Guidance on the Assessment of Radiation Doses to Members of the Public due to the Operation of Nuclear Installations under Normal Conditions

K A Jones, C Walsh, A Bexon, J R Simmonds, A L Jones, M Harvey, A Artmann[#] and R Martens[#]

 # GESELLSCHAFT FÜR ANLAGEN-UND-REAKTORSICHERHEIT, GERMANY

ABSTRACT

The assessment of radiation doses to individuals in the population is an important part of the system of radiation protection. A significant concept in such assessments is the identification of groups in the population likely to receive the highest doses; so-called reference or critical groups. Member States of the European Union currently use different approaches both to identify reference groups and to calculate their doses. The European Commission, therefore, identified the need for a common methodology to assist in harmonisation of the approach for calculating such doses and to the application of standards throughout the EU. This report gives guidance on all aspects of the assessment of doses to reference groups from the routine operations of nuclear installations. The work was developed in consultation with a working party on realistic assessment of the impact of nuclear installations on members of the public (RAIN) of the standing group of experts under Article 31 of the Euratom directive. This work was the main basis of the European Commission document, RP129, Guidance on the realistic assessment of radiation doses to members of the public due to the operation of nuclear installations under normal conditions.

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EXECUTIVE SUMMARY

The assessment of radiation doses to individuals in the population is an important part of the system of radiation protection. A significant concept in such assessments is the identification of groups in the population likely to receive the highest doses; so-called reference or critical groups. Member States of the European Union currently use different approaches both to identify reference groups and to calculate their doses. The European Commission, therefore, identified the need for a common methodology to assist in harmonisation of the approach for calculating such doses and to the application of standards throughout the EU. This report gives guidance on all aspects of the assessment of doses to reference groups from the routine operations of nuclear installations. The work was developed in consultation with a working party on realistic assessment of the impact of nuclear installations on members of the public (RAIN) of the standing group of experts under Article 31 of the Euratom directive. This work was the main basis of the European Commission document, RP 129, Guidance on the realistic assessment of radiation doses to members of the public due to the operation of nuclear installations under normal conditions.

The emphasis is on retrospective assessments. However many ideas are applicable to prospective assessments. An important point is that in order to perform a realistic assessment as much site-specific information as possible should be used. The main steps are outlined here.

Source term

The type and amount of radionuclides being discharged, nature and location of release must be determined. Where chemical or physical form is likely to have a significant effect on doses this should be identified. Unless a significant proportion of the annual discharge is discharged in a short time it can be assumed that the discharges are continuous given the other uncertainties in the assessment process.

Exposure pathways

The importance of different exposure pathways following particular discharges to atmosphere and water bodies has been examined based on a series of calculations detailed in the appendices. The calculations were intended to be illustrative rather than realistic. The report separates the exposure pathways into three types, those that should;

almost always be considered (e.g. consumption of foods, external irradiation from and inhalation of plume and external irradiation from sediments)

be examined depending on local conditions (e.g. consumption of milk from animals grazing on salt marshes).

not normally be considered (e.g. inhalation of seaspray).

The main focus of the assessment should be on pathways contributing the highest doses to the reference group.

Methods for assessing doses

The most realistic method is by extensive monitoring of the exposure pathways. However this is time-consuming, costly and levels in the environment may be below the analytical limits of detection. Typically an assessment will involve a combination of measurement data and estimates from models. Any models used should be robust, fit for purpose and have been validated against measurement data. A realistic assessment relies on the parameter values in the model and the habit data used being a realistic representation of the situation.

An assessment may need to take account of accumulation in the environment e.g. for ^{239}Pu which has a long half-life and does not disperse quickly in the environment and progeny ingrowth e.g. if a site discharges ^{241}Pu the dose from the progeny ^{241}Am must also be considered.

Reference groups

Reference groups are intended to be representative of individuals likely to receive highest doses. The group should be small enough to have relatively similar habits and will usually be up to a few tens of persons. It is not appropriate to use extreme habits. However, where the normal behaviour of one or two individuals results in them being significantly more highly exposed than any other individuals, then the reference group should be deemed to comprise of only those individuals.

The report provides generalised habit data for use where site-specific information is not available. It is noted that there is a paucity of published data concerning the consumption and occupancy rates by people in EU countries.

Reference groups will need to have combinations of habits, both high and average, based on local knowledge and plausible assumptions. These combinations will need to be realistic and not lead to implausible situations, for example someone having an excessive calorific intake

Dose coefficients

The dose coefficients published in the EURATOM directive should be used. Where data are provided for more than one chemical form of an element and the actual chemical form is not known, the defaults should be taken from ICRP 72. Expert judgement should be used to determine the most appropriate chemical form rather than simply assuming the chemical form that leads to the highest dose coefficient.

Age groups

The report recommends that it is sufficient to consider 3 age groups; 1 y olds, 10 y olds and adults. Fetal doses should be considered if significant amounts of radioactive isotopes of calcium and phosphorus (which are important for skeletal growth) are discharged.

Issues in achieving realistic assessments

In order for an assessment to be realistic there must be a good understanding of local conditions around the installation being assessed. The estimated mean dose to the reference group is within a distribution of possible doses and the uncertainty/variability associated with any assessment should be recognised. Whether a full analysis of uncertainties is worthwhile depends on the scale of the estimated doses. By using any measurements that have been made around a nuclear installation a more realistic estimate of doses can be obtained than by using modelled results alone. For retrospective assessments the most realistic assessment of doses is obtained by using measured activity concentrations in environmental media. An assessment in which the limit of detection is assumed to be the actual activity concentration will not give a realistic assessment of doses. Rather the assessment should be based on modelling with the model results being checked to ensure that they are less than the detection limits. Modelling will be required for prospective assessments although measurement data are still valuable to determine the accuracy of the models for the local conditions.

The methodology presented in this report is intended to assist member states in the realistic assessment of radiation doses to members of the public due to the discharge of radioactive effluents from nuclear installations during normal operations. It provides guidance on all stages in the assessment of doses to reference groups. The most important factor in ensuring that an assessment is realistic is that local conditions are considered.

CONTENTS

1 INTRODUCTION

The assessment of radiation doses to individuals in the population is an important part of the system of radiation protection. A significant concept for calculating such doses is that of reference groups in the population. Reference groups correspond to critical groups as defined by the International Commission on Radiological Protection (ICRP) ((ICRP, 1977) (ICRP, 1991)) and are intended to be representative of those people in the population who receive the highest doses. The ICRP (ICRP, 1991) has recommended that the mean dose to the critical group should be compared with the dose limit and dose constraint for members of the public. Article 45 of the European Union's Basic Safety Standards Directive (Directive of the Council 96/29/Euratom (CEC, 1996)) explicitly requires that Member States competent authorities shall ensure that estimates of dose from practices subject to prior authorisation shall be made as realistic as possible for the population as a whole and for reference groups.

European Union (EU) Member States currently use different approaches both to identify reference groups and to calculate the resultant doses. The European Commission, therefore, identified the need for a common methodology to assist in harmonisation of the approach for calculating such doses and to the application of standards throughout the EU. The European Commission (EC), therefore, established a project to develop a common methodology considering all aspects of the assessment of doses to reference groups from the routine operations of nuclear installations releasing radionuclides to the environment. This project builds on and takes into account previous work carried out for the EC, for example see (Simmonds et al. 1995), (CEC, 1990), (Nielsen, 2000), EC (2000a) and (Centner and Vandeperre, 1999). This report contains guidance on the realistic assessment of radiation doses to reference groups of the population resulting from discharges from the normal operation of existing nuclear installations. The work was developed in consultation with a working party[1] on realistic assessment of the impact of nuclear installations on members of the public (RAIN) of the standing group of experts under Article 31 of the Euratom directive. This work was the main basis of the EC document, Guidance on the realistic assessment of radiation doses to members of the public due to the operation of nuclear installations under normal conditions: Recommendations of the group of experts set up under the terms of Article 31 of the Euratom Treaty (EC, 2002).

1.1 Scope of guidance

The primary application of this guidance is for retrospective assessments due to the discharge of radioactive effluents from nuclear installations during normal operations.

However the guidance is also relevant to non-nuclear industries e.g. hospitals, pharmaceutical facilities etc. Installations associated with each stage of the nuclear fuel cycle have been considered excluding those involving the milling and mining of uranium. The emphasis of this guidance is on the realistic assessment of doses. The

[1] Members of the Working Party were A Sugier (Chairperson), D Cancio, J Cooper, I McAulay, P Smeesters, A Susanna and E Wirth

aim of a realistic assessment is to estimate doses as close as possible to those that would actually be received by members of the public. This is not straightforward and requires judgement but the aim is to avoid significant over or under estimation. Retrospective assessments consider doses that are currently being received or that were received in the past. It is likely that information will be available on the location and behaviour of reference groups and measurements of radionuclides in the environment may also be available. Prospective assessments consider doses that may be received in the future say from planned discharges. In this case judgement is needed on what may happen in the future, for example regarding changes in land use, and normally such assessments include an element of caution in the assumptions adopted. The guidance in this report is primarily related to retrospective assessments but much of it is also relevant to prospective assessments.

The aim of this report is to provide general guidance on all stages in the assessment of doses to reference groups. It considers: the specification of the source term, including the likely discharges from the different types of nuclear installations; what exposure pathways should be considered and their relative importance; methods for assessing doses from the important exposure pathways; issues to be considered in identifying reference groups; other factors involved in dose assessments such as the implications of short term releases, variability and uncertainty, the use of measurement data and the need to assess doses to different age groups. The guidance can necessarily only be general in nature and if an assessment is to be realistic it is essential that local conditions are considered. This guidance does not necessarily apply to methods and advice issued by Member States for regulatory purposes, for example connected with the authorisation of releases of radionuclides to the environment.

2 SOURCE TERMS

The first stage in radiological assessments is to determine what radionuclides are being released and to which part of the environment they are being released. To do a realistic dose assessment it is essential to obtain as much information as possible for the site being assessed. Data will need to include;

- Type and amount of radionuclides being discharged e.g. 0.2 TBq of ^{35}S
- Type of release i.e. vapour, particles or liquid
- Location of release e.g. atmospheric release from stack of height of 80 m or vent from building, river or coastal area to which liquid releases are being discharged.

Typically discharges are reported for groups of radionuclides with the same type of activity (e.g. total alpha activity or total beta activity). Assessments of doses can only be carried out on a radionuclide specific basis and so where groups of radionuclides have been reported it is necessary either to split the discharge for the groups of nuclides between the radionuclides known to have been discharged, or to use a ‘representative’ radionuclide. Thus, it might be cautiously assumed that ^{239}Pu is representative of total alpha activity and ^{137}Cs is representative of total beta activity. However in order to perform a realistic assessment it is necessary that site-specific assumptions are made based on the radionuclides known to be discharged from the site. To help in doing this, Appendix A gives the likely discharge rates from typical nuclear installations and the likely breakdown of any aggregated discharges. Reprocessing plants are too specific for generic discharges to be given. Therefore typical discharges for the two plants in the EU (Sellafield, UK and Cap de la Hague, France) are given. The information is intended only as an indicative guide to discharges from nuclear installations and is based on actual past discharges from sites in the EU. Individual sites will not have exactly these discharges and different radionuclides may be discharged. These data could be used for comparison with information provided by an operator for verification purposes, as an indication of the minimum information required from operators or to supplement incomplete data. For realistic assessments the source term data should be as site specific as possible. This also applies to assessments from other sites discharging radionuclides e.g. hospitals and research establishments, where source terms need to be site specific and as detailed as possible.

In some cases the chemical form of the discharged radionuclide can have a significant effect on radiation doses e.g. for tritium, ^{14}C, ^{35}S and isotopes of iodine, plutonium and uranium. Therefore, where chemical form is likely to be important in a dose assessment the operator should provide the relevant information. This also applies to physical form, for example for particulate releases to atmosphere where the size of the particles can affect the subsequent doses from the discharges.

Reference group doses are typically assessed on the assumption of annual discharges. This assumes that the activity is discharged continuously and uniformly throughout the year. In practice, discharges will never be entirely uniformly continuous. Indeed, in the case of liquid radioactive waste, this is generally accumulated in tanks prior to discharge during a short period each day to the aquatic environment or sewers. However, in the case of discharges directly to the marine environment, discharges are generally made during the most favourable period in the tidal cycle. Given the other uncertainties in the assessment process, the results based on continuous release still remain valid for these normal operational daily variations in discharges.

However, if a significant proportion of the annual discharge was discharged in a short time period, this could lead to higher annual reference group doses than those assessed for a uniform release rate over the year depending on the conditions at the time of release. The assessment would need to take account of the month or seasons as dispersion, crop harvesting and outdoor occupancy varies over the year. The following factors could lead to higher doses:

Over the short time period that the release occurred, dispersion in the environment could be more localised than average dispersion over a year. This could lead to higher activity concentrations in some sectors of the environment, including the food chain. In the case of discharges to atmosphere, this might be due to occurrence of meteorological conditions leading to poor dispersion (e.g. inversion conditions at night or during anticyclones). For discharges to water, this could be a result of low flow conditions in rivers etc, such as can occur during summer months.

For releases to atmosphere during rainfall this will lead to enhanced deposited activity.

Occupancy habits may change through the seasons. For example, fishing may be likely to occur more frequently in summer.

Food may be ready for harvesting shortly after the release leading to higher activity concentrations in the food than would have been assumed. Also, some foods (e.g. root vegetables and fruit) may be stored for consumption for many months after harvesting, giving prolonged exposure.

It should be noted that, conversely, high activity short term releases could occur at times which would lead to lower doses (e.g. during winter when few crops are harvested).

Where it is assumed that foods are harvested (e.g. root vegetables, green vegetables), then peak activity concentrations (taking account of radioactive decay) should be used in the assessment. It is not realistic to assume that foods would be consumed containing these peak concentrations for a period of more than about two months, unless they can be stored (e.g. root vegetables or fruit). In this case, storage beyond 6 months would not be normal. It should be noted that these assumptions remain cautious since it is unlikely that the whole of an individual's intake of a particular group of foods (e.g. green vegetables) is affected by a short term release.

For the production of animal products (e.g. milk, beef, lamb), the time-integrated activity concentrations over a period of one year following the short term release should ideally be used to assess the ingestion dose. This approach is appropriate for milk production which continues at a reasonably continuous rate throughout the year.

3 EXPOSURE PATHWAYS

When radionuclides are released into the environment there are a number of different ways in which they can lead to radiation doses to individuals. The different ways are referred to as exposure pathways and radiation doses need to be assessed for each important exposure pathway. There are many different possible exposure pathways and it is not necessary to consider every possibility in a realistic assessment of doses. This section discusses the importance of different pathways and makes recommendations on which pathways should nearly always be considered in an assessment, those which may need to be considered and those which rarely need to be considered. The recommendations are based on a series of illustrative calculations to investigate the relative importance of different exposure pathways following particular discharges to atmosphere and water bodies. A number of different discharges were considered and doses were estimated for six age groups as given in Table 1. Discharge data for different nuclear installations were used, taken mainly from the EU discharge database (EC, 2000b) (see Appendix A) and generalised so as to be representative of a generic type of nuclear installation. Additional calculations were carried out to determine the relative importance of the different exposure pathways for discharges of individual radionuclides. For exposure pathways, as for other aspects considered in this guidance, it is important to take account of local and regional factors in determining which pathways to consider.

3.1 Atmospheric discharges

The illustrative calculations carried out for releases to atmosphere are described in Appendix B, which gives the methodology used and presents the detailed results. Five different release scenarios were examined for discharges to atmosphere from; reprocessing plants (Sellafield, UK and Cap de la Hague, France), a boiling water reactor, a pressurised water reactor and a gas cooled reactor. The results were then used to separate the exposure pathways into three types: those that should always be considered (Table 2); those that should be considered depending on local conditions (Table 3); those that should not normally be considered (Table 4). These pathways are discussed below. The relative importance of different exposure pathways was also determined for unit releases of individual radionuclides and these results given in Appendix B, were also used to develop Tables 2 to 4 given in the main text.

3.1.1 Pathways that should always be considered

Table 2 lists the exposure pathways that should nearly always be considered in an assessment. In general terms these pathways are;

- Ingestion of radionuclides in terrestrials foods (e.g. milk, meat, vegetables and fruit)
- Inhalation of radionuclides in the atmosphere.
- External irradiation from radionuclides in the atmosphere and deposited on the ground.

For any assessment it is important to consider the agricultural practices around the nuclear installation being considered. The foods considered are general groups, for example, green vegetables includes all types of leafy and leguminous vegetables. The calculations of dose from meat and milk given in Appendix B have been based on cows. However if local information indicates that there are no cows in the vicinity of the site but that sheep or goats are present then these pathways should be considered. Local conditions may also affect which foods should be considered and the relative importance of these foods but in general it is important to consider the ingestion of terrestrial foods when assessing radiation doses from releases to atmosphere.

3.1.2 Pathways dependent on local conditions

As already stated it is important to take account of local conditions when deciding on the exposure pathways to include in a dose assessment. The ingestion of radionuclides in 'free foods' is an example of a potential exposure pathway, which should be considered only when local habit data suggests this may be of relevance. Free foods include berries, mushrooms, rabbits, pheasants, reindeer etc. When considering the ingestion of free foods, it is essential to have information on local habit data. Regional or national habit data cannot take account of the free foods available in an area and large variability is observed between regions. In addition, soil to plant transfer factors for many wild plants e.g. lichen are difficult to obtain and can vary widely. For example many different species of mushroom grow in different areas, and since radionuclide uptake is species specific it would be very difficult to assess accurately doses due to ingestion of wild mushrooms in a general way. It is, therefore, not possible to give generic guidance on how to calculate realistic radiation doses from this pathway due to the site specific nature of the assessment.

It is not normally necessary to consider products from pigs and poultry that are housed inside and supplied with feed from a number of sources most of which will be some distance from the site of interest. However, they may be important in specific locations if other foods are not grown close to the location of interest.

Grain is produced around many nuclear installations and could be important in terms of dose, particularly due to discharges of ^{14}C. However any grain produced for human consumption is normally mixed with other supplies obtained over a wide area before processing and distribution. Therefore, it is unlikely that an individual or group of individuals would consume grain produced by themselves. However if site-specific information indicates that the grain is produced and consumed locally then this pathway should be included.

3.1.3 Pathways not normally considered

Doses from drinking water and consumption of fish, where the discharge is to atmosphere with subsequent deposition onto land and water surfaces, were found to be negligible. Details are given in the Appendix B.

The deliberate ingestion of soil by children or adults does not need to be considered in assessments because this pathway is a recognised medical condition, known as *pica*, which tends to occur for a relatively short time. Inadvertent ingestion of soil and dust was considered in the Appendix B but was found to be relatively unimportant, so does not normally need to be considered.

3.2 Aquatic discharges

The illustrative calculations carried out for releases to aquatic environments are described in Appendix C. Five different release scenarios were examined: reprocessing plants (Sellafield, UK and Cap de la Hague, France); a boiling water reactor; a pressurised water reactor; and a gas cooled reactor. Additionally, releases to three different water bodies were considered: marine environments; estuarine environments; and rivers. The pathways have been separated into several types. This identifies those pathways that should always be considered; those that should be considered depending on local conditions; and those that should not normally be considered. For marine and river releases, the local-specific pathways have been split into; those that will give rise to significant doses compared with those from pathways that should always be considered; and those that could give rise to less significant doses. Less significant doses are those likely to be around one order of magnitude less than the most dominant ‘conventional’ pathway. A ‘conventional’ pathway is one which is typically found at the majority of sites e.g. consumption of fish, time spent on intertidal areas. Unconventional pathways are those that may occur around a few sites, e.g.

consumption of cow's milk from animals grazing on salt marshes, but are not characteristic of most sites.

Discharges to the aquatic environment can result in markedly different doses for the same release rates depending on the receiving water body. For example, the doses received from discharges to a river would be dependent on the volumetric flow of the river. Similarly, discharges to the marine environment would result in doses that are affected by the currents in the area. Additionally, radionuclides exhibit differing sediment partitioning and biota uptake in marine and freshwater environments. In general, dose assessments due to aquatic discharges must include an element of site-specificity in the modelling of their impact.

3.2.1 Marine discharges

3.2.1.1 Pathways that should always be considered

Table 5 lists the exposure pathways that should nearly always be considered in an assessment involving discharges to the marine environment. These pathways are most likely to result in the highest doses, be present at all locations and can be considered 'conventional' pathways. In general terms, these pathways are:

- Ingestion of radionuclides in the main marine foods (e.g. fish, crustaceans, and molluscs);
- External irradiation from gamma-emitting radionuclides on beaches.

3.2.1.2 Important pathways to consider if local conditions indicate appropriate

Table 6 presents pathways that should always be considered if they are likely to occur in the locality of the site. These pathways give rise to relatively important doses for the majority of sites, irrespective of the local dispersion conditions in the locality of the site. The pathways also represent those likely to give doses of the order of the most dominant 'conventional' pathway.

The illustrative calculations demonstrate that if there are indications that local people consume marine plants then the doses received from this pathway can form a significant proportion of the total dose received by an individual. Habit surveys should be used, where possible, to identify whether individuals ingest marine plants in the locality of a site.

Other pathways which can result in relatively important doses if local conditions suggest they occur are the consumption of marine biota other than plants e.g. aphrodite aculeate (sea mice) and the ingestion of animal products produced from animal grazing on salt marshes. However as the process of uptake of radionuclides into such biota is not fully understood and the accumulation of radionuclides into salt marshes cannot be easily modelled then dose estimates should be based on environmental measurement data.

3.2.1.3 Pathways that could be considered if local conditions indicate appropriate

The ingestion of crops grown on soil conditioned using seaweed (e.g. grain, root vegetables) could be significant (Table 7) if this practice occurs in the locality of the site. Seaweed can be used as a conditioner to improve soil fertility. This allows radionuclides incorporated in the seaweed to be available for uptake by crops grown on such soil. The illustrative calculations suggest that this pathway should be considered if deemed necessary as it could be a significant contributor to doses.

Exposure while swimming could be relevant if there are individuals who spend long periods of time swimming e.g. a hour a day.

An additional pathway for consideration is desalinated water used for drinking water. The importance of this pathway will be very much dependent on the location of the abstraction of the seawater compared to the discharge point and whether the desalinated water is used for drinking water.

3.2.1.4 Pathways not normally considered

Table 8 indicates those pathways that should not normally be considered for dose assessments. Illustrative calculations of doses including such pathways are given in Appendix C.

Inhalation of seaspray was found to be unimportant in the five discharge scenarios considered and the unit release scenario described in Appendix C. Inadvertent ingestion of seawater while swimming was identified as being an unimportant pathway. Doses from crops or animals farmed on land exposed to seaspray or reclaimed from the sea were found to be negligible. Inadvertent ingestion of beach sediment was found to lead to insignificant doses. However for infants although the doses from this pathway were insignificant, i.e. order of few μSv y^{-1}, as infants receive less exposure from the conventional pathways (e.g. consumption of seafood, exposure from sediments) then the relative contribution from this pathway is higher.

Negligible doses were found to be received from beta-emitters in beach sediment and the inadvertent ingestion of seawater. The doses from beta and gamma-emitters entrained in fishing gear gave extremely small doses. The exposure of individuals who spend time on boats does not lead to significant doses. The inhalation of resuspended sediments or conditioned soil were both found to be insignificant contributors to dose.

3.2.2 Estuarine discharges

For discharges to the estuarine environment two discharge scenarios were considered; a PWR and a GCR.

3.2.2.1 Pathways that should always be considered

Table 9 lists the exposure pathways that should nearly always be considered in an assessment involving discharges to an estuarine environment. In general terms, these pathways are:

- Ingestion of radionuclides in the foods taken from estuaries (e.g. fish, crustaceans, and molluscs);
- External irradiation from gamma-emitting radionuclides on estuarine sediments.

3.2.2.2 Pathways dependent on local conditions

The illustrative calculations demonstrate that it is important to consider the ingestion of aquatic plants taken from an estuary as a pathway (Table 10). The doses received from this pathway can form a significant proportion of the total dose received by an individual. Habit surveys should be used, where possible, to identify whether individuals ingest aquatic plants in the locality of a site.

3.2.2.3 Pathways not normally considered

Table 11 indicates those pathways that should not normally be considered for dose assessments. Illustrative calculations of doses, including such pathways, are given in Appendix C.

Inhalation of seaspray and inadvertent ingestion of seawater and estuarine sediment were found to be unimportant in the two discharge scenarios considered. Doses from crops or animals farmed on land exposed to seaspray and crops grown on soil conditioned with seaweed were found to be negligible. Insignificant doses were found to be received from beta-emitters in estuarine sediment and from beta and gamma-emitters entrained in fishing gear. The skin dose received while bait-digging was found to be negligible. The inhalation of resuspended sediments or conditioned soil were both found to be insignificant contributors to dose. The exposure of individuals who spend time on boats did not lead to significant exposures.

3.2.3 Riverine discharges

3.2.3.1 Pathways that should always be considered

Table 12 lists the exposure pathways that should nearly always be considered in an assessment involving discharges to a riverine environment. These pathways are:

- Ingestion of radionuclides in fish taken from rivers;
- External irradiation from gamma-emitting radionuclides on river-bank sediments.

3.2.3.2 Important pathways to consider if local conditions indicate appropriate

External exposure on houseboats can be a relatively important pathway due to the amount of time spent on the water with relatively little shielding (Table 13). Data on occupancy times should be taken from habits surveys, if available.

3.2.3.3 Pathways that could be considered if local conditions indicate appropriate

Table 14 presents pathways that may be considered if they are likely to occur in the locality of the site. These pathways give rise to relatively important doses for some of the sites, dependent on the local dispersion conditions in the vicinity of the site. The pathways also represent those likely to give doses less than the most dominant 'conventional' pathway. Some of these pathways are unlikely to be additive to the 'conventional' pathways e.g. it is unlikely that someone would spend 300 h y^{-1} swimming in addition to spending 500 h y^{-1} on the river bank.

The illustrative calculations demonstrate that it can be important to consider the ingestion of freshwater molluscs and crustaceans. Ingestion of animal meat or milk from animals drinking river water should be considered as a pathway if likely to occur. These pathways give rise to relatively important doses from some of the sites dependent on the local dispersion conditions in the locality of the site. The ingestion of crops grown on previously flooded land can form a significant proportion of the total dose, especially to infants. The inadvertent ingestion of river-bank sediment becomes important for younger age groups, depending on the mix of radionuclides released to the river. External exposure during swimming or while using boats for recreational purposes can be important dependent on the occupancy and radionuclides released. Skin doses from fishing gear should be considered. Although the ingestion of treated drinking water was found to give relatively small doses in Appendix C, the ingestion of untreated drinking water can occur and in some local circumstances may give rise to relatively important doses. This has, therefore, been included in the pathways in Table 14.

All these pathways should be considered only if local habit surveys have identified them as taking place.

3.2.3.4 Pathways not normally considered

Table 15 indicates those pathways that should not normally be considered for dose assessments of riverine discharges. Illustrative calculations of doses, including such pathways, are given in Appendix C.

The ingestion of treated drinking water taken from the river into which a site discharged was found to be an insignificant contributor to dose. Consumption of freshwater plant and waterfowl was generally found to be a minor contributor. The ingestion of crops irrigated using river water or crops grown on soil conditioned using river plants were both found to contribute little to the total dose received. Inadvertent ingestion of river water while swimming is shown to be an insignificant pathway. The external exposure of individuals on previously flooded land and the exposure from beta-emitters on river-bank sediment were found to contribute only a small proportion to the overall dose. The inhalation of resuspended river-bank sediments should also not generally be considered.

3.2.4 Lake discharges

For discharges to lakes the situation will be similar to that for discharges to rivers. The same exposure pathways should be considered with local factors taken into account. Limited calculations for discharges to a lake in the UK indicate that doses are likely to be higher for discharges to a lake than for the equivalent discharges to a river because of the limited movement of water out of the lake.

4 METHODOLOGY

The most realistic method for assessing doses to the members of the public is extensive monitoring of the exposure pathways e.g. measuring activity concentrations in foods, air etc. and conducting surveys of habits of local people e.g. the amount of locally grown food eaten, amount of time spent on beach etc. However this approach is costly both in monetary terms and time. In addition, discharges may be at a level where the actual levels in the environmental media are below the analytical limits of detection.

Typically, an assessment would use a combination of measurement and modelled data with either, the modelled data providing information where the measured data is at the limit of analytical detection, or the measurement data being used to verify the modelled data.

A number of models are available and, although no specific recommendations are made, (IAEA, 2001) and (Simmonds et al. 1995) are useful references. However it must be noted that the model given in (IAEA, 2001) is intended for screening purposes and uses conservative generic values. If a realistic assessment is intended these values would need to be replaced by more realistic and preferably site-specific values. It is necessary that any models used are robust and fit for purpose. Measures should have been taken to ensure that the models are valid. This means that the models should have been tested to ensure that they are behaving as intended and where possible should be compared with measurement data to ensure that they are an adequate representation of reality. For example an IAEA programme called VAMP (Validation of Environmental Model Predictions) (Koehler et al. 1991) tested the predictions of the mathematical models against results of measurements made after the Chernobyl accident. It is important to emphasise that any realistic assessment of doses relies on the model parameter values and the habit data used being a realistic representation of the situation near the site.

4.1 Atmospheric discharges

If models are used to predict activity concentrations in the air and on the ground account should be taken of the range of meteorological conditions that occur in the course of a year. The effects of wet and dry deposition should be considered as well as radioactive decay. The meteorological conditions should be appropriate for the site in question and should preferably be averaged from several years of data. Such data may be available for the site itself or from nearby meteorological stations. The atmospheric dispersion model also needs to consider the height of the release taking into account the effects of nearby buildings and any plume rise due to the thermal buoyancy and/or momentum of the released material. Gaussian plume dispersion, based on the use of stability category meteorological data (Pasquill, 1976) can be used. A new generation of models has been developed, e.g. ADMS (Carruthers et al. 1994) and AERMOD (Cimorelli et al. 1998). However when considering continuous releases there is little difference between the new models and the Gaussian plume model e.g. as implemented in PC-CREAM (Mayall et al. 1997).

It is common practice to use a generic model for the transfer of radionuclides through terrestrial foodchains. In such models similar foods are grouped together for modelling purposes, for example green vegetables and root vegetables are considered rather than specific crops such as cabbage or carrots. In most cases it will be acceptable to use generic parameter values for the foodchain model. However, if extensive measurements have been made close to the site then it may be appropriate to use site specific values for particular parameter values.

For modelling the resuspension of radionuclides deposited on the ground two approaches are possible (Simmonds et al. 1995). The first uses a resuspension factor to relate the ground deposition to the activity concentration in air while the second uses a dust loading approach.

A model may also be required to calculate external radiation exposures from deposited material. This should allow for the downward migration of radionuclides in the soil as well as the build up of activity due to continuous deposition.

4.2 Aquatic discharges

Radionuclides discharged to water bodies are dispersed due to general water movements and sedimentation processes. Liquid radioactive wastes may be discharged to freshwater, marine or estuarine environments (see page section 4.5 on discharge to sewers). Much depends on the local characteristics of the receiving environment and it is not possible to have a totally generic model for liquid releases. Discussion on the various models available for simulating transfer in the aquatic environment occurred previously in an European Commission Concerted Action (Simmonds et al. 2000). Models available vary in purpose and complexity and should be selected appropriately. Examples of compartmental models available for marine discharges are PC CREAM (Mayall et al. 1997) and Poseidon (Lepicard et al. 1998). Both of these models represent the European marine waters as a series of inter-linked water and sediment compartments. Another approach is that used for CSERAM (Aldridge J N, 1998). This is a more complex model used for a specific region of the marine environment, i.e. Irish Sea. For continuous routine releases all of these models are likely to give similar results.

If water is discharged into a river, then the influential parameters are the discharge rate and the river flow rates, the river size, the sedimentation rate and the nature of the sediment. Generally speaking, the maximum concentration within the water body is near the discharge point. At some kilometres' distance downstream, around 10 km, homogeneity in the radionuclide concentrations in the water body exists (SSK, 1992). However, additional dispersion occurs due to sedimentation and the presence of tributary waters leading to a reduction in radionuclide concentration.

The amount of dispersion may be different for the different pathways e.g. water for irrigation purposes is abstracted solely during summer dry periods. The amount of dispersion for this pathway should therefore to be based on the summertime flow rate (SSK, 1992). The fish habitat may comprise of tributaries of small rivers and streams both up- and downstream of the discharge point. The amount of dispersion will be an average weighted over the different compartments of the river that are used to calculate the radionuclide concentration in the fish.

If a lake is the receiving medium, then the maximum dispersion depends on the flow rate of the water passing through the lake. In countries with seasonal drought the concentration of radionuclides in the lake may vary throughout the year, especially if the draining from the lake ceases completely for a period of time.

In assessing doses to the reference group, the highest activity concentrations and hence doses will generally arise close to the discharge point. However, there is the possibility of exposures arising from further afield, for example where drinking water is abstracted or where there is a major fishery. Freshwater may be used for irrigation of agricultural land and then the transfer of radionuclides to the terrestrial foodchains needs to be considered. The models discussed above for releases to atmosphere can be used also where the source of radionuclides is via irrigation water.

4.3 Accumulation of radionuclides in the environment

When radionuclides are continuously discharged they accumulate in the environment up to the point where equilibrium conditions are reached. Equilibrium conditions mean that the rate of discharge of a radionuclide equals the rate of transfer out of the environment being considered. The point at which equilibrium conditions are reached is dependent on the behaviour, chemical form and radioactive half-life of the nuclide. For example ^{131}I reaches equilibrium very quickly as it has a radioactive half-life of 8 days. Technetium-99 also achieves equilibrium conditions relatively quickly despite having a half-life of 212860 years. This is due to the fact that it usually disperses rapidly in the environment. For radionuclides such as ^{239}Pu which have long half-lives and are not chemically mobile it can take many decades before equilibrium is reached. For assessments which are based on past discharges any models used need to take account of this build-up in the environment.

The length of time needed to account for build-up will depend on the likely lifetime of the plant and whether a similar plant could be built at the same locations. Plant lifetimes are likely to be in the range of 30 to 100 years. Simmonds et al, 1995 assume continuous discharges for 50 years to represent the estimated lifetime of nuclear installations.

4.4 Progeny ingrowth

A radionuclide may decay into a progeny which is also radioactive and this may need to be taken into account in realistic dose assessments. In some cases, the decay products may have higher dose coefficients than the parent and so it is important to consider the ingrowth. An example of this is ^{241}Pu (a beta emitter) which decays into ^{241}Am (an alpha emitter). Although the maximum possible activity concentration of ingrown ^{241}Am is 30 times lower than that of the parent ^{241}Pu, the ingestion and inhalation dose coefficients for ^{241}Am are a factor of 50 and 70 times higher, respectively, than those of ^{241}Pu. The peak of ^{241}Am activity will occur about 75 years after the discharge of ^{241}Pu. Therefore when assessing doses from a site which discharges ^{241}Pu the doses from ^{241}Am must also be considered.

In other cases the situation is simpler in that the progeny has a short radioactive half-life and can be considered to be in equilibrium with the parent. In this case the two radionuclides are simply considered together. For example, this is the case for ^{137}Cs and its progeny ^{137m}Ba, which are always considered together. In some cases for very long lived radionuclides the ingrowth of any progeny takes place on such a long timescale that it is not necessary to include this in assessments of routine discharges.

4.5 Discharges to sewage works

It is intended that this guidance should be also relevant to non-nuclear sites such as hospitals and research facilities. Although nuclear power production sites do not discharge directly to sewage works there are examples of hospitals and research facilities which do so. Work by Titley et al. 2000 has indicated that if radioactive waste from a non-nuclear site is discharged directly to a sewage works then there is the potential for sewage workers to receive significant doses. Therefore if assessing doses from a site which directly discharges to a sewage plant it is important that the doses to sewage workers are assessed. Account also has to be taken of the radiation doses that could arise from the disposal of the sewage sludge. Possibilities include incineration of the sludge or using the sludge as land treatment (see (Titley et al. 2000), (NRPB, 1998) and (NRPB, 2000)).

5 REFERENCE GROUPS

In specifying reference groups two broad approaches are possible. The first involves carrying out surveys of the local population to determine their habits, where they live etc. From these surveys the people who are receiving or who received the highest doses can be identified. The second approach involves using more generalised data to establish generic groups of people who are likely to receive the highest doses. The two approaches can be used separately or a combination of both used for example local surveys of consumption of seafood used in conjunction with consumption rates of terrestrial food based on more generic data.

Reference groups can be identified for retrospective dose assessments through local knowledge and site-specific habit surveys supplemented as necessary by the use of generic studies of habits. Reference groups for prospective assessments can be identified in the same way but consideration must be given as to whether the selected habits are likely to be sustained or new habits occur during the time period of interest.

This report provides information in a generalised form (Appendix D) that can be used where limited or no local information is available or to establish generic reference groups. In general it is better to use local or regional data for the purposes of defining reference groups. However, generalised data could be used where doses are considered low, for example in relation to limits or constraints, and where regional variations are likely to be small. Generalised data may also be used when assessments extend over long time periods and relate to future rather than past exposures. It is important that any data used for reference groups are applicable over the time period being considered. It is also useful to compare the generalised data with the local habit data to enable the local data to be put into context.

Reference groups are intended to be representative of individuals likely to receive the highest doses. There are many different potential exposure pathways but they vary markedly in importance. It is therefore not necessary or helpful to look at every possibility in order to make a realistic estimate of dose as long as the important pathways have been considered. For example in Table 5 it is recommended that the marine pathways that should always be considered are consumption of fish, crustaceans and molluscs and exposure to contaminated beach sediments. Assessment of dose from these four pathways will typically ensure that the reference group dose is adequately estimated e.g. some individuals in the reference group may swim frequently but the dose from this pathway is negligible compared to the doses due to consumption of seafood. However if a local survey indicates that no fish are locally caught then closer attention may have to be paid to the less important pathways e.g. handling of fishing gear to ensure that the reference group dose is fully represented.

Reference groups should be small enough to have relatively similar habits and will usually be up to a few tens of persons. It is not appropriate to use extreme habits. However, where the normal behaviour of one or two individuals results in them being significantly more highly exposed than any other individuals, then the reference group should be deemed to comprise only those individuals. Normal behaviour is taken to mean behaviour which is likely to occur on a continuing basis, e.g. exposure arising as a result of the location of a house or a form of employment, and is not dependent on the presence of a particular individual. It is important that when occupancy or dietary habits are used they are appropriate for the entire year e.g. if the dietary survey is done in the summer account must be taken that diets are likely to be different in the winter.

The following sections discuss factors relevant to the identification of reference groups for the key routes of exposure. The people who are the most exposed will depend on the radionuclides discharged and the particular environment. It may be necessary to consider more than one group of people to determine which is most exposed. For a few installations direct external irradiation from the site itself is the dominant exposure pathway (Robinson et al. 1994). In this case the reference group is identified by measurements made around the site combined with knowledge as to the location and occupancy of nearby dwellings. Since this pathway is important for only a few nuclear sites it is not discussed further in the following sections.

5.1 Atmospheric discharges

The radiation exposures will depend on the concentrations of radionuclides in air and on the ground around the site resulting from the discharges. This depends in turn on the location of the discharge points, the height of the release and the atmospheric conditions.

5.1.1 Inhalation

For inhalation of radionuclides in the plume, individuals working or living at locations with the highest air concentration will generally receive the highest doses from this pathway. Account has to be taken of occupancies as well as the activity concentrations in air in determining the location with the highest doses from inhalation. Inhalation rates for various age groups from the ICRP Task Group report on the model of the respiratory tract (ICRP, 1994) are provided (Table 16).

5.1.2 External irradiation

People can be exposed to external irradiation in two ways; from material deposited on the ground or in the atmosphere. For external irradiation from deposited material groups located where there is the highest ground deposition are likely to receive the highest exposures. However due to the movement of radionuclides in the atmosphere the area of highest ground deposition is not necessarily the area with the highest activity concentration in air. Therefore individuals who receive the highest exposure due to irradiation from deposited material may not coincide with the individuals with the highest doses due to irradiation from the atmosphere.

For time spent indoors account should be taken of the degree of shielding offered by the building to reduce the external irradiation exposure and the occupancy of the building. Table 17 gives percentages of time spent indoors for 1 y olds, 10 y olds and adults based on (Roy and Courtay, 1991) (more detail is given in Appendix D). The dose indoors is reduced by a factor of 0.2 for irradiation from the cloud and 0.1 from deposited activity due to shielding (Brown J and Jones J A, 1993). Doses to people outdoors from the external gamma exposure from the cloud in an urban area are also likely to be smaller than those outdoors in a rural area due to shielding by surrounding buildings. (Brown J and Jones J A, 1993) indicates that dose rates outdoors from the external gamma exposure from the cloud outdoors in urban areas can be obtained by multiplying dose rates outdoors in rural areas by 0.7. For doses outdoors from exposure to deposited activity no reduction in dose for either rural or urban areas was recommended.

If the building is a workplace then assuming occupancy during working hours only is sufficient. The combination of occupancy and shielding may mean that the nearest building to the source is not the location for the most exposed group.

5.1.3 Consumption of terrestrial foods

Atmospheric discharges lead to a transfer of radionuclides to terrestrial foods. People who subsequently ingest these foods must be considered. The areas of land used for agricultural production where the deposition from atmosphere is highest need to be identified. It is possible for people to grow vegetables in their gardens and this should be considered if appropriate. Local factors should be taken into account in determining the foods to consider e.g. reindeer grazing on lichen may be an important pathway for certain regions.

Agricultural production occurs over large areas and so it is unrealistic to assume that all food consumed could be produced close to the source of the discharge. It might be cautiously assumed that a few foods could be produced over an area, which has a centre at a distance of few hundred metres from a discharge site's boundary. However, where it assumed that a number of different types of foods (e.g. milk, meat and vegetables) are produced close to the source of discharge, then it is more realistic to take account of the need for larger grazing areas, movement of livestock around a farm and rotation of crops. Thus, a distance of 500 m from the site fence would be a more realistic minimum distance for the production of food.

Intake rates of different terrestrial foods are required to estimate doses. Information is available for the EU of the amount of food consumed for the population as a whole and Table 18 gives the average per capita consumption for the EU and further information is given in Appendix D. For estimating doses to reference groups higher intakes are used for the key foods as the aim is to calculate doses to the group that is most exposed. There are two difficulties with this. The first is in knowing what higher intake rates to use and the second is knowing how many foods are eaten at higher rates. Ideally survey information would be available showing the distributions in intakes for different foods and for combinations of foods. In the absence of this, use has to be made of the information that is available as discussed in Appendix D.

It is unlikely that people will eat all of their foods with a high intake and therefore high intake rates have been derived for each EU country for the four food types most likely to give rise to the highest doses. Table 19 gives the high consumption rates for milk, root vegetables, fruit and green vegetables. There is evidence from UK national and regional habit surveys that people rarely consume more than two foods at high rates (Ministry of Agriculture Fisheries and Food, 1996). In realistic assessments local knowledge should be used to determine which foods are consumed at high rates and which foods are consumed at average rates. The foods chosen for consumption at the highest rates should be those that give rise to the highest dose. The amount of food derived from local sources will also need to be determined as local agricultural practices and lifestyles will vary according to the site considered. The most cautious assumption will be to assume that all the terrestrial foods are locally produced. However this will probably be unrealistic and will lead to an overestimation in doses.

There is little information available on food consumption rates for infants and children. The information available is discussed in Appendix D and can be used to determine generic intake rates in the absence of local information. Table 20 gives scaling factors which could be applied to the average and high consumption rates (Table 18 and Table 19) to give consumption rates of 1 y and 10 y olds for EU countries. However these factors are based on UK data (Byrom et al. 1995) and patterns of consumption vary between EU countries and between age groups. Therefore it is preferable to use data gathered in the region being considered.

5.2 Aquatic discharges

5.2.1 Marine discharges

For discharges to the marine environment, the most exposed groups are likely to include those persons who consume higher than average amounts of locally caught seafood (fish, crustaceans and molluscs) and those people who spend a relatively large amount of time on areas of sediment or sand and so are exposed to external irradiation (this could also include handling sediment or sand). It should be noted that the reference group for marine discharges does not necessarily live close to the source of the discharge. The activity concentration of seafood is very dependent on the site where the fish, crustaceans etc. inhabit. Therefore it is important to obtain local information on the activity concentrations in seafood likely to be significant contributors to dose i.e. for those foods which are consumed in large amounts or those which may particularly concentrate the radionuclides. Table 21 gives the marine food consumption rates for the EU member states. Table 22 gives generic occupancy rates over intertidal sediments for reference groups. Appendix D gives details on the source of these data.

5.2.2 Freshwater discharges

For discharges to freshwater the exposure pathways of concern may include consumption of freshwater fish and exposure due to irradiation whilst on river banks. Table 23 gives the consumption rate data of freshwater fish for EU Countries for average and high intake rates and Table 22 gives the occupancies on river banks.

5.3 Combinations of habits

Reference groups will need to have combinations of habits, both high and average, based on local knowledge and plausible assumptions. These combinations of habits will need to be realistic and not lead to implausible situations, for example someone having an excessive intake of calories. Again a full range of exposure pathways should be considered for each of the potential reference groups. However, in most cases it is not realistic to assume that the same people are most exposed from all pathways and so a simple addition of doses attributed to different pathways is not necessarily appropriate. Instead, a combination of habits typical of average and most exposed people may be assumed i.e. both average habit data and higher than average habit data are required to assess doses. For example, members of the reference group who eat locally produced terrestrial foods at higher than average rates, could be assumed to eat a proportion of locally produced aquatic foods at average rates.

5.4 Age groups

The (CEC, 1996) gives dose coefficients for the ingestion and inhalation of radionuclides for six age groups. For both atmospheric and aquatic releases illustrative dose calculations were done for all six age group (as detailed in Appendix B and C respectively).

5.4.1 Atmospheric

In Appendix B, Table B10 summarises the principal exposure pathways and radionuclides following releases to the atmosphere. For all five discharge scenarios the highest doses were received by a 1 y old, 10 y old or adult. For unit releases of individual radionuclides the limiting age group depended on the radionuclide as shown in Table B13. For ^{3}H, ^{14}C and ^{131}I a 1 y old was found to be the limiting age while for ^{239}Pu, ^{137}Cs and ^{85}Kr, the limiting age group was found to be adults.

5.4.2 Aquatic

In Appendix C, Table C18, C24 and C30 summarise the principal exposure pathways and radionuclides following releases to the marine, river and estuary environment respectively. For releases to the marine and estuarine environments the highest doses were received by adults. For the river environment 15 y olds received slightly higher doses than the adults but as these are within the overall uncertainties in general it can be assumed that adults are the limiting group. For unit releases of individual radionuclides the limiting age group depended on the radionuclide as shown in Table C32 and Table C34 for the marine and river environment. For ^{60}Co and ^{137}Cs the 15 y olds were found to be the limiting group for the marine environment with the adults for ^{99}Tc, ^{106}Ru, ^{239}Pu and ^{241}Am. For the river environment the adults were the limiting groups for all radionuclides apart from ^{3}H for which the 1 y olds were the limiting group.

In summary the calculation for all scenarios indicate that the highest doses are received by 1 y olds, 10 y olds or adults, except for releases to the river environment where the 15 y olds received slightly higher but not significantly different doses to those of the adults. Therefore it is not necessary to consider all six age groups, given in Table 1, as the limiting dose will be adequately represented by assessing doses to 1 y olds, 10 y olds and adults.

5.5 Fetus and breast-fed infants

This section considers whether the fetus and the breast-fed infant need to be considered in addition to the three age groups recommended in Section 5.4; 1 y olds, 10 y olds and adults.

The radionuclides chosen for the illustrative calculations (^{3}H, ^{14}C, ^{90}Sr, ^{131}I, ^{137}Cs and ^{239}Pu) are those which are typically discharged from nuclear installations and which cover a range of biological behaviour in the body. For ^{14}C it must be noted that the transfer of isotopes of carbon can be significantly influenced by the chemical form.

5.5.1 Breast-fed infants

Typically assessments will estimate doses to infants consuming cow's milk rather than breast milk. The purpose of this section is to examine whether a breast-fed infant (3 months old) or a 1 y old infant consuming cow's milk will receive the higher doses.

Table 24 gives the values for the ratio of doses to breast-fed infants relative to adult doses for some of the important radionuclides. These ratios (Phipps A, 2001) are based on acute intakes by the mother at birth. Results for acute intakes have been used as they were the published data currently available and will result in the maximum doses to the breast-fed infant.

Tritiated water is distributed uniformly throughout body water and passes freely from the mother's body to milk, with the result that up to about 30% of the mother's intake could be transferred to the breast-feeding infant. This results in doses to the infant that are comparable with those to the adult. Caesium behaves similarly to potassium in the body in terms of uptake into all living cells and considerable transfer to milk would be expected. There are good human data on the transfer of ^{137}Cs to milk following the Chernobyl accident which support an estimate of up to 25% as the fraction of activity ingested by the mother which is transferred to the infant. This can result in doses to the infant of up to 40% of the adult dose. Strontium, being chemically similar to calcium which is required by the fetus for skeletal growth, is also transferred to milk at considerable levels. Up to around 8% of ^{90}Sr ingested by the mother could be transferred to the infant; this would result in doses to the infant of about 20% of the adult dose. Only a very small fraction of a ^{14}C intake is transferred to the infant since the major part of carbon in milk is supplied from the large reserve of stable carbon present in the mother's body; again doses to the infant are much lower than doses to the adult. Limited animal data show that isotopes of the actinides are not transferred to milk to any great degree; doses to the infant would be much lower than doses to the adult. In the case of iodine, transfer to milk in humans has been shown to be noteworthy; up to 30% of activity ingested by the mother can be transferred to the infant. When this factor is combined with the high dose coefficient for ^{131}I for the infant, the result is that the dose to the infant can be around 2.5 times higher than the adult dose.

From Table 24 it can be seen that ^{131}I has the highest ratio of infant to adult dose and therefore this nuclide was examined in more detail. As an illustrative calculation a unit release of 1 TBq y^{-1} of ^{131}I to atmosphere was estimated to result in a dose of 84 μSv y^{-1} to the mother. The corresponding dose to the breast fed infant will be 84 x 2.5 i.e. 210 μSv y^{-1}. For an infant assumed to be consuming cow's milk the dose for a unit release of 1 TBq y^{-1} was calculated at 440 μSv y^{-1}. Therefore the 1 y old infant consuming cow's milk receives a higher estimated dose than the breast-fed infant. It may be concluded that consideration of dose to a 1 y old infant consuming cow's milk will give a more restrictive estimate than obtained for an infant consuming breast milk.

5.5.2 Fetus

Fetal doses are not normally included in assessments of radiation doses for members of the public exposed due to routine discharges from nuclear installations. However the recent publication of (ICRP, 2001) permits the assessment of fetal doses. Table 25 gives the ratio of fetus to adult dose coefficients.

In the case of tritiated water and ^{14}C essentially all of the ingested activity enters the maternal circulation and is distributed to body tissues. The placenta does not generally present a barrier to transfer of these elements into the fetus. Doses received by the offspring are similar to adult doses.

Strontium is of particular interest since fetal demand for calcium particularly towards the end of the pregnancy, can lead to significant fetal uptake of radioisotopes of calcium and, because of its chemical similarity, of strontium. In an illustrative calculation of doses resulting from a unit release of 1 TBq y^{-1} of ^{90}Sr to atmosphere, the dose to the fetus was estimated to be 1.5 times higher than the adult dose i.e. 120 μSv y^{-1} (the adult dose being 78 μSv y^{-1}). However the dose to the 10 y old child is 180 μSv y^{-1} and therefore the fetus is not the most exposed group.

For ^{131}I the dose to the fetus is slightly higher than the adult dose due to the selective uptake of iodine by the fetal thyroid in later stages of pregnancy. Using the example of a unit release of 1 TBq y^{-1} of ^{131}I, as in the section above, the dose to the fetus would be 92 μSv y^{-1} (adult dose x 1.1). This dose is lower than that assessed for an infant assumed to be consuming cow's milk, 44 μSv y^{-1}, and therefore the fetus is not the most exposed group.

For radionuclides such as ^{239}Pu low gut uptake and placental discrimination mean that dose coefficients to the offspring are much lower than those for the adult and therefore the adult will receive higher doses than the fetus.

However recent work published indicates that radioisotopes of the elements required by the fetus for skeletal growth such as those of calcium (ICRP, 2001) and phosphorous (Phipps et al. 2001) which are also important in the growth of mineral bone, may result in the fetus being the most restrictive group. If making an assessment where there are significant discharges of radioactive isotopes of these elements, i.e. where the adult doses due to these isotopes are of the order of tens or hundreds of μSv y^{-1}, then fetal doses should be considered.

5.6 Dose coefficients

For dose assessments the dose coefficients published in the EURATOM directive should be used. Where data are provided for more than one chemical form of an element and the actual chemical form is not known, the defaults should be taken from (ICRP, 1996). If required dose coefficients for tritium and ^{14}C in a vapour state should be taken from a Communication regarding the EURATOM directive (EC, 1998). Expert judgement should be used to determine the most appropriate chemical form for use in the assessment rather than assuming the chemical form that leads to the highest dose coefficient.

6 ISSUES IN ACHIEVING REALISTIC ASSESSMENTS

6.1 Realism of assessment

The assessment must reflect the transfer of the radionuclides through the environment to man. This is not an easy task. Discrepancies can occur at many stages, for example;

- If modelling radionuclides in the environment is not a true representation e.g. if the model predicts activity concentrations of ^{129}I in milk significantly greater than those measured.
- When measurement data are not an accurate reflection of the real environment e.g. a few measurements of the concentrations of ^{239}Pu in offal are taken as representative of the local area but if more measurements were made the average concentration could be significantly higher.
- If significant exposure pathways are omitted e.g. consumption of reindeer meat (which have been eating lichen with high uptakes of caesium) has not been included
- If assumptions relating to the habit data for the reference group are not representative e.g. it is assumed all fish consumed is locally caught, whereas in reality only 10% is local.

These points emphasise the importance of having a good understanding of local conditions around the installation being assessed. When deciding whether to investigate further any discrepancies it is advisable to consider the extent of the discrepancy as obtaining site-specific data can be time-consuming and costly. For example, if the dose estimated for the reference group is 200 μSv y^{-1}, which is mainly due to the consumption of molluscs based on assumed consumption rates, then it would useful to determine the local consumption rates. However, if the dose is of the order of a few μSv y^{-1} then a detailed survey of local consumption rates may not be justified.

6.2 Variability and uncertainty

Assessments of doses necessarily entail a series of assumptions about the behaviour of the reference group and about the transfer of radionuclides in the environment. The estimated mean dose to the reference group is therefore within a distribution of possible doses. There are two aspects to this distribution referred to as the uncertainty and the variability. The uncertainty reflects the amount of knowledge about the system being investigated and relates to how accurately the dose can be estimated; for example, how well are all of the parameter values in the calculation of doses known? The variability refers to the actual differences that occur both in transfer in different environments and between individuals within a group; for example, differences in how much of a particular food is eaten or where individuals spend their time. This topic is discussed in more detail in (IAEA, 1989) and a number of studies have been carried out to investigate uncertainty and variability (eg (Smith K R et al. 1998), (Jones et al. 2000)). In addition this subject has been examined in France by the Nord-Contentin Radioecology Group (GRNC, 2002).

When performing an uncertainty/variability analysis one of the important first steps is to estimate the dose using 'best estimates' of the parameter values. This will indicate whether it is worthwhile proceeding with the work e.g. if doses are of order of 10 μSv y^{-1} which is considered a trivial dose (IAEA, 1988) then it may not be effective continuing with the work. The 'best estimate' dose is also a useful benchmark against which to compare any results from the uncertainty/variability analysis e.g. if 'best estimate' dose is 200 μSv y^{-1} but the uncertainty/variability analysis indicates a distribution of doses from 200 μSv y^{-1} to 600 μSv y^{-1} with the mean being 400 μSv y^{-1} then it would advisable to re-examine the distribution associated with the input parameters.

Another useful exercise is to identify the input parameters which have the greatest influence on the doses. This is done by performing a sensitivity analysis. For this various parameters and assumptions are varied and the effects of these changes on the estimated doses are studied.

A workshop (Walsh et al. 2000) was held in the UK to consider the implications of distributions in critical group doses for the system of radiological protection. Participants included representatives from regulators and operators of nuclear establishments, the European Commission (D-G Environment) and ICRP. It was concluded from the workshop that variability studies are useful when examining the composition of reference groups, to ensure it is not composed only of individuals with extremes of behaviour, and to ensure it adheres to the ICRP homogeneity criteria (ICRP, 1985). It was concluded that a uncertainty/variability study need not be carried out for every assessment, but could be valuable to improve understanding of reference group dose assessments.

6.3 Use of measurement data

By using any measurements that have been made around a nuclear installation a more realistic estimate of doses can be obtained than by using modelled results alone. For retrospective assessments the most realistic assessment of doses is obtained by using measured activity concentrations in environmental media. This is not always possible as a comprehensive set of measurement data may not be available or measurements are below limits of detection and modelling is then required. The Article 37 Working Group mentioned in section 2 is currently looking at a harmonised approach to the handling of values below the decision threshold/detection limit and summation procedures. An assessment in which the limit of detection is assumed to be the actual activity concentration will not give a realistic assessment of doses. Rather the assessment should be based on modelling with the model results being checked to ensure that they are less than the detection limits. Similarly where most activity concentrations are below limits of detection except for one or two actual measurements it is worth comparing the results with model predictions to check their validity. Modelling is also required for prospective assessments. However, measurement data are still valuable to determine the accuracy of the models for the local conditions. It must be remembered that measurement data could include contributions from sources other than that of the site being considered, e.g. natural radionuclides, fallout from atmospheric weapons testing and the Chernobyl accident and other sites discharging radionuclides into the environment.

In order to get an understanding of the extent of the difference between using measurements and modelled results the following calculations were done using an earlier study where measured activity concentrations had been used to estimate doses. Reference group doses around a number of nuclear sites in England and Wales were estimated in (Robinson et al. 1994). The doses estimated for Sellafield for 1991 were used for the purposes of comparison as many measured data were available. For the aquatic pathways i.e. consumption of aquatic foods and external irradiation the doses had been calculated entirely on the basis of environmental measurements. However for releases to atmosphere where site-specific monitoring data were not always available, were incomplete or were lower than the detection limits the results of predictive environmental models had been used to supplement the measurement data.

In order to see the effect of using model results rather than measurements, doses were re-calculated for Sellafield. The ratios presented in Table 26 are doses calculated due to a combination of measurements and modelled results used in the original study compared to modelled results alone. The ratio of 0.7 for aquatic foods is mainly due to the model predicting higher activity concentrations of ^{106}Ru and ^{239}Pu than were measured. However for the consumption of terrestrial food and inhalation pathways the measurements are higher than the modelled predictions. This is due to the measurements including the build-up of ^{90}Sr, ^{137}Cs and ^{239}Pu from previous discharges from Sellafield whereas the modelled results were based on a single year's discharge.

Measurement data are valuable for validating models being used for an assessment. If the data indicate that the modelled results are deviating significantly from the measurements there are two approaches that can be taken. Firstly it may be necessary to revise the model. Secondly if it is judged that in general the model works well but there are peculiarities specific to the site of interest then the measurement data can be used to correct the modelled results. Obviously for retrospective assessments it is more realistic to use the measurement data themselves. However for prospective assessments this will not be possible. Therefore the model can be run on the basis of past discharges and the results compared to the measurement data. It is important that the build-up of radionuclides in the environment is modelled as the measurement data will inherently include contributions from past discharges. The ratio of the predicted to observed data can then be applied to modelled results required for prospective assessments.

7 CONCLUSIONS AND RECOMMENDATIONS

The primary application of this guidance is for realistic assessments of doses to members of the public from nuclear installations during normal operation. The emphasis is on retrospective assessments although many of the ideas are applicable to prospective assessments as well.

The guidance covers all stages of an assessment of doses to members of the public, see Figure 1 for summary of stages. In order to perform a realistic assessment the most important recommendation is;

- To obtain as much site-specific information as possible.

The following recommendations are a summary of the points made in the main text;

Specification of source term

The type and amount of radionuclides being discharged, and the type and location of release must be determined. Unless a significant proportion of the annual discharge is discharged in a short time it can be assumed that the discharges are continuous given the other uncertainties in the assessment process.

Determination of Exposure pathways

The report separates the exposure pathways into 3 types, those that should;

- almost always be considered e.g. consumption of food;
- be examined depending on local conditions e.g. consumption of milk from animal grazing on salt marshes
- not normally be considered e.g. inhalation of seaspray

The main focus of the assessment should be on the pathways contributing the highest doses to the reference group.

Methods for assessing doses

The most realistic method for assessing dose is by the extensive monitoring of the main exposure pathways. However this is time-consuming, costly and levels in the environment may be below the analytical limits of detection. Typically an assessment will involve a combination of measurement and modelled data. Any models used should be robust, fit for purpose and have been validated against measurement data. Models need to take account of both accumulation in the environment (e.g. ^{239}Pu has a long half-life and can build-up in the local environment) and progeny in-growth (e.g. ^{241}Pu decays into ^{241}Am which has a higher dose coefficient than ^{241}Pu). A realistic assessment relies on the parameter values in the model and the habit data used being a realistic representation of the situation around the site.

Identification of reference groups

Reference groups are intended to be representative of individuals likely to receive highest doses. The group should be small enough to have relatively similar habits and will usually be up to a few tens of individuals. It is not appropriate to use extreme habits. However, where the normal behaviour of one or two individuals results in them being significantly more highly exposed than any other individuals, then the reference group should be deemed to comprise of only those individuals.

The report provides generalised habit data for use where site-specific information is not available. There is a paucity of published data concerning the consumption and occupancy rates for EU countries. More information for the different age groups is needed on;

- Indoor/outdoor occupancies
- Occupancies over intertidal areas and riverbanks
- Consumption of terrestrial and aquatic foods for both average and high rate consumers for different age groups

Reference groups will need to have combinations of habits, both high and average, based on local knowledge and plausible assumptions. These combinations of habits will need to be realistic and not lead to implausible situations, for example someone having an excessive intake of calories.

For dose assessments the dose coefficients published in the EURATOM directive (CEC, 1996) should be used. Where data are provided for more than one chemical form of an element and the actual chemical form is not known, the defaults should be taken from (ICRP, 1996). If required dose coefficients for tritium and ^{14}C in a vapour state should be taken from a Communication regarding the EURATOM directive (EC, 1998). Expert judgement should be used to determine the most appropriate chemical form for use in the assessment rather than assuming the chemical form that leads to the highest dose coefficient.

The report recommends that it is sufficient to consider 3 age groups; 1 y old, 10 y old and adults. Fetal doses should be borne in mind if significant amounts of radioactive isotopes of calcium and phosphorus, which are used by fetus for skeletal growth, are discharged.

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9 TABLES

Table 1 Age groups listed with the age ranges that they represent

Default Age	Age Range
3 Month	From 0 to 1 year of age
1 y	More than 1 year to 2 years
5 y	More than 2 years to 7 years
10 y	More than 7 years to 12 years
15 y	More than 12 years to 17 years
Adult	More than 17 years

Data source: (ICRP, 1995)

Table 2 Exposure pathways resulting from a release to atmosphere that should be considered

Exposure Route	Exposure Pathway
Inhalation	Inhalation of radionuclides in the plume
External radiation	External gamma from airborne radionuclides
	External beta from airborne radionuclides
	External gamma from deposited radionuclides
Ingestion	Meat
	Milk
	Milk products
	Green vegetables
	Root vegetables
	Fruit

Table 3 Exposure pathways resulting from a release to the atmosphere that should be considered if local condition indicate appropriate

Exposure Route	Exposure Pathway
Ingestion	Chicken
	Pork
	Grain
	Eggs
	Free foods

Table 4 Exposure pathways resulting from a release to the atmosphere that should not normally be considered

Exposure Route	Exposure Pathway
Inhalation	Inhalation of resuspended activity
	Inhalation of dust resuspended into the indoor environment
External radiation	External beta from deposited radionuclides
Inadvertent Ingestion	Inadvertent ingestion of house dust
	Inadvertent ingestion of soil
Ingestion	Water
	Fish

Table 5 Exposure pathways resulting from a discharge to the marine environment that should always be considered

Exposure Route	Exposure Pathway
Ingestion	Marine fish
	Marine molluscs
	Marine crustaceans
External radiation	Exposure to gamma-emitters on beach sediment

Table 6 Important exposure pathways resulting from a release to the marine environment to consider if local habits indicate appropriate

Exposure Route	Exposure Pathway
Ingestion	Marine plants (e.g. porphyra)
	Other marine biota (e.g. aphrodite aculeate, echinoidea.)
	Ingestion of animal meat from animals grazing on salt marsh (e.g. cow, sheep, goat)
	Ingestion of animal milk from animals grazing on salt marsh (e.g. cow, sheep, goat)

Table 7 Exposure pathways resulting from a release to the marine environment that could be considered if local habits indicate appropriate

Exposure Route	Exposure Pathway
Ingestion	Ingestion of crops grown on soil conditioned using seaweed (e.g. grain, root vegetables)
	Exposure during swimming (if assume swimming 300 h y^{-1} for adults and 10 y olds and 30 h y^{-1} for infants)
	Drinking of desalinated water

Table 8 Exposure pathways resulting from a release to the marine environment that should not normally be considered

Exposure Route	Exposure Pathway
Ingestion	Inadvertent ingestion of beach sediment
	Inadvertent ingestion of seawater while swimming
	Crops/animal products on coastal area exposed to seaspray
	Farming of crops/animals on land reclaimed from the sea
External radiation	Exposure from fishing gear
	Exposure on boats during recreational use
	Exposure from beta-emitters on beach sediment
Inhalation	Sea spray
	Resuspended sediments/conditioned soil

Table 9 Exposure pathways resulting from a release to the estuarine environment that should always be considered

Exposure Route	Exposure Pathway
Ingestion	Estuarine fish
	Estuarine molluscs
	Estuarine crustaceans
External radiation	Exposure to gamma-emitters on beach sediment

Table 10 Important exposure pathways resulting from a release to an estuarine environment to consider if local conditions indicate appropriate

Exposure Route	Exposure Pathway
Ingestion	Estuarine plants (e.g. porphyra)

Table 11 Exposure pathways resulting from a release to the estuarine environment that should not normally be considered

Exposure Route	Exposure Pathway
Ingestion	Inadvertent ingestion of estuarine sediment
	Inadvertent ingestion of seawater while swimming
	Crops/animal products on coastal area exposed to sea spray
	Ingestion of crops grown on soil conditioned using seaweed (e.g. grain, root vegetables)
External radiation	Exposure from fishing gear
	Exposure from beta-emitters on estuarine sediment
	Exposure on boats during recreational use
	Exposure while swimming
Inhalation	Sea spray
	Resuspended sediments/conditioned soil

Table 12 Exposure pathways resulting from a release to the riverine environment that should always be considered

Exposure Route	Exposure Pathway
Ingestion	Freshwater fish
External radiation	Exposure to gamma-emitters on river-bank sediment

Table 13 Important exposure pathways resulting from a release to the riverine environment to consider if local habits indicate appropriate

Exposure Route	Exposure Pathway
External radiation	Exposure on houseboats

Table 14 Exposure pathways resulting from a release to the riverine environment that could be considered if local habits indicate appropriate

Exposure Route	Exposure Pathway
Ingestion	Freshwater crustaceans and molluscs
	Ingestion of animal meat from animals drinking river water
	Ingestion of animal milk from animal drinking river water
	Ingestion of crops grown on previously flooded land
	Inadvertent ingestion of river-bank sediment
	Ingestion of untreated drinking water
External radiation	Exposure during swimming (if assume swimming 300 h y^{-1} for adults and 10 y olds and 30 h y^{-1} for infants)
	Skin doses from fishing gear
	Exposure on boats during recreational use

Table 15 Exposure pathways resulting from a release to the riverine environment that should not normally be considered

Exposure Route	Exposure Pathway
Ingestion	Ingestion of treated drinking water
	Ingestion of waterfowl
	Ingestion of freshwater plants
	Ingestion of crops irrigated by river water
	Ingestion of crops grown on soil conditioned using river plants (e.g. grain, root vegetables)
	Inadvertent ingestion of river water while swimming
External radiation	Exposure from previously flooded land
	Exposure from beta-emitters on river-bank sediment
Inhalation	Resuspended sediments/conditioned soil

Table 16 Generalised inhalation rates (l y^{-1})

Age Group	Inhalation rate
1 y old	$1.9\ 10^{6}$
10 y old	$5.5\ 10^{6}$
Adult	$7.3\ 10^{6}$

Data source: (ICRP, 1994)

Table 17 Indoor occupancy rate (% of day)

Age group	% of day spent indoors
1 y old	95
10 y old	90
Housewife	95
Employed person	90
Outdoor worker	70

Data source: (Roy and Courtay, 1991)

Table 18 Average Per Capita consumption rates for EU countries for 1996 from Food and Agricultural Organisation database (kg y^{-1})

Food	Austria	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Nether-lands	Portugal	Spain	Sweden	UK
Cereals	50	54	47	57	50	75	68	80	39	59	51	50	50
Root Vegetables	32	38	37	37	44	35	69	20	47	74	48	34	60
Fruit	49	42	34	43	57	66	43	62	67	55	49	44	40
Green Vegetables	18	16	12	22	15	32	14	25	16	27	22	12	15
Eggs	11	11	8	12	10	8	7	10	12	7	11	10	8
Milk	106	95	140	104	97	97	93	104	138	76	68	147	95
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	0.7	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	2	7	3	3	15	3	2	4	3	1.3	2

Data Source: ((FAOSTAT, 2000), 1996 Food Balance Sheets)

Table 19 High ingestion rates of terrestrial foods for EU member states (kg y^{-1})

Food	Austria	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Nether-lands	Portugal	Spain	Sweden	UK
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
Milk	268	241	354	264	246	245	236	264	348	192	171	372	240

Data Source: ((FAOSTAT, 2000), 1996 Food Balance Sheets)

Table 20 Factors to scale adult consumption rates to other age groups

Scaling factors (High rates)

	1 y	10 y
Cow's meat	0.2	0.7
Cow's milk	1.3	1.0
Cow's milk products	0.8	0.8
Cow's liver	0.3	0.5
Sheep meat	0.1	0.4
Sheep liver	0.3	0.5
Green Veg	0.2	0.4
Root Veg	0.3	0.7
Grain	0.3	0.8
Fruit	0.5	0.7
Pork	0.1	0.6
Poultry	0.2	0.5
Eggs	0.6	0.8
Freshwater fish	0.1	0.3
Marine Fish	0.1	0.2
Marine Crustacea	0.0	0.3
Marine Mollusca	0.0	0.3

Scaling factors (Average rates)

	1 y	10 y
Cow's meat	0.2	0.7
Cow's milk	1.3	1.2
Cow's milk products	0.8	0.8
Cow's liver	0.2	0.5
Sheep meat	0.2	0.5
Sheep liver	0.2	0.5
Green Veg	0.2	0.3
Root Veg	0.3	0.8
Grain	0.3	0.9
Fruit	0.5	1.0
Pork	0.1	0.5
Poultry	0.1	0.5
Eggs	0.6	0.8
Freshwater fish	0.3	0.7
Marine Fish	0.3	0.7
Marine Crustacea	0.0	0.6
Marine Mollusca	0.0	0.6

Data source: (Byrom et al. 1995) and (FAO, 1996 Food Balance Sheets) – see Appendix D for details

Table 21 Average and high ingestion rates (kg y^{-1}) of marine foods for EU member states

Country	Fish		Crustaceans		Molluscs	
	Average	High	Average	High	Average	High
Belgium	7	68	1.4	28	7	23
Denmark	38	349	5	92	1.0	3
Finland	20	185	0.0	0.2	0.0	0.1
France	7	67	3	61	9	31
Germany	5	47	0.5	10	0.4	1.5
Greece	3	80	0.3	18	0.6	5
Ireland	21	191	0.8	15	0.7	3
Italy	3	42	0.7	32	2	21
Netherlands	11	99	3	57	5	18
Portugal	26	239	2	39	4	14
Spain	12	125	1.2	35	2	12
Sweden	16	150	1.1	23	1.2	4
United Kingdom	10	91	1.0	20	1.0	3

Data Source: (ICES,). High rates of ingestion derived by scaling from average using (Nord-Cotentin Radioecology Group, 2000) – see Appendix D for details

Table 22 Occupancy rates on intertidal areas and river banks (h y^{-1})

Age group	Occupancy rate (h y^{-1})	
	Intertidal area	River bank
1 y old	30	30
10 y old	300	500
Adult	2000	500

Data sources: (Doddington et al. 1990) and (Research Surveys of Great Britain Ltd., 1991)

Table 23 Average and high ingestion rates (kg y^{-1}) of freshwater fish for EU member states

Country	Average	High
Austria	2.9	29
Denmark	4.1	41
Finland	7.6	76
France	3.3	33
Germany	2.2	22
Greece	3.1	31
Ireland	3.3	33
Italy	1.8	18
Netherlands	2.5	25
Portugal	0.4	4
Spain	1.8	18
Sweden	3.9	39
UK	2.3	23

Data Source: (FAO, 1996 Food Balance Sheets)

Table 24 Doses to infant from intakes of milk as fraction of adult

Nuclide	Ratio
HTO	1.1
^{14}C	0.0
^{90}Sr	0.2
^{131}I	2.5
^{137}Cs	0.4
^{239}Pu	0.0

Data Source: (Phipps A, 2001)

Table 25 Ratio of fetus to adult dose coefficient

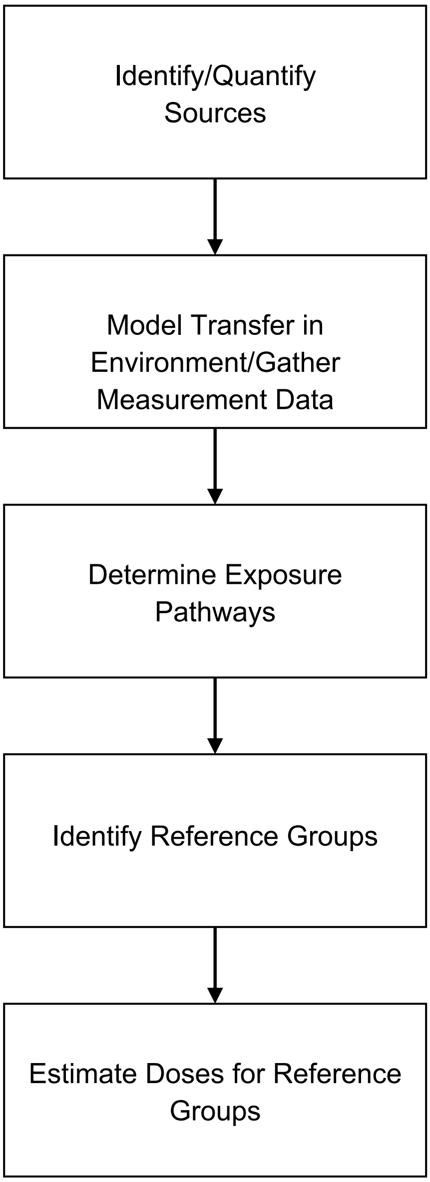
Nuclide	Inhalation		Ingestion
	Type	Ratio	Ratio
HTO	V	1.7	1.7
^{14}C	V	0.62	1.4
^{90}Sr	M	0.24	1.5
^{131}I	F	1.1	1.1
^{137}Cs	F	0.43	0.44
^{239}Pu	M	0.024	0.038

Data Source: (ICRP, 2001)

Table 26 Ratio of combined measurements and modelled results to modelled results alone

Pathway	Ratio
Consumption of aquatic foods	0.65
Consumption of terrestrial foods	7.3
Inhalation	4.0
External irradiation over sediment	1.2

Figure 1 **Stages of an assessment**



APPENDIX A Illustrative source terms

Information on the types and operational status of nuclear power stations and installations which are part of the nuclear fuel cycle can be obtained from two databases maintained by the IAEA. The first one, Power Reactor Information System (PRIS) (IAEA, 2001a) gives general and design information in addition to the operating experience of the power plants. The second database, Nuclear Fuel Cycle Information System (NFCIS) (IAEA, 2001b) is a directory of civilian fuel cycle facilities. However no data on discharges from the facilities are included in either database.

The information on discharge rates for the generic reactor types given below is derived from a discharge database compiled for the EU based on the years 1995-1999 (EC, 2000). For the sake of brevity only radionuclides which are discharged in significant quantities (greater than 10% of total discharges) or are significant in terms of doses (greater than 5% of total dose as estimated by (Smith et al. 2002) for more than one site) have been included. These criteria are only for use here and are not recommended for selecting radionuclides when carrying out an assessment. Small amounts of alpha-emitting radionuclides are discharged from most sites but due to the low levels are neither significant in terms of contribution to dose or quantity discharged. Therefore no discharge rates for alpha-emitting radionuclides for reactors have been given.

It must be stressed that these discharges are generic and individual installations may discharge different radionuclides or have higher/lower discharge rates. For example for gaseous discharges of BWRs given in section A2.1 the beta discharges are assumed to consist of ^{60}Co and ^{65}Zn. However Ringhals 1, Sweden, discharges relatively large amounts of ^{88}Rb. However these discharges are not typical of the other reactors and were therefore not included.

There are large differences in the minimum and maximum values given in the Tables for the generic reactor types. One of the reasons is the variation in energy output from different reactors even if they are of same type. If discharge rates normalised to the energy output were presented, as done in (UNSCEAR, 2000), the range in values would be reduced as one source of variation would have been removed.

A1 ADVANCED GAS COOLED REACTORS (AGR)

The average energy output for AGRs for the years 1995-1999 was 580 GWh y^{-1}. This is based on information in the EU discharge database.

A1.1 Gaseous discharges

Table A1 Atmospheric discharge rates for AGRs

	Discharge rate (GBq y^{-1})		
Nuclide	Minimum	Average	Maximum
^{3}H	$6\ 10^{2}$	$2\ 10^{3}$	$5\ 10^{3}$
^{14}C	$2\ 10^{2}$	$1\ 10^{3}$	$2\ 10^{3}$
^{35}S	5	$5\ 10^{1}$	$4\ 10^{2}$
^{41}Ar	$2\ 10^{2}$	$2\ 10^{4}$	$7\ 10^{4}$
^{131}I	$3\ 10^{-3}$	$2\ 10^{-1}$	1
Beta	$4\ 10^{-3}$	2	$7\ 10^{1}$

Table A2 Likely percentage breakdown of reported beta

Nuclide	Likely percentage contribution
^{65}Zn	100

A1.2 Liquid discharges

Table A3 Liquid discharge rates for AGRs

	Discharge rate (GBq y^{-1})		
Nuclide	Minimum	Average	Maximum
^{3}H	$2\ 10^{4}$	$3\ 10^{5}$	$5\ 10^{5}$
^{35}S	5	$6\ 10^{2}$	$3\ 10^{3}$
Beta	1	$1\ 10^{1}$	$3\ 10^{1}$

Table A4 Likely percentage breakdown of reported beta

Nuclide	Likely percentage contribution
^{60}Co	50
^{134}Cs	20
^{137}Cs	30

A2 BOILING WATER REACTORS (BWR)

The average energy output for BWRs for the years 1995-1999 was 840 GWh y^{-1}.

A2.1 Gaseous discharges

Table A5 Atmospheric discharge rates for BWRs

	Discharge rate (GBq y^{-1})		
Nuclide	Minimum	Average	Maximum
^{3}H	$1\ 10^{1}$	$4\ 10^{2}$	$2\ 10^{3}$
^{14}C	$1\ 10^{1}$	$5\ 10^{2}$	$2\ 10^{3}$
^{131}I	$1\ 10^{-4}$	$5\ 10^{-1}$	$1\ 10^{1}$
Noble gases	1	$5\ 10^{5}$	$2\ 10^{7}$
Beta	$6\ 10^{-5}$	4	$8\ 10^{1}$

Table A6 Likely percentage breakdown of reported noble gases

Nuclide	Likely percentage contribution
^{85}Kr	20
^{87}Kr	5
^{88}Kr	10
^{89}Kr	5
^{133}Xe	20
^{135}Xe	30
^{138}Xe	10

Table A7 Likely percentage breakdown of reported beta

Nuclide	Likely percentage contribution
^{60}Co	85
^{65}Zn	15

A2.2 Liquid discharges

Table A8 Liquid discharge rates for BWRs

	Discharge rate (GBq y^{-1})		
Nuclide	Minimum	Average	Maximum
^{3}H	$2\ 10^{1}$	$4\ 10^{3}$	$1\ 10^{4}$
Beta	$2\ 10^{-3}$	$2\ 10^{1}$	$2\ 10^{2}$

Table A9 Likely percentage breakdown of reported beta

Nuclide	Likely percentage contribution
^{51}Cr	15
^{55}Fe	20
^{58}Co	5
^{60}Co	40
^{65}Zn	5
^{134}Cs	5
^{137}Cs	10

A3 PRESSURIZED WATER REACTORS (PWR)

The average energy output for PWRs for the years 1995-1999 was 1030 GWh y^{-1}.

A3.1 Gaseous discharges

Table A10 Atmospheric discharge rates for PWRs

	Discharge rate (GBq y^{-1})		
Nuclide	Minimum	Average	Maximum
^{3}H	$3\ 10^{1}$	$1\ 10^{3}$	$8\ 10^{3}$
^{14}C	$1\ 10^{-2}$	$2\ 10^{2}$	$7\ 10^{2}$
^{131}I	$6\ 10^{-6}$	$4\ 10^{-2}$	$8\ 10^{-1}$
Noble gases	$1\ 10^{1}$	$1\ 10^{4}$	$6\ 10^{4}$
Beta	$7\ 10^{-6}$	$1\ 10^{-1}$	4

Table A11 Likely percentage breakdown of reported noble gases

Nuclide	Likely percentage contribution
^{41}Ar	20
^{133}Xe	70
^{135}Xe	10

Table A12 Likely percentage breakdown of reported beta

Nuclide	Likely percentage contribution
^{60}Co	45
^{90}Sr	20
^{110m}Ag	10
^{124}Sb	25

A3.2 Liquid discharges

Table A13 Liquid discharge rates for PWRs

	Discharge rate (GBq y^{-1})		
Nuclide	Minimum	Average	Maximum
^{3}H	$2\ 10^{2}$	$3\ 10^{4}$	$9\ 10^{4}$
^{131}I	$2\ 10^{-5}$	$5\ 10^{-2}$	1
Beta	$9\ 10^{-6}$	$8\ 10^{1}$	$2\ 10^{4}$

Table A14 Likely percentage breakdown of reported beta

Nuclide	Likely percentage contribution
^{58}Co	25
^{60}Co	25
^{63}Ni	25
^{110m}Ag	7.5
^{134}Cs	7.5
^{137}Cs	10

A4 GAS COOLED REACTORS (GCR)

The average energy output for GCRs for the years 1995-1999 was 160 GWh y^{-1}.

A4.1 Gaseous discharges

Table A15 Atmospheric discharge rates for GCRs

	Discharge rate (GBq y^{-1})		
Nuclide	Minimum	Average	Maximum
^{3}H	$5\ 10^{2}$	$2\ 10^{5}$	$2\ 10^{6}$
^{14}C	$1\ 10^{2}$	$2\ 10^{3}$	$4\ 10^{3}$
^{35}S	$1\ 10^{1}$	1 102	$3\ 10^{2}$
^{41}Ar	$2\ 10^{4}$	$1\ 10^{6}$	$3\ 10^{6}$
Beta	$2\ 10^{-2}$	$2\ 10^{-1}$	1

Table A16 Likely percentage breakdown of reported beta

Nuclide	Likely percentage contribution
^{60}Co	25
^{137}Cs	75

A4.2 Liquid discharges

Table A17 Liquid discharge rates for GCRs

	Discharge rate (GBq y^{-1})		
Nuclide	Minimum	Average	Maximum
^{3}H	$1\ 10^{2}$	$2\ 10^{3}$	$1\ 10^{4}$
^{35}S	7	$1\ 10^{1}$	$2\ 10^{1}$
Beta	$4\ 10^{1}$	$5\ 10^{2}$	$1\ 10^{3}$

Table A18 Likely percentage breakdown of reported beta

Nuclide	Likely percentage contribution
^{90}Sr	30
^{134}Cs	5
^{137}Cs	65

A5 NUCLEAR REPROCESSING AND WASTE TREATMENT PLANTS

In the European Union there are currently two reprocessing and waste treatment plants in operation, Sellafield and Cap de la Hague. The types of fuel reprocessed and the treatment of waste varies between the two plants. In addition both plants have additional operations on the site for example the Sellafield site has 4 gas cooled reactors which discharge liquid waste to sea via the same pipeline as the reprocessing plant. This means that the discharges from each site are too specific to enable an generic set of discharges to be estimated. Therefore recent discharges from Sellafield and Cap de la Hague are given separately.

A5.1 Cap de la Hague

Gaseous discharges

The discharges given below are those reported for 1996 by the (Nord-Cotentin Radioecology Group, 2000).

Table A19 Atmospheric discharges from Cap de la Hague 1996

Radionuclide	Discharges (TBq y^{-1})
^{3}H	$7.5\ 10^{1}$
^{14}C	$1.9\ 10^{1}$
^{60}Co	$1.6\ 10^{-7}$
^{85}Kr	$2.9\ 10^{5}$
^{106}Ru	$1.3\ 10^{-5}$
^{125}Sb	$4.4\ 10^{-4}$
^{129}I	$3.8\ 10^{-2}$
^{131}I	$1.5\ 10^{-3}$
^{133}I	$4.1\ 10^{-4}$
^{134}Cs	$3.0\ 10^{-8}$
^{137}Cs	$3.5\ 10^{-7}$
^{238}Pu	$1.6\ 10^{-8}$
$^{239/240}Pu$	$8.1\ 10^{-9}$
^{241}Pu	$8.6\ 10^{-7}$
^{241}Am	$1.6\ 10^{-8}$
^{244}Cm	$1.3\ 10^{-8}$

Liquid discharges

Table A20 Liquid discharges from Cap de la Hague 1996

Radionuclide	Discharges (TBq y^{-1})
^{14}C	$1.9\ 10^{1}$
^{55}Fe	$4.7\ 10^{-2}$
^{60}Co	$1.6\ 10^{-7}$
^{65}Zn	$2.7\ 10^{-3}$
^{90}Sr	$1.1\ 10^{1}$
^{106}Ru	$1.7\ 10^{1}$
^{125}Sb	2.0
^{134}Cs	$1.7\ 10^{-1}$
^{137}Cs	$2.4\ 10^{0}$
^{238}Pu	$1.1\ 10^{-2}$
$^{239/240}Pu$	$4.6\ 10^{-3}$
^{241}Pu	$4.9\ 10^{-1}$
^{241}Am	$4.6\ 10^{-3}$
^{244}Cm	$1.9\ 10^{-3}$

A5.2 Sellafield

Gaseous discharges

Data was taken from (EC, 2000) for 1998.

Table A21 Atmospheric discharges from Sellafield 1998

Radionuclide	Discharge rate ($GBq\ y^{-1}$)
^{3}H	$2.50\ 10^{5}$
^{14}C	$2.92\ 10^{3}$
^{35}S	$1.50\ 10^{2}$
^{41}Ar	$2.53\ 10^{6}$
^{60}Co	$5.30\ 10^{-2}$
^{85}Kr	$9.90\ 10^{7}$
^{90}Sr	$6.00\ 10^{-2}$
^{106}Ru	1.10
^{125}Sb	$1.90\ 10^{-1}$
^{129}I	$2.68\ 10^{1}$
^{131}I	3.17
^{137}Cs	$4.41\ 10^{-1}$
Pu alpha	$3.40\ 10^{-2}$
^{241}Pu	$2.67\ 10^{-1}$
^{241}Am + ^{242}Cm	$4.98\ 10^{-2}$

Liquid discharges

Data was taken from (BNFL, 1999) for 1998.

Table A22 Liquid discharges from Sellafield 1998

Radionuclides	Discharge rate (GBq y^{-1})
^{3}H	$3.01\ 10^{6}$
^{14}C	$1.06\ 10^{4}$
^{35}S	$8.80\ 10^{2}$
^{54}Mn	$5.00\ 10^{1}$
^{55}Fe	$4.00\ 10^{1}$
^{60}Co	$4.29\ 10^{2}$
^{63}Ni	$3.40\ 10^{2}$
^{65}Zn	$1.20\ 10^{2}$
Sr-89	$2.90\ 10^{2}$
^{90}Sr	$1.60\ 10^{4}$
^{95}Z + ^{95}Nb	$1.15\ 10^{3}$
^{99}Tc	$1.55\ 10^{5}$
^{103}Ru	$2.00\ 10^{2}$
^{106}Ru	$9.01\ 10^{3}$
^{110m}Ag	$1.30\ 10^{2}$
^{125}Sb	$6.70\ 10^{3}$
^{129}I	$4.12\ 10^{2}$
^{134}Cs	$2.71\ 10^{2}$
^{137}Cs	$1.03\ 10^{4}$
^{144}Ce	$7.79\ 10^{2}$
^{147}Pm	$4.20\ 10^{2}$
^{152}Eu	$1.40\ 10^{2}$
^{154}Eu	$8.00\ 10^{1}$
^{155}Eu	$5.00\ 10^{1}$
^{237}Np	$4.00\ 10^{1}$
Pu-alpha	$2.09\ 10^{2}$
^{241}Pu	$4.35\ 10^{3}$
^{241}Am	$7.36\ 10^{1}$
^{242}Cm	9.00
$^{243+244}Cm$	7.00

A6 GENERIC DISCHARGES FOR CONVERSION, ENRICHMENT AND FUEL FABRICATION PLANTS

The normalised discharges from fuel conversion, enrichment and fabrication facilities given below were taken from (UNSCEAR, 1993). Uranium enrichment of the fuel is required for PWRs, BWRs and AGRs but not GCRs. For the enrichment process the uranium ore concentrate produced at the mining and milling installations is further processed, purified and converted to uranium hexafluoride. It is then enriched in the isotope ^{235}U, before being converted into uranium oxide or metal and fabricated into fuel elements.

Table A23 Normalised annual atmospheric discharges (MBq GW y^{-1}) from conversion, enrichment and fuel fabrication plants

Radionuclide	Normalised annual atmospheric discharges (MBq GW y^{-1})		
	Conversion	Enrichment	Fabrication
^{228}Th	0.022		
^{230}Th	0.4		
^{232}Th	0.022		
^{234}Th	130	1.3	0.34
^{234}U	130	1.3	0.34
^{235}U	6.1	0.06	0.0014
^{238}U	130	1.3	0.34

Table A24 Normalised annual liquid discharges (MBq GW y^{-1}) from conversion, enrichment and fuel fabrication plants

Radionuclide	Normalised annual liquid discharges (MBq GW y^{-1})		
	Conversion	Enrichment	Fabrication
^{226}Ra	0.11		
^{234}Th			170
^{234}U	94	10	170
^{235}U	4.3	0.5	1.4
^{238}U	94	10	170

The OECD have also recently published a report (OECD Nuclear Energy Agency, 2000), which includes details on discharges from conversion, enrichment and fabrication plants.

A7 REFERENCES

BNFL (1999) Annual Report on Discharges and Monitoring of the Environment, 1998. Risley British Nuclear Fuels plc.

EC (2000) EC Discharge Database *bilcom97.mdb* including data from: Schnepf R et al. Radioactive effluents from nuclear power stations and nuclear fuel reprocessing plants in the European Community 1987-1991, Radiation Protection 84, European Commission EUR 16901 EN (1996). Willemenot JM et al. Radioactive effluents from nuclear power stations and nuclear fuel reprocessing plants in the European Community 1991-1995, Radiation Protection 104, European Commission (1999). EC.

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UNSCEAR (1993) Sources and Effects of Ionizing Radiation, 1993, Report to the General Assembly with annexes. New York United Nations.

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APPENDIX B Illustrative calculations to determine the important exposure pathways and age groups for releases to atmosphere

B1 METHODOLOGY FOR ASSESSMENT

Discharges to the atmosphere can lead to exposure to the public by a variety of pathways. A series of illustrative calculations to investigate the relative importance of different exposure pathways following particular discharges to the atmosphere was considered, and the results are presented here.

A general methodology was established to assess radiation doses received by a reference group for discharges to atmosphere. Five release scenarios were considered: reprocessing plants (Sellafield and Cap de la Hague), a boiling water reactor, a pressurised water reactor and a gas cooled reactor release scenario. An advanced gas cooled reactor was also considered, but as the results did not significantly differ from the other reactor types, they are not given here.

Discharge data for different nuclear installations were used, taken from the EU discharge database (see Appendix A) and generalised so as to be representative of a generic type of nuclear installation.

A list of potential exposure pathways considered in this study are listed in Table B 1. In most situations, the radionuclide activity concentrations in environmental media are too low to be measured and used for calculations of public exposure. It is for this reason that mathematical models are used to simulate the transfer of the radionuclides in the environment. The doses presented here have been calculated using the radiological impact assessment software PC CREAM (Mayall et al. 1997) which was developed for the European Commission and is a personal computer (PC) implementation of CREAM (Consequences of Releases to the Environment: Assessment Methodology) (Simmonds et al. 1995a).

Dispersion of the radionuclides as they are blown downwind was estimated using a Gaussian Plume model (Simmonds et al. 1995a). All discharges were assumed to have been emitted from a 30 m stack in uniform windrose meteorological conditions, using meteorological conditions suggested in CREAM (Simmonds et al. 1995a) for use when measured values are not available. Both wet and dry deposition to the ground was considered. Dry deposition was estimated using a source depletion model and a deposition velocity of 10^{-3} m s^{-1}, a value appropriate for 1 μm particles (Mayall et al. 1997). Wet deposition was estimated using a washout coefficient of 10^{-4} s^{-1}. Isotopes of iodine were assumed to have a dry deposition velocity (Simmonds et al. 1995a); (Mayall et al. 1997) of 10^{-2} m s^{-1}. Noble gases, tritium and ^{14}C are assumed not to deposit under either wet or dry conditions. Tritium and ^{14}C are assumed to reach equilibrium rapidly with the ground and its vegetative cover, so the net deposition of these radionuclides is taken to be zero.

External gamma exposure from the radionuclides in the plume was estimated using a finite cloud model (Simmonds et al. 1995a), (Mayall et al. 1997) and external beta exposure was estimated using data (Simmonds et al. 1995a). The transfer of deposited activity into local foods was calculated using the FARMLAND model, which is part of the suite of PC CREAM models and is described in (Brown and Simmonds, 1995). The activity concentrations in air due to wind driven resuspension and the external dose due to deposited activity were estimated using models described in (Simmonds et al. 1995a)

A number of exposure pathways listed in Table B 1 are not included in PC CREAM, and doses were calculated for these pathways using activity concentrations predicted by

PC CREAM. These pathways were the inadvertent ingestion of house dust, the inadvertent ingestion of soil and the consumption of pork, chicken, eggs, goat's milk, and sheep's milk. It was assumed that the diet of pigs and chickens consisted solely of cereals (MAFF, 1990) grown 1 km from the discharge point. The concentration of radionuclides in cereals was obtained from PC-CREAM. The equilibrium transfer factors for pork, chickens and eggs were taken from (Ng et al. 1982), while those for sheep and goat's milk were taken from (IAEA, 1994). Models for the transfer of radionuclides from atmosphere into drinking water supplies were taken from (Dionan and Linsley, 1983), and the activity concentrations in the river or reservoir predicted by these models were used to calculate the activity concentration of fish from those water bodies.

Table B 1 Exposure pathways resulting from a release to the atmosphere

Inhalation	
	Inhalation of radionuclides in the plume
	Inhalation of resuspended activity
	Inhalation of dust resuspended into the indoor environment
External Irradiation	
	External gamma from airborne radionuclides
	External beta from airborne radionuclide.
	External gamma from deposited radionuclides
	External beta from deposited radionuclides.
Inadvertent Ingestion	
	Inadvertent ingestion of house dust
	Inadvertent ingestion of soil
Ingestion	
	Cow meat
	Cow's milk
	Cow's milk products
	Cow liver
	Sheep meat
	Sheep liver
	Green vegetables
	Root vegetables
	Grain
	Fruit
	Pork, chicken and eggs
	Goat milk and sheep milk

Dose coefficients were taken from the Euratom Directive (CEC, 1996) apart from those for ^{3}H and ^{14}C (assumed to be in vapour form), which were taken from ((EC, 1998)) from a Communication regarding the EURATOM directive for the basic safety standards.

B2 DOSE CALCULATIONS

For each release scenario doses were calculated to the six different age groups listed in Table 1 of the main text.

For each age group higher than average consumption rates for the UK have been used as representative of the reference group. The consumption rates for the different age groups were based on (Byrom et al. 1995). In this report no data were presented for 5 y olds. Therefore these were estimated by scaling the values for 10 y old children to the energy requirements of 5 y olds. It was assumed that the source of all terrestrial foods was 1 km from the discharge point, and that all foods were produced locally.

For some regions of the EU sheep and goats may be the main milk producing herds rather than cows. Therefore dose calculations were done on the basis of the ingestion rate for goat’s milk or sheep’s milk being assumed to be equal to that for cow’s milk in order to quantify any differences in dose.

It was assumed that all individuals live 1 km from the discharge point. The percentage of time spent outside is given in Table 17 of the main text (the adult was assumed to be an outdoor worker). It was assumed that the individual resided at the chosen location throughout the year (8760 hours).

B3 PATHWAYS NOT INCLUDED IN DOSE CALCULATIONS

A number of potential pathways due to a release of radionuclides into the environment were not included in the assessments carried out for this report. These include ingestion of free foods and deliberate ingestion of soil (pica). Free foods include berries, mushrooms, crab apples, rabbits, pheasants etc. When considering the ingestion of free foods, it is essential to have information on local habit data. Regional or national habit data can not take account of the free food available in an area and large variability is observed between regions (Green et al. 1999). In addition, soil to plant transfer factors for many wild plants are difficult to obtain. For example many species of mushroom grow in some areas, and since radionuclide uptake is species specific (Barnett et al. 1996) it would be very difficult to assess accurately the dose due to ingestion of wild mushrooms. It is, therefore, not possible to consider the ingestion of free foods in a generic way.

The deliberate ingestion of soil by children or adults was not considered in this assessment because this pathway is a recognised medical condition, known as *pica*, which tends to occur for a relatively short time. Inadvertent ingestion of soil was however included.

B3.1 Inadvertent Ingestion

Soil

Inadvertent ingestion rates appropriate for soil are based on a study by (van Wijnen et al. 1990) on the soil ingestion habits of children aged between 6 months and 5 years. This work provides soil ingestion rates under normal and extreme conditions (children staying in a campsite). These data are used as the basis for the average and high daily ingestion rates for 1 y old children given in Table B 2. The corresponding values for older ages are estimated assuming an exponential decrease in soil ingestion with each year of life up to the age of 18 (Sedman and Mahmood, 1994). It is assumed there is no inadvertent ingestion of soil for 3 month old infants.

House Dust

An intake rate of 100 mg d^{-1} of house dust is generally considered appropriate for infants and 5 y olds, and has been used in previous assessments (Simmonds et al. 1995b). 10 and 15 y old children and adults are assumed to have intakes of a factor of 10 lower. It is assumed there is no inadvertent ingestion of house dust for 3 month old children.

Table B 2 Inadvertent ingestion rates of soil

	Ingestion rate (mg d^{-1})	
Age Group	Average	High
3 Month old	-	-
1 y old	100	300
5 y old	50	200
10 y old	30	100
15 y old	20	50
Adult	10	30

B4 RESULTS FOR EACH RELEASE SCENARIO

B4.1 Boiling water reactor

The estimated doses to individuals for discharges (given in A2.1) are given in

Table B 3.

Table B 3 Estimated doses calculated for a boiling water reactor discharge scenario

Age group	Individual Dose (μSv y^{-1})
3 Month old	1.6
1 y old	2.7
5 y old	2.4
10 y old	2.0
15 y old	1.7
Adult	2.0

The most important radionuclide was found to be ^{14}C (53% to 74%) for all age groups. The most important exposure pathway was estimated to be ingestion of milk (3 months, 1 y old and 5 y old) and ingestion of grain (10 y old, 15 y old and adults). For these illustrative calculations it has been assumed that all grain is locally produced. This is not a realistic assumption as most grain produced for human consumption is normally mixed with other supplies obtained over a wide area before processing and distribution.

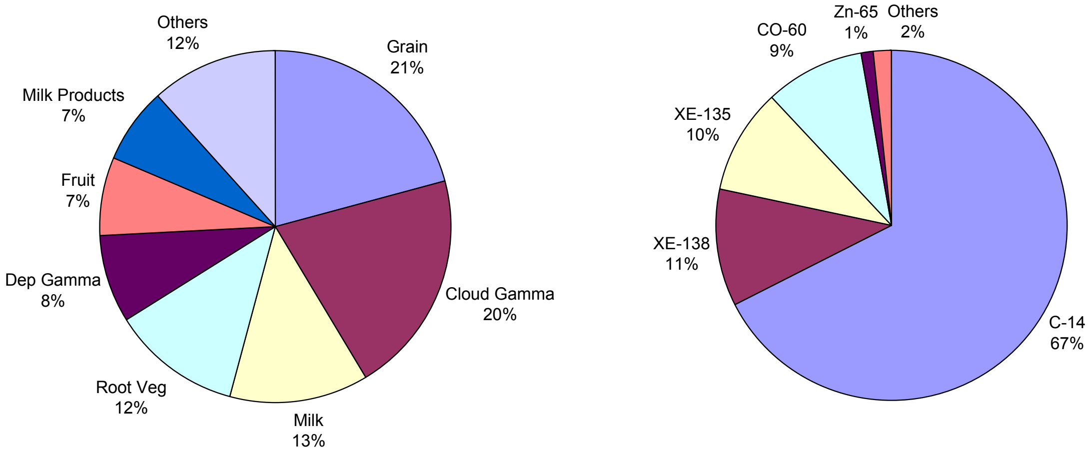


Figure B 1 Breakdown of individual dose to an adult due to atmospheric discharges from a typical boiling water reactor by pathway and radionuclide. (Only pathways with a contribution greater than 5% of total dose and radionuclides with a contribution greater than 1% are plotted)

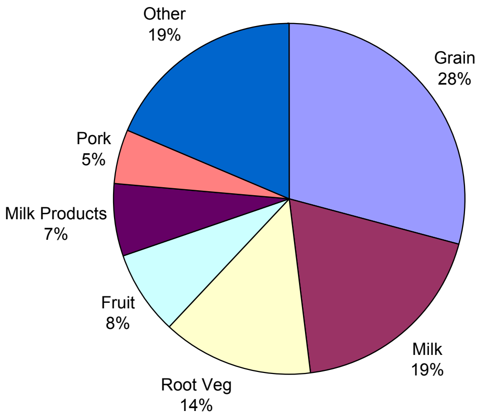
B4.2 Pressurised Water Reactor

The estimated doses to individuals for discharges (given in A3.1) are given in Table B 4.

Table B 4 Estimated doses calculated for a pressurised water reactor discharge scenario

Age group	Individual Dose ($\mu Sv\ y^{-1}$)
3 Month	0.4
1 y	0.9
5 y	0.8
10 y	0.9
15 y	0.9
Adult	0.7

The most important radionuclide was found to be ^{14}C with a percentage contribution greater than 84% for all age groups. The most important exposure pathway was estimated to be milk for 3 month old and 1 y old children and grain for all other age groups.



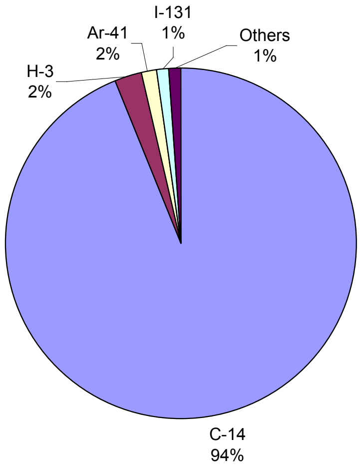


Figure B 2 Breakdown of individual dose to an adult due to atmospheric discharges from a typical pressurised water reactor by pathway and radionuclide. (Only pathways with a contribution greater than 5% of total dose and radionuclides with a contribution greater than 1% are plotted)

B4.3 Gas Cooled Reactor

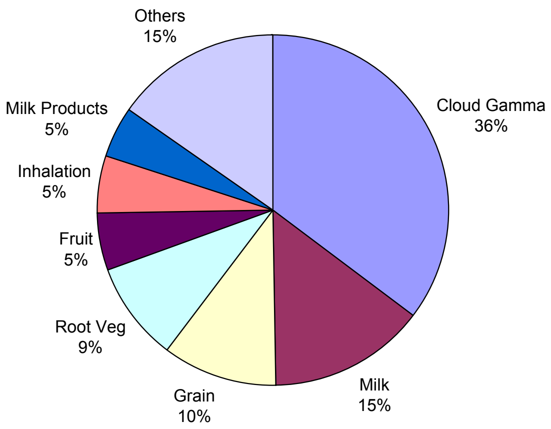
The estimated doses to individuals for discharges (given in A4.1) are given in Table B 5.

Table B 5 Estimated doses calculated for a GCR reactor discharge scenario

Age group	Individual Dose ($\mu Sv\ y^{-1}$)
3 Month	16.7
1 y	22.0
5 y	17.0
10 y	15.0
15 y	13.1
Adult	15.6

In this case three radionuclides make a significant contribution to dose, ^{3}H, ^{14}C and ^{41}Ar. ^{3}H is most important radionuclide for 3 months old and ^{14}C for all other ages.

The most important exposure pathway was found to be milk for 3 months old, 1 y old and 5 y old and external radiation from airborne radionuclides for all other age groups.



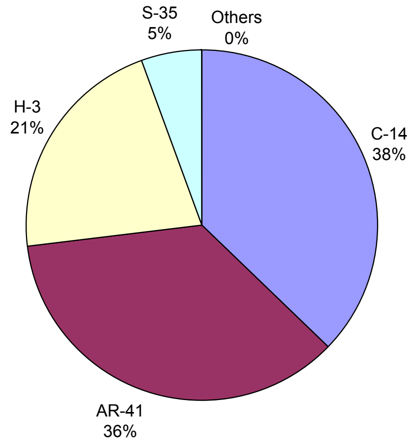
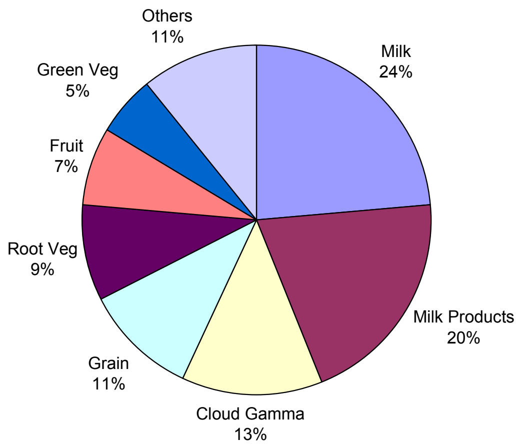


Figure B 3 Breakdown of individual dose to an adult due to atmospheric discharges from a typical GCR reactor by pathway and radionuclide. (Only pathways with a contribution greater than 5% of total dose and radionuclides with a contribution greater than 1% are plotted)

B4.4 Reprocessing Plant

Sellafield

The most important radionuclide for all age groups was estimated to be ^{129}I, with a minimum percentage contribution to dose of 65% for a 3 month old and a maximum contribution of 79% for a 10 y old. Other radionuclides with percentage contributions greater than 5% were ^{3}H, ^{14}C, ^{35}S, ^{41}Ar and ^{85}Kr. The most important exposure pathway was found to be milk (3 months old, 1 y old, 5 y old and 15 y old) or milk products (10 y old and adult)



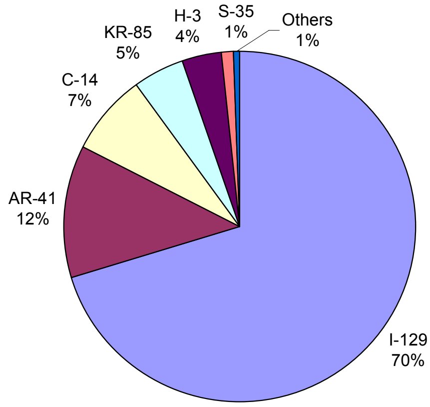


Figure B 4 Breakdown of individual dose to an adult due to atmospheric discharges from Sellafield by pathway and radionuclide. (Only pathways with a contribution greater than 5% of total dose and radionuclides with a contribution greater than 1% are plotted)

Cap de la Hague

The most important radionuclide for all age groups was estimated to be ^{129}I, with a minimum percentage contribution to dose of 61% for a 3 months old and a maximum contribution of 76% for a 10 y old. Other radionuclides with percentage contributions greater than 5% were ^{14}C and ^{85}Kr. The most important exposure pathway was found to be milk for all age groups, with milk products also important for all age groups except for 3 month olds.

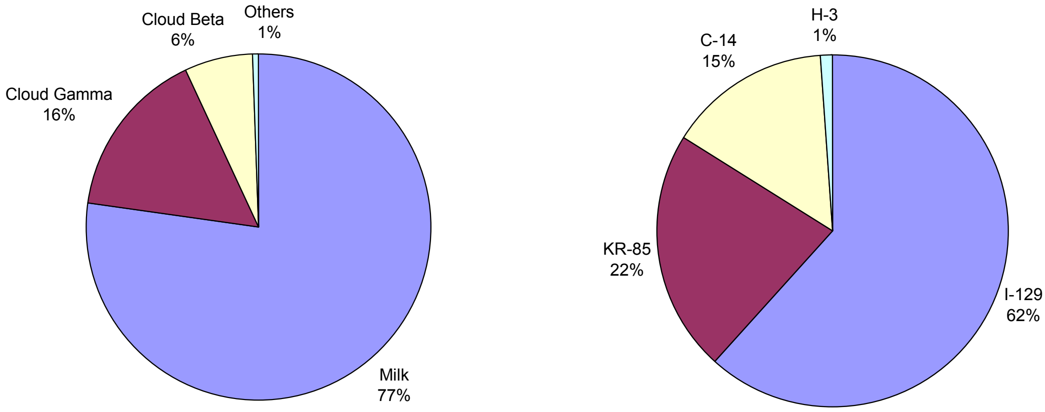


Figure B 5 Breakdown of individual dose to an adult due to atmospheric discharges from Cap de la Hague by pathway and radionuclide. (Only pathways with a contribution greater than 5% of total dose and radionuclides with a contribution greater than 1% are plotted)

B5 GROUPED RESULTS

From the assessments carried out for the four discharge scenarios detailed above, it was possible to compile tables listing the most important exposure pathways by radionuclide for each age group. In all cases, the dominant pathways for 5 y old children were the same as for 10 y olds. Similarly, for 15 y olds the dominant pathways were identical to those for adults.

Table B 6 Principal exposure pathways following releases to the environment for a 3 month old child

Nuclide	Dominant Pathway
^{3}H	Ingestion of foodstuffs (milk), Inhalation of radionuclides in the plume
^{14}C	Ingestion of foodstuffs (milk), Inhalation of radionuclides in the plume
^{35}S	Ingestion of foodstuffs (milk), Inhalation of radionuclides in the plume
^{41}Ar	External gamma from airborne radionuclides
^{51}Cr	Ingestion of foodstuffs (milk), external gamma from deposited radionuclides
^{54}Mn	Ingestion of foodstuffs (milk), external gamma from deposited radionuclides
^{58}Co	External gamma from deposited radionuclides, Ingestion of foodstuffs (milk).
^{60}Co	External gamma from deposited radionuclides, Ingestion of foodstuffs (milk)
^{85}Kr	External beta and gamma from airborne radionuclides
^{89}Sr	Ingestion of foodstuffs (milk), Inhalation of radionuclides in the plume
^{90}Sr	Ingestion of foodstuffs (milk), Inhalation of radionuclides in the plume
^{95}Nb	External gamma from deposited radionuclides
^{106}Ru	Inhalation of radionuclides in the plume, External gamma from deposited radionuclides
^{124}Sb	External gamma from deposited radionuclides, Ingestion of foodstuffs (milk)
^{125}Sb	External gamma from deposited radionuclides, Ingestion of foodstuffs (milk)
^{129}I	Ingestion of foodstuffs (milk), External gamma from deposited radionuclides
^{131}I	Ingestion of foodstuffs (milk), External gamma from deposited radionuclides
^{133}I	Ingestion of foodstuffs (milk), External beta from deposited radionuclides
^{133}Xe	External gamma and beta from airborne radionuclides
^{135}Xe	External gamma and beta from airborne radionuclides
^{137}Cs	Ingestion of foodstuffs (milk products), External gamma from deposited radionuclides
^{141}Ce	External gamma from deposited radionuclides
^{239}Pu	Inhalation of radionuclides in the plume, Inhalation of resuspended house dust
^{241}Pu	Inhalation of radionuclides in the plume, Inhalation of resuspended house dust
^{241}Am	Inhalation of radionuclides in the plume, Inhalation of resuspended house dust

Table B 7 Principal exposure pathways following releases to the environment for a 1 y old child

Nuclide	Dominant Pathway
^{3}H	Ingestion of foodstuffs (milk, root vegetables)
^{14}C	Ingestion of foodstuffs (milk, grain)
^{35}S	Ingestion of foodstuffs (milk, milk products)
^{41}Ar	External gamma from airborne radionuclides
^{51}Cr	Ingestion of foodstuffs (milk products, milk)
^{54}Mn	Ingestion of foodstuffs (milk products, milk)
^{58}Co	Ingestion of foodstuffs (milk products, milk)
^{60}Co	Ingestion of foodstuffs (milk products, milk)
^{85}Kr	External beta and gamma from airborne radionuclides
^{89}Sr	Ingestion of foodstuffs (milk products, milk)
^{90}Sr	Ingestion of foodstuffs (milk products, milk)
^{95}Nb	External gamma from deposited radionuclides
^{106}Ru	Inhalation of radionuclides in the plume, External gamma from deposited radionuclides
^{124}Sb	Ingestion of foodstuffs (sheep liver, cow liver)
^{125}Sb	External gamma from deposited radionuclides, Ingestion of foodstuffs (sheep liver)
^{129}I	Ingestion of foodstuffs (milk products, milk)
^{131}I	Ingestion of foodstuffs (milk products, milk)
^{133}I	Ingestion of foodstuffs (milk, milk products)
^{133}Xe	External gamma and beta from airborne radionuclides
^{135}Xe	External gamma and beta from airborne radionuclides
^{137}Cs	Ingestion of foodstuffs (milk products, milk)
^{141}Ce	External gamma from deposited radionuclides
^{239}Pu	Inhalation of radionuclides in the plume, Inhalation of resuspended house dust
^{241}Pu	Inhalation of radionuclides in the plume, Ingestion of foodstuffs (green vegetables)
^{241}Am	Inhalation of radionuclides in the plume, Inhalation of resuspended house dust

Table B 8 Principal exposure pathways following releases to the environment for a 5 and 10 y old child

Nuclide	Dominant Pathway
^{3}H	Ingestion of foodstuffs (milk), Inhalation of radionuclides in the plume
^{14}C	Ingestion of foodstuffs (grain, milk products)
^{35}S	Ingestion of foodstuffs (milk products, milk)
^{41}Ar	External gamma from airborne radionuclides
^{51}Cr	Ingestion of foodstuffs (milk products, milk)
^{54}Mn	External gamma from deposited radionuclides, Ingestion of foodstuffs (sheep liver)
^{58}Co	External gamma from deposited radionuclides, Ingestion of foodstuffs (milk products)
^{60}Co	External gamma from deposited radionuclides, Ingestion of foodstuffs (milk products)
^{85}Kr	External beta and gamma from airborne radionuclides
^{89}Sr	Ingestion of foodstuffs (milk products), Inhalation of radionuclides in the plume
^{90}Sr	Ingestion of foodstuffs (milk products, milk)
^{95}Nb	External gamma from deposited radionuclides
^{106}Ru	Inhalation of radionuclides in the plume, Ingestion of foodstuffs (green vegetables)
^{124}Sb	Ingestion of foodstuffs (sheep liver), External gamma from deposited radionuclides
^{125}Sb	External gamma from deposited radionuclides, Ingestion of foodstuffs (sheep liver)
^{129}I	Ingestion of foodstuffs (milk products, milk)
^{131}I	Ingestion of foodstuffs (milk products, milk)
^{133}I	Ingestion of foodstuffs (milk), External beta from deposited radionuclides
^{133}Xe	External gamma and beta from airborne radionuclides
^{135}Xe	External gamma and beta from airborne radionuclides
^{137}Cs	External gamma from deposited radionuclides, Ingestion of foodstuffs (milk products)
^{141}Ce	External gamma from deposited radionuclides
^{239}Pu	Inhalation of radionuclides in the plume, Inhalation of resuspended house dust
^{241}Pu	Inhalation of radionuclides in the plume, Ingestion of foodstuffs (green vegetables)
^{241}Am	Inhalation of radionuclides in the plume, Inhalation of resuspended house dust

Table B 9 Principal exposure pathways following releases to the environment for a 15 y old and an adult

Nuclide	Dominant Pathway
^{3}H	Ingestion of foodstuffs (milk), Inhalation of radionuclides in the plume
^{14}C	Ingestion of foodstuffs (grain dominant for adult ingestion habits used here)
^{35}S	Ingestion of foodstuffs (milk products, sheep meat)
^{41}Ar	External gamma from airborne radionuclides
^{51}Cr	Ingestion of foodstuffs (milk products), External gamma from deposited radionuclides.
^{54}Mn	Ingestion of foodstuffs (sheep liver), External gamma from deposited radionuclides
^{58}Co	External gamma from deposited radionuclides, Ingestion of foodstuffs (milk products).
^{60}Co	External gamma from deposited radionuclides, Ingestion of foodstuffs (milk products
^{85}Kr	External beta and gamma from airborne radionuclides
^{89}Sr	Ingestion of foodstuffs (milk products), Inhalation of radionuclides in the plume
^{90}Sr	Ingestion of foodstuffs (milk products, green vegetables)
^{95}Nb	External gamma from deposited radionuclides
^{106}Ru	Inhalation of radionuclides in the plume, External gamma from deposited radionuclides
^{124}Sb	External gamma from deposited radionuclides, Ingestion of foodstuffs (sheep liver)
^{125}Sb	External gamma from deposited radionuclides, Ingestion of foodstuffs (sheep liver)
^{129}I	Ingestion of foodstuffs (milk products, milk)
^{131}I	Ingestion of foodstuffs (milk products, milk)
^{133}I	External gamma from deposited radionuclides, Ingestion of foodstuffs (milk)
^{133}Xe	External gamma and beta from airborne radionuclides
^{135}Xe	External gamma and beta from airborne radionuclides
^{137}Cs	External gamma from deposited radionuclides, Ingestion of foodstuffs (milk products)
^{141}Ce	External gamma from deposited radionuclides
^{239}Pu	Inhalation of radionuclides in the plume, Inhalation of resuspended house dust
^{241}Pu	Inhalation of radionuclides in the plume, Ingestion of foodstuffs (green vegetables)
^{241}Am	Inhalation of radionuclides in the plume, Inhalation of resuspended house dust

The results for the five different discharge groups (BWR, GCR, PWR and the 2 reprocessing sites) considered are summarised in the following table.

Table B 10 Principal exposure pathways and radionuclides following atmospheric releases to the environment

	Reprocessing Plant		BWR		GCR		PWR	
3 Month.	Milk	^{129}I	Milk	^{14}C/ ^{131}I	Milk	^{3}H/^{35}S	Milk	^{14}C
1 y old	Milk Milk Products	^{129}I	Milk Milk Products	^{14}C/ ^{131}I	Milk Cloud Gamma	^{3}H/^{14}C/ ^{35}S	Milk Grain	^{14}C
5 y old	Milk Milk Products	^{129}I	Milk Grain	^{14}C/ ^{131}I	Milk Cloud Gamma	^{14}C/^{3}H	Milk Grain	^{14}C
10 y old	Milk Milk Products	^{129}I	Milk Grain	^{14}C/ ^{38}Xe	Milk Cloud Gamma	^{14}C/^{41}Ar	Grain Milk	^{14}C
15 y old	Milk Milk Products	^{129}I	Milk Grain	^{14}C/^{138}Xe	Milk Cloud Gamma	^{14}C/^{41}Ar	Grain Milk	^{14}C
Adult	Milk Milk Products	^{129}I	Cloud Gamma Grain	^{14}C/^{138}Xe	Milk Cloud Gamma	^{14}C/^{41}Ar	Grain Milk	^{14}C

Shaded boxes indicate highest dose is to that age group (for a reprocessing plant: the highest dose is to a 10 y old for Sellafield, and to a 1 y old for Cap de la Hague)

B6 INFLUENCE OF CONSUMPTION HABITS

The results presented so far in this appendix were obtained using consumption rates applicable to the UK. To examine the effect of using consumption rates applicable to other EU countries, the doses were re-estimated using data for the Netherlands and Spain, as presented in Table 18 and 19 of the main text. The results are shown in Figure B 6. The total dose to an individual in the UK was calculated to be 0.7 μSv y^{-1}, in the Netherlands 0.68 μSv y^{-1}, and in Spain 0.77 μSv y^{-1}. The effect of changing between average consumption rates (as calculated using FAO data (FAOSTAT, 2000)) is small. However, site specific consumption rates should be used when available.

For some countries in the EU, the sheep and goat's milk may be consumed instead of cow's milk. If habit data indicates this is a potential pathway, it will be important to consider the consumption of goat's milk or sheep's milk as an alternative to cow's milk. Equilibrium transfer factors were not available for every radionuclide, and thus it was not possible to calculate the dose due to the consumption of goat's or sheep's milk for most discharge scenarios. For a unit release of ^{131}I, the doses calculated for an adult from the consumption of 320 kg y^{-1} of cow's milk, goat's milk and sheep's milk are given in Table B 11.

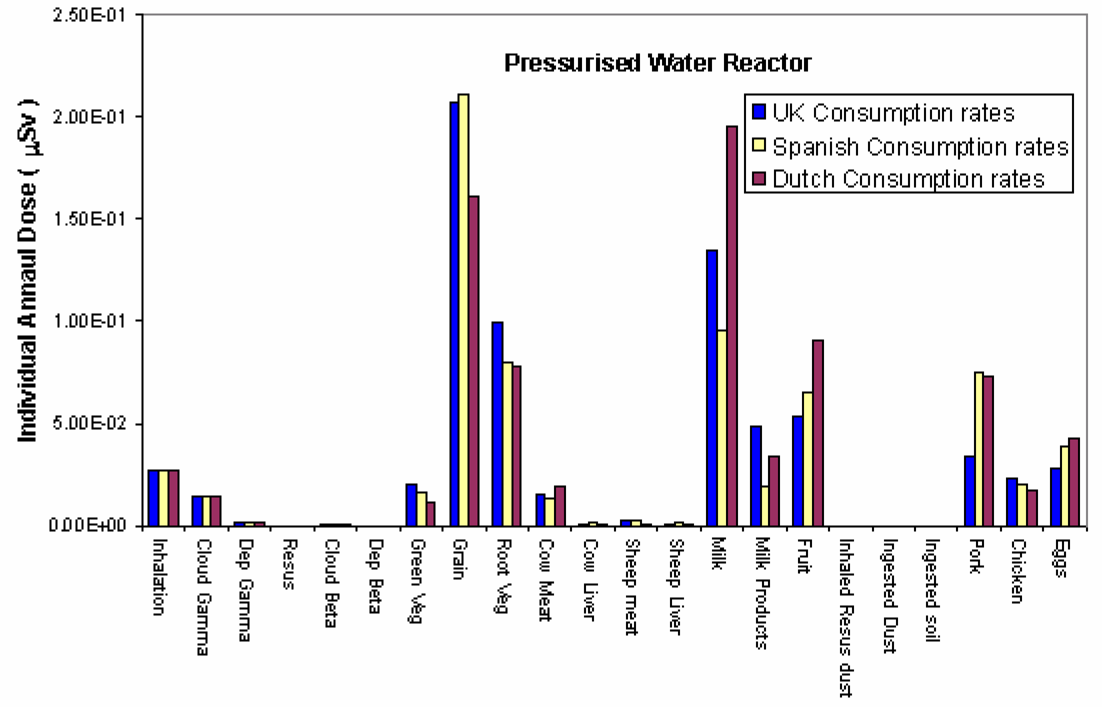


Figure B 6 Calculated doses by pathway for a discharge from a Pressurised Water Reactor assuming UK, Spanish and Dutch consumption rates (see appendix D)

Table B 11 Estimated doses to an adult due to consumption of cow's milk, goat's milk and sheep's milk following a unit release of ^{131}I to the atmosphere

Consumption pathway	Effective Dose (µSv y^{-1})
Cow milk	36
Goat Milk	160
Sheep Milk	180

From these results it is seen that the doses from consuming goat's milk or sheep's milk would be higher than that from cow's milk, if the same amount of each type of milk was consumed. Therefore, if iodine is a significant component of discharges and either of these types of milk are likely to be produced close to the site of interest, goats or sheep should be considered in the dose assessment rather than cows.

B7 UNIT RELEASES

Radiation doses were also estimated for unit releases (1GBq y^{-1}) for a range of radionuclides. The purpose of these calculations was to illustrate the importance of different pathways for various radionuclides.

Table B 12 Unit discharges modelled

Unit Releases
^{3}H
^{14}C
^{85}Kr
^{131}I
^{137}Cs
^{239}Pu

The breakdown of individual dose to an adult due to a unit release of a nuclide is shown by pathway in Figure B 7.

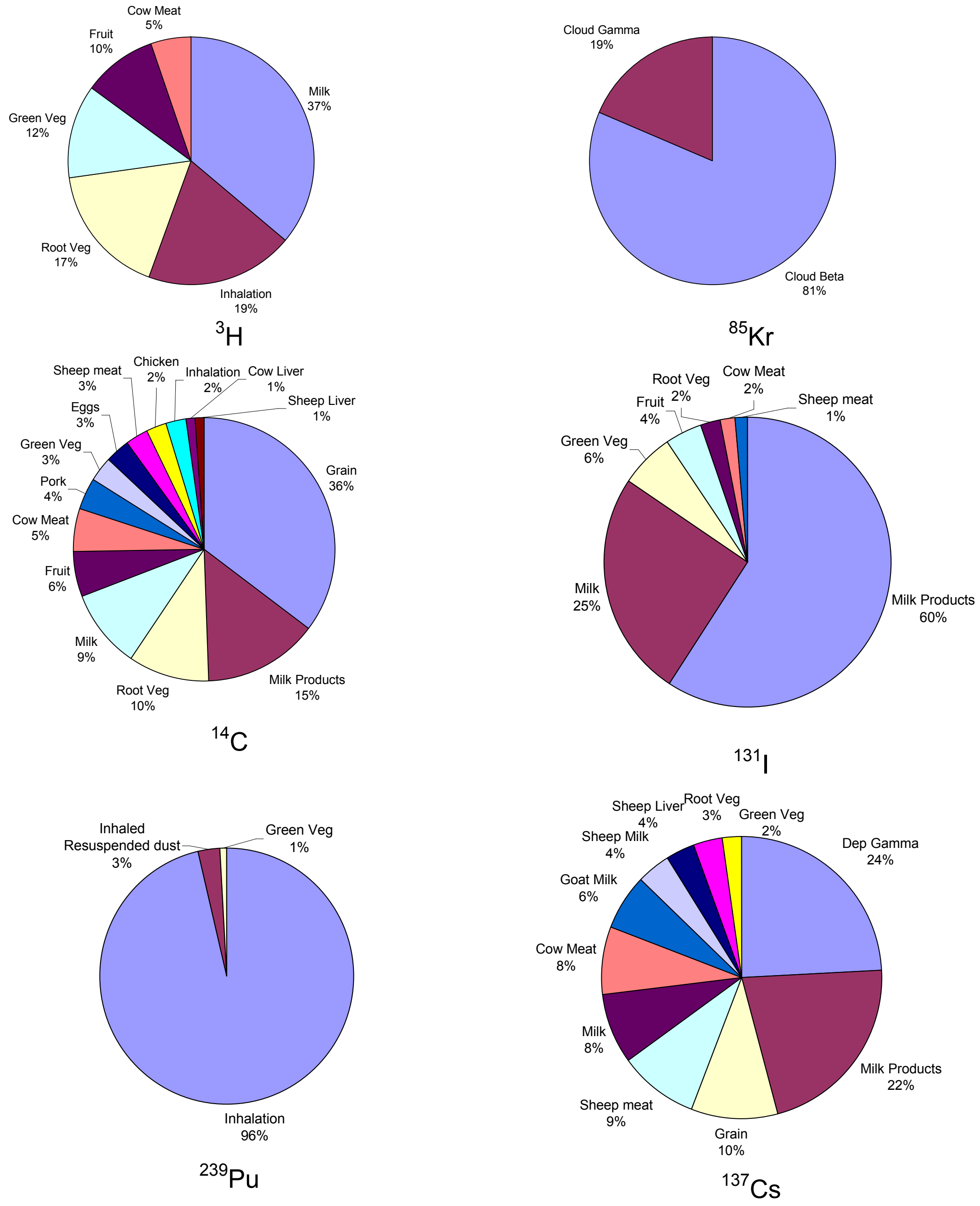


Figure B 7 Breakdown of individual dose to an adult due to a unit release of a nuclide is shown by pathway. (Only pathways with a contribution greater than 1% of total dose are plotted)

The resulting doses to each age group by radionuclide in μSv y^{-1} are given in Table B 13.

Table B 13 Estimated doses calculated for a unit release scenario

Radionuclide	3 month old	1 y old	5 y old	10 y old	15 y old	Adult
^{3}H	$2.2\ 10^{-5}$	$2.9\ 10^{-5}$	$1.6\ 10^{-5}$	$1.7\ 10^{-5}$	$1.6\ 10^{-5}$	$1.7\ 10^{-5}$
^{14}C	$1.7\ 10^{-3}$	$4.1\ 10^{-3}$	$3.0\ 10^{-3}$	$3.2\ 10^{-3}$	$2.7\ 10^{-3}$	$2.9\ 10^{-3}$
^{85}Kr	$5.1\ 10^{-8}$	$5.1\ 10^{-8}$	$5.3\ 10^{-8}$	$5.3\ 10^{-8}$	$5.4\ 10^{-8}$	$5.4\ 10^{-8}$
^{131}I	$3.9\ 10^{-1}$	$6.1\ 10^{-1}$	$1.6\ 10^{-1}$	$1.6\ 10^{-1}$	$7.4\ 10^{-2}$	$8.4\ 10^{-2}$
^{137}Cs	$2.6\ 10^{-2}$	$3.8\ 10^{-2}$	$4.3\ 10^{-2}$	$4.4\ 10^{-2}$	$6.1\ 10^{-2}$	$6.6\ 10^{-2}$
^{239}Pu	$1.7\ 10^{0}$	$1.8\ 10^{0}$	$3.1\ 10^{0}$	$3.1\ 10^{0}$	$4.3\ 10^{0}$	$4.4\ 10^{0}$

B7.1 Dose via ingestion of drinking water and ingestion of freshwater fish

For additional information radiation doses via the ingestion of drinking water and the ingestion of freshwater fish were also estimated for unit releases (1GBq y^{-1}) for a range of radionuclides, listed in the table below (radionuclides for which transfer models were available).

Table B 14 Unit discharges modelled

Unit Releases
^{90}Sr
^{131}I
^{137}Cs
^{239}Pu

The resulting doses to each age group by radionuclide via ingestion of drinking water in μSv y^{-1} are given below.

Table B 15 Estimated doses via ingestion of drinking water calculated for a unit release scenario

	3 Mo	1 y	5 y	10 y	15 y	Adult
^{90}Sr in upland reservoir	$1.8\ 10^{-2}$	$4.0\ 10^{-3}$	$3.0\ 10^{-3}$	$4.4\ 10^{-3}$	$7.9\ 10^{-3}$	$3.5\ 10^{-3}$
^{137}Cs in upland reservoir	$7.6\ 10^{-5}$	$3.1\ 10^{-5}$	$2.8\ 10^{-5}$	$3.5\ 10^{-5}$	$6.0\ 10^{-5}$	$7.7\ 10^{-5}$
^{131}I in upland reservoirs	$2.0\ 10^{-5}$	$1.4\ 10^{-5}$	$9.2\ 10^{-6}$	$5.6\ 10^{-6}$	$4.9\ 10^{-6}$	$4.1\ 10^{-6}$
^{90}Sr in river	$1.1\ 10^{-2}$	$2.6\ 10^{-3}$	$1.9\ 10^{-3}$	$2.8\ 10^{-3}$	$5.0\ 10^{-3}$	$2.3\ 10^{-3}$
^{137}Cs in river	$5.2\ 10^{-5}$	$2.1\ 10^{-5}$	$1.9\ 10^{-5}$	$2.4\ 10^{-5}$	$4.1\ 10^{-5}$	$5.3\ 10^{-5}$
^{239}Pu in river	$1.5\ 10^{-2}$	$1.0\ 10^{-3}$	$9.5\ 10^{-4}$	$9.0\ 10^{-4}$	$1.1\ 10^{-3}$	$1.4\ 10^{-3}$

The resulting doses to each age group by radionuclide via ingestion of freshwater fish in μSv y^{-1} are given on the next page.

Table B 16 Estimated doses via ingestion of freshwater fish calculated for a unit release scenario

	3 Mo	1 y	5 y	10 y	15 y	Adult
^{90}Sr in upland reservoir	$0.0\ 10^{0}$	$9.2\ 10^{-4}$	$2.5\ 10^{-3}$	$3.8\ 10^{-3}$	$5.0\ 10^{-3}$	$7.1\ 10^{-3}$
^{137}Cs in upland reservoir	$0.0\ 10^{0}$	$2.4\ 10^{-5}$	$8.1\ 10^{-5}$	$9.9\ 10^{-5}$	$1.3\ 10^{-4}$	$5.1\ 10^{-4}$
^{131}I in upland reservoirs	$0.0\ 10^{0}$	$1.1\ 10^{-6}$	$2.6\ 10^{-6}$	$1.6\ 10^{-6}$	$1.0\ 10^{-6}$	$2.7\ 10^{-6}$
^{90}Sr in river	$0.0\ 10^{0}$	$5.9\ 10^{-4}$	$1.6\ 10^{-3}$	$2.4\ 10^{-3}$	$3.2\ 10^{-3}$	$4.5\ 10^{-3}$
^{137}Cs in river	$0.0\ 10^{0}$	$1.6\ 10^{-5}$	$5.5\ 10^{-5}$	$6.7\ 10^{-5}$	$8.8\ 10^{-5}$	$3.5\ 10^{-4}$
^{239}Pu in river	$0.0\ 10^{0}$	$1.4\ 10^{-3}$	$4.7\ 10^{-3}$	$4.5\ 10^{-3}$	$4.0\ 10^{-3}$	$1.7\ 10^{-2}$

Doses estimated from ingestion of drinking water and freshwater fish are many orders of magnitude lower than those calculated in Table B 13 i.e. for the main exposure pathways for atmospheric discharges. Therefore drinking water and fish were included in Table 4; pathways resulting from a release to atmosphere that should not normally be considered.

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APPENDIX C Illustrative calculations to determine the important exposure pathways and age groups for releases to the aquatic environment

C1 METHODOLOGY FOR ASSESSMENT

Discharges to the aquatic environment can lead to exposure to the public by a variety of pathways. A series of illustrative calculations to investigate the relative importance of different exposure pathways following particular discharges to the aquatic environment was carried out, and the results are presented here.

A general methodology was established to assess radiation doses received by a critical group for discharges to the aquatic environment. Five release scenarios were considered: reprocessing plants (Sellafield, UK and Cap de la Hague, France), a boiling water reactor, a pressurised water reactor and a gas cooled reactor. Additionally, three different receiving water bodies for the releases were considered: marine; estuarine; and river. Discharge data were taken from the EU database (EC, 2000) for 1998 and generalised to be representative of a generic nuclear installation.

Discharges to the aquatic environment can lead to exposure to the public by a variety of pathways. In most situations, the radionuclide activity concentrations in environmental media are too low to be measured and used for calculations of public exposure. It is for this reason that mathematical models are used to simulate the transfer of the radionuclides in the environment. The doses presented here have, where possible, been calculated using the radiological impact assessment software PC CREAM (Mayall et al. 1997) which was developed for the European Commission and is a personal computer (PC) implementation of CREAM (Consequences of Releases to the Environment: Assessment Methodology (Simmonds et al. 1995). The doses from pathways given in PC-Cream have been calculated for all age groups except for 3 month year olds. For this age group it was assumed they consumed only milk and had no occupancy over intertidal areas or river banks. Therefore they receive no exposure from any of the aquatic pathways. The pathways included in PC-Cream are given in Table C 1 for marine and estuarine scenarios and Table C 2 for riverine scenarios.

For the pathways unavailable in PC-Cream, alternative calculation methods have been used. These methods are described further in sections C1.1-C1.2. Details of all exposure pathways considered are provided in Tables C 3-C 5. Doses for these other pathways were calculated for 1 y olds, 10 y olds and adults alone. The reason for not calculating the other age groups is that the habit data for these age groups are scarce and in many cases the habit data has been scaled from the adult data. Additionally, calculations for the PC-Cream pathways indicate that there are not significant differences in doses between the age groups i.e. doses to a 15 y old lie somewhere between those for 10 y old and adult.

For 1 y olds, 10 y olds and adults, the pathways were divided into two categories; conventional and unconventional. This was done as it would be unrealistic to assume that an individual would receive exposure from all the pathways considered. Conventional pathways represent those that can be realistically combined e.g. consumption of fish, exposure from sediments and will be common to the majority of sites and reference groups. Unconventional pathways are those that may be important but will not be relevant to many sites or reference groups e.g. exposure whilst swimming. Tables C7 to C12 present the doses for 1 y olds, 10 y olds and adults for conventional pathways. Below each of the tables is a discussion of the unconventional pathways and presentation of doses for the more important ones.

Table C 1 Marine and estuarine exposure pathways considered in PC-Cream

Exposure Route	Exposure Pathway
Ingestion	Fish
	Molluscs (e.g. winkles)
	Crustaceans (e.g. lobster)
Inhalation	Spray
External	Exposure on beaches/mud flats
	Exposure from fishing gear

Table C 2 Riverine exposure pathways considered in PC-Cream

Exposure Route	Exposure Pathway
Ingestion	Fish
	Drinking water
External	Exposure on river banks

Table C 3 Exposure pathways resulting from a discharge to the marine environment

Exposure Route	Exposure Pathway
Ingestion	Drinking water (desalinated water)
	Marine fish
	Marine molluscs (e.g. winkles)
	Marine crustaceans (e.g. lobster)
	*Marine plants (e.g. laverbread)
	*Other marine biota (e.g. sea mice, urchins etc.)
	*Inadvertent ingestion of seawater while swimming
	Inadvertent ingestion of beach/bed sediment
	*Ingestion of animal meat from animals grazing on salt marsh (e.g. cow, sheep, goat)
	*Ingestion of animal milk from animals grazing on salt marsh (e.g. cow, sheep, goat)
	*Ingestion of crops fertilised by seaweed (e.g. grain, root vegetables)
	*Crops/animal products on coastal area exposed to seaspray
	*Farming of crops/animals on land reclaimed from the sea
Inhalation	Sea spray
	Resuspended sediments/conditioned soil
External	Exposure on beaches
	*Exposure on boats
	*Exposure whilst swimming/wading
	*Exposure from fishing gear
	*Skin doses whilst bait digging

* indicates unconventional pathway

Table C 4 Exposure pathways resulting from a discharge to an estuary

Exposure Route	Exposure Pathway
Ingestion	Fish
	Molluscs (e.g. mussels)
	Crustaceans (e.g. crabs)
	*Plants (e.g. seaweed)
	*Inadvertent ingestion of estuary water whilst swimming
	*Inadvertent ingestion of estuary sediment
	*Wildfowl
	*Ingestion of animal meat from animals grazing on salt marsh (e.g. cow, sheep, goat)
	*Ingestion of animal milk from animals grazing on salt marsh (e.g. cow, sheep, goat)
	*Ingestion of crops fertilised by seaweed (e.g. grain, root vegetables)
	*Crops/animal products on coastal area exposed to estuary spray
Inhalation	Estuary spray
	*Resuspended sediments/conditioned soil
External	Exposure on mud flats
	Skin doses whilst bait digging
	*Exposure on boats
	*Exposure whilst swimming/wading
	*Skin doses from fishing gear

* indicates unconventional pathway

Table C 5 Exposure pathways resulting from a discharge to a river

Exposure Route	Exposure Pathway
Ingestion	Drinking water (treated or untreated)
	Freshwater fish
	*Freshwater molluscs (e.g. mussels)
	*Freshwater crustaceans (e.g. crayfish)
	*Freshwater plants (e.g. water cress)
	*Inadvertent ingestion of river water whilst swimming
	Inadvertent ingestion of river bank sediment/conditioned soil/irrigated soil
	*Wildfowl
	*Ingestion of animal meat from animals drinking river water (e.g. cow, sheep, goat)
	*Ingestion of animal milk from animals drinking river water (e.g. cow, sheep, goat)
	*Ingestion of crops irrigated by river water/conditioned by river sediment/plants/flooded land (e.g. grain, root vegetables)
Inhalation	Resuspended sediments/irrigated soil
External	Exposure on river banks
	*Exposure on boats (recreational & houseboats)
	*Exposure whilst swimming/wading
	*Skin doses from fishing gear
	*Exposure from water during floods
	Exposure from previously flooded land

* indicates unconventional pathway

C1.1 Marine and Estuary Dispersion Model

Modelling the dispersion of discharges to the marine and estuarine environments was based on the marine dispersion model described in (Simmonds et al. 1995). The model comprises two components, a generic regional model and a site-specific local model. The model describes the fluxes of water within northern European waters and the behaviour of radionuclides within the water column and sediment by means of a compartmental model. The model for the interaction of radionuclides with sediments includes the return of radionuclides from the seabed to the water column together with diffusive mixing in the seabed and burial of radionuclides by continuing sediment deposition. Mixing within the seabed and the transport of radionuclides back to the water column are modelled using a diffusion coefficient and a bioturbation coefficient, the latter being a diffusive-type coefficient. The sorption of radionuclides within the seabed is also taken into account through the use of an equilibrium sediment distribution coefficient, K_d. Radionuclides released back into the water column are assumed to exhibit the same behaviour as radionuclides in solution and those sorbed on suspended sediment, i.e. instantaneous equilibrium. Values of the sediment distribution coefficient used were those published by the International Atomic Energy Agency (IAEA, 1985).

The model was used to compute the radionuclide concentrations in unfiltered seawater, filtered seawater and the top 10 cm of the seabed for the modelled discharges. Predicted external dose rates over intertidal sand were obtained from these activity concentrations using the model given by Hunt (Hunt, 1984). Radionuclide concentrations in seafood were obtained from the predicted concentrations in filtered seawater through the use of element-dependent concentration factors. The concentration factors used in this assessment were those published by IAEA (IAEA, 1985).

The transfer of radionuclides in seaspray/estuary spray was calculated using empirical relationships linking deposition on land, as a function of distance from the shoreline, with activity concentrations in seawater (Howarth and Eggleton, 1988).

A number of exposure pathways are not included in PC CREAM, and doses were calculated for these pathways using activity concentration data produced by the marine dispersion model.

- To calculate the dose due to the consumption of seaweed, radionuclide dependent concentration factors from (IAEA, 1985) were used with an ingestion rate of 5 kg y^{-1} from (Robinson, 1996)
- To calculate the dose due to the ingestion of other marine biota (sea mice, urchins etc), measurement data for Sellafield was used (MAFF and SEPA, 1999), using an ingestion rate of 8.3 kg y^{-1} from the same reference.
- To calculate the inadvertent ingestion of seawater whilst swimming, an ingestion rate of water from a previous assessment was used (Stather et al. 1984). The water concentration was taken to be the unfiltered seawater calculated using PC CREAM output.
- The ingestion rate for the inadvertent ingestion of seabed sediment was assumed to be equal to that quoted in Appendix B for inadvertent ingestion of soil, based on the work of (van Wijnen et al. 1990) and (Sedman and Mahmood, 1994).
- To calculate the dose due to the ingestion of waterfowl, the waterfowl's diet was assumed to consist solely of sea plants, and daily intake by waterfowl was estimated from data published in (Lowe and Horrill, 1986).
- To calculate the dose due to the ingestion of animal meat/milk from animals grazing on salt marsh, Sellafield measurement data were used, as it is not possible to model radionuclide accumulation in generic salt marshes. RIFE-2 (MAFF and SEPA, 1997) gives the activity concentration of particular radionuclides in salt marsh pasture. An ingestion rate of 13 kg y^{-1} dry weight of pasture of cattle is assumed (Brown and Simmonds, 1995). Equilibrium transfer factors for cattle were taken from (Brown and Simmonds, 1995), although different equilibrium transfer factors may be relevant for saltmarshes due to the radioactivity being bound to sediment.
- To calculate the dose due to the ingestion of crops grown on soil conditioned by seaweed, it was assumed that the applied seaweed is ploughed in to a depth of 30 cm, and that all the activity within the seaweed is available for uptake in plants grown on the soil. An application rate of seaweed applied to soil is assumed to be 5 kg m^{-2} fresh mass, as suggested in (Wilkins, 1994).

- To calculate the dose due to the ingestion of crops/animal products grown on a coastal area exposed to sea/estuary spray, it was assumed that this was similar to the land being irrigated with sea water. The irrigation rate was assumed to be 1 m^3 y^{-1} per m of coastline and is assumed to be evenly deposited over 500 m inland (Simmonds et al. 1995).

- To calculate the dose due to the ingestion of crops/animal products grown on reclaimed land, no established models were available. Therefore, as a scoping estimation, a plot of land studied on the English coast was used to obtain an estimate of doses (Green et al. 1995). The study includes measurements of soil activity concentrations between 1989 and 1991 and estimated soil to plant transfer factors for such land.

- To calculate the dose due to the inhalation of resuspended sediments, an ambient dust loading of 10^{-7} kg m^{-3} was assumed (Simmonds et al. 1995).

- To calculate external exposure whilst on boats and swimming/wading, Hunt's models were used (Hunt, 1984).

C1.2 River Dispersion Model

Modelling of the dispersion of discharges to the riverine environment was based on the dynamic river model described in (Simmonds et al. 1995). The river models contained in PC CREAM calculate the transfer of radionuclides downstream as a function of the velocity and length of the modelled river sections, assuming mixing in each river section occurs instantaneously. Two types of model are available, a screening model and a dynamic river model. The dynamic model is a semi-empirical, compartmental model based on Schaeffer's (Schaeffer, 1976) approach. The dynamic river model is a compartmental model that enables the user to customise each river stretch with respect to length, width, depth, bed sediment depth and river velocity. The model uses a sediment distribution coefficient, k_d factor, to simulate sorption and desorption of activity to and from suspended sediment and includes transport of activity downstream in both the river water column and bed sediment. The settlement of suspended sediments to the riverbed is estimated using a factor called k' or Schaeffer's parameter. The transfer of activity is the product of k' and the river water velocity. Values of k' were obtained by applying an empirical formula, developed by Schaeffer (Schaeffer, 1976), to measurements of activity concentrations in sediment per unit length of the river Molse Nete (Zeevaert et al. 1987). External exposure to radioactivity deposited in river sediments is calculated using models suggested in (Hunt, 1984). Radionuclide concentrations in freshwater fish were obtained from the predicted activity concentrations in filtered water using element-dependent concentration factors. The concentration factors used in this assessment are given in (Simmonds et al. 1995). A number of exposure pathways listed in Table C 5 are not included in PC CREAM, and doses were calculated for these pathways using data from the output runs of the dynamic river model.

- To calculate the radionuclide concentration in freshwater molluscs and crustaceans, element dependent concentration factors from (IAEA, 1982) were used.
- To calculate the dose due to the ingestion of waterfowl, the waterfowl's diet was assumed to consist solely of river plants, and the daily intake by waterfowl was estimated from data published in (Lowe and Horrill, 1986).
- To calculate the dose due to the ingestion of animal meat/milk from animals' drinking river water, it was assumed that the cow obtains 50% of its water from the river. An ingestion rate for cows of 55 l d^{-1}, and for sheep of 4 l d^{-1} was assumed in line with the values suggested by (Scott Russell, 1966).
- To calculate the dose due to the ingestion of crops grown on soil conditioned by river plants, it was assumed that the applied river plants are ploughed in to a depth of 30 cm, and that all the activity within the river plant is available for uptake in plants grown on the soil. An application rate of plant applied to soil is assumed to be 5 kg m^{-2} fresh mass, as suggested in (Wilkins, 1994).
- To calculate the dose due to the ingestion of crops grown on previously flooded land, it was assumed that the activity in the unfiltered flood water is a combination of the activity from the river bed and the river water, before flooding, which is then diluted by the ratio of the mean annual flow and the flow of the mean annual flood.
- To calculate the dose due to the inhalation of resuspended sediments, an ambient dust loading of 10^{-7} kg m^{-3} was assumed (Simmonds et al. 1995).
- To calculate external exposure whilst on boats, swimming/wading, and handling fishing gear, Hunt's models were used (Hunt, 1984).

C2 DOSE CALCULATIONS

For each age group, higher than average consumption rates for the UK have been used as representative of the critical group. The reference group consumption rates were taken from (Byrom et al. 1995) for all age groups, except for the 5 y olds. These were estimated by scaling the values for 10 y old children to the energy requirements of 5 y olds. Average consumption rates were taken from (Mayall et al. 1997), and it was assumed that the data for the child age group are appropriate for both the 10 y old and the 15 y old child, as suggested in (Byrom et al. 1995) for reference rates.

It was assumed that for marine/estuarine crustaceans and molluscs all intake was sourced from the local compartment, for marine/estuarine fish 10% of the catch came from the local compartment, with the remaining 90% from the regional compartment (i.e. 100% from the area). For the river assessments, it was assumed that all aquatic foods were sourced in the section of the river to which the site discharged. Drinking water from rivers was assumed to be abstracted from the section of the river to which the site discharged, and water treatment (coagulation, sedimentation and filtration) was assumed. Water intake rates are given in Table C 6 are derived from (ICRP, 1975). No data were available for the 5 y olds, but the rates were estimated from the values for 10 y old children by scaling to the energy requirements of 5 y olds.

Intertidal occupancy, fishing and the inhalation of seaspray were all assumed to take place in the local compartment. River bank occupancy and fishing in rivers were assumed to occur at the section of the river to which the site discharged. Occupancy data are presented in Table 22 of the main text and discussed in Appendix D.

Table C 6 Intake rates of drinking water (l y^{-1})

Age group	Intake rate (l y^{-1})
1 y old	260
10 y old	350
Adult	600

C3 PATHWAYS NOT INCLUDED IN DOSE ASSESSMENTS

The deliberate ingestion of sediment by children or adults was not considered in this assessment because this pathway is a recognised medical condition, known as *pica*, which tends to occur for a relatively short time. Inadvertent ingestion of sediment was however included (refer to Appendix B).

C4 RESULTS FOR EACH RELEASE SCENARIO

For the scenarios given below, illustrative calculations have been carried out to allow conclusions to be drawn regarding important exposure pathways. In many cases, a generic source-term has been used rather than site-specific discharge data. Therefore, the doses presented should not be taken to be representative of the actual doses received in the vicinity of the sites. The doses should not be scaled for other sites due to the site-specificity of aquatic discharge dose assessments.

Percentage contributions of pathways and nuclides are indicated within brackets.

C4.1 Pressurised Water Reactor

Pressurised Water Reactor discharging to marine environment

The estimated doses received by the different age groups from generic discharges (given in A3.2) are given in the table below.

Table C 7 Estimated doses due to a release to the marine environment for a pressurised water reactor discharge scenario. The doses to the age groups of 3 month-old, 5 y-old and 15 y-old consider PC CREAM pathways only.

Age group	Individual Dose (μSv y^{-1})
1 y	2.9 10^{-3}
5 y	0.18
10 y	0.20
15 y	0.28
Adult	0.38

For 1 y olds, the two most dominant pathways were consumption of fish (59%) and external exposure (gamma) on sediments (41%). ^{60}Co (81%) is the most important radionuclide for this age group.

For 10 y olds and adults, the two most dominant pathways are consumption of crustaceans (56% and 45%) and consumption of molluscs (37% and 32%). ^{60}Co (50% and 57%) and ^{110m}Ag (29% and 35%) are the most important radionuclide for these age groups.

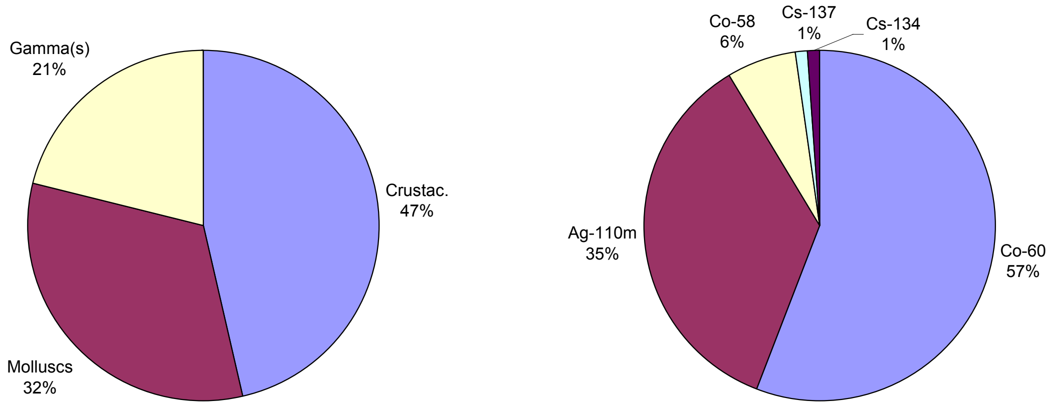


Figure C 1 Breakdown of individual dose to an adult due to aquatic discharges from a typical PWR discharging to the marine by pathway and radionuclide. (Currently, only pathways with a contribution greater than 5% of total dose and radionuclides with a contribution greater than 1% are plotted, 'others' categories to be included, therefore percentages do not currently agree with the text)

Other pathways, which should only be considered when local data indicates a habit is present:

Ingestion of marine plants. 10 y old dose: 0.03 μSv y^{-1}, adult dose: 0.02 μSv y^{-1}

Other 'unconventional' pathways considered which did not contribute significantly to dose for any age group: ingestion of crops on soil conditioned by seaweed, exposure ingestion of crops grown on coastal area exposed to sea spray, exposure on boats (recreational) and exposure whilst swimming

Pressurised Water Reactor discharging to an estuary

The estimated doses received by the different age groups from generic discharges (given in A3.2) are given in the table below.

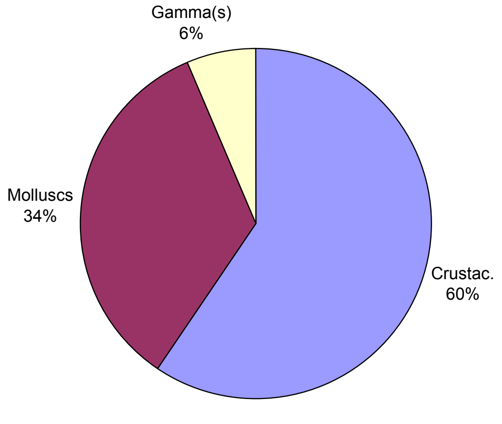
Table C 8 Estimated doses due to a release to an estuarine environment for a pressurised water reactor discharge scenario. The doses to the age groups of 3 month-old, 5 y-old and 15 y-old consider PC CREAM pathways only.

Age group	Individual Dose (μSv y^{-1})
1 y	0.01
5 y	0.8
10 y	0.9
15 y	0.6
Adult	2.0

For 1 y olds, the two most dominant pathways are consumption of fish (81%) and external exposure (gamma) on sediments (19%). ^{60}Co (34%) and ^{110m}Ag (43%) are the most important radionuclides for this age group.

For 10 y olds the two most dominant pathways are consumption of crustaceans (62%) and consumption of molluscs (34%). ^{110m}Ag (79%) is the most important radionuclide for this age group.

For adults the two most dominant pathways are consumption of crustaceans (58%) and consumption of molluscs (33%). ^{110m}Ag (78%) is the most important radionuclide for this age group.



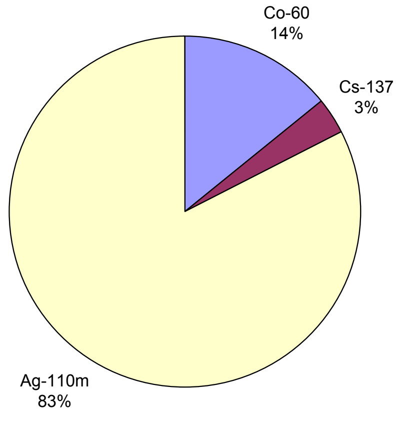


Figure C 2 Breakdown of individual dose to an adult due to aquatic discharges from a typical PWR discharging to an estuary by pathway and radionuclide. (Currently, only pathways with a contribution greater than 5% of total dose and radionuclides with a contribution greater than 1% are plotted, ‘others’ categories to be included, therefore percentages do not currently agree with the text)

Other 'unconventional' pathways considered which did not contribute significantly to dose for any age group: ingestion of crops on soil conditioned by seaweed, ingestion of crops grown on coastal area exposed to sea spray, exposure on boats (recreational) and exposure whilst swimming. Ingestion of marine plants did not contribute significantly to the adult or 10 y old dose.

Pressurised Water Reactor discharging to a river

The estimated doses received by the different age groups from generic discharges (given in A3.2) are presented in the table below.

Table C 9 Estimated doses due to a release to a river for a pressurised water reactor discharge scenario. The doses to the age groups of 3 month-old, 5 y-old and 15 y-old consider PC CREAM pathways only.

Age group	Individual Dose (μSv y^{-1})
1 y	0.23
5 y	0.39
10 y	2.9
15 y	3.4
Adult	3.4

For 1 y olds the dominant pathways are exposure on riverbanks (71%), consumption of fish (15%) and ingestion of drinking water taken from the river (12%). ^{60}Co (65 %) and ^{137}Cs (13%) are the most important radionuclides for this age group.

For 10 y olds the dominant pathway is exposure on riverbanks (94%). ^{60}Co (82 %) and ^{137}Cs (10%) are the most important radionuclides for this age group.

For an adult the dominant pathways are exposure on river banks (80%) and consumption of fish (20%). ^{60}Co (69 %), ^{137}Cs (16%) and ^{134}Cs (13%) are the most important radionuclides for this age group.

Other pathways, which should only be considered when local data indicates a habit is present:

- Skin doses from fishing gear. Dose to adults and 10 y olds 0.2 μSv y^{-1}.
- External exposure whilst swimming. Dose to all age groups 0.6 μSv y^{-1}.
- Ingestion of animal meat from animals drinking river water. 1 y old dose: 0.1 μSv y^{-1}, 10 y old dose: 0.2 μSv y^{-1}, adult dose: 0.3 μSv y^{-1}.
- Ingestion of animal milk from animals drinking river water. 1 y old dose: 7 μSv y^{-1}, 10 y old dose: 2.5 μSv y^{-1}, adult dose: 2 μSv y^{-1}.
- Exposure on boats (houseboats). Dose to all age groups 3.9 μSv y^{-1}.
- Exposure on boats (recreational). Dose to all age groups 0.5 μSv y^{-1}.

Other 'unconventional' pathways considered which did not contribute significantly to dose for any age group: ingestion of river plants, ingestion of waterfowl, ingestion of crops irrigated by river water, ingestion of crops on soil conditioned by river plants and ingestion of crops grown on previously flooded land, ingestion of water whilst swimming.

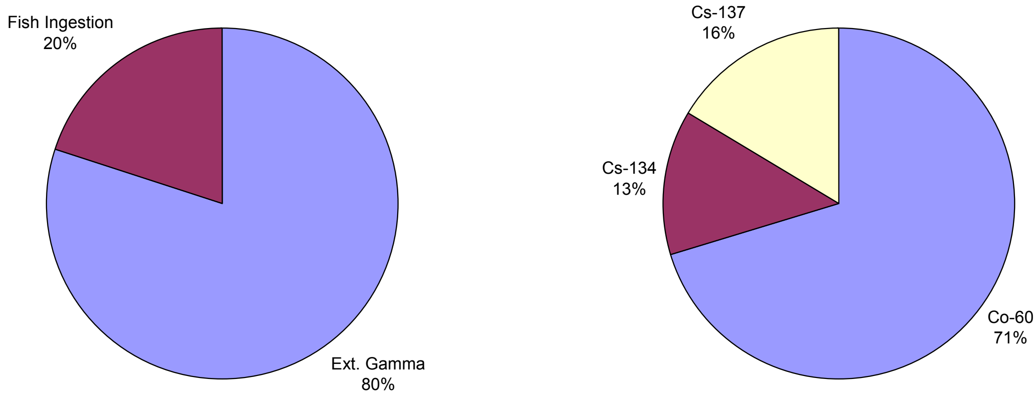


Figure C 3 Breakdown of individual dose to an adult due to aquatic discharges from a typical PWR discharging to a river by pathway and radionuclide. (Currently, only pathways with a contribution greater than 5% of total dose and radionuclides with a contribution greater than 1% are plotted, 'others' categories to be included, therefore percentages do not currently agree with the text)

C4.2 Gas Cooled Reactors

Gas Cooled Reactor discharging to marine environment

The estimated doses received by the different age groups from generic discharges (given in A4.2) are given in the table below.

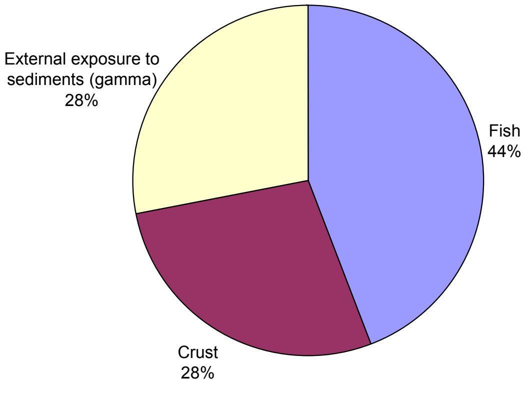
Table C 10 Estimated doses due to a release to the marine environment for a gas cooled reactor discharge scenario. The doses to the age groups of 3 month-old, 5 y-old and 15 y-old consider PC CREAM pathways only.

Age group	Individual Dose ($\mu Sv\ y^{-1}$)
1 y	0.021
5 y	0.092
10 y	0.14
15 y	0.37
Adult	0.86

For a 1 y old, the most dominant pathway is ingestion of fish (83%). ^{137}Cs (88%) and ^{90}Sr (5%) are the most important radionuclides for an 1 y old.

For a 10 y old and an adult, the dominant pathways are consumption of fish (42% and 42%), consumption of crustaceans (27% and 26%) and external exposure to sediments

(25% and 27%). ^{137}Cs (85% and 90%) is the most important radionuclide for these age groups.



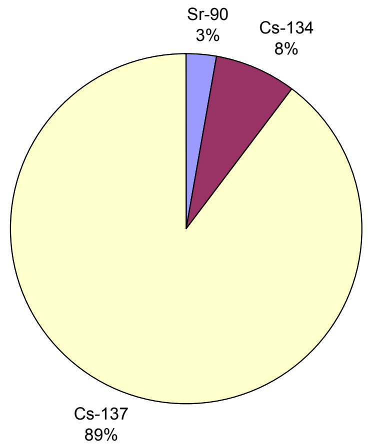


Figure C 4 Breakdown of individual dose to an adult due to aquatic discharges from a typical GCR discharging to the marine by pathway and radionuclide. (Currently, only pathways with a contribution greater than 5% of total dose and radionuclides with a contribution greater than 1% are plotted, 'others' categories to be included, therefore percentages do not currently agree with the text)

Other pathways, which should only be considered when local data indicates a habit is present:

Ingestion of marine plants. 10 y old dose: 0.04 μSv y^{-1}, adult dose: 0.1 μSv y^{-1}.

Other 'unconventional' pathways considered which did not contribute significantly to the dose for any age group: ingestion of crops on soil conditioned by seaweed, ingestion of crops grown on coastal area exposed to sea spray, exposure on boats (recreational) and exposure whilst swimming.

Gas Cooled Reactor discharging to an estuary

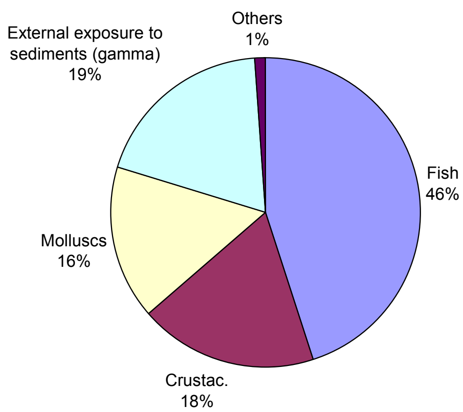
The estimated doses received by the different age groups from generic discharges (given in A4.2) are given in the table below.

Table C 11 Estimated doses due to a release to an estuarine environment for a gas cooled reactor discharge scenario. The doses to the age groups of 3 month-old, 5 y-old and 15 y-old consider PC CREAM pathways only.

Age group	Individual Dose (μSv y^{-1})
1 y	0.003
5 y	0.012
10 y	0.015
15 y	0.024
Adult	0.090

For a 1 y old, the most dominant pathways are consumption of fish (88%) and external exposure (gamma) on mud flats (12%). ^{137}Cs (87%) and ^{90}Sr (5%) are the most important radionuclides for this age group.

For a 10 y old and an adult, the most dominant pathways are consumption of fish (51% and 53%), consumption of crustaceans (23% and 22%) and external exposure (gamma) on mud flats (20% and 22%). ^{137}Cs (84% and 89%) is the most important radionuclides for these age groups.



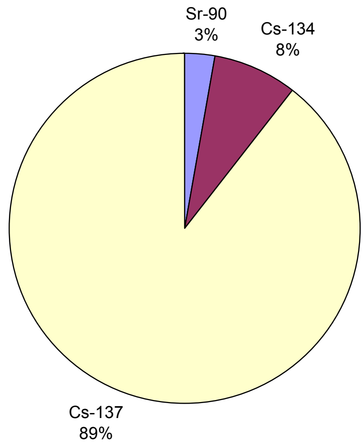


Figure C 5 Breakdown of individual dose to an adult due to aquatic discharges from a typical GCR discharging to an estuary by pathway and radionuclide. (Currently, only pathways with a contribution greater than 5% of total dose and radionuclides with a contribution greater than 1% are plotted, 'others' categories to be included, therefore percentages do not currently agree with the text)

Other pathways, which should only be considered when local data indicates a habit is present:

Ingestion of marine plants. 10 y old dose: 3.5 10^{-3} μSv y^{-1}, adult dose: 8.6 10^{-3} μSv y^{-1}.

Other 'unconventional' pathways considered which did not contribute significantly to dose for any age group: ingestion of crops on soil conditioned by seaweed, ingestion of crops grown on coastal area exposed to sea spray, exposure on boats (recreational) and exposure whilst swimming.

Gas Cooled Reactor discharging to a river

The estimated doses received by the different age groups from generic discharges (given in A4.2) are given in the table below.

Table C 12 Estimated doses due to a release to a river for a gas cooled reactor discharge scenario. The doses to the age groups of 3 month-old, 5 y-old and 15 y-old consider PC CREAM pathways only.

Age group	Individual Dose (μSv y^{-1})
1 y	1.3
5 y	15
10 y	16
15 y	22
Adult	22

For 1 y olds, the dominant pathways are exposure on riverbanks (63%) and consumption of fish (28%).

For 10 y olds and adults, the dominant pathways are exposure on riverbanks (89% and 64%), and consumption of fish (10% and 35%).

^{137}Cs is the dominant radionuclide (>83%) for all age groups.

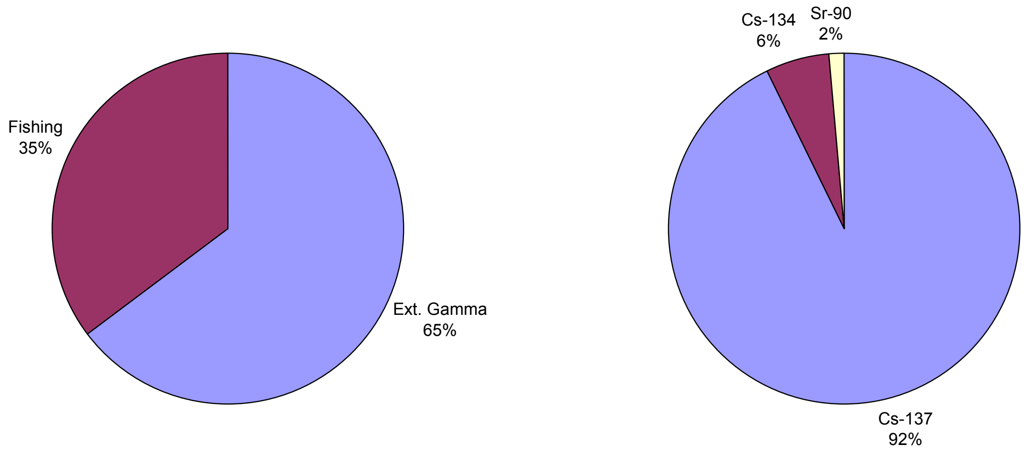


Figure C 6 Breakdown of individual dose to an adult due to aquatic discharges from a typical GCR discharging to a river by pathway and radionuclide. (Currently, only pathways with a contribution greater than 5% of total dose and radionuclides with a contribution greater than 1% are plotted, 'others' categories to be included, therefore percentages do not currently agree with the text)

Other pathways, which should only be considered when local data indicates a habit is present:

- Exposure on boats (houseboats). Dose to all age groups 6 μSv y^{-1}.
- Consumption of freshwater molluscs and crustaceans. 10 y old dose: 1.4 μSv y^{-1}, Adult dose: 3.9 μSv y^{-1}.

Other 'unconventional' pathways considered which did not contribute significantly to dose for any age group: ingestion of animal meat/milk from animals drinking river water, ingestion of river plants, ingestion of waterfowl, ingestion of crops irrigated by river water, ingestion of crops on soil conditioned by river plants, ingestion of crops grown on previously flooded land, ingestion of water whilst swimming, exposure whilst swimming, exposure on boats (recreational).

C4.3 Reprocessing Plant

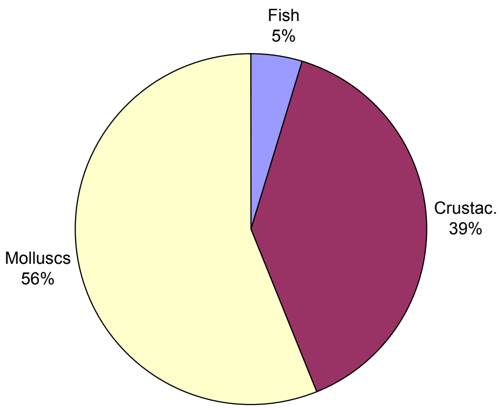
It was assumed that reprocessing plants discharge only into marine environments, and therefore discharges to an estuary, or river were not modelled. There are currently two reprocessing plants in the European Union: Sellafield, UK and Cap de la Hague, France. Both of these have been considered below.

Reprocessing plant discharging to marine

Cap de la Hague

The most important radionuclide for 1 y olds was found to be ^{14}C (94%), for 10 y olds ^{106}Ru (52%) and ^{14}C (46%) and for adults ^{14}C (56%) and ^{106}Ru (40%). No other radionuclides had contributions greater than 5%.

The most significant pathway for 1 y olds is fish consumption (98%). The most significant pathways for 10 y olds are the consumption of crustaceans (63%) and the consumption of molluscs (34%). The most significant pathways for adults are the consumption of crustaceans (56%), the consumption of molluscs (39%) and the consumption of fish (5%).



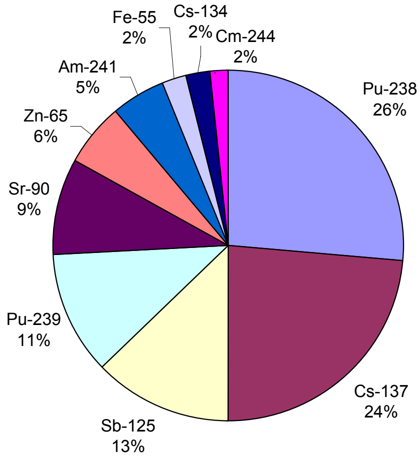


Figure C 7 Breakdown of individual dose to an adult due to aquatic discharges from Cap de la Hague by pathway and radionuclide. (Currently, only pathways with a contribution greater than 5% of total dose and radionuclides with a contribution greater than 1% are plotted, 'others' categories to be included, therefore percentages do not currently agree with the text)

Another pathway that should only be considered when local data indicates the habit is present is the ingestion of marine plants. 10 y old dose: 13 % of dose from conventional pathways, adult dose: 31%. (^{106}Ru and ^{14}C are the dominant radionuclides for this pathway).

Sellafield

The most important radionuclide for 10 y olds and adults was found to be ^{99}Tc (32% and 23% respectively), and ^{14}C (32%) for 1 y olds. Other radionuclides with percentage contributions greater than 5% were ^{65}Zn, ^{125}Sb, ^{152}Eu, ^{154}Eu.

The two most significant pathways for 1 y olds are the consumption of fish (77%) and external exposure (gamma) to sediments (22%). The most significant pathways for 10 y olds are the consumption of crustaceans (48%), external exposure to sediments (22%), consumption of molluscs (14%) and the consumption of fish (12%).

The most significant pathways for adults are external exposure to sediments (39%), consumption of crustaceans (37%), the consumption of fish (12%), and consumption of molluscs (9%).

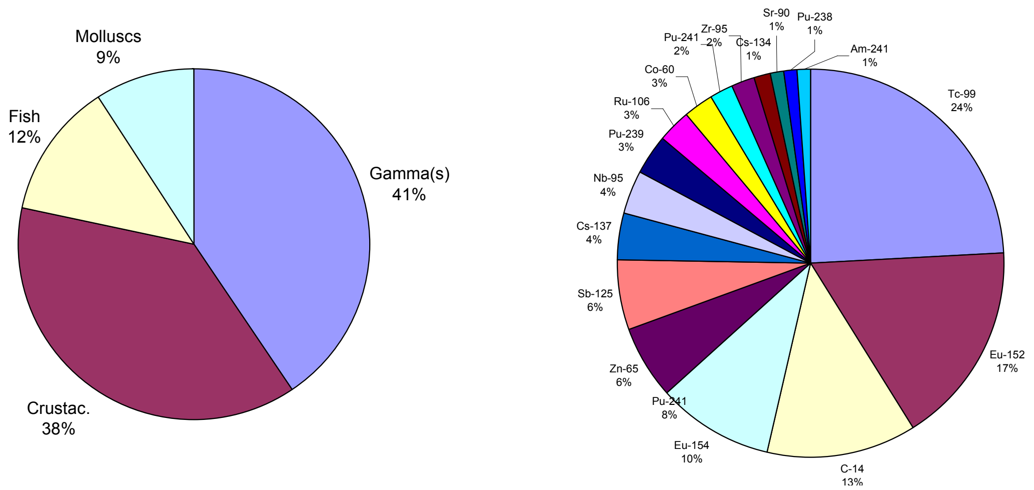


Figure C 8 Breakdown of individual dose to an adult due to aquatic discharges from Sellafield by pathway and radionuclide. (Currently, only pathways with a contribution greater than 5% of total dose and radionuclides with a contribution greater than 1% are plotted, 'others' categories to be included, therefore percentages do not currently agree with the text)

Other pathways, which should only be considered when local data indicates a habit is present:

- Ingestion of marine plants. 10 y old dose: 91% of dose from conventional pathways, adult dose: 33%. (^{106}Ru, ^{99}Tc, ^{14}C and ^{129}I are the dominant radionuclides for this pathway)

- Ingestion of other marine biota. 1 y old dose was not calculated, 10 y old dose: 280 % of dose from conventional pathways, adult dose: 292 %. (^{241}Am and ^{239}Pu are the dominant radionuclides for this pathway)
- Ingestion of animal meat from animals grazing on salt marsh. 1 y old dose: 13 % of dose from conventional pathways, 10 y old dose: 112 %, adult dose: 161 %. (^{137}Cs is the dominant radionuclide for this pathway)
- Ingestion of animal milk from animals grazing on salt marsh. 1 y old dose: 528 % of dose from conventional pathways, 10 y old dose: 146 %, adult dose: 141 %. (^{137}Cs is the dominant radionuclide for this pathway)
- Ingestion of crops on soil conditioned by seaweed. 1 y old dose: 165 % of dose from conventional pathways, 10 y old dose: 32 %, adult dose: 9 %. (^{99}Tc is the dominant radionuclide for this pathway)

Other 'unconventional' pathways considered which did not contribute significantly to dose for any age group: ingestion of crops grown on coastal area exposed to sea spray and farming of crops on land reclaimed from the sea

C5 GROUPED RESULTS

From the assessments carried out for the three discharge scenarios detailed above and for releases into the four receiving bodies of water, it was possible to compile tables listing the most important exposure pathways (in order of importance) for each age group. These tables detail the dominant pathways grouped over discharge scenario, for each of the receiving bodies of water.

Table C13 Principal exposure pathways following releases to the marine environment for a 1 y-old child

Radionuclide	Dominant pathways
^{3}H	Ingestion of foodstuffs (fish)
^{14}C	Ingestion of foodstuffs (fish)
^{35}S	Ingestion of foodstuffs (fish)
^{58}Co	Ingestion of foodstuffs (fish), External exposure (gamma) to sediments
^{60}Co	Ingestion of foodstuffs (fish), External exposure (gamma) to sediments
^{63}Ni	Ingestion of foodstuffs (fish)
^{65}Zn	Ingestion of foodstuffs (fish), External exposure (gamma) to sediments
^{90}Sr	Ingestion of foodstuffs (fish)
^{99}Tc	Ingestion of foodstuffs (fish)
^{106}Ru	Inadvertent ingestion of sediments, Ingestion of foodstuffs (fish)
^{110m}Ag	Ingestion of foodstuffs (fish)
^{131}I	Ingestion of foodstuffs (fish)
^{134}Cs	Ingestion of foodstuffs (fish)
^{137}Cs	Ingestion of foodstuffs (fish), External exposure (gamma) to sediments
^{238}Pu	Ingestion of foodstuffs (fish)
^{239}Pu	Ingestion of foodstuffs (fish)
^{241}Pu	Ingestion of foodstuffs (fish)
^{241}Am	Inadvertent ingestion of sediments

Table C14 Principal exposure pathways following releases to the marine environment for a 5 y-old child

Radionuclide	Dominant pathways
^{3}H	Ingestion of foodstuffs (fish, crustaceans)
^{14}C	Ingestion of foodstuffs (fish, crustaceans)
^{35}S	Ingestion of foodstuffs (fish, crustaceans, molluscs)
^{58}Co	Ingestion of foodstuffs (crustaceans, molluscs)
^{60}Co	Ingestion of foodstuffs (crustaceans, molluscs), External exposure (gamma) to sediments
^{63}Ni	Ingestion of foodstuffs (crustaceans, fish)
^{65}Zn	Ingestion of foodstuffs (crustaceans, molluscs)
^{90}Sr	Ingestion of foodstuffs (fish, crustaceans)
^{99}Tc	Ingestion of foodstuffs (crustaceans, molluscs)
^{106}Ru	Ingestion of foodstuffs (molluscs, crustaceans)
^{110m}Ag	Ingestion of foodstuffs (crustaceans, molluscs)
^{131}I	Ingestion of foodstuffs (crustaceans, molluscs)
^{134}Cs	Ingestion of foodstuffs (crustaceans, molluscs), External exposure (gamma) to sediments
^{137}Cs	Ingestion of foodstuffs (crustaceans, molluscs), External exposure (gamma) to sediments
^{238}Pu	Ingestion of foodstuffs (molluscs, crustaceans)
^{239}Pu	Ingestion of foodstuffs (molluscs, crustaceans)
^{241}Pu	Ingestion of foodstuffs (molluscs, crustaceans)
^{241}Am	Ingestion of foodstuffs (molluscs), External exposure (gamma) to sediments

(Above table relates to PC-Cream pathways alone)

Table C15 Principal exposure pathways following releases to the marine environment for a 10 y-old child

Radionuclide	Dominant pathways
^{3}H	Ingestion of foodstuffs (fish, crustaceans)
^{14}C	Ingestion of foodstuffs (fish, crustaceans)
^{35}S	Ingestion of foodstuffs (fish, crustaceans)
^{58}Co	Ingestion of foodstuffs (crustaceans), External exposure (gamma) to sediments
^{60}Co	Ingestion of foodstuffs (crustaceans), External exposure (gamma) to sediments
^{63}Ni	Ingestion of foodstuffs (crustaceans, molluscs)
^{65}Zn	Ingestion of foodstuffs (crustaceans, molluscs)
^{90}Sr	Ingestion of foodstuffs (crustaceans, molluscs)
^{99}Tc	Ingestion of foodstuffs (crustaceans, molluscs)
^{106}Ru	Ingestion of foodstuffs (molluscs, crustaceans)
^{110m}Ag	Ingestion of foodstuffs (crustaceans, molluscs)
^{131}I	Ingestion of foodstuffs (crustaceans, molluscs)
^{134}Cs	Ingestion of foodstuffs (crustaceans, molluscs), External exposure (gamma) to sediments
^{137}Cs	Ingestion of foodstuffs (crustaceans, molluscs, fish)
^{238}Pu	Ingestion of foodstuffs (molluscs, crustaceans), Inadvertent ingestion of sediments
^{239}Pu	Ingestion of foodstuffs (molluscs, crustaceans), Inadvertent ingestion of sediments
^{241}Pu	Ingestion of foodstuffs (molluscs, crustaceans), Inadvertent ingestion of sediments
^{241}Am	Inhalation of resuspended sediments, Ingestion of foodstuffs (molluscs)

Table C16 Principal exposure pathways following releases to the marine environment for a 15 y-old child

Radionuclide	Dominant pathways
^{3}H	Ingestion of foodstuffs (fish, crustaceans)
^{14}C	Ingestion of foodstuffs (fish, crustaceans)
^{35}S	Ingestion of foodstuffs (fish, crustaceans, molluscs)
^{58}Co	External exposure (gamma) to sediments, Ingestion of foodstuffs (crustaceans, molluscs)
^{60}Co	External exposure (gamma) to sediments, Ingestion of foodstuffs (crustaceans, molluscs)
^{63}Ni	Ingestion of foodstuffs (crustaceans, fish)
^{65}Zn	Ingestion of foodstuffs (crustaceans)
^{90}Sr	Ingestion of foodstuffs (crustaceans, fish)
^{99}Tc	Ingestion of foodstuffs (crustaceans, molluscs)
^{106}Ru	Ingestion of foodstuffs (molluscs, crustaceans)
^{110m}Ag	Ingestion of foodstuffs (crustaceans, molluscs), External exposure (gamma) to sediments
^{131}I	Ingestion of foodstuffs (crustaceans, molluscs)
^{134}Cs	External exposure (gamma) to sediments, Ingestion of foodstuffs (crustaceans, molluscs, fish)
^{137}Cs	External exposure (gamma) to sediments, Ingestion of foodstuffs (crustaceans, molluscs, fish)
^{238}Pu	Ingestion of foodstuffs (molluscs, crustaceans)
^{239}Pu	Ingestion of foodstuffs (molluscs, crustaceans)
^{241}Pu	Ingestion of foodstuffs (molluscs, crustaceans)
^{241}Am	Ingestion of foodstuffs (molluscs), External exposure (gamma) to sediments

(Above table relates to PC-Cream pathways alone)

Table C17 Principal exposure pathways following releases to the marine environment for an adult

Radionuclide	Dominant pathways
^{3}H	Ingestion of foodstuffs (fish, crustaceans)
^{14}C	Ingestion of foodstuffs (fish, crustaceans)
^{35}S	Ingestion of foodstuffs (fish, crustaceans, molluscs)
^{58}Co	Ingestion of foodstuffs (crustaceans, molluscs)
^{60}Co	Ingestion of foodstuffs (crustaceans, molluscs), External exposure (gamma) to sediments
^{63}Ni	Ingestion of foodstuffs (crustaceans, molluscs)
^{65}Zn	Ingestion of foodstuffs (crustaceans)
^{90}Sr	Ingestion of foodstuffs (fish, crustaceans)
^{99}Tc	Ingestion of foodstuffs (crustaceans, molluscs)
^{106}Ru	Ingestion of foodstuffs (molluscs, crustaceans)
^{110m}Ag	Ingestion of foodstuffs (crustaceans, molluscs, fish)
^{131}I	Ingestion of foodstuffs (crustaceans, molluscs, fish)
^{134}Cs	Ingestion of foodstuffs (crustaceans, molluscs, fish), External exposure (gamma) to sediments
^{137}Cs	Ingestion of foodstuffs (crustaceans, molluscs, fish), External exposure (gamma) to sediments
^{238}Pu	Ingestion of foodstuffs (crustaceans, molluscs)
^{239}Pu	Ingestion of foodstuffs (crustaceans, molluscs)
^{241}Pu	Ingestion of foodstuffs (crustaceans, molluscs)
^{241}Am	Ingestion of foodstuffs (molluscs), External exposure (gamma) to sediments

The results for the five discharge scenarios considered are summarised in the following table. The dominant pathways and radionuclides are presented.

Table C18 Principal exposure pathways and radionuclides following releases to the marine environment

Age	Discharge Scenario					
Group	Reprocessing Plant		GCR		PWR	
1 y	Fish	^{14}C	Fish	^{137}Cs	Fish/ External Exposure	^{60}Co
5 y	Fish	$^{239}Pu/^{241}Am$	External Exposure/ Fish	^{137}Cs	Crustaceans / Molluscs	$^{60}Co/^{110m}Ag$
10 y	Crustaceans/ Molluscs / External Exposure	$^{99}Tc/^{14}C$	Fish/ Crustaceans / External Exposure	^{137}Cs	Crustaceans / Molluscs	$^{60}Co/^{110m}Ag$
15 y	Fish/ Crustaceans / External Exposure	$^{99}Tc/^{152}Eu$	External Exposure/ Fish	^{137}Cs	Crustaceans / Molluscs	$^{137}Cs/ ^{60}Co$
Adult	Crustaceans/ External Exposure	$^{99}Tc/^{152}Eu$	Fish/ External Exposure	^{137}Cs	Crustaceans / Molluscs	$^{60}Co/^{110m}Ag$

Shaded boxes indicate highest dose is to that age group

Table C19 Principal exposure pathways following releases to an estuarine environment for a 1 y-old child

Radionuclide	Dominant pathways
^{3}H	Ingestion of foodstuffs (fish)
^{35}S	Ingestion of foodstuffs (fish)
^{58}Co	Ingestion of foodstuffs (fish), External exposure (gamma) to sediments
^{60}Co	Ingestion of foodstuffs (fish), External exposure (gamma) to sediments
^{63}Ni	Ingestion of foodstuffs (fish)
^{90}Sr	Ingestion of foodstuffs (fish)
^{110m}Ag	Ingestion of foodstuffs (fish)
^{134}Cs	Ingestion of foodstuffs (fish)
^{137}Cs	Ingestion of foodstuffs (fish), External exposure (gamma) to sediments

Table C20 Principal exposure pathways following releases to an estuarine environment for a 5 y-old child

Radionuclide	Dominant pathways
^{3}H	Ingestion of foodstuffs (crustaceans, molluscs, fish)
^{35}S	Ingestion of foodstuffs (fish, crustaceans, molluscs)
^{58}Co	Ingestion of foodstuffs (crustaceans, molluscs)
^{60}Co	Ingestion of foodstuffs (crustaceans, molluscs)
^{63}Ni	Ingestion of foodstuffs (crustaceans, molluscs, fish)
^{90}Sr	Ingestion of foodstuffs (crustaceans, fish, molluscs)
^{110m}Ag	Ingestion of foodstuffs (crustaceans, molluscs)
^{134}Cs	Ingestion of foodstuffs (crustaceans, fish, molluscs)
^{137}Cs	Ingestion of foodstuffs (crustaceans, fish, molluscs), External exposure (gamma) to sediments

(Above table relates to PC-Cream pathways alone)

Table C21 Principal exposure pathways following releases to an estuarine environment for a 10 y-old child

Radionuclide	Dominant pathways
^{3}H	Ingestion of foodstuffs (crustaceans, fish, molluscs)
^{35}S	Ingestion of foodstuffs (fish, crustaceans, molluscs)
^{58}Co	Ingestion of foodstuffs (crustaceans, molluscs)
^{60}Co	Ingestion of foodstuffs (crustaceans, molluscs), External exposure (gamma) to sediments
^{63}Ni	Ingestion of foodstuffs (crustaceans, molluscs, fish)
^{90}Sr	Ingestion of foodstuffs (crustaceans, fish)
^{110m}Ag	Ingestion of foodstuffs (crustaceans, molluscs)
^{134}Cs	Ingestion of foodstuffs (crustaceans, fish, molluscs)
^{137}Cs	Ingestion of foodstuffs (crustaceans, fish, molluscs)

Table C22 Principal exposure pathways following releases to an estuarine environment for a 15 y-old child

Radionuclide	Dominant pathways
^{3}H	Ingestion of foodstuffs (crustaceans, fish, molluscs)
^{35}S	Ingestion of foodstuffs (fish, crustaceans, molluscs)
^{58}Co	Ingestion of foodstuffs (crustaceans, molluscs)
^{60}Co	External exposure (gamma) to sediments, Ingestion of foodstuffs (crustaceans, molluscs)
^{63}Ni	Ingestion of foodstuffs (crustaceans, molluscs, fish)
^{90}Sr	Ingestion of foodstuffs (crustaceans, fish)
^{110m}Ag	Ingestion of foodstuffs (crustaceans, molluscs)
^{134}Cs	Ingestion of foodstuffs (crustaceans, fish, molluscs)
^{137}Cs	External exposure (gamma) to sediments, Ingestion of foodstuffs (crustaceans, molluscs, fish)

(Above table relates to PC-Cream pathways alone)

Table C23 Principal exposure pathways following releases to an estuarine environment for an adult

Radionuclide	Dominant pathways
^{3}H	Ingestion of foodstuffs (crustaceans, fish)
^{35}S	Ingestion of foodstuffs (fish, crustaceans, molluscs)
^{58}Co	Ingestion of foodstuffs (crustaceans, molluscs)
^{60}Co	Ingestion of foodstuffs (crustaceans, molluscs), External exposure (gamma) to sediments
^{63}Ni	Ingestion of foodstuffs (crustaceans, molluscs, fish)
^{90}Sr	Ingestion of foodstuffs (crustaceans, fish)
^{110m}Ag	Ingestion of foodstuffs (crustaceans, molluscs)
^{134}Cs	Ingestion of foodstuffs (crustaceans, fish, molluscs)
^{137}Cs	Ingestion of foodstuffs (crustaceans, fish, molluscs), External exposure (gamma) to sediments

The results for the five discharge scenarios considered are summarised in the following table. The dominant pathways and radionuclides are presented.

Table C24 Principal exposure pathways and radionuclides following releases to an estuarine environment

Age	Discharge Scenario			
Group	GCR		PWR	
1 y	Fish / External Exposure	$^{137}Cs/^{134}Cs$	Fish/ External Exposure	$^{60}Co/^{110}Ag$
5 y	Fish/ Crustaceans / External Exposure	$^{137}Cs/^{134}Cs$	Crustaceans/ Molluscs / External Exposure	$^{60}Co/^{110}Ag$
10 y	Fish/ Crustaceans / External Exposure	$^{137}Cs/^{134}Cs$	Crustaceans/ Molluscs / External Exposure	$^{60}Co/^{110}Ag$
15 y	Fish/ Crustaceans / External Exposure	$^{137}Cs/^{134}Cs$	Crustaceans/ Molluscs / External Exposure	$^{60}Co/^{110}Ag$
Adult	Fish/ Crustaceans / External Exposure	$^{137}Cs/^{134}Cs$	Crustaceans/ Molluscs / External Exposure	$^{60}Co/^{110}Ag$

Shaded boxes indicate highest dose is to that age group

Table C25 Principal exposure pathways following releases to a river environment for a 1 y-old child

Radionuclide	Dominant pathways
^{3}H	Ingestion of drinking water
^{14}C	Ingestion of foodstuffs (fish)
^{32}P	Ingestion of drinking water
^{35}S	Ingestion of foodstuffs (fish), Ingestion of drinking water
^{58}Co	External exposure (gamma) from riverbank, Ingestion of foodstuffs (fish)
^{60}Co	External exposure (gamma) from riverbank
^{90}Sr	Ingestion of drinking water, Ingestion of foodstuffs (fish)
^{110m}Ag	Ingestion of drinking water
^{131}I	Ingestion of drinking water, Ingestion of foodstuffs (fish)
^{134}Cs	External exposure (gamma) from riverbank, Ingestion of foodstuffs (fish)
^{137}Cs	External exposure (gamma) from riverbank, Ingestion of foodstuffs (fish)

Table C26 Principal exposure pathways following releases to a river environment for a 5 y-old child

Radionuclide	Dominant pathways
^{3}H	Ingestion of drinking water
^{14}C	Ingestion of foodstuffs (fish)
^{32}P	Ingestion of foodstuffs (fish)
^{35}S	Ingestion of drinking water, Ingestion of foodstuffs (fish),
^{58}Co	External exposure (gamma) from riverbank
^{60}Co	External exposure (gamma) from riverbank
^{90}Sr	Ingestion of foodstuffs (fish), Ingestion of drinking water
^{110m}Ag	External exposure (gamma) from riverbank, Ingestion of drinking water
^{131}I	Ingestion of drinking water, Ingestion of foodstuffs (fish)
^{134}Cs	External exposure (gamma) from riverbank, Ingestion of foodstuffs (fish)
^{137}Cs	External exposure (gamma) from riverbank, Ingestion of foodstuffs (fish)

(Above table relates to PC-Cream pathways alone)

Table C27 Principal exposure pathways following releases to a river environment for a 10 y-old child

Radionuclide	Dominant pathways
^{3}H	Ingestion of drinking water
^{14}C	Ingestion of foodstuffs (fish)
^{32}P	Ingestion of drinking water
^{35}S	Ingestion of foodstuffs (fish), Ingestion of drinking water
^{58}Co	External exposure (gamma) from riverbank
^{60}Co	External exposure (gamma) from riverbank
^{90}Sr	Ingestion of foodstuffs (fish), Ingestion of drinking water
^{110m}Ag	External exposure (gamma) from riverbank, Ingestion of drinking water
^{131}I	Ingestion of drinking water, Ingestion of foodstuffs (fish)
^{134}Cs	External exposure (gamma) from riverbank, Ingestion of foodstuffs (fish)
^{137}Cs	External exposure (gamma) from riverbank, Ingestion of foodstuffs (fish)

Table C28 Principal exposure pathways following releases to a river environment for a 15 y-old child

Radionuclide	Dominant pathways
^{3}H	Ingestion of drinking water
^{14}C	Ingestion of foodstuffs (fish)
^{32}P	Ingestion of drinking water
^{35}S	Ingestion of foodstuffs (fish), Ingestion of drinking water
^{58}Co	External exposure (gamma) from riverbank
^{60}Co	External exposure (gamma) from riverbank
^{90}Sr	Ingestion of foodstuffs (fish), Ingestion of drinking water
^{110m}Ag	External exposure (gamma) from riverbank, Ingestion of drinking water
^{131}I	Ingestion of foodstuffs (fish), Ingestion of drinking water
^{134}Cs	Ingestion of foodstuffs (fish), External exposure (gamma) from riverbank
^{137}Cs	Ingestion of foodstuffs (fish), External exposure (gamma) from riverbank

(Above table relates to PC-Cream pathways alone)

Table C29 Principal exposure pathways following releases to a river environment for an adult

Radionuclide	Dominant pathways
^{3}H	Ingestion of drinking water
^{14}C	Ingestion of foodstuffs (fish)
^{32}P	Ingestion of drinking water
^{35}S	Ingestion of foodstuffs (fish), Ingestion of drinking water
^{58}Co	External exposure (gamma) from riverbank, Ingestion of foodstuffs (fish)
^{60}Co	External exposure (gamma) from riverbank
^{90}Sr	Ingestion of foodstuffs (fish), Ingestion of drinking water
^{110m}Ag	External exposure (gamma) from riverbank, Ingestion of drinking water
^{131}I	Ingestion of foodstuffs (fish), Ingestion of drinking water
^{134}Cs	Ingestion of foodstuffs (fish), External exposure (gamma) from riverbank
^{137}Cs	Ingestion of foodstuffs (fish), External exposure (gamma) from riverbank

Table C30 Principal exposure pathways and radionuclides following releases to a river environment

Age	Discharge Scenario			
Group	GCR		PWR	
1 y	External Exposure/ Fish Ingestion	$^{137}Cs/^{90}Sr$	External Exposure/ Fish Ingestion	$^{60}Co/^{137}Cs$
5 y	External Exposure/ Fish Ingestion	^{137}Cs	External Exposure	$^{60}Co/^{137}Cs$
10 y	External Exposure/ Fish Ingestion	^{137}Cs	External Exposure	$^{60}Co/^{137}Cs$
15 y	External Exposure/ Fish Ingestion	^{137}Cs	External Exposure/ Fish Ingestion	$^{60}Co/^{137}Cs$
Adult	External Exposure/ Fish Ingestion	^{137}Cs	External Exposure/ Fish Ingestion	$^{60}Co/^{137}Cs$

Shaded boxes indicate highest dose is to that age group

C6 INFLUENCE OF CONSUMPTION HABITS

The results presented so far in this appendix were obtained using consumption rates applicable to the UK. To examine the effect of using consumption rates applicable to other EU countries, the doses were re-estimated using data for other EU countries, as presented in appendix D.

The results for a PWR discharge to the marine environment are shown in Figure C 9. The total dose to an individual in the UK was calculated to be 0.38 μSv y^{-1}, in Denmark 1.0 μSv y^{-1} and in Italy 1.2 μSv y^{-1}.

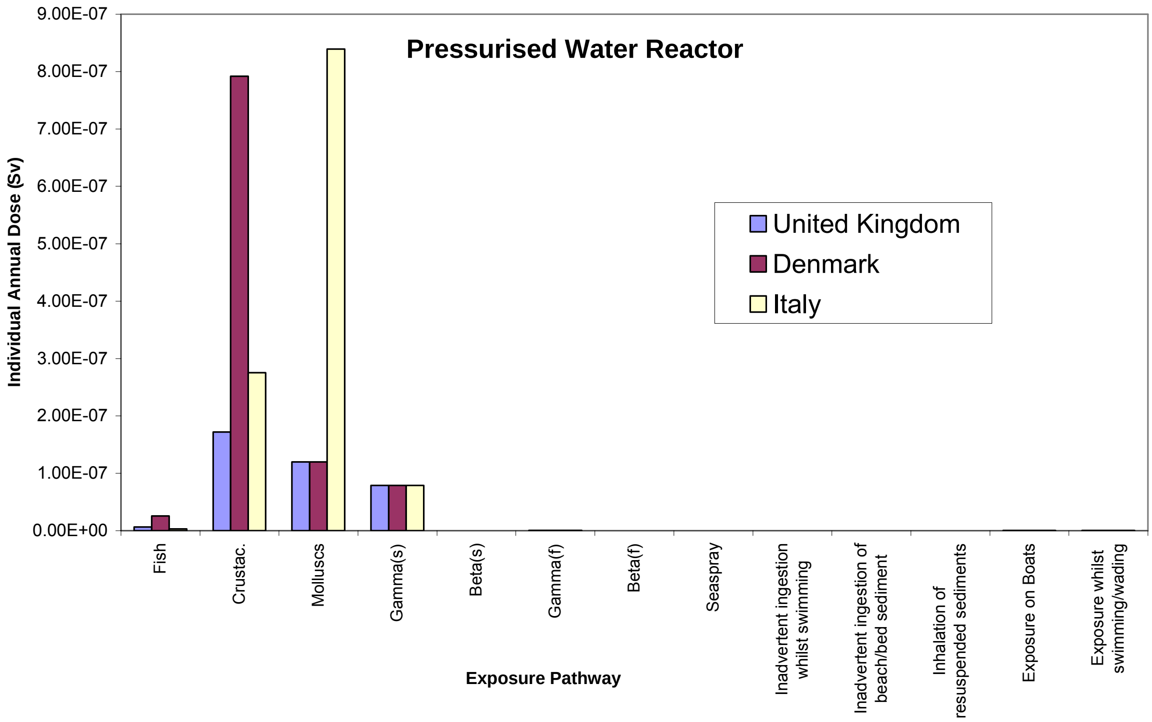


Figure C 9 Calculated doses by pathway for a discharge from a pressurised water reactor to the marine assuming UK, Danish and Italian consumption rates (see appendix D)

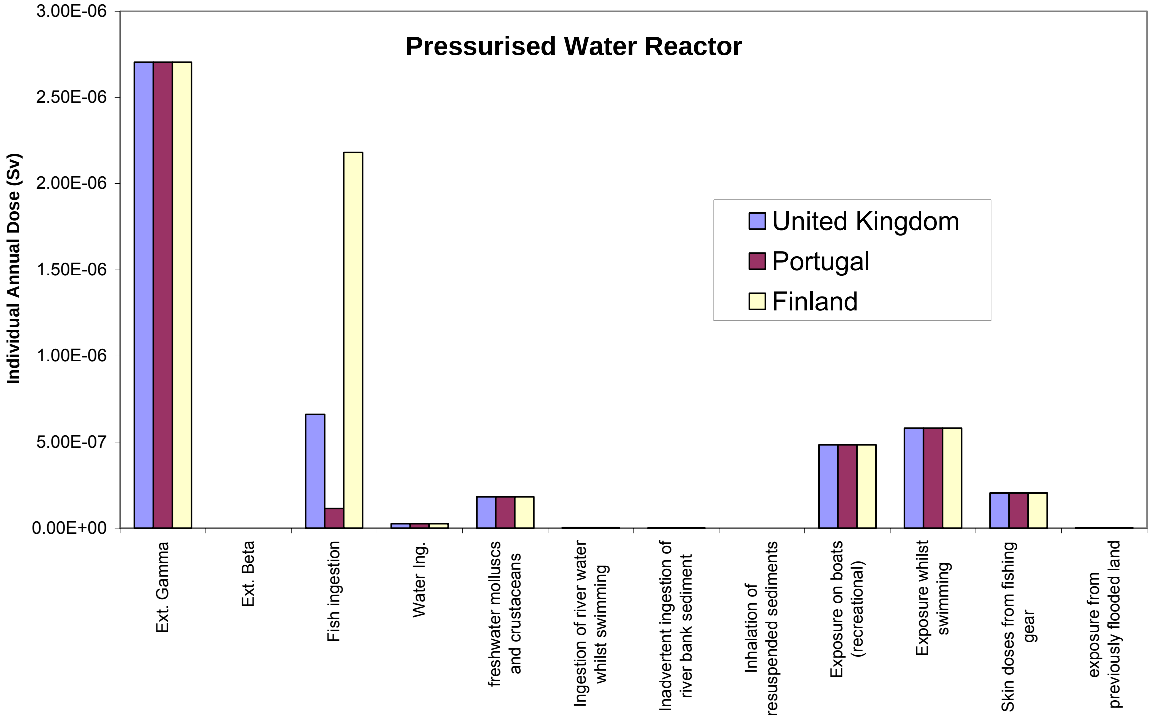


Figure C 10 Calculated doses by pathway for a discharge from a pressurised water reactor to a river assuming UK, Portuguese and Finnish consumption rates (see appendix D)

The results for a PWR discharge to a river are shown in Figure C 10. The total dose to an individual in the UK was calculated to be 4.9 μSv y^{-1}, the dose to an individual in Portugal was calculated to be 4.3 μSv y^{-1}, and the dose to an individual in Finland was calculated to be 6.4 μSv y^{-1}.

Although there are not large differences between the doses differences do exist. This illustrates the importance of using site specific consumption rates when available.

C7 UNIT RELEASES

Doses were also estimated for releases at unit rates (1 GBq y^{-1}) for a range of radionuclides. These radionuclides were chosen to represent differing behaviours in the environment and so illustrate the significance of this in terms the pathways through which individuals are exposed.

These calculations are generic, and therefore should not be used for scaling doses. As dispersion is very dependent on the local aquatic conditions, it is important to use site specific information where possible.

C7.1 Marine Discharges

An assessment was carried out for two sites, assuming unit releases from each site. This was to ensure that the conclusions drawn were not specific to one set of local conditions. The local boxes of the two sites had different volumes, exchange rates, suspended sediment load and sedimentation rate. Therefore, the average of the results from the two sites would be more representative than results from a single site, when considering a generic discharge. The important pathways in each assessment were compared, found to be similar. The percentage contribution of each pathway in Figure C 11 is the average contribution of that pathway for both sites.

Table C31 Unit releases modelled for the marine environment

Unit releases (1 GBq y^{-1})
^{60}Co
^{99}Tc
^{106}Ru
^{137}Cs
^{239}Pu
^{241}Am

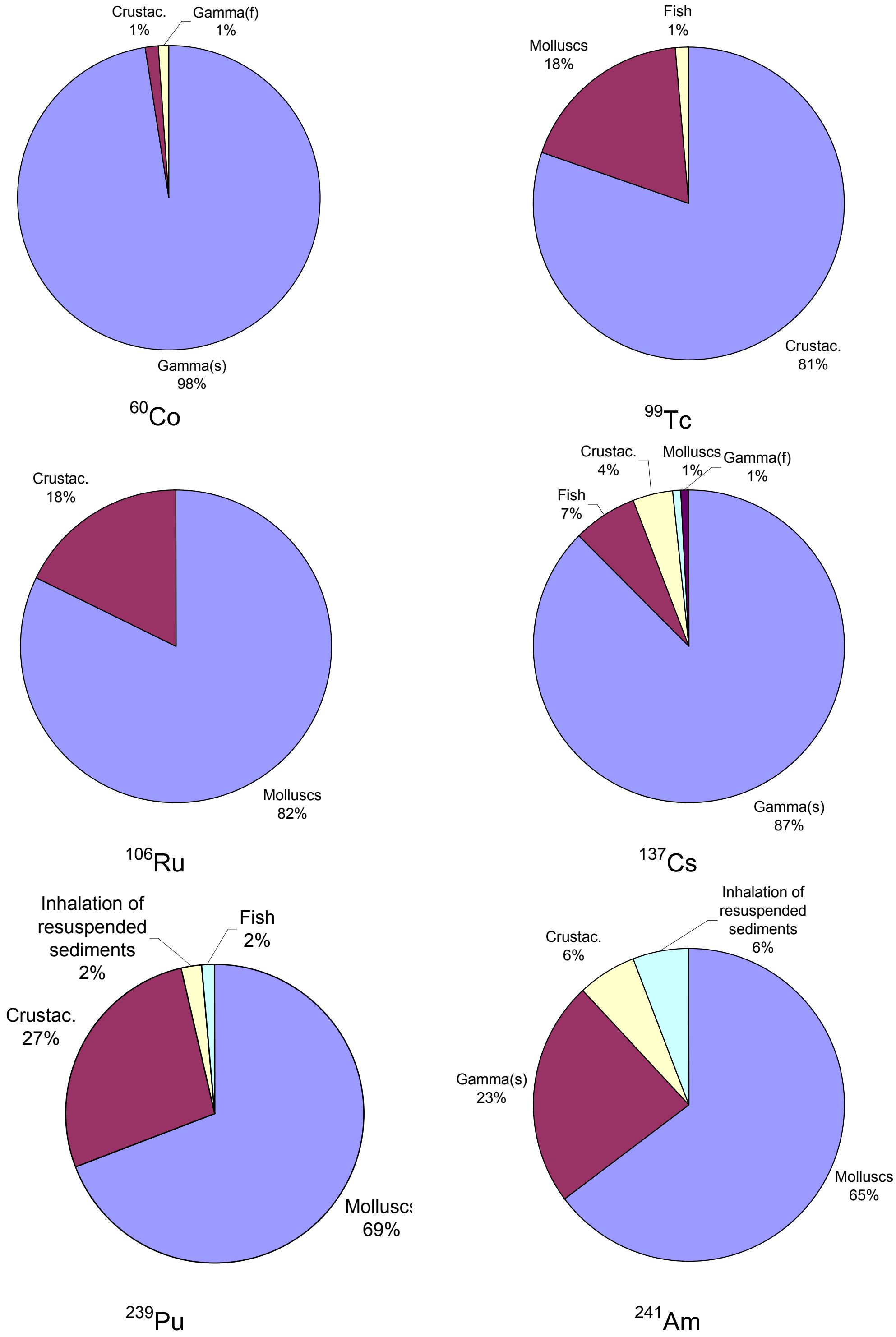


Figure C 11 Breakdown of individual dose to an adult due to a unit release of a nuclide to a marine environment is shown by pathway. (Currently, only pathways with a contribution greater than 1% of total dose are plotted, 'others' categories to be included, therefore percentages do not currently agree with the text)

The resulting doses to each age group by radionuclide are given in Table C32. The doses to the age groups of 3 month-old, 5 y-old and 15 y-old consider PC CREAM pathways only.

Table C32 Estimated doses calculated for unit releases to the marine environment

	Dose (μSv y^{-1})				
Radionuclide	1 y-old	5 y-old*	10 y-old	15 y-old*	Adult
Co-60	7.7 10^{-3}	8.1 10^{-2}	8.2 10^{-2}	8.0 10^{-1}	5.1 10^{-1}
Tc-99	6.9 10^{-6}	6.2 10^{-4}	6.1 10^{-4}	4.1 10^{-4}	1.4 10^{-3}
Ru-106	5.4 10^{-6}	3.5 10^{-3}	3.5 10^{-3}	2.1 10^{-3}	6.6 10^{-3}
Cs-137	2.8 10^{-4}	2.3 10^{-3}	2.5 10^{-3}	2.6 10^{-2}	1.6 10^{-2}
Pu-239	6.7 10^{-4}	3.6 10^{-2}	5.4 10^{-2}	4.5 10^{-2}	1.9 10^{-1}
Am-241	9.5 10^{-4}	1.8 10^{-2}	2.8 10^{-2}	2.1 10^{-2}	9.6 10^{-2}

* doses to these age groups presented for PC CREAM pathways only

C7.2 River Discharges

For this assessment, a major European river was modelled. The pathway contributions are only illustrative as discharging to a river with different flow or volume may alter the results significantly.

Table C33 Unit releases modelled for the river environment

Unit releases (1 GBq y^{-1})
^{3}H
^{60}Co
^{137}Cs
^{239}Pu

The resulting doses to each age group by radionuclide are given in Table C34 below. The doses to the age groups of 3 month-old, 5 y-old and 15 y-old consider PC CREAM pathways only.

Table C34 Estimated doses calculated for unit releases to the river environment

	Dose (μSv y^{-1})				
Radionuclide	1 y-old	5 y-old*	10 y-old	15 y-old*	Adult
^{3}H	3.2 10^{-7}	2.8 10^{-7}	2.1 10^{-7}	2.8 10^{-7}	2.9 10^{-7}
^{60}Co	1.3 10^{-2}	1.6 10^{-1}	1.6 10^{-1}	1.6 10^{-1}	1.6 10^{-1}
^{137}Cs	6.3 10^{-3}	4.5 10^{-2}	5.0 10^{-2}	4.6 10^{-2}	8.9 10^{-2}
^{239}Pu	6.7 10^{-4}	2.7 10^{-4}	9.1 10^{-3}	2.8 10^{-4}	7.7 10^{-2}

* doses to these age groups presented for PC CREAM pathways only

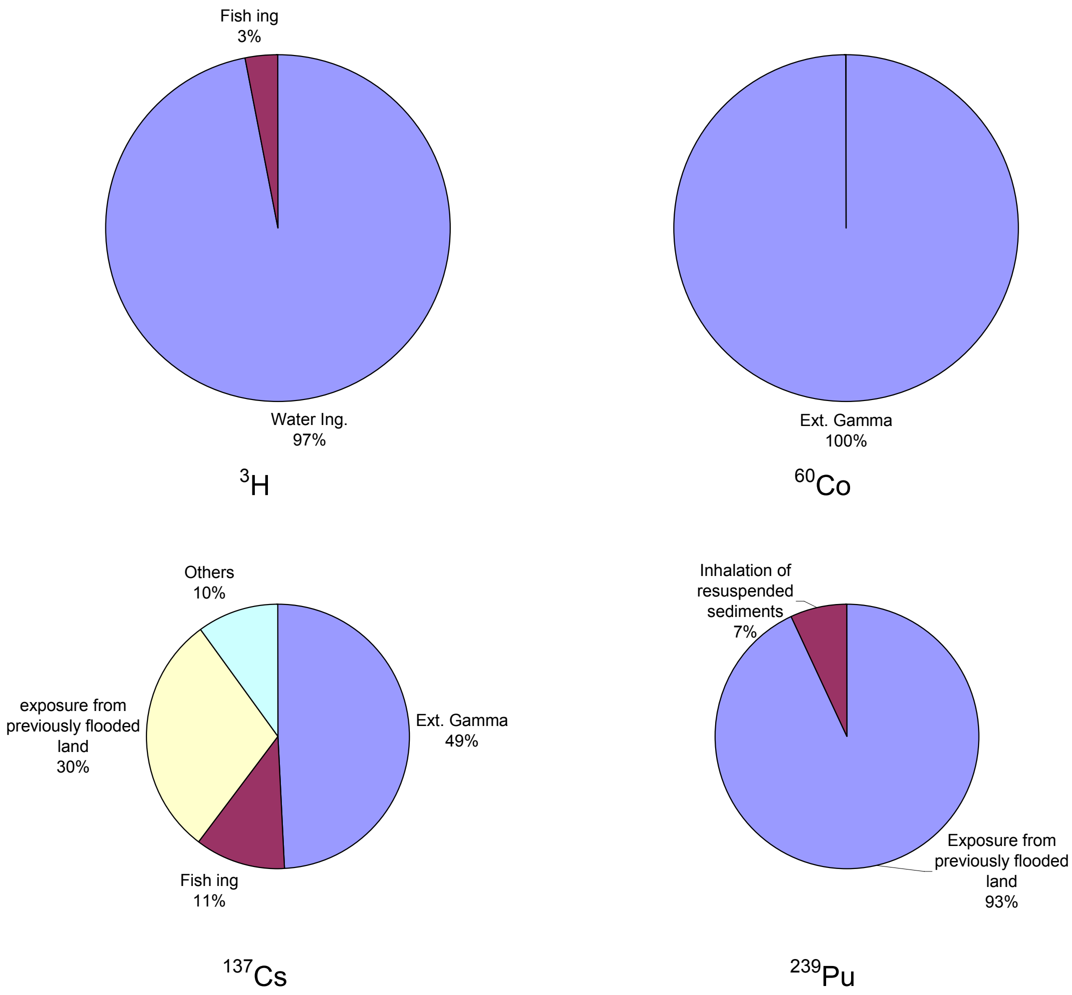


Figure C 12 Breakdown of individual dose to an adult due to a unit release of a nuclide to a river is shown by pathway. (Currently, only pathways with a contribution greater than 1% of total dose, 'others' categories to be included, therefore percentages do not currently agree with the text)

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APPENDIX D Generic data

This section details the derivation of the generic habit data given in this report. Where possible information is provided for the six age groups for which the EURATOM directive (CEC, 1996) gives dose coefficients.

D1 INHALATION RATES

The ICRP Task Group report on the model of the respiratory tract provides inhalation rates for various age groups (ICRP, 1994). These inhalation rates are calculated from ventilation rates measured at a number of exercise levels using assumptions regarding the time spent exercising at these levels for each age group. ICRP provides separate values for adults for males and females, based on a sedentary lifestyle, but for general uses the average of these inhalation rates should be used. The inhalation rates are given in Table 16 of the main text.

D2 OCCUPANCY DATA

D2.1 Indoor occupancy rates

There is the potential for reduction in dose, from external exposure and inhalation from radioactivity in the environment during periods spent inside buildings. As a result, information on the amount of time spent indoors is required for many dose assessment purposes. As stated in the recommendations there is little information available on occupancy rates. The information given in this report is based on Northern European data and there may be differences in occupancies throughout Europe depending on the climate.

Two adult population groups are of interest for general assessment purposes: Those who work predominately outdoors and those who spend a significant amount of their time indoors at home, work or school

Data on time budgets have been gathered by the Multinational Comparative Time Budget Research Project and discussed by (Szalai A, 1972) in 1972. About 30,000 people from 12 countries in Europe, the United States, Peru and the Soviet Union participated in this study. To update this study with more recent data (Roy and Courtay, 1991) reviewed data based on time budgets and activity of adults and teenagers surveys published in France by the Institut de Statistique et études économiques (Contours et Caratères, 1988; Grimer, 1989; Arnal et al. 1989; Garrigues, 1989; Galland, 1989; Roy, 1989). For children of school age, the Educational Ministry rules (Office National d'Information sur les Enseignements at les Profèssions et Ministere de l'Education Nationale, 1987) were used and for children younger than 3 years, the data were extrapolated from the mothers time budget. They cross-checked the data with those given by a TV viewing survey made by (Aglietta, 1990). Outdoor workers were not included in the INSEE surveys, for these people they assumed the same working place time budget as for sedentary workers. No relation between time spent indoors and climate was noted in these papers.

Hours spent at home, indoors elsewhere and outdoors were quoted as a percentage of daytime. The British Broadcasting Corporation (BBC) carried out a survey on the time budgets of the UK population aged 5 or over. This was summarised by (Brown, 1985) and used for the (UNSCEAR, 1998) report. Brown concluded that the average indoor occupancy is 90%, which is consistent with the numbers in Table 17 of the main text for an employed man or woman.

As very little information is available, and the review by Roy and Courtay includes data from several European countries, updated and validated with relatively recent French data, it is recommended that the values in Table 17 be adopted if no country or site specific data are available.

D2.2 Occupancy rates over intertidal area and river banks

As with the previous section there is a paucity of data on occupancy rates on intertidal areas and river banks for EU countries. The data presented in this section are based on information gathered for the UK and there will undoubtedly be variability in the occupancies over intertidal areas and river banks throughout the EU.

Table 22 in the main text gives generic occupancy rates for reference groups i.e. individuals who are likely to have very high shoreline occupancies e.g. bait diggers and fishermen.

Occupancy rates over intertidal areas for adults are based on information gathered around UK sites over a number of years for example in (Doddington et al. 1990). Data for children are based on information given in (Research Surveys of Great Britain Ltd., 1991). A lower value of 30 h y^{-1} was inferred for 1 y olds.

Occupancy rates over river banks are based on occupational data for anglers in a survey of the River Thames. The data presented in Table 22 was considered appropriate for adults and children. For 1 y olds a value of 30 h y^{-1} is given, since it is consistent with the approach for intertidal areas.

These data could be used if necessary but ideally regional or site-specific data should form the basis of a realistic assessment of doses.

D3 INGESTION RATE DATA

The consumption of foods both terrestrial and aquatic are important exposure pathways. The basis of the data presented for terrestrial food and freshwater fish intake rates is the United Nations Food and Agricultural Organisation (FAO) food supply balance sheets (FAOSTAT, 2000). These are based on statistics on population, import, export and utilisation of crops and animal products. The results therefore show the total food available for national consumption. In principle, edible parts can be estimated from these data, and consumption per capita estimated.

However one shortcoming is that, in many cases, losses and wastage between production and consumption cannot be taken into account, and so in practice this procedure is likely to overestimate the amount actually consumed. Thus for example values for meat include a proportion of bone and fat, while those for fruit include a proportion of stones and skin that would be discarded. In addition, this approach does not take any account of age or gender. To ensure losses were fully accounted for, the FAO ingestion rates were scaled by suitable data from habit surveys, and this is described in the following sections.

D3.1 Terrestrial Foods

The data derived from the FAO database for the UK have been compared with the average values for adults agreed by NRPB and the Ministry of Agriculture, Fisheries and Food, which were derived from habit surveys (Byrom et al. 1995). From Table D1 it can be seen that there is reasonable agreement between the datasets for eggs, beef and offal. The agreement for eggs and offal is expected, as there is little loss in mass during preparation of these foodstuffs. There is a factor of 1.5 to 2.5 difference between the data for pork, root vegetables, cereals, mutton, fruit and milk, all of which would have production losses. The difference between the data for poultry, green vegetables and milk products is between 3.0 and 6.7. The highest value is for milk products, where large losses during production would be expected. In order to take account of these losses, it is also assumed that the conversion factor from UK average (Byrom et al. 1995) to UK FAO intakes rates can be applied to all EU member states, in the absence of other data.

EU countries not represented in the FAO are Belgium and Luxembourg. Correspondence analysis has been done to group countries by diet (CEC, 1991), and the results of that study can be used here to group countries with no data to a country with data. Therefore using reference (CEC, 1991) Belgium and Luxembourg are grouped with Germany. The per capita consumption rate for each country obtained by following this procedure is shown in Table 18 in the main text.

The 97.5th percentile values for the UK (Byrom et al. 1995) have been used in previous studies (Robinson et al. 1994; Haywood S M, 1997) to represent the consumption rates for high rate consumers. The 97.5th percentile values were compared to the average FAO values for selected foods to calculate a conversion factor from average to high intake rates for the UK (Table D 1). It is assumed that milk, root vegetables, green vegetables and fruit are consumed at high rates while all other foods are consumed at average rates. These four food groups were chosen as they are most likely to be locally produced and consumed and to give rise to the highest doses. It is assumed that the conversion factor from average to high intake rates for the UK can be applied to all EU member states, in the absence of other data. The high consumption rate for each country is shown in Table 19 in the main text.

D3.2 Marine Foods

Data from (Simmonds et al. 1995) were used to calculate the fish/crustaceans/molluscs consumption of a country from the sea area nearby, which were taken from International Council for the Exploration of the Sea (ICES) annual reports (ICES,).

In (Simmonds et al. 1995) ,ICES data are presented for every EU member state, as annual marine fish consumption (t y^{-1}) by country. This was converted to edible fractions by multiplying by a factor, given in (Simmonds et al. 1995) for fish, crustaceans and molluscs, and dividing by the population (taken from FAO, 1996) to calculate per capita values. In order to take account of any waste, it is assumed that the conversion factor from UK average (Byrom et al. 1995) to UK ICES intake rates can be applied to all EU member states, in the absence of other data.

As the data are per capita, a conversion is required to high rates. A scaling factor was calculated by comparing the ICES per capita data from France, to habit data for a reference group from a recent French study (Nord-Cotentin Radioecology Group, 2000). The scaling factors are shown in Table D 2. These were applied to the ICES data for each EU member state, and the results are shown in Table 21 in the main text.

D3.3 Freshwater fish

The FAO database also includes ingestion rates of freshwater fish for each EU member state. Again, to ensure wastes were fully accounted for, the FAO ingestion rate of freshwater fish was compared to that used in the UK (Byrom et al. 1995). There was no difference between these values, and therefore no conversion factor was required. The high rates used in the UK (Byrom et al. 1995) were compared to the average FAO values for freshwater fish to calculate a conversion factor from average to high intake rates for the UK. This was found to be a factor of 10. It is also assumed that the conversion factor from average to high intake rates for the UK can be applied to all EU member states, in the absence of other data. The average and high consumption rate for each country is shown in Table 23 in the main text.

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Table D 1 Conversion factor from per capita to high rates for terrestrial foods for the UK

	FAO (kg y^{-1})	UK average (kg y^{-1})	UK average/ FAO	UK 97.5th (kg y^{-1})	UK 97.5th /FAO
Cereals	94.5	50	0.5	100	
Root Vegetables	**111**	**60**	0.5	**130**	**1.2**
Fruit	**81**	**15**	0.2	**75**	**0.9**
Green Vegetables	**64**	**30**	0.5	**80**	**1.2**
Eggs	10	8	0.8	25	
Milk	**233**	**95**	0.4	**240**	**1.0**
Milk Products	3	20	6.7	60	
Beef	15.2	15	1.0	45	
Mutton	6.9	3	0.4	25	
Poultry	26.1	7.5	0.3	30	
Pork	24.2	15	0.6	40	
Offal	2.7	2	0.7	20	

Data sources: (FAOSTAT, 2000), UK data taken from (Byrom et al. 1995)

Table D 2 Conversion factor from per capita to high ingestion rates for marine foods for France

	ICES data (France) (kg y^{-1})	Habit data from Nord-Cotentin study (kg y^{-1})	Factor High/Average
Fish	4	67	17
Crustaceans	0.33	61	185
Molluscs	0.66	31	47

Data sources: (ICES,) and (Nord-Cotentin Radioecology Group, 2000)