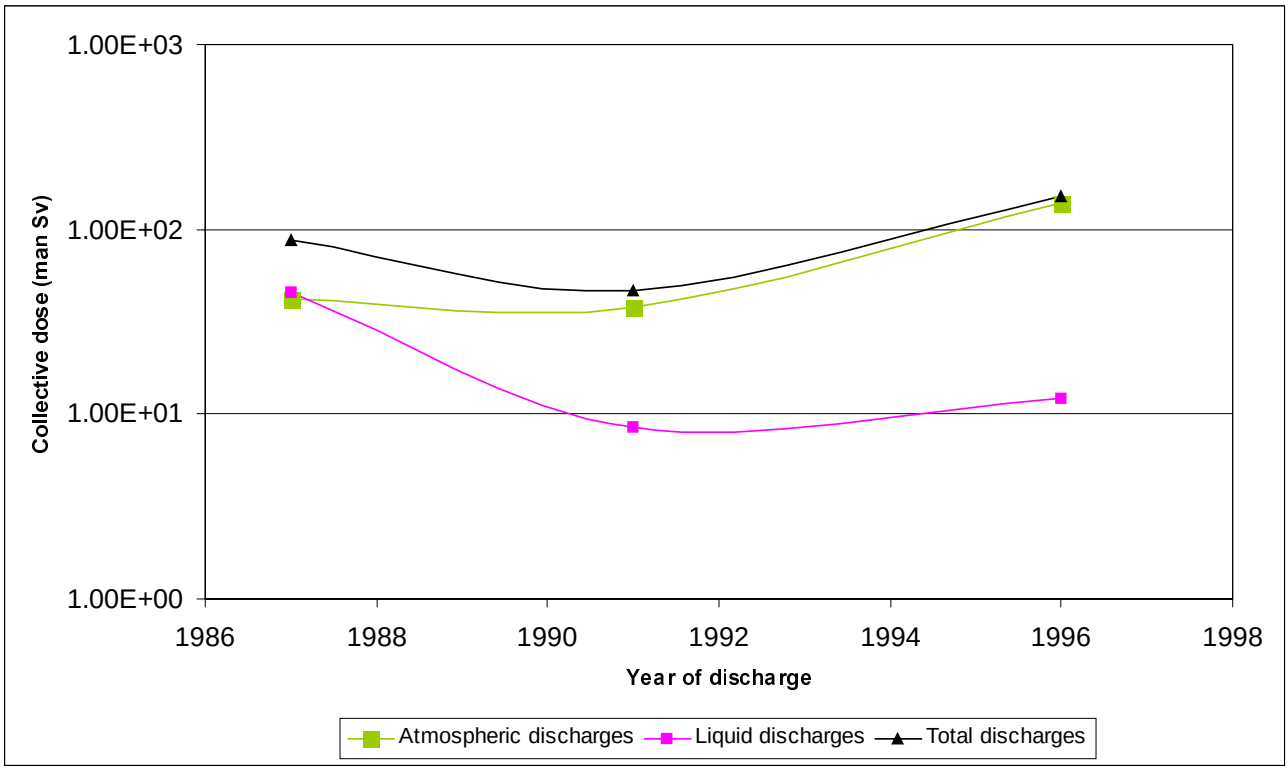


Figure 3 Collective dose truncated at 500 years from discharges from all sites

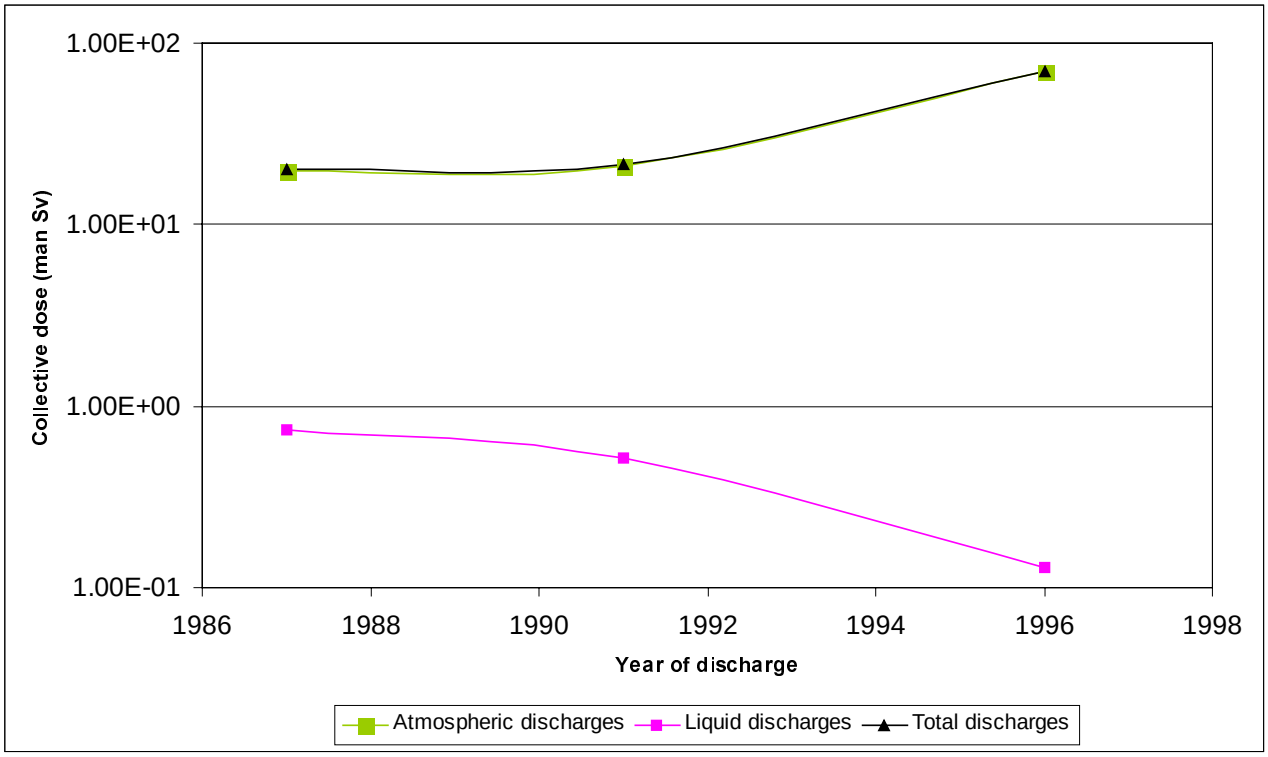


Figure 4 Collective dose truncated at 500 years from discharges from all nuclear power plants

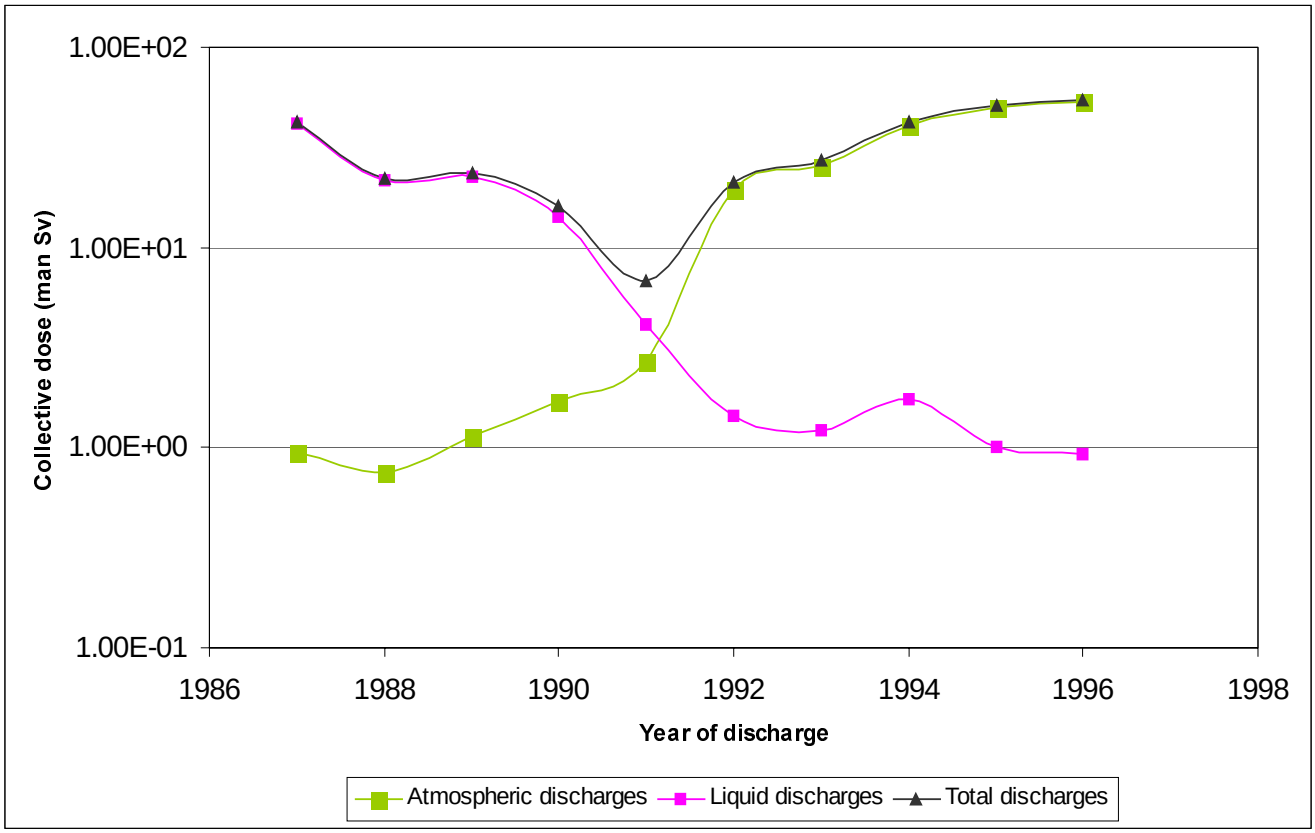


Figure 5 Collective dose truncated at 500 years from discharges from Cap de la Hague

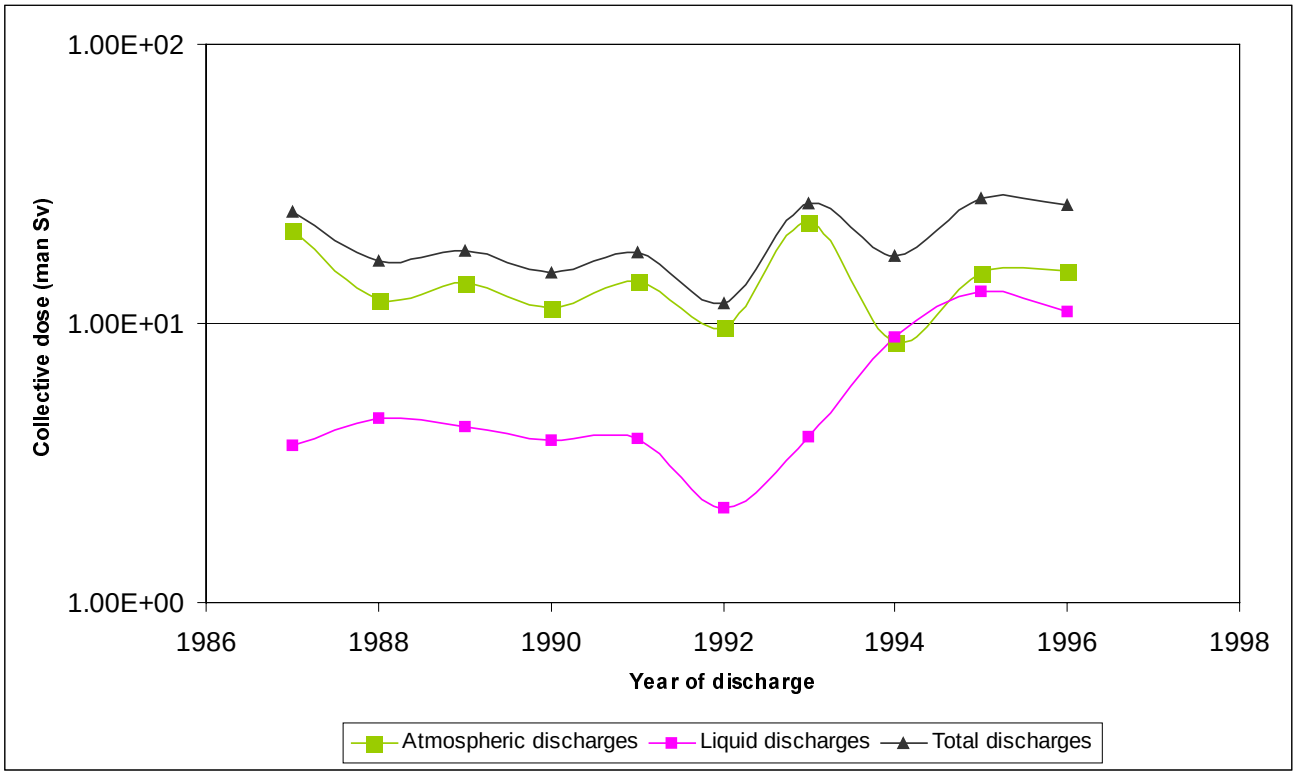


Figure 6 Collective dose truncated at 500 years from discharges from Sellafield

Appendix A EC Discharge Database Interface and Supplementary Data

This interface has been developed to extract data from the EC discharge database Bilcom97 and reproduce it in a format that can be read by PC CREAM. The interface has been written using Microsoft Visual Basic 6.0 and is called the **E**C **D**ischarge **D**atabase **I**nterface (EDDI). The overall function of EDDI was to provide an interface that would allow the interrogation of the Bilcom97 database and produce *.ROF, *.mds and *.rds files for input to PC CREAM. The purpose of these files is described in reference 4.

For liquid and atmospheric discharges EDDI reads data from the Bilcom97 database and, if necessary, will process these data before writing them to file. This processing involves the breakdown of aggregated discharge categories into individual radionuclides using data provided by GRS. For atmospheric discharges EDDI performs an additional function, which is to read in site-specific data and write these to a *.ROF file along with the discharge data so that a dose assessment can be carried out. A comprehensive set of site-specific data have been compiled, see section 4.2 of the main report, and are held in a separate database.

During the development of EDDI tests were carried out on the Bilcom97 database which highlighted a number of incorrect and missing entries. Where possible corrections were made and alternative data sources used (see Tables A1 and A2).

TABLE A1 Additions and changes made to data in Bilcom97 database for the purposes of this assessment[1]

Atmospheric Discharges		
Site	**Years**	**Comment**
Cap de la Hague	1992 to 1996	No discharges exist on database. Data taken from reference 8 is given in Table A2.
Sellafield	1990 and 1991	^{14}C discharges on the Bilcom97 database were found to be a factor of 1 10^3 too small and were corrected.
	1987 to 1993	^{41}Ar discharges on the Bilcom97 database were found to be a factor of 1 10^3 too small and were corrected.
Hinkley Point A	1996	The discharges for this site appear to be the same as those for Hinkley Point B in 1996. Data from the Magnox Electric Environmental Report for1996-1997 have been used.
Olkiluoto (TVO 1+2)	1987	Additional data supplied by DG Environment, personal communication
Loviisa	1987	Additional data supplied by DG Environment, personal communication
Dounreay	1996	Noble gases should read 2.18E+03 GBq
Hunterston B1+B2	1995	Beta total should read 7.40E-02 GBq
	1996	Beta total should read 3.56E-02 GBq
Cofrentes	1996	Beta total should read 5.38E-01 GBq
José Cabrera (Zorita)	1995	Beta total should read 1.07E-02 GBq
Liquid discharges		
Almaraz 1+2	1994	Beta(excluding H-3) should read 1.74E+01 GBq
Vandellos 2	1994	Beta(excluding H-3) should read 3.09E+01 GBq
José Cabrera (Zorita)	1995	Beta(excluding H-3) should read 2.48E-01 GBq
	1996	Beta(excluding H-3) should read 2.19E+00 GBq

Note

(1) This table identifies the changes made to the database for this assessment only. It is not an exhaustive list and other errors or omissions may exist on Bilcom97 database.

TABLE A2 Airborne discharge rates from Cap de la Hague for most significant radionuclides (see reference 8)

	Activity Discharged in years 1992 to 1996 (Bq y^{-1})				
Radionuclide	1992	1993	1994	1995	1996
H-3	3.00E+13	4.20E+13	5.50E+13	8.40E+13	7.50E+13
C-14	7.10E+12	9.90E+12	1.50E+13	1.80E+13	1.90E+13
Co-60	8.00E+04	9.50E+04	1.30E+05	1.50E+05	1.60E+05
Kr-85	1.30E+17	1.60E+17	2.40E+17	2.90E+17	2.90E+17
Ru-106	7.80E+05	5.40E+07	1.40E+06	1.50E+07	1.30E+07
Sb-125	2.70E+08	3.40E+08	4.20E+08	4.00E+08	4.40E+08
I-129	1.10E+10	1.00E+10	2.10E+10	3.20E+10	3.80E+10
I-131	3.80E+08	5.80E+08	4.90E+08	7.80E+08	1.50E+09
I-133	1.10E+08	2.30E+08	2.20E+08	2.70E+08	4.10E+08
Cs-134	2.40E+04	2.00E+04	4.40E+04	1.10E+04	3.00E+04
Cs-137	1.60E+05	1.50E+05	3.90E+05	1.40E+05	3.50E+05
Pu-241	1.30E+07	1.00E+06	7.20E+05	5.50E+05	8.60E+05
Pu-238	1.10E+04	1.30E+04	9.00E+03	7.30E+03	1.60E+04
Pu-239	1.10E+05	9.10E+03	6.40E+03	5.10E+03	8.10E+03
Am-241	1.70E+05	1.40E+04	1.20E+04	1.00E+04	1.60E+04
Cm-244	1.50E+05	1.10E+04	1.20E+04	9.30E+03	1.30E+04

Appendix B Index to information held on accompanying CD-ROM

1. **CD-ROM:\reports\NRG Report**. Report by NRG, Netherlands, giving details of the dose assessment carried out for liquid discharges from EC nuclear sites.

2. **CD-ROM:\reports\GRS Report**. Report by GRS, Germany, making recommendations on the radionuclide breakdown of the aggregated discharge categories as given on the EC-discharge database Bilcom97.

3. **CD-ROM:\calculations\atmospheric\sssyydrr*.***. Standard PC CREAM results giving individual and collective doses arising from atmospheric discharges. Doses are broken down by radionuclide and pathway. The key is as follows: sss=site code, yy=year, d=dose type and rr=reactor code. Dose type 'i' represents individual dose and dose type 'c' represents collective dose.

Note: In order to read the PC CREAM files they should be opened with / linked to simple text readers such as MS-Wordpad or Quick View Plus.

4. **CD-ROM:\calculations\aquatic*.xls**. Summaries of dose arising from liquid discharges.

5. **CD-ROM:\calculations\aquatic\coastal*.xls**. Excel spreadsheets holding the results of the PC CREAM dose assessment for unit liquid discharges and details of the calculations carried out to scale these doses to the actual discharges from coastal sites.

6. **CD-ROM:\calculations\aquatic\inland*.xls**. Excel spreadsheets holding the results of the PC CREAM dose assessment for unit liquid discharges and details of the calculations carried out to scale these doses to the actual discharges from coastal sites.

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