ENVIRONMENT AGENCY
FOOD STANDARDS AGENCY
NORTHERN IRELAND ENVIRONMENT AGENCY
SCOTTISH ENVIRONMENT PROTECTION AGENCY

Radioactivity in Food and the Environment, 2009 Appendix 1 CD Supplement

RIFE – 15

October 2010

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1. Introduction

This appendix contains a summary of the sampling, measurement, presentation and assessment methods and data used in producing the RIFE report. This information is included as a separate file on the CD accompanying the printed report. Accompanying this file on the CD is a further set of files giving full details of each assessment of *total dose* summed over all sources at each site.

Annexes are provided to this appendix giving further information on:

- Modelling to extend or improve the results of monitoring
- Consumption, occupancy and other habit data
- Dosimetric data
- Estimates of concentrations of natural radionuclides

References in this appendix are given in the printed report.

2. Methods of sampling, measurement and presentation

This section explains the scope of the monitoring programmes presented in this report and summarises the methods and data used to measure and assess radioactivity in food and the environment. The bulk of the programmes and assessment methods and data have continued from 2008 unchanged. The main changes are:

- Sampling and measurement
- Sellafield particles – additional discussion of monitoring for radioactive particles on beaches at Sellafield is provided
- Special sampling at nuclear sites – this was continued where there were unusual short-term increases in discharges and inadvertent releases

Assessment and presentation

- *Total Dose* – a further site has been assessed using the *Total Dose* assessment methodology – Derby
- New charts – are provided of discharge and concentration trends at various sites
- Site maps – maps of sites and sampling locations have been revised and updated
- New habits data – consumption and occupancy rates for critical groups have been updated with the benefit of recent habit survey results at Amersham, Derby, Sellafield and Wylfa
- Dredge spoil disposal – an assessment of the impact of dredge spoil disposal from Oldbury is provided
- Research related to the monitoring programmes has been reviewed and relevant results have been presented in Appendix 5

2.1 Sampling programmes

The primary purpose of the programmes is to check on levels of radioactivity in food and the environment. The results are used to demonstrate that the safety of people is not compromised and that doses, as a result of discharges of radioactivity, are below the dose limit. The scope extends throughout the UK and the Insular States (the Channel Islands and the Isle of Man) and is undertaken independently of the industries which discharge wastes to the environment. Samples of food, water and other materials are collected from the environment and analysed in specialist laboratories. In situ measurements of radiation dose rates and contamination are also made and the results of the programme are assessed in terms of limits and trends in this report. Subsidiary objectives for the programmes are:

- To provide information to assess the impact on non-human species
- To enable indirect confirmation of compliance with authorisations for disposal of radioactive wastes
- To determine whether undisclosed releases of radioactivity have occurred from sites
- To establish a baseline from which to judge the importance of accidental releases of radioactivity should they occur
- To demonstrate compliance with OSPAR obligations

Sampling is focused on nuclear sites licensed by the HSE under the Nuclear Installations Act, 1965 (United Kingdom – Parliament, 1965) since these generally discharge more radioactivity and have a greater impact on the environment. The programmes also serve to provide information to assist the environment agencies to fulfil statutory duties under the Radioactive Substances Act, 1993 (United Kingdom – Parliament, 1993) and the Environmental Permitting (England and Wales) Regulations, 2010 (United Kingdom – Parliament, 2010a). Additional sampling is conducted in areas remote from nuclear sites to establish the general safety of the food chain, drinking water and the environment. Results from this sampling generate data that are used as background levels to compare with results from around nuclear sites and to show the variation in levels across the UK. Levels in the environment can also be affected by disposals of radioactive waste from nuclear sites abroad and show the legacy of atmospheric fallout from both past nuclear weapons testing and the nuclear reactor accident in 1986 at Chernobyl in the Ukraine.

Various methods for undertaking sampling and analysis are available. The Environment Agency has supported research to identify and provide guidance on best practice techniques for monitoring programmes related to the Radioactive Substances Act. The outcome of the most recent review has been published recently following a workshop involving UK experts (Leonard, 2007). The programmes are primarily directed at relatively widespread contamination where the likelihood of encounter or consumption is certain. Where a source of potential exposure to particles of radioactivity is concerned, the likelihood of encounter is an important factor. This is considered separately in the main report in site specific programmes targeted at contamination from radioactive particles.

The programmes can be divided into three main sectors largely on the basis of the origin of radioactivity in the environment:

1. Nuclear sites discharging gaseous and liquid radioactive wastes
2. Industrial and landfill sites
3. Chernobyl and regional monitoring

2.1.1 Nuclear sites

Nuclear sites are the prime focus of the programme as they are responsible for the largest individual discharges of radioactive waste. Sampling and direct monitoring is conducted close to each of the sites shown in Figure 1.1 of the main text. In the case of Sellafield some radionuclides discharged in liquid effluent can be detected in the marine environment in many parts of north-European waters and so the programme for this site extends beyond national boundaries.

The frequency and type of measurement and the materials sampled vary from site to site and are chosen to be representative of existing exposure pathways. Knowledge of such pathways is gained from surveys of local peoples' diets and way of life. As a result the programme varies from site to site and from year to year. Detailed information on the scope of the programme at individual sites is given in the tables of results. The routine programme is supplemented by additional monitoring when necessary, for example, in response to incidents or reports of unusual or high discharges of radioactivity with the potential to get into the food chain or the environment. The results of both routine and additional monitoring are included in this report.

The main aim of the programme is to monitor the environment and diet of people who live or work near nuclear sites in order to estimate exposures for those small groups of people who are most at risk from disposals of radioactive waste. It is assumed that if the most exposed people have a dose below the national and international legal limit then all others should be at an even lower level of risk. For liquid wastes, the pathways that are the most relevant to discharges are the ingestion of seafood and freshwater fish, drinking water and external exposure from contaminated materials. For gaseous wastes, the effects are due to the ingestion of terrestrial foods, inhalation of airborne activity and external exposure from material in the air and deposited on land. Inhalation of airborne activity and external exposure from airborne material and surface deposition are difficult to assess by direct measurement but can be assessed using environmental models. The main thrust of the monitoring is therefore directed at a wide variety of foodstuffs and measurements of external dose rates on the shores of seas, rivers and lakes. The programme also includes some key environmental indicators, in order that levels can be put in an historic context.

The European Commission undertakes a verification programme of discharge and environmental monitoring programmes in support of the objectives of Articles 35 and 36 of the Euratom Treaty. The objectives are for Member States to have monitoring programmes to ensure compliance with the Basic Safety Standards (Commission of the European Communities, 1996). The Commission undertakes periodic inspections of operator and Government facilities in the UK and has embarked on a project to investigate the need for harmonisation of procedures across the Community (Hunt et al., 2007). The UK Government is supporting the project and has provided information to the Commission regarding the scope of UK programmes.

2.1.2 Industrial and landfill sites

Whilst the main focus of the programme is the nuclear industry, a watching brief is kept on other activities, which may have a radiological impact on people and the food chain. This part of the programme considers the impact of disposals of naturally-occurring and man-made radionuclides from non-nuclear industries and of disposal into landfill sites other than at Dounreay (which is considered separately in Section 3.2 of the main report).

The impact of the non-nuclear industry was studied at one main site, Whitehaven, in 2009. In addition, a small-scale programme was undertaken near Hartlepool over and above that directed at the effects of the power station itself. In each case the sampling and analysis was directed at materials potentially containing enhanced levels of naturally-occurring radionuclides from non-nuclear industrial activity (i.e. Technologically enhanced Naturally-Occurring Radioactive Materials (TNORM)). There are also occasional specific programmes that consider, for example, the effects of discharges from non-nuclear sites such as hospitals.

The distribution of landfill sites considered in 2009 is shown in Figure 7.1 of the main text. They were studied to assess the extent, if any, of the contamination leaching from the site and re-entering the terrestrial environment in leachates collected in surface waters close to the sites. The most significant site is the engineered facility at Drigg, in Cumbria.

2.1.3 Chernobyl fallout and regional monitoring

Monitoring of the effects of the 1986 Chernobyl accident was undertaken in relation to the continuing restrictions on the movement, sale and slaughter of sheep in parts of Cumbria, North Wales and Scotland. Monitoring of other foodstuffs is now at a much-reduced rate as levels have declined significantly since the accident, but there remains a small-scale survey of radiocaesium in freshwater fish taken from a small number of upland lakes.

The programme of regional monitoring considers the levels of radionuclides in the environment in areas away from specific sources as an indication of general contamination of the food supply and the environment. The component parts of this programme are:

- Monitoring of the Channel Islands, the Isle of Man and Northern Ireland
- Dietary surveys
- Sampling of milk, crops, and meat
- Drinking water sources, rain and airborne particulates
- Seawater surveys

In addition, special sampling exercises were undertaken in 2009 to investigate the effects of disposal of dredged spoil from Oldbury and to check concerns over the possible loss of radioactivity at sea due to a shipwreck near Newcastle-Upon-Tyne.

Channel Islands, Isle of Man and Northern Ireland

The programmes for the Insular States and Northern Ireland are designed to complement that for the rest of the UK and to take account of the possibility of long-range transport of radionuclides.

Channel Islands monitoring is conducted on behalf of the Channel Island States. It consists of sampling and analysis of seafood, crops and indicator materials as a measure of the potential effects of UK and French disposals into the English Channel and historic disposal of solid waste in the Hurd Deep.

Monitoring on the Isle of Man for terrestrial foodstuffs is conducted on behalf of the Department of Local Government and the Environment. Sampling is undertaken of a range of foodstuffs that are analysed for Chernobyl, Sellafield and Heysham related radionuclides. Monitoring of seafood is primarily directed at the effects of disposals from Sellafield.

The Northern Ireland programme is directed at the far-field effects of disposals of liquid radioactive wastes into the Irish Sea. Dose rates are monitored on beaches and seafood and indicator materials are collected from a range of coastal locations including marine loughs.

General diet

The purpose of the general diet surveys is to provide information on radionuclides in the food supply to the whole population, rather than to those in the vicinity of particular sources of contamination such as the nuclear industry. This programme provides background information that is useful in interpreting site-related measurements and also helps ensure that all significant sources of contamination form part of the site-related programme. As part of the Total Diet Study (TDS), representative mixed diet samples are collected from towns throughout the UK (see Section 8 of the main report). Normal culinary techniques are used in preparing samples (e.g. removal of outer leaves of leafy vegetables if necessary) and samples are combined in amounts that reflect the relative importance of each food in the average UK diet. Some samples are analysed for a range of contaminants including radionuclides. Data are also supplied as part of the UK submission to the EC under Article 36 of the Euratom Treaty* to allow comparison with those from other EU Member States (e.g. Joint Research Centre, 2009). They account for the 'dense' and 'sparse' networks for mixed diet (Commission of the European Communities, 2000a) required by the EC. The EC compile data into a report of results from all Member States. At the time of writing, the last report covered data for 2004 – 2006 (Joint Research Centre, 2009).

Specific foods, freshwater, rain and airborne particulates

Further background information on the relative concentrations of radionuclides is gained from the sampling and analysis of foods, particularly milk, crops and meat. Freshwater, rain and airborne particulates are also analysed to add to the understanding of radionuclide intakes by the population via ingestion and inhalation and as general indicators of the state of the environment.

Milk sampling took place at dairies throughout the UK in 2009. Samples were taken monthly and data are also supplied as part of the UK submission to the EC under Article 36 of the Euratom Treaty to allow comparison with those from other EU Member States (e.g. Joint Research Centre, 2009).

Other food sampling complements the regional dairy programme described above. Crop samples were taken from locations throughout the UK. The results are used to give an indication of background levels of radioactive contamination from naturally-occurring and man-made sources (nuclear weapon tests and Chernobyl fallout) for comparison with samples collected from around nuclear sites. In 2009, sampling exercises were undertaken at ports because food consignments had triggered the radiation screening equipment.

Freshwater used for the supply of drinking water was sampled throughout England, Northern Ireland, Scotland and Wales (Figure 8.2 of the main text). Regular measurements of radioactivity in air and rain water were also made. The UK provides information from these programmes of work to the EC under Article 36 of the Euratom Treaty.

Seawater surveys

Seawater surveys are conducted in the seas around the UK on behalf of Defra to provide information on radionuclide levels and fluxes in the coastal seas of northern Europe. Such information is used to support international studies of the health of the seas under the aegis of the OSPAR Conventions (OSPAR, 2000b), to which the UK is a signatory and in support of research on the fate of radionuclides discharged to sea. These surveys are mounted using government research vessels and are supplemented by a programme of spot sampling of seawater at coastal locations.

2.2 Methods of measurement

There are two basic types of measurement made: (i) dose rates are measured directly in the environment; and (ii) samples collected from the environment are analysed for their radionuclide content in a laboratory.

* *The treaty establishing the European Atomic Energy Community (Euratom) was signed in Rome on 25th March 1957.*

2.2.1 Sample analysis

The analyses conducted on samples vary according to the nature of the radionuclide under investigation. The types of analysis can be broadly categorised into two groups: (i) gamma-ray spectrometry: and (ii) radiochemical methods. The former is a cost-effective method of detecting a wide range of radionuclides commonly found in radioactive wastes and is used for most samples. The latter comprise a range of analyses involving chemical separation techniques to quantify the alpha and beta emitting radionuclides under study. They are sensitive but more labour intensive. They are, therefore, only used when there is clear expectation that information is needed on specific radionuclides that are not detectable using gamma-ray spectrometry (see 2.4 for discussion on limits of detection).

Several laboratories analysed samples in the programmes described in this report. Their main responsibilities were as follows:

- Cefas Centre for Environment, Fisheries and Aquaculture Science, analysis of food related aquatic samples in England, Wales, Northern Ireland, Isle of Man and the Channel Islands

- HPA Health Protection Agency, gamma-ray spectrometry and radiochemistry of samples from Scotland, Total Diet and canteen meals from England and Wales and freshwater for Northern Ireland

- LGC Laboratory of the Government Chemist, analysis of drinking water in England and Wales

- SL Scientifics Ltd, gamma-ray spectrometry and radiochemistry of environment related samples in England and Wales

- VLA Veterinary Laboratories Agency, gamma-ray spectrometry and radiochemistry (excluding total uranium analysis) of food related terrestrial samples in England, Wales, the Channel Islands and the Isle of Man

- WELL Winfrith Environmental Level Laboratory (Amec NNC Ltd) gamma-ray spectrometry and radiochemistry of air and rain samples in England, Wales, Northern Ireland and the Shetland Islands

Each laboratory operates quality control procedures to the standards required by the environment agencies and the Food Standards Agency. In most cases, contractors are third-party assessed for their operating procedures, i.e. they are accredited by an agency such as the UK Accreditation Service that certifies they meet the requirements of the international standard ISO 17025 (International Organisation for Standardisation, 2005). Regular calibration of detectors is undertaken and intercomparison exercises are held with participating laboratories. The quality assurance procedures and data are made available to the UK environment agencies and the Food Standards Agency for auditing. The methods of measurement include alpha and gamma-ray spectrometry, beta and Cerenkov scintillation counting and alpha and beta counting using proportional detectors.

In 2007, the analytical and sampling performance of two laboratories was compared and published (Leonard et al., 2007). Cefas and Scientifics Limited conducted collection and subsequent radioanalysis of samples of sediments and seaweed at eight locations near nuclear facilities. Analysis included gamma spectrometry and radiochemistry for tritium and technetium-99. Both laboratories were accredited to ISO 17025. Results of sub samples for gamma emitting radionuclides were found to be reasonably consistent. Some variation was found in results for samples taken separately and this could be due to either difference in the environment or in analytical performance. Some of the larger variations, up to a factor of 2, were found for results for technetium-99 in seaweed but it is known that (i) uptake of this nuclide into seaweed is dependent on local conditions at the time of sampling and (ii) concentrations vary significantly from one part of the plant to another. Overall the exercise showed that the variations in the results of the two laboratories were not excessive when considered against the aims of the monitoring programmes.

Corrections are made for the radioactive decay of short-lived radionuclides between the time of sample collection and measurement in the laboratory. This is particularly important for sulphur-35 and iodine-131. Where bulking of samples is undertaken, the date of collection of the bulked sample is assumed to be in the middle of the bulking period. Otherwise the actual collection date for the sample is used. In a few cases where short-lived radionuclides are part of a radioactive decay chain, the additional activity ('in-growth' and equilibrium status) produced as a result of radioactive decay of parent and daughter radionuclides after sample collection is also considered. Corrections to the activity present at the time of measurement are made to take this into account for the radionuclides protactinium-233 and thorium-234.

The analysis of foodstuffs is conducted on that part of the sampled material that is normally eaten, for example, the shells of shellfish and the pods of some of the legumes are discarded before analysis. Foodstuff samples are prepared in such a way so as to minimise losses of activity during the analytical stage. Most shellfish samples are boiled soon after collection to minimise losses from the digestive gland. Although some activity may be lost, these generally reflect the effects of the normal cooking process for shellfish. Most other foodstuffs are analysed raw, as it is conceivable that all of the activity in the raw foodstuff could be consumed.

2.2.2 Measurement of dose rates and contamination

Measurements of gamma dose in air over intertidal and other areas are normally made at 1 m above the ground using Mini Instruments* environmental radiation meters type 680 and 690 with compensated Geiger-Muller tubes type MC-71. For certain key activities, for example for people living on houseboats or for wildfowlers lying on the ground, measurements at other distances from the ground may be made. External beta doses are measured on contact with the source, for example fishing nets, using Berthold* LB 1210B or Mini 900/EP 15* contamination monitors. These portable instruments are calibrated against recognised reference standards and the inherent instrument background is subtracted. There are two quantities that can be presented as measures of external gamma dose rate, total gamma dose rate or terrestrial gamma dose rate. Total gamma dose rate includes all sources external to the measuring instrument. Terrestrial gamma dose rate excludes cosmic sources of radiation but includes all others. In this report we have presented the total gamma dose rate. The HPA reports terrestrial gamma dose rates to SEPA. Terrestrial gamma dose rate is converted to total gamma dose rate by the addition of 0.037 μGy h^{-1} which is an approximation of the contribution made by cosmic radiation (Her Majesty's Inspectorate of Pollution, 1995).

Beta/gamma monitoring of contamination on beaches or riverbanks is undertaken using similar instrumentation to that for measurements of dose rates. In England and Wales, a Mini Instruments series 900 mini monitor with a beach monitoring probe is used. The aim is to cover a large area including strand-lines where radioactive debris may become deposited. Any item found with activity levels in excess of the action levels is removed for analysis. An action level of 100 counts per second (equivalent to 0.01 mSv h^{-1}) is used in England and Wales. At Dounreay, in Scotland, and at Sellafield, in Cumbria, special monitoring procedures are in place due to the potential presence of radioactive particles on beaches. Further information regarding Dounreay and Sellafield is provided in the main report.

2.3 Presentation of results

The following tables of monitoring results contain summarised values of observations obtained during the year under review. The data are generally rounded to two significant figures. Values near to the limits of detection will not have the precision implied by using two significant figures. Observations at a given location for radioactivity levels and dose rates may vary throughout the year. This variability may be due to changes in rates of discharge, different environmental conditions and uncertainties arising from the methods of sampling and analysis.

The method of presentation of the summarised results allows the data to be interpreted in terms of public radiation exposures for comparison with agreed safety standards.

For milk samples, the most appropriate quantity for use in assessments is the arithmetic mean in the year sampled for the farm where the highest single concentration is observed. This is labelled 'max' in the tables of results to distinguish it from the values that are averaged over a range of farms. For other terrestrial foods, an alternative approach is adopted since it is recognised that the possible storage of foods harvested during a particular time of the year has to be taken into account. Greater public exposures would be observed when foods are harvested at times when levels of contamination are high. For such foods, we have presented the maximum concentration observed of each radionuclide at any time in the relevant year well as the mean value. The maximum is labelled 'max' in the tables and forms the basis for the assessment of dose.

Results are presented for each location or source of supply where a sample is taken or a measurement is made. Sample collectors are instructed to obtain samples from the same location during the year. Spatial averaging is therefore not generally undertaken though it is inherent in the nature of some samples collected. A fish may move some tens of kilometres in an environment of changing concentrations in seawater, sediments and lower tropic levels. The resulting level of contamination therefore represents an average over a large area. Similarly cows providing milk at a farm may feed on grass and other fodder collected over a distance of a few kilometres of the farm. In the case of dose rate measurements, the position where the measurement is conducted is within a few metres of other measurements made within a year. Each observation consists of the mean of a number of instrument readings at a given location.

The numbers of farms that were sampled to provide information on activities in milk at nuclear sites are indicated in the tables of results. Milk samples collected weekly or monthly are generally bulked to provide four quarterly samples for analysis each year. For some radionuclides weekly, monthly or annual bulks are taken for analysis. Otherwise, the number of sampling observations in the tables of concentrations refers to the number of samples that were prepared for analysis during the year. In the case of small animals such as molluscs, one sample may include several hundred individual animals.

The number of sampling observations does not necessarily indicate the number of individual analyses conducted for a specific radionuclide. In particular, determinations by radiochemical methods are sometimes conducted less frequently than those by gamma-ray spectrometry. However, the results are often based on bulking of samples such that the resulting determination remains representative.

2.4 Detection limits

There are two main types of results presented in the tables (i) positive values and (ii) values preceded by a 'less than' symbol ("<"). Where the results are an average of more than one datum, and each datum is positive, the result is positive. Alternatively, where there is a mixture of data, or all data are

* *The reference to proprietary products in this report should not be construed as an official endorsement of those products, nor is any criticism implied of similar products which have not been mentioned.*

at the LoD or MRL, the result is preceded by a 'less than' symbol. Gamma-ray spectrometry can provide a large number of 'less than' results. In order to minimise the presentation of redundant information for gamma-ray spectrometry, 'less than' values are only reported for one, or more, of the following reasons: (i) the radionuclide is one which is in the relevant authorisation, (ii) it has been analysed by radiochemistry, (iii) it has been reported as being a positive value in that table in the previous 5 years, (iv) a positive result is detected in any other sample presented in the table in the relevant year. Naturally occurring radionuclides measured by gamma-ray spectrometry are not usually reported unless they are intended to establish whether there is any enhancement above the expected background levels.

Limits of detection are governed by various factors relating to the measurement method used and these are described in earlier reports (Ministry of Agriculture, Fisheries and Food, 1995). There are also a few results quoted as 'not detected' (ND) by the methods used. This refers to the analysts' judgement that there is insufficient evidence to determine whether the radionuclide is present or absent.

2.5 Additional information

The main aim of this report is to present all the results of routine monitoring from the programmes described previously. However, it is necessary to carry out some averaging for clarity and to exclude some basic data that may be of use only to those with particular research interests. Full details of the additional data are available from the environment agencies and the Food Standards Agency. Provisional results of concentrations of radionuclides in food samples collected in the vicinity of nuclear sites in England and Wales are published quarterly through the internet (www.food.gov.uk).

The main categories of additional data are:

- Data for individual samples prior to averaging
- Uncertainties in measurements
- Data for very short-lived radionuclides supported by longer-lived parents
- Data which are not relevant to a site's discharges for naturally-occurring radionuclides and for artificial radionuclides below detection limits
- Measurements conducted as part of the research programme described in Appendix 5 of the main report.

Very short-lived radionuclides such as yttrium-90, rhodium-103m, rhodium-106m, barium-137m and protactinium-234m, which are formed by, decay of, respectively, strontium-90, ruthenium-103, ruthenium-106, caesium-137 and thorium-234 are taken into account when calculations of exposure are made. They are not listed in the tables of results. As a first approximation, their concentrations can be taken to be the same as those of their respective parents.

3. Assessment methods and data

3.1 Radiation protection standards

The monitoring results in this report are interpreted in terms of radiation exposures of the public, commonly termed 'doses'. This section describes the dose standards that apply in ensuring protection of the public.

Current UK practice relevant to the general public is based on the recommendations of the ICRP as set out in ICRP Publication 60 (International Commission on Radiological Protection, 1991). The dose standards are embodied in national policy on radioactive waste (United Kingdom – Parliament, 1995b) and in guidance from the IAEA in their Basic Safety Standards for Radiation Protection (International Atomic Energy Agency, 1996). Legislative dose standards are contained in the Basic Safety Standards Directive 96/29/Euratom (Commission of the European Communities, 1996) and subsequently incorporated into UK law in the Ionising Radiations Regulations 1999 (United Kingdom – Parliament, 1999). In order to implement the Basic Safety Standards Directive, Ministers have provided the Environment Agency and SEPA with Directions concerning radiation doses to the public and their methods of estimation and regulation for all pathways (Department of the Environment, Transport and the Regions, 2000 and Scottish Executive, 2000). In Northern Ireland, regulations were made to implement the requirements of the BSS Directive in the Radioactive Substances (Basic Safety Standards) Regulations (Northern Ireland) 2003 (Northern Ireland Assembly, 2003). The methods and data used in this report are consistent with the Directions.

The ICRP issued revised recommendations for a system of radiological protection in 2007 (International Commission on Radiological Protection, 2007). The HPA have provided advice on the application of the ICRP 2007 recommendations to the UK (Health Protection Agency, 2009). Overall, they consider that the new recommendations do not imply any major changes to the system of protection applied in the UK. In particular, limits for effective and skin doses remain unchanged. Dose coefficients are also unchanged until such a time as new values are available and receive legislative endorsement.

International Commission on Radiological Protection (2007) use the term 'representative person' for assessing doses to members of the public. It is defined as 'an individual receiving a dose that is representative of the more highly exposed individuals in the population'. The new term is equivalent to 'critical group' which has been used in previous RIFE reports. Where appropriate we have adopted the term 'representative person' in this report. The implications of the new ICRP recommendations in relation to the EU and UK radiation protection law and standards are being considered. For example the EU is updating the Basic Safety Standards Directive (Commission of the European Communities, 1996) and a draft Directive has been published (Commission of the European Communities, 2010). Changes in EU and UK radioprotection law and standards will be taken into account for future issues of this report.

The relevant dose limits for members of the public are 1 mSv (millisievert) per year for whole-body (more formally 'committed effective') dose and 50 mSv per year specifically for skin. The latter limit exists to ensure that specific effects on skin due to external exposure are prevented. It is applicable, for example, in the case of handling of fishing gear. The dose limits are for use in assessing the impact of direct radiations and controlled releases (authorised discharges) from radioactive sources. These limits are appropriate for 'certain' exposure situations where the encounter with radioactivity is expected to occur. In situations where this is not certain, 'potential' exposure routes and standards are determined. These are discussed further by Dale et al. (2008) in relation to particles of radioactivity. Where contamination due to particles is known in the UK, a site-specific assessment is considered in the relevant section of the main report.

The mean dose received by the 'representative person' is compared with the dose limit. The term 'representative person' refers to those who are most exposed to radiation. In this report they are generally people who eat large quantities of locally grown food (high-rate consumers) or who spend long periods of time in areas where radiation sources may exist. The limits apply to all age groups. Children may receive higher doses than adults because of their physiology, anatomy and dietary habits. The embryo/fetus can also receive higher doses than its mother. Consequently doses have been assessed for different age groups, i.e. adults, 10-year-old children, 1-year-old infants and prenatal children, and from this information it is possible to determine which of these age groups receives the highest doses.

For drinking water, the World Health Organisation (WHO) has provided screening levels to compare with the results of measurements of gross alpha and gross beta activity (World Health Organisation, 2004). The screening levels are 0.5 and 1.0 Bq l^{-1}, respectively, and are based on consideration of the dose that would result from radium-226 (alpha) and strontium-90 (beta) intakes. These were chosen as representative of the most radiotoxic radionuclides likely to be present in significant quantities. The values represent concentrations below which water can be considered potable without any further radiological examination. The Commission of the European Communities (CEC) has prepared a directive on the quality of water intended for human consumption, which includes parameters for tritium (with a reference value of 100 Bq l^{-1})

and total indicative dose with a reference value of 0.1 mSv per year (Commission of the European Communities, 1998).

Accidental releases may be judged against EU and ICRP standards in emergency situations (Commission of the European Communities, 1989 and International Commission on Radiological Protection, 2007). In addition, it is Government policy that EU food intervention levels will be taken into account when setting discharge limits. Guidelines for radionuclides in foods following accidental radiological contamination for use in international trade has been published by the Codex Alimentarius Commission (Codex Alimentarius Commission, 2006).

The main focus of this report, and radiological regulation and monitoring more generally, is towards protection of man. However, ICRP in its 2007 recommendations has concluded that there is a need for a systematic approach for the radiological assessment of non-human species to support the management of radiation effects in the environment (International Commission on Radiological Protection, 2007). In its most recent publication concerning protection of the environment (International Commission on Radiological Protection, 2008), ICRP considers the use of a set of Reference Animals and Plants (RAPs) for dose assessments. Whilst this approach is being developed, no dose limits are proposed to apply. The Habitats Directive (Commission of the European Communities, 1992) requires a 3-stage approach to the assessment of the impact of radioactive discharges on sensitive habitats. Details are provided in Section 1.2.4 of the main text of this report.

3.2 Assessment methods

Calculations of exposures to members of the public from waste disposals are primarily based on the environmental monitoring data for the year shown in this report. The methods used have been assessed for conformity with the principles endorsed by the UK National Dose Assessment Working Group (Allott, 2005), and were found to be compatible (Camplin and Jenkinson, 2007). The data provide information on two main pathways:

- Ingestion of foodstuffs and
- External exposure from contaminated materials in the aquatic environment
- Monitoring data are also used to assess doses from pathways, which are generally of lesser importance:
- Drinking water
- Inadvertent ingestion of water and sediments and
- Inhalation of resuspended soil and sediment
- In addition, models are used to supplement the monitoring data in four situations:
- Atmospheric dispersion models are used for non-food pathways where monitoring is not an effective method of establishing concentrations or dose rates in the environment.
- Food chain models provide additional data to fill gaps and to adjust for high-limits of detection and
- Modelling of exposures of sewage workers is undertaken for discharges from Amersham and Cardiff
- Modelling of exposures from the use of sewage sludge pellets at Cardiff

Full details are given in Annex 1.

For pathways involving intakes of radionuclides, the data required for assessment are:

- Concentrations in foodstuffs, drinking water sources, sediments or air
- The amounts eaten, drunk or inhaled
- The dose coefficients that relate an intake of activity to a dose

For external radiation pathways, the data required are:

- The dose rate from the source, for example a beach or fishermen's nets, and
- The time spent near the source

In both cases, the assessment estimates exposures from these pathways for people who are likely to be most exposed.

3.3 Concentrations of radionuclides in foodstuffs, drinking water sources, sediments and air

In nearly all cases, the concentrations of radionuclides are determined by monitoring and are given in the main text of this report. The concentrations chosen for the assessment are intended to be representative of the intakes of the most exposed consumers in the population. All of the positively determined concentrations tabulated are included irrespective of the origin of the radionuclide. In some cases, this means that the calculated exposures could include contributions due to disposals from other sites as well as from weapon test fallout and activity deposited following the Chernobyl accident. Where possible, corrections for background concentrations of naturally-occurring radionuclides are made in the calculations of dose (see Section 3.7).

For aquatic foodstuffs, drinking water sources, sediments and air, the assessment is based on the mean concentration near the site in question. For milk, the mean concentration at a nearby farm with the highest individual result is used in the dose assessment. This procedure accounts for the possibility that any farm close to a site can act as the sole source of supply of milk to high-rate consumers.

For other foodstuffs, the maximum concentrations are selected for the assessment. This allows for the possibility of storage of food harvested at a particular time when the peak levels in a year may have been present in the environment.

The tables of concentrations include 'less than' values as well as positive determinations. This is particularly evident for gamma-ray spectrometry of terrestrial foodstuffs. Where a result is presented as a 'less than' value, the dose assessment methodology treats it as if it were a positive determination as follows: (i) when that radionuclide is specified in the relevant authorisation (gaseous or liquid), (ii) when that radionuclide was determined using radiochemical methods or (iii) when a positive result is reported for that radionuclide in another sample from the same sector of the environment at the site (aquatic or terrestrial). Although this approach may produce an overestimation of dose, particularly at sites where levels are low, it ensures that estimated exposures are unlikely to be understated.

3.4 Consumption, drinking and inhalation rates

Two basic types of assessment are undertaken. 'Routine' assessments are applied separately to the effects of gaseous and liquid discharges. 'Total dose' assessments take into account all sources in combination. This subsection considers consumption, drinking and inhalation rates that are applied in 'routine' assessments. 'Total dose' assessments are considered further in Section 3.8 and Appendix 4 of the main report.

In the assessment of the effects of disposals of liquid effluents, the amounts of fish and shellfish consumed are determined by site-specific dietary habit surveys. Data are collected primarily by direct interviews with potential high-rate consumers who are often found in fishing communities. Children are rarely found to eat large quantities of seafood and their resulting doses are invariably less than those of adults. The calculations presented in this report are therefore representative of adult seafood consumers or their unborn children if the fetal age group is more restrictive.

In assessments of terrestrial foodstuffs, the amounts of food consumed are derived from national surveys of diet and are defined for three ages: adults, 10-year-old children and 1-year-old infants (based on Byrom et al., 1995). Adult consumption rates are used in the assessment of fetal doses. For each food type, consumption rates at the 97.5th percentile of consumers have been taken to represent the people who consume a particular foodstuff at a high level (the 'representative person' consumption rate).

Drinking and inhalation rates are general values for the population, adjusted according to the times spent in the locations being studied.

The consumption, drinking and inhalation rates are given in Annex 2. Estimates of dose are based on the most up to date information available at the time of writing the report. New survey data were introduced at Derby, Wylfa and Amersham and Sellafield in 2009. Where appropriate, the data from site-specific surveys are averaged over a period of 5 years following the recommendation of the report of the Consultative Exercise on Dose Assessments (CEDA) (Food Standards Agency, 2001a).

The assessment of terrestrial foodstuffs is based on two assumptions: (i) that the foodstuffs eaten by the most exposed individuals are those that are sampled for the purposes of monitoring; and (ii) that the consumption of such foodstuffs is sustained wholly by local sources. The two food groups resulting in the highest dose are taken to be consumed at 'high level' consumption rates, while the remainder are consumed at mean rates. The choice of two food groups at the higher consumption rates is based on statistical analysis of national diet surveys. This shows that only a very small percentage of the population were critical rate consumers in more than two food groups (Ministry of Agriculture, Fisheries and Food, 1996). Locally grown cereals are not considered in the assessment of exposures as it is considered highly unlikely that a significant proportion of cereals will be made into locally consumed (as opposed to nationally consumed) foodstuffs, notably bread.

3.5 Dose coefficients

Dose calculations for intakes of radionuclides by ingestion and inhalation are based on dose coefficients taken from ICRP Publication 72 (International Commission on Radiological Protection, 1996a), ICRP Publication 88 (International Commission on Radiological Protection, 2001) and National Radiological Protection Board (2005).

These coefficients (often referred to as 'dose per unit intake') relate the committed dose received to the amount of radioactivity ingested or inhaled. The dose coefficients used in this report are provided in Annex 3 for ease of reference.

Calculations are performed for four ages: adults, 10-year-old children, 1-year-old infants and prenatal children as appropriate to the pathways being considered. The prenatal age group was introduced following the publication of recommendations by the National Radiological Protection Board in 2005 (National Radiological Protection Board, 2005). We have assumed that the 'representative person' is pregnant in order for the dose assessment of the embryo and fetus to be valid. This assumption is considered reasonable in the context of making comparisons with dose limits because it is difficult to demonstrate otherwise. When applied in practice, the doses estimated for the prenatal group are rarely larger than the values for other age groups.

The dose assessments include the use of appropriate gut uptake factors (proportion of radioactivity being absorbed from the digestive tract). Where there is a choice of gut uptake factors for a radionuclide, we have generally chosen the one that gives the highest predicted exposure. In particular where results for total tritium are available, we have assumed that the tritium content is wholly in an organic form. However, we have also taken into account specific research work of relevance to the foods considered in this report. This affects the assessments for tritium, polonium, plutonium and americium radionuclides as discussed in Annex 3.

3.6 External exposure

In the assessment of external exposure, there are two factors to consider: (i) the dose rate from the source and (ii) the time spent near the source. In the case of external exposure to penetrating gamma radiation, uniform whole body exposure has been assumed. The radiation as measured is in terms of the primary quantity known as 'air kerma rate', a measure of the energy released when the radiation passes through air. This has been converted into exposure using the factor 1 milligray = 0.85 millisievert (International Commission on Radiological Protection, 1996b). This factor applies to a rotational geometry with photon energies ranging from 50 keV to 2 MeV. This is appropriate for the instrument used whose sensitivity is much reduced below 50 keV, and to the geometry of deposits of artificial radionuclides. Applying an isotropic geometry gives a value of 0.70 Sv Gy^{-1} which would be more appropriate for natural background radiation. The choice of 0.85 will therefore tend to overestimate dose rates for the situations considered in this report which include both artificial and natural radiation.

For external exposure of skin, the measured quantity is contamination in Bq cm^{-2}. In this case, dose rate factors in Sv y^{-1} per Bq cm^{-2} are used, which are calculated for a depth in tissue of 7 mg cm^{-2} (Kocher and Eckerman, 1987). The times spent near sources of external exposure are determined by site-specific habits surveys in a similar manner to consumption rates of seafood. The occupancy and times spent handling fishing gear are given in Annex 2.

3.7 Subtraction of 'background levels'

When assessing internal exposures due to ingestion of carbon-14 and radionuclides in the uranium and thorium decay series in seafood, concentrations due to natural background levels are subtracted. Background carbon-14 concentrations in terrestrial foods are also subtracted. The estimates of background concentrations are given in Annex 4. When assessing the man-made effect on external exposures to gamma radiation, dose rates due to background levels are subtracted. On the basis of measurements made previously as part of the programmes reported here, the gamma dose rate backgrounds in the aquatic environment are taken to be 0.05 μGy h^{-1} for sandy substrates, 0.07 μGy h^{-1} for mud and salt marsh and 0.06 μGy h^{-1} for other substrates. These data are compatible with those presented by McKay et al. (1995). However, where it is difficult to distinguish the result of a dose rate measurement from natural background, the method of calculating exposures based on the concentrations of man-made radionuclides in sediments is used (Hunt, 1984). Estimates of external exposures to beta radiation include a component due to naturally-occurring (and un-enhanced) sources because of the difficulty in distinguishing between naturally-occurring and man-made contributions. Such estimates are therefore conservative when compared with the relevant dose limit that excludes natural sources of radiation.

3.8 Summation of doses from different pathways

The dose standards formally require the summation of contributions from all practices under control. In the context of this report, individual members of the public will be exposed to disposals from the nuclear site under study and, in the case of widespread contamination, from other sites. However, they may also be exposed to other controlled practices such as the transportation of radioactive materials, the use of consumer products containing radioactivity (e.g. some smoke detectors and tritium lights) and direct radiation from nuclear sites and other sources.

The environmental data and the individuals affected that are assessed in this report naturally fall into two separate cases: those affected by liquid waste disposal and those by gaseous waste disposal. We have therefore calculated doses separately in these two cases and within each we have summed contributions from the dominant pathways involved. These calculations form the basis of our 'routine assessments'.

The dose limits apply to all exposures from regulated sources (other than medical exposure of patients) and there is a need to estimate the total dose by adding contributions to exposure from different sources. The simple addition of 'liquid' and 'gaseous' doses from 'routine assessments' will overestimate the dose received due to radioactive waste disposal because those people most affected by atmospheric and liquid discharges tend to be different. An individual is unlikely to consume both aquatic and terrestrial foods at high rates. With the benefit of habits survey information gained for all pathways of significance, an assessment of the total dose at specific nuclear sites is provided in Appendix 4. This includes consideration of the effects of liquid and gaseous waste disposal and direct radiation from nuclear sites. Direct radiation is assessed with the benefit of information provided by the HSE.

3.9 Uncertainties in dose assessment

Various methods are used to reduce the uncertainties in the process of dose estimation for critical groups from monitoring programmes. These address the following main areas of concern:

- Programme design
- Sampling and in situ measurement
- Laboratory analysis
- Description of pathways to man
- Radiation dosimetry
- Calculational and presentational error
- Quantitative estimation of uncertainties in doses is beyond the scope of this report.

4. References

References for the CD supplement are given in Section 9 of the main report.

Annex 1. Modelling of concentrations of radionuclides in foodstuffs, air and sewage systems

A1.1 Foodstuffs

At Sellafield, Drigg, Ravenglass and the Isle of Man, a simple food chain model has been used to provide concentrations of activity in milk and livestock for selected radionuclides to supplement data obtained by direct measurements. This is done where relatively high limits of detection exist or where no measurements were made.

Activities in milk, meat and offal were calculated for technetium-99, ruthenium-106, cerium-144, promethium-147 and plutonium-241 using the equations:

$$C_m = F_m Ca\ Q_f \quad \text{and}$$
$$C_f = F_f\ Ca\ Q_f \quad \text{where}$$

C_m is the concentration in milk (Bq l^{-1}),
C_f is the concentration in meat or offal (Bq kg^{-1} (fresh)),
F_m is the fraction of the animal's daily intake by ingestion transferred to milk (d l^{-1})
F_f is the fraction of the animal's daily intake by ingestion transferred to meat or offal (d kg^{-1} (fresh)),
Ca is the concentration in fodder (Bq kg^{-1} (dry)),
Q_f is the amount of fodder eaten per day (kg (dry) d^{-1})

No direct account is taken of radionuclide decay or the intake by the animal of soil associated activity. The concentration in fodder is assumed to be the same as the maximum observed concentration in grass, or in the absence of such data, in leafy green vegetables. The food chain data for the calculations are given in Table X1.1 (Simmonds *et al*., 1995; Brenk *et al*., unpublished) and the estimated concentrations in milk, meat and offal are presented in Table X1.2.

The Cardiff East Waste Water Treatment Works provides dried sludge pellets, containing elevated concentrations of tritium, to farms for use as a soil conditioner. The transfer of tritium from treated soil into crops is a potential pathway of exposure. An FSA-funded research project (Ham et al., 2007) estimated the aggregated transfer quotient, relating the concentration in the edible part of the crop to the amount of activity applied to the soil, to be approximately 2 10^{-4}. This assumed a conservative application rate of 2 kg m^{-2}. These values can be used to perform an assessment of exposure from consuming foodstuffs grown in soil conditioned with sludge pellets near Cardiff.

A1.2 Air

For some sites, discharges to air can lead to significant doses. Doses may arise from radionuclides transferred from the plume to food crops and animal products, inhalation of radionuclides in the plume itself and external doses from radionuclides in the plume.

Average annual concentrations of radionuclides in the air at nearest habitations were calculated using a Gaussian plume model, PC CREAM (Mayall *et al*., 1997), and the reported discharges of radionuclides to air. Site-specific meteorological data were used in the assessments. The key modelling assumptions (i.e. discharge height, habitations) are shown in Table X1.3.

External radiation doses from radionuclides in the plume and from deposited activity were calculated taking into account occupancy indoors and outdoors and location factors to allow for building shielding. During the time people are assumed to be indoors, the standard assumption that the dose from gamma-emitting radionuclides in the plume will be reduced by 80 per cent (i.e. shielding factor of 0.2) has been made. Internal radiation doses from inhalation of discharged radionuclides were assessed using breathing rates. Doses were initially assessed for three age groups: infants (1y), children (10 y) and adults. All ages are assumed to have year-round occupancy at the nearest habitation. The inhalation and occupancy rates assumed in this assessment are shown in Table X1.4. The dose to the fetal age group was taken to be the same as that for an adult.

A1.3 Sewage systems

The radiochemical production facilities at Amersham and Cardiff discharge liquid radioactive waste to local sewers. Wastes are processed at local sewage treatment works (STW). The prolonged proximity to raw sewage and sludge experienced by sewage treatment workers could lead to an increase in the dose received, via a combination of external irradiation from the raw sewage and sludge and the inadvertent ingestion and inhalation of resuspended radionuclides.

An assessment of the dose received by workers at the Maple Lodge STW, near Amersham, and at the Cardiff East Waste Water Treatment Works (WWTW) has been conducted using the methodology and data given in Environment Agency (2006a,b). The flow rate through the sewage works are used to calculate a mean concentration in raw sewage and sludge of each nuclide discharged. These mean concentrations are combined with habits data concerning the workers' occupancy near raw sewage and sludge, external and internal dosimetric data, and physical data such as inhalation rates to provide estimates of dose. Workers are assumed to spend 75 per cent of a working year in proximity to the raw sewage, and the other 25 per cent in proximity to the sewage sludge. Where liquid discharges are not nuclide-specific, a composition has been assumed based on advice from the operators and concentrations calculated accordingly.

The model parameters and habits data used to assess the dose to sewage treatment workers are given in Table X1.5, and the amounts of radioactivity discharged from each site can be found in Appendix 2 of the main report.

Table X1.1. Data for food chain model

Parameter	Nuclide	Food				
		Milk	Beef	Beef offal	Sheep	Sheep offal
Q_f		13	13	13	1.5	1.5
F_m or F_f	^{99}Tc	10^{-2}	10^{-2}	$4\ 10^{-2}$	10^{-1}	$4\ 10^{-1}$
	^{106}Ru	10^{-6}	10^{-3}	10^{-3}	10^{-2}	10^{-2}
	^{144}Ce	$2\ 10^{-5}$	10^{-3}	$2\ 10^{-1}$	10^{-2}	2
	^{147}Pm	$2\ 10^{-5}$	$5\ 10^{-3}$	$4\ 10^{-2}$	$5\ 10^{-2}$	$3\ 10^{-1}$
	^{241}Pu	10^{-6}	10^{-4}	$2\ 10^{-2}$	$4\ 10^{-4}$	$3\ 10^{-2}$

Table X1.2. Predicted concentrations of radionuclides from food chain model used in assessments of exposures

Foodstuff	Location	Radioactivity concentration (fresh weight), Bq kg^{-1}			
		^{99}Tc	^{106}Ru	^{144}Ce	^{241}Pu
Milk	Sellafield	a	$1.08\ 10^{-4}$	b	$6.37\ 10^{-6}$
	Ravenglass	a	$1.68\ 10^{-4}$	$1.84\ 10^{-3}$	$8.41\ 10^{-6}$
	Drigg	a	$2.17\ 10^{-4}$	$2.60\ 10^{-3}$	$1.34\ 10^{-5}$
	Isle of Man	a	$1.73\ 10^{-4}$	b	$8.15\ 10^{-6}$
Beef	Sellafield	a	$1.08\ 10^{-1}$	b	$6.37\ 10^{-4}$
	Ravenglass	a	$1.68\ 10^{-1}$	$9.18\ 10^{-2}$	$8.41\ 10^{-4}$
	Drigg	$1.67\ 10^{-1}$	$2.17\ 10^{-1}$	$1.30\ 10^{-1}$	$1.34\ 10^{-3}$
	Isle of Man	$3.47\ 10^{-2}$	$1.73\ 10^{-1}$	b	$8.15\ 10^{-4}$
Sheep	Sellafield	a	$1.24\ 10^{-1}$	b	$2.94\ 10^{-4}$
	Ravenglass	a	$1.94\ 10^{-1}$	$1.06\ 10^{-1}$	$3.88\ 10^{-4}$
	Drigg	a	$2.50\ 10^{-1}$	$1.50\ 10^{-1}$	$6.20\ 10^{-4}$
	Isle of Man	$4.00\ 10^{-2}$	$2.00\ 10^{-1}$	b	$3.76\ 10^{-4}$
Beef offal	Sellafield	a	$1.08\ 10^{-1}$	b	a
	Ravenglass	a	$1.68\ 10^{-1}$	a	a
	Drigg	$6.67\ 10^{-1}$	$2.17\ 10^{-1}$	$2.60\ 10^{1}$	$2.69\ 10^{-1}$
	Isle of Man	$1.39\ 10^{-1}$	$1.73\ 10^{-1}$	b	$1.63\ 10^{-1}$
Sheep offal	Sellafield	a	$1.24\ 10^{-1}$	b	$2.20\ 10^{-2}$
	Ravenglass	a	$1.94\ 10^{-1}$	a	$2.91\ 10^{-2}$
	Drigg	a	$2.50\ 10^{-1}$	a	a
	Isle of Man	$1.60\ 10^{-1}$	$2.00\ 10^{-1}$	b	$2.82\ 10^{-2}$

a *Positive result used, or LoD result used because modelling result greater than LoD*
b *No grass or Leafy Green Vegetable data available*

Table X1.3. Air concentrations modelling assumptions

Nuclear site	Stack height, m	Estimated site diameter, km	Estimated distance from stack to nearest habitation, km	Frequency of Pasquill stability catergory D
Aldermaston	15	2	0.3	60
Amersham	20	1	0.3	55
Berkeley	20	1.6	0.4	55
Bradwell	14	0.4	0.3	65
Burghfield	15	0.6	0.3	60
Capenhurst	15	1.1	0.3	65
Cardiff	20	0.4	0.4	60
Chapelcross	30	1.2	0.7	60
Derby	50	0.5	0.5	55
Devonport	15	1	0.3	65
Dounreay	15	1	1	75
Dungeness	17	1	0.3	70
Hartlepool	23	0.6	2	70
Harwell	20	1	0.2	55
Heysham	21	1	0.5	70
Hinkley	21	0.8	1	55
Hunterston	15	0.4	0.4	60
Oldbury	20	0.8	0.7	55
Sellafield	93	2	0.5	65
Sizewell	18	0.4	1	70
Springfields	27	1	0.3	70
Torness	72	0.5	0.6	70
Trawsfynydd	18	0.6	0.6	70
Winfrith	15	1.6	0.4	60
Wylfa	17	1	0.4	70

Table X1.4. Inhalation and occupancy data for dose assessment of discharges to air

Age group, y	Inhalation rates, $m^3 h^{-1}$	Fraction of time indoors
1	0.22	0.9
10	0.64	0.8
Adult	0.92	0.7

Table X1.5. Sewage workers dose assessment modelling assumptions and occupancy data

Flow rate, $m^3 d^{-1}$	Amersham (Maple Lodge STW)	$1.5\ 10^{5}$ [a]
	Cardiff (Cardiff East WWTW)	$2.6\ 10^{4}$ [b]
Occupancy - sewage, $h\ y^{-1}$		1380
Occupancy - sludge, $h\ y^{-1}$		460[c]
Inadvertent ingestion rate, $kg\ h^{-1}$		$5\ 10^{-6}$ [d]
Inhalation rate, $m^3 h^{-1}$		1.2[d]
Airborne concentration of sewage or sludge, $kg\ m^{-3}$		$1\ 10^{-7}$ [d]
Density of raw sewage and treated sludge, $kg\ l^{-1}$		1[d]

[a] *Based on average flow rate of 1.8 $m^3 s^{-1}$ (Jobling et al., 2006)*
[b] *Based on an average flow rate of 0.3 $m^3 s^{-1}$, this has been derived as 5% of the maximum flow rate at the works (McTaggart, 2003)*
[c] *A working year is assumed to be 40 hours per week and 48 weeks per year*
[d] *Parameter values used in Environment Agency methodology (see text for reference)*

Annex 2. Consumption, inhalation, handling and occupancy rates

This annex gives the consumption, handling and occupancy rate data used in the routine assessment of exposures from terrestrial consumption and aquatic pathways. Consumption rates for terrestrial foods are based on Byrom *et al.* (1995) and are given in Table X2.1. These are derived from national statistics and are taken to apply at each site. Site-specific data for aquatic pathways based on local surveys are given in Table X2.2. The site-specific data has been supplemented with generic information from Environment Agency (2002a) and Smith and Jones (2003) where appropriate. Occupancy over intertidal areas and rates of handling from local surveys have been reassessed to take account of a change in the factor used to determine the range of rates typical of those most exposed. Previously, when using the 'cut-off' method to define those most exposed (Hunt *et al*., 1982; Preston, *et al.,* 1974), a factor of 1.5 was used to describe the ratio of the maximum to the minimum rate within the group. From 2002, sites in England and Wales with new local surveys were adjusted to adopt a factor of 3.0 to make the selection process consistent with that used for consumption pathways. From 2003, all sites in Scotland were adjusted. Data used for routine assessments of external and inhalation pathways from gaseous discharges are given in Annex 1.

Table X2.1. Consumption rates for terrestrial foods

Food Group	Consumption rates (kg y^{-1})					
	Average			Above average consumption rate*		
	Adult	10 year old	Infant	Adult	10 year old	Infant
Beef	15	15	3	45	30	10
Cereals	50	45	15	100	75	30
Eggs	8.5	6.5	5	25	20	15
Fruit	20	15	9	75	50	35
Game	6	4	0.8	15	7.5	2.1
Green vegetables	15	6	3.5	45	20	10
Honey	2.5	2	2	9.5	7.5	7.5
Legumes	20	8	3	50	25	10
Milk	95	110	130	240	240	320
Mushrooms	3	1.5	0.6	10	4.5	1.5
Nuts	3	1.5	1	10	7	2
Offal	5.5	3	1	20	10	5.5
Pig	15	8.5	1.5	40	25	5.5
Potatoes	50	45	10	120	85	35
Poultry	10	5.5	2	30	15	5.5
Root crops	10	6	5	40	20	15
Sheep	8	4	0.8	25	10	3
Wild fruit	7	3	1	25	10	2

* *These rates are the 97.5th percentile of the distribution across all consumers*

Table X2.2 Consumption, inhalation, handling and occupancy rates for aquatic pathways

Site (Year of Last Survey)	Group[a]	Rates
Aldermaston (2002)	A	1 kg y^{-1} pike
		320 h y^{-1} over riverbank
	B	1.2 kg y^{-1} crayfish
Amersham (2009)		1 kg y^{-1} pike
		1100 h y^{-1} over riverbank
Berkeley and Oldbury (2007)		14 kg y^{-1} eels and other fish
		2.7 kg y^{-1} shrimps
		900 h y^{-1} over mud, stones and saltmarsh
Bradwell (2007)		25 kg y^{-1} fish
		1.1 kg y^{-1} crabs and lobsters
		2.9 kg y^{-1} Pacific and European oysters
		3100 h y^{-1} over mud
Capenhurst (2008)	10 year old children	500 h y^{-1} over sediment
		5 10^{-3} kg y^{-1} sediment by inadvertent ingestion
		20 l y^{-1} water by inadvertent ingestion
Cardiff	A (2003)	24 kg y^{-1} fish
		3.8 kg y^{-1} prawns and lobster
		500 h y^{-1} over mud
	B (NA)	500 h y^{-1} over bank of River Taff
		2.5 10^{-3} kg y^{-1} sediment by inadvertent ingestion
		34 l y^{-1} water by inadvertent ingestion
	C (2003)	5.6 kg y^{-1} wildfowl
Channel Islands (1997)		62 kg y^{-1} fish
		30 kg y^{-1} crabs, spider crabs and lobsters
		30 kg y^{-1} scallops and whelks
		1400 h y^{-1} over mud and sand
Chapelcross (2005)	A	31 kg y^{-1} salmonids
		950 h y^{-1} over mud
	B	450 h y^{-1} over salt marsh
		19 kg y^{-1} wildfowl
	C	390 h y^{-1} handling nets
		610 h y^{-1} handling sediment
Culham (NA)		600 l y^{-1} water
Derby (2009)		600 l y^{-1} water
		1 kg y^{-1} pike
		610 h y^{-1} over riverbank
Devonport (2004)	A	32 kg y^{-1} fish
		3.5 kg y^{-1} crabs, prawns and shrimps
		1.7 kg y^{-1} scallops
		980 h y^{-1} over sediment and shale
	B	2000 h y^{-1} over mud
Dounreay (2008)	A	1700 h y^{-1} handling fishing gear
	B	18 kg y^{-1} fish
		21 kg y^{-1} crab and lobster
		2.1 kg y^{-1} winkles and mussels
		470 h y^{-1} over sand
	C	8 h y^{-1} in a Geo
Drigg (NA)		35 l y^{-1} water
Drinking water (NA)	Adults	600 l y^{-1}
	10 y	350 l y^{-1}
	1 y	260 l y^{-1}
Dungeness (2005)	A	51 kg y^{-1} fish
		9.3 kg y^{-1} crabs and shrimps
		17 kg y^{-1} king scallops
		1500 h y^{-1} over mud and sand
	B (Rye Harbour houseboats)	2000 h y^{-1} over mud

Table X2.2 continued

Site (Year of Last Survey)	Group[a]	Rates
Faslane (2006)		19 kg y^{-1} fish 0.17 kg y^{-1} mussels 570 h y^{-1} over stones
Hartlepool (2008)	A	28 kg y^{-1} fish 19 kg y^{-1} crab and lobster 5.8 kg y^{-1} winkles and whelks 600 h y^{-1} over sand
	B	1200 h y^{-1} over sand and sea coal
Harwell (2007)		1.1 kg y^{-1} fish 1.1 kg y^{-1} crayfish 420 h y^{-1} over riverbank
Heysham (2006)		25 kg y^{-1} fish 16 kg y^{-1} shrimps 4.5 kg y^{-1} cockles, whelks and mussels 1300 h y^{-1} over mud
Hinkley Point (2006)		40 kg y^{-1} fish 12 kg y^{-1} shrimps 1.9 kg y^{-1} whelks 1300 h y^{-1} over mud
Holy Loch (1989)		730 h y^{-1} over mud
Hunterston (2007)		47 kg y^{-1} fish 18 kg y^{-1} *Nephrops* and squat lobsters 21 kg y^{-1} king scallops 440 h y^{-1} over mud, sand or stones
Landfill (NA)		2.5 l y^{-1} water
Rosyth (2005)	A	31 kg y^{-1} fish 28 kg y^{-1} crabs and lobsters
	B	14 kg y^{-1} winkles and mussels 730 h y^{-1} over sediments
Sellafield	A (Sellafield fishing community) (2009)	40 kg y^{-1} cod (25%) and other fish (75%) 16 kg y^{-1} crab (30%), lobster (50%) and *Nephrops* (20%) 28 kg y^{-1} winkles (60%) and other molluscs (40%) 960 h y^{-1} over mud and sand
	B (Fishermen's nets and pots) (2008)	980 h y^{-1} handling nets and pots
	C (Bait digging and mollusc collecting) (2008)	960 h y^{-1} handling sediment
	D (Whitehaven commercial) (1998)	40 kg y^{-1} plaice and cod 9.7 kg y^{-1} *Nephrops* 15 kg y^{-1} whelks
	E (Morecambe Bay)	see Heysham
	F (Fleetwood) (1995)	93 kg y^{-1} plaice and cod 29 kg y^{-1} shrimps 23 kg y^{-1} whelks
	G (Dumfries and Galloway) (seafood) (2007)	51 kg y^{-1} fish 15 kg y^{-1} *Nephrops*, crab and lobster 5.7 kg y^{-1} mussels and cockles 780 h y^{-1} over mud
	H (Laverbread) (1972)	47 kg y^{-1} laverbread
	I (Dumfries and Galloway (wildfowling) (2007)	670 h y^{-1} over saltmarsh 22 kg y^{-1} wildfowl
	J (Typical fish consumer) (NA)	15 kg y^{-1} cod and plaice
	K (Isle of Man) (NA)	100 kg y^{-1} fish 20 kg y^{-1} crustaceans 20 kg y^{-1} molluscs
	L (Northern Ireland) (2000)	99 kg y^{-1} haddock and other fish 34 kg y^{-1} *Nephrops* and crabs 7.7 kg y^{-1} mussels and other molluscs 1100 h y^{-1} over mud and sand

Table X2.2 continued

Site (Year of Last Survey)	Group[a]	Rates
	M (North Wales) (NA)	100 kg y^{-1} fish
		20 kg y^{-1} crustaceans
		20 kg y^{-1} molluscs
		300 h y^{-1} over mud and sand
	N (Sellafield fishing community 2005-2009) (NA)	19 kg y^{-1} cod
		22 kg y^{-1} other fish
		9.8 kg y^{-1} crabs
		5.1 kg y^{-1} lobsters
		3.8 kg y^{-1} *Nephrops*
		18 kg y^{-1} winkles
		14 kg y^{-1} other molluscs
		820 h y^{-1} over mud and sand
	O (Typical recreational use over beaches, muddy areas or salt marsh) (NA)	300 h y^{-1} over intertidal substrates
	P (Typical beach user e.g. tourist) (NA)	1 kg y^{-1} fish
		0.2 kg y^{-1} crustaceans
		0.2 kg y^{-1} molluscs
		30 h y^{-1} over sand
	Q (Ravenglass nature warden) (2009)	160 h y^{-1} over salt marsh
		520 h y^{-1} over mud and sand
		2.7 10^{-3} kg y^{-1} mud by inadvertent ingestion
		5.0 10^{-5} kg y^{-1} mud by resuspension and inhalation
Clyde (small users) (NA)		20 kg y^{-1} molluscs
Sizewell (2005)		23 kg y^{-1} fish
		11 kg y^{-1} crab and lobster
		5.1 kg y^{-1} Pacific oysters and mussels
		720 h y^{-1} over mud
Springfields	A (2006)	54 kg y^{-1} fish
		21 kg y^{-1} shrimps
		350 h y^{-1} over mud
	B (2006)	690 h y^{-1} handling nets
	C (Ribble Estuary houseboats) (2005-2009) (NA)	3400 h y^{-1} over mud
	D (10 year old children) (NA)	30 h y^{-1} over mud
		3 10^{-4} kg y^{-1} mud by inadvertent ingestion
		1.9 10^{-6} kg y^{-1} mud by resuspension and inhalation
	E (Farmers) (2006)	750 h y^{-1} over salt marsh
Torness (2006)	A	29 kg y^{-1} fish
		22 kg y^{-1} crab and lobster
		7.8 kg y^{-1} winkles
		470 h y^{-1} over sand
	B	1100 h y^{-1} handling fishing gear
Trawsfynydd (2005)		1.3 kg y^{-1} brown trout
		60 kg y^{-1} rainbow trout
		450 h y^{-1} over lake shore
Upland lake (NA)		37 kg y^{-1} fish
Winfrith (2003)		40 kg y^{-1} fish
		15 kg y^{-1} crabs and lobsters
		14 kg y^{-1} scallops and whelks
		300 h y^{-1} over sand and stones
Wylfa (2009)		29 kg y^{-1} fish
		16 kg y^{-1} crabs, lobsters and prawns
		6.9 kg y^{-1} mussels
		390 h y^{-1} over mud and sand

[a] *Where more than one group exists at a site the groups are denoted A, B etc. Year of habits survey is given where appropriate*
NA Not appropriate

Annex 3. Dosimetric data

The dose coefficients used in assessments in this report are provided in Table X3.1 for ease of reference. For adults and postnatal children they are based on generic data contained in International Commission on Radiological Protection Publication 72 (International Commission on Radiological Protection, 1996a). Doses for prenatal children have been obtained primarily from ICRP 88 (International Commission on Radiological Protection, 2001) and National Radiological Protection Board (2005). For a few radionuclides where prenatal dose coefficients are unavailable the relevant adult dose coefficient has been used.

In the case of tritium, polonium, plutonium and americium radionuclides, dose coefficients have been adjusted according to specific research work of relevance to assessments in this report.

A3.1 Polonium

The current ICRP advice is that a gut uptake factor of 0.5 is appropriate for dietary intakes of polonium by adults (International Commission on Radiological Protection, 1994). A study involving the consumption of crab meat containing natural levels of polonium-210 has suggested that the factor could be as high as 0.8 (Hunt and Allington, 1993). More recently, similar experiments with mussels, cockles and crabs suggested a factor in the range 0.15 to 0.65, close to the ICRP value of 0.5 (Hunt and Rumney, 2004 , 2005 and 2007). Previous assessments have considered the effects of a factor of 0.8 when considering monitoring results in RIFE. In view of the most recent review (Hunt and Rumney, 2007), a value of 0.5 has been adopted for all food, consistent with the ICRP advice.

A3.2 Plutonium and americium

Studies using adult human volunteers have suggested a gut uptake factor of 0.0002 is appropriate for the consumption of plutonium and americium in winkles from near Sellafield (Hunt et al., 1986, 1990). For these and other actinides in food in general, the NRPB (now part of HPA) considers a factor of 0.0005 to be a reasonable best estimate (National Radiological Protection Board, 1990) to be used when data for the specific circumstances under consideration are not available. In this report, when estimating doses to consumers of winkles from Cumbria, a gut uptake factor of 0.0002 is used for plutonium and americium and this is consistent with HPA advice. For other foods and for winkles outside Cumbria, the factor of 0.0005 is used for these radioelements. This choice is supported by studies of cockle consumption (Hunt, 1998).

A3.3 Technetium-99

Volunteer studies have been extended to consider the transfer of technetium-99 in lobsters across the human gut (Hunt *et al.,* 2001). Although values of the gut uptake factor found in this study were lower than the ICRP value of 0.5, dose coefficients are relatively insensitive to changes in the gut uptake factor. This is because the effective dose is dominated by 'first pass' dose to the gut (Harrison and Phipps, 2001). In this report, we have therefore retained use of the standard ICRP factor and dose coefficient for technetium-99.

A3.4 Tritium

In 2002, the HPA reviewed the use of dose coefficients for tritium associated with organic material (Harrison *et al.*, 2002). Subsequently HPA published a study of the uptake and retention of organically bound tritium in rats fed with fish from Cardiff Bay (Hodgson *et al.*, 2005). These experiments suggested that the dose coefficient for OBT in fish from the Severn Estuary near Cardiff should be 6.0 10-11 Sv Bq-1, higher than the standard ICRP value for OBT ingestion. The higher value is used for adults in the assessment of seafood collected near the Cardiff site in this report, and the standard ICRP value for other assessments. This approach is consistent with recent advice from the HPA, (Cooper, 2008) which takes account of the conclusions reached by the HPA Independent Advisory Group on Ionising Radiation concerning relative biological effectiveness and radiation weighting (Health Protection Agency, 2007). More recent experimental evidence provided by Hunt *et al.* (2009) involving adult volunteers who ate samples of sole from Cardiff Bay confirms that this approach is indeed cautious.

Table X3.1. Dosimetric data

Radionuclide	Half Life (years)	Mean β energy (MeV per disintegration)	Mean γ energy (MeV per disintegration)	Dose per unit intake by ingestion using ICRP-60 methodology (Sv Bq^{-1})			
				Adults	10 yr.	1 yr.	Fetus
H-3	1.24E+01	5.68E-03	0.00E+00	1.8E-11	2.3E-11	4.8E-11	3.1E-11
H-3 (f)				4.2E-11	5.7E-11	1.2E-10	6.3E-11
H-3 (h)				6.0E-11	8.0E-11	2.0E-10	9.0E-11
C-14	5.73E+03	4.95E-02	0.00E+00	5.8E-10	8.0E-10	1.6E-09	8.0E-10
P-32	3.91E-02	6.95E-01	0.00E+00	2.4E-09	5.3E-09	1.9E-08	2.5E-08
S-35 (g)	2.39E-01	4.88E-02	0.00E+00	7.7E-10	1.6E-09	5.4E-09	1.6E-09
Ca-45	4.46E-01	7.72E-02	0.00E+00	7.1E-10	1.8E-09	4.9E-09	8.7E-09
Cr-51	7.59E-02	0.00E+00	3.20E-01	3.8E-11	7.8E-11	2.3E-10	3.8E-11
Mn-54	8.56E-01	4.22E-03	8.36E-01	7.1E-10	1.3E-09	3.1E-09	7.1E-10
Fe-55	2.70E+00	4.20E-03	1.69E-03	3.3E-10	1.1E-09	2.4E-09	8.1E-11
Co-57	7.42E-01	1.86E-02	1.25E-01	2.1E-10	5.8E-10	1.6E-09	1.1E-10
Co-58	1.94E-01	3.41E-02	9.98E-01	7.4E-10	1.7E-09	4.4E-09	5.8E-10
Co-60	5.27E+00	9.66E-02	2.50E+00	3.4E-09	1.1E-08	2.7E-08	1.9E-09
Zn-65	6.67E-01	6.87E-03	5.85E-01	3.9E-09	6.4E-09	1.6E-08	4.1E-09
Se-75	3.28E-01	1.45E-02	3.95E-01	2.6E-09	6.0E-09	1.3E-08	2.7E-09
Sr-90†	2.91E+01	1.13E+00	3.16E-03	3.1E-08	6.6E-08	9.3E-08	4.6E-08
Zr-95†	1.75E-01	1.61E-01	1.51E+00	1.5E-09	3.0E-09	8.8E-09	7.6E-10
Nb-95	9.62E-02	4.44E-02	7.66E-01	5.8E-10	1.1E-09	3.2E-09	3.7E-10
Tc-99	2.13E+05	1.01E-01	0.00E+00	6.4E-10	1.3E-09	4.8E-09	4.6E-10
Ru-103†	1.07E-01	7.48E-02	4.69E-01	7.3E-10	1.5E-09	4.6E-09	2.7E-10
Ru-106†	1.01E+00	1.42E+00	2.05E-01	7.0E-09	1.5E-08	4.9E-08	3.8E-10
Ag-110m†	6.84E-01	8.70E-02	2.74E+00	2.8E-09	5.2E-09	1.4E-08	2.1E-09
Sb-124	1.65E-01	1.94E-01	1.69E+00	2.5E-09	5.2E-09	1.6E-08	1.0E-09
Sb-125	2.77E+00	1.01E-01	4.31E-01	1.1E-09	2.1E-09	6.1E-09	4.7E-10
Te-125m	1.60E-01	1.09E-01	3.55E-02	8.7E-10	1.9E-09	6.3E-09	8.7E-10
I-125	1.65E-01	1.94E-02	4.21E-02	1.5E-08	3.1E-08	5.7E-08	9.1E-09
I-129	1.57E+07	6.38E-02	2.46E-02	1.1E-07	1.9E-07	2.2E-07	4.4E-08
I-131†	2.20E-02	1.94E-01	3.81E-01	2.2E-08	5.2E-08	1.8E-07	2.3E-08
Cs-134	2.06E+00	1.63E-01	1.55E+00	1.9E-08	1.4E-08	1.6E-08	8.7E-09
Cs-137†	3.00E+01	2.49E-01	5.65E-01	1.3E-08	1.0E-08	1.2E-08	5.7E-09
Ba-140†	3.49E-02	8.49E-01	2.50E+00	4.6E-09	1.0E-08	3.1E-08	3.5E-09
Ce-144†	7.78E-01	1.28E+00	5.28E-02	5.2E-09	1.1E-08	3.9E-08	3.1E-11
Pm-147	2.62E+00	6.20E-02	4.37E-06	2.6E-10	5.7E-10	1.9E-09	2.6E-10
Eu-154	8.80E+00	2.92E-01	1.24E+00	2.0E-09	4.1E-09	1.2E-08	2.0E-09
Eu-155	4.96E+00	6.34E-02	6.06E-02	3.2E-10	6.8E-10	2.2E-09	3.2E-10
Pb-210†	2.23E+01	4.28E-01	4.81E-03	6.9E-07	1.9E-06	3.6E-06	1.4E-07
Bi-210	1.37E-02	3.89E-01	0.00E+00	1.3E-09	2.9E-09	9.7E-09	6.6E-12
Po-210(c)	3.79E-01	0.00E+00	0.00E+00	1.2E-06	2.6E-06	8.8E-06	1.3E-07
Po-210(d)				1.9E-06	4.2E-06	1.4E-05	2.1E-07
Ra-226†	1.60E+03	9.56E-01	1.77E+00	2.8E-07	8.0E-07	9.6E-07	3.2E-07
Th-228†	1.91E+00	9.13E-01	1.57E+00	1.4E-07	4.3E-07	1.1E-06	2.4E-07
Th-230	7.70E+04	1.46E-02	1.55E-03	2.1E-07	2.4E-07	4.1E-07	8.6E-09
Th-232	1.41E+10	1.25E-02	1.33E-03	2.3E-07	2.9E-07	4.5E-07	9.4E-09
Th-234†	6.60E-02	8.82E-01	2.10E-02	3.4E-09	7.4E-09	2.5E-08	1.5E-11
U-234	2.44E+05	1.32E-02	1.73E-03	4.9E-08	7.4E-08	1.3E-07	1.5E-08
U-235†	7.04E+08	2.15E-01	1.82E-01	4.7E-08	7.1E-08	1.3E-07	1.4E-08
U-238†	4.47E+09	8.92E-01	2.24E-02	4.8E-08	7.5E-08	1.5E-07	1.3E-08
Np-237†	2.14E+06	2.67E-01	2.38E-01	1.1E-07	1.1E-07	2.1E-07	3.6E-09
Pu-238(a)	8.77E+01	1.06E-02	1.81E-03	2.3E-07	2.4E-07	4.0E-07	9.0E-09
Pu-238(b)				9.2E-08	9.6E-08	1.6E-07	3.6E-09
Pu-239(a)	2.41E+04	6.74E-03	8.07E-04	2.5E-07	2.7E-07	4.2E-07	9.5E-09
Pu-239(b)				1.0E-07	1.1E-07	1.7E-07	3.8E-09
Pu-α(e)	2.41E+04	6.74E-03	8.07E-04	2.5E-07	2.7E-07	4.2E-07	9.5E-09
Pu-240(a)	6.54E+03	1.06E-02	1.73E-03	2.5E-07	2.7E-07	4.2E-07	9.5E-09
Pu-240(b)				1.0E-07	1.1E-07	1.7E-07	3.8E-09
Pu-241(a)	1.44E+01	5.25E-03	2.55E-06	4.8E-09	5.1E-09	5.7E-09	1.1E-10
Pu-241(b)				1.9E-09	2.0E-09	2.3E-09	4.4E-11
Am-241(a)	4.32E+02	5.21E-02	3.25E-02	2.0E-07	2.2E-07	3.7E-07	2.7E-09
Am-241(b)				8.0E-08	8.8E-08	1.5E-07	1.1E-09
Cm-242	4.46E-01	9.59E-03	1.83E-03	1.2E-08	2.4E-08	7.6E-08	4.7E-10
Cm-243	2.85E+01	1.38E-01	1.35E-01	1.5E-07	1.6E-07	3.3E-07	1.5E-07
Cm-244	1.81E+01	8.59E-03	1.70E-03	1.2E-07	1.4E-07	2.9E-07	2.2E-09

Table X3.1. continued

Radionuclide	Dose per unit intake by inhalation using ICRP-60 methodology (Sv Bq^{-1})			
	Adults	10 yr.	1 yr.	Fetus
H-3	4.5E-11	8.2E-11	2.7E-10	2.6E-12
H-3(f)	4.1E-11	5.5E-11	1.1E-10	6.3E-11
C-14	2.0E-09	2.8E-09	6.6E-09	6.6E-11
P-32	3.4E-09	5.3E-09	1.5E-08	6.5E-09
S-35(g)	1.4E-09	2.0E-09	4.5E-09	1.5E-11
Ca-45	2.7E-09	3.9E-09	8.8E-09	1.7E-09
Cr-51	3.7E-11	6.6E-11	2.1E-10	3.7E-11
Mn-54	1.5E-09	2.4E-09	6.2E-09	1.5E-09
Fe-55	3.8E-10	6.2E-10	1.4E-09	6.6E-11
Co-57	5.5E-10	8.5E-10	2.2E-09	6.1E-11
Co-58	1.6E-09	2.4E-09	6.5E-09	2.5E-10
Co-60	1.0E-08	1.5E-08	3.4E-08	1.2E-09
Zn-65	1.6E-09	2.4E-09	6.5E-09	7.4E-10
Se-75	1.0E-09	2.5E-09	6.0E-09	1.1E-09
Sr-90†	3.8E-08	5.4E-08	1.2E-07	1.0E-08
Zr-95†	6.3E-09	9.0E-09	2.1E-08	4.6E-10
Nb-95	1.5E-09	2.2E-09	5.2E-09	1.6E-10
Tc-99	4.0E-09	5.7E-09	1.3E-08	8.3E-11
Ru-103†	2.4E-09	3.5E-09	8.4E-09	1.1E-10
Ru-106†	2.8E-08	4.1E-08	1.1E-07	4.1E-10
Ag-110m†	7.6E-09	1.2E-08	2.8E-08	1.5E-09
Sb-124	6.4E-09	9.6E-09	2.4E-08	4.4E-10
Sb-125	4.8E-09	6.8E-09	1.6E-08	2.6E-10
Te-125m	3.4E-09	4.8E-09	1.1E-08	3.4E-09
I-125	5.1E-09	1.1E-08	2.3E-08	3.1E-09
I-129	3.6E-08	6.7E-08	8.6E-08	1.5E-08
I-131†	7.4E-09	1.9E-08	7.2E-08	8.1E-09
Cs-134	6.6E-09	5.3E-09	7.3E-09	3.0E-09
Cs-137†	4.6E-09	3.7E-09	5.4E-09	2.0E-09
Ba-140†	6.2E-09	9.6E-09	2.6E-08	1.4E-09
Ce-144†	3.6E-08	5.5E-08	1.6E-07	4.2E-10
Pm-147	5.0E-09	7.0E-09	1.8E-08	5.0E-09
Eu-154	5.3E-08	6.5E-08	1.5E-07	5.3E-08
Eu-155	6.9E-09	9.2E-09	2.3E-08	6.9E-09
Pb-210†	1.2E-06	1.6E-06	4.0E-06	6.1E-08
Bi-210	9.3E-08	1.3E-07	3.0E-07	9.1E-12
Po-210	3.3E-06	4.6E-06	1.1E-05	1.9E-08
Ra-226†	3.5E-06	4.9E-06	1.1E-05	9.9E-08
Th-228†	4.3E-05	5.9E-05	1.4E-04	2.5E-07
Th-230	1.4E-05	1.6E-05	3.5E-05	2.6E-08
Th-232	2.5E-05	2.6E-05	5.0E-05	2.8E-08
Th-234†	7.7E-09	1.1E-08	3.1E-08	6.7E-12
U-234	3.5E-06	4.8E-06	1.1E-05	4.9E-08
U-235†	3.1E-06	4.3E-06	1.0E-05	4.5E-08
U-238†	2.9E-06	4.0E-06	9.4E-06	4.4E-08
Np-237†	2.3E-05	2.2E-05	4.0E-05	4.3E-07
Pu-238	4.6E-05	4.4E-05	7.4E-05	1.1E-06
Pu-239	5.0E-05	4.8E-05	7.7E-05	1.2E-06
Pu-α(e)	5.0E-05	4.8E-05	7.7E-05	1.2E-06
Pu-240	5.0E-05	4.8E-05	7.7E-05	1.2E-06
Pu-241	9.0E-07	8.3E-07	9.7E-07	1.4E-08
Am-241	4.2E-05	4.0E-05	6.9E-05	3.2E-07
Cm-242	5.2E-06	7.3E-06	1.8E-05	5.1E-08
Cm-243	3.1E-05	3.1E-05	6.1E-05	3.1E-05
Cm-244	2.7E-05	2.7E-05	5.7E-05	2.6E-07

† *Energy and dose per unit intake data include the effects of radiations of short-lived daughter products*
(a) *Gut transfer factor 5.00E-4 for consumption of all foodstuffs except Cumbrian winkles*
(b) *Gut transfer factor 2.00E-4 for consumption of Cumbrian winkles*
(c) *Gut transfer factor 0.5*
(d) *Gut transfer factor 0.8*
(e) *Pu-239 data used*
(f) *Organically bound tritium*
(g) *Organically bound sulphur*
(h) *Organically bound tritium for seafood near the Cardiff site*

Annex 4. Estimates of concentrations of natural radionuclides

A4.1 Aquatic foodstuffs

Table X4.1 gives estimated values of concentrations of radionuclides due to natural sources in aquatic foodstuffs. The values are based on sampling and analysis conducted by Cefas (Young et al., 2002; 2003). Data for lead-210 and polonium-210 are from a detailed study and are quoted as medians with minimum and maximum values given in brackets. Dose assessments for aquatic foodstuffs are based on activity concentrations of these radionuclides net of natural background.

A4.2 Terrestrial foodstuffs

The values of carbon-14 in terrestrial foodstuffs due to natural sources that are used in dose assessments are given in Table X4.2 (Ministry of Agriculture, Fisheries and Food, 1995).

Table X4.1. Concentrations of radionuclides in seafood due to natural sources

Radionuclide	Concentration of radioactivity (Bq kg^{-1} (fresh))[a]									
	Fish	Crustaceans	Crabs	Lobsters	Molluscs	Winkles	Mussels	Cockles	Whelks	Limpets
Carbon-14	23	27			23					
Lead-210	0.042	0.02	0.24	0.080	1.2	1.5	1.6	0.94	0.39	1.5
	(0.0030-0.55)	(0.013-2.4)	(0.043-0.76)	(0.02-0.79)	(0.18-6.8)	(0.69-2.6)	(0.68-6.8)	(0.59-1.3)	(0.18-0.61)	(0.68-4.9)
Polonium-210	0.82	9.1	19	5.3	17	13	42	18	6.5	8.4
	(0.18-4.4)	(1.1-35)	(4.1-35)	(1.9-10)	(1.2-69)	(6.1-25)	(19-69)	(11-36)	(1.2-11)	(5.9-15)
Radium-226	0.04	0.03	0.03	0.06	0.08	0.08				
Thorium-228	0.0054	0.0096	0.04	0.0096	0.37	0.46		0.37		
Thorium-230	0.00081	0.0026	0.008	0.0026	0.19	0.26		0.19		
Thorium-232	0.00097	0.0014	0.01	0.0014	0.28	0.33		0.28		
Uranium-234	0.0045	0.040	0.055	0.040	0.99	0.99				
Uranium-238	0.0039	0.035	0.046	0.035	0.89	0.89				

[a] *Values are quoted as medians with minimum and maximum values given in brackets*

Table X4.2. Carbon 14 in terrestrial foodstuffs due to natural sources

Food Category	% Carbon content (fresh)	Concentration of carbon-14 (Bq kg^{-1} (fresh))
Milk	7	18
Beef meat	17	44
Sheep meat	21	54
Pig meat	21	54
Poultry	28	72
Game	15	38
Offal	12	31
Eggs	15	38
Green vegetables	3	8
Root vegetables	3	8
Legumes / other domestic vegetables	8	20
Dry beans	20	51
Potato	9	23
Cereals	41	105
cultivated fruit	4	10
Wild fruit	4	10
Mushrooms	2	5
Honey	31	79
Nuts	58	148