Initial radiological assessment tool 2: part 2 methods and input data

Chief Scientist's Group report

November 2022

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Dr Robert Bradburne
Chief Scientist

Executive summary

The Environmental Permitting (England and Wales) Regulations 2016 (EPR 2016) provides the framework for controlling the generation and disposal of solid, liquid and gaseous radioactive waste so as to protect the public and the environment. EPR 2016 requires the disposal or discharge of radioactive waste to the environment to be permitted. When deciding whether to grant a permit for a disposal or discharge of radioactive waste, the Environment Agency is required to ensure that radiation doses to the public do not exceed specified dose constraints. We must also ensure that permitted discharges do not have adverse effects on wildlife to protect ecosystems, designated conservation areas and protected species.

Our initial radiological assessment methodology provides a system for undertaking a simple and cautious prospective assessment of the dose arising from discharges of radioactive waste into the environment. The methodology allows assessment of the release of over 100 radionuclides via the following routes:

- to air
- to estuary/coastal water
- to river/stream
- to public sewer

Doses can be calculated for eight different groups of the public, and to four age groups (adult, 10 year old, 1 year old and the fetus) who may receive doses as a result of discharges via these routes. Dose rates can also be calculated for wildlife inhabiting terrestrial, coastal or river environments.

The initial radiological assessment methodology is supported by four spreadsheet tools, which perform the calculations set out in the methodology. The spreadsheets are available on request from the Environment Agency.

The initial radiological assessment methodology was first published in 2006. We have now revised our initial radiological assessment methodology to use up to date models and data, include additional radionuclides and exposure groups and formally incorporate an assessment of dose rates to wildlife. We refer to the updated version of the methodology and spreadsheets as the Initial Radiological Assessment Tool 2 or 'IRAT2', and it is described in 2 reports.

In the first report 'Initial Radiological Assessment Tool 2 – Part 1 User Report', we describe how to apply the initial radiological assessment methodology, how to carry out initial assessments using the IRAT2 spreadsheets and provide some worked examples. That Part 1 document also contains all the DPUR factors required to carry out initial assessment calculations.

The initial radiological assessment methodology is based on pre-calculated dose per unit release (DPUR) factors. The key assumptions which have been used to calculate the DPUR factors for IRAT2 are described in this Part 2 report. 'The methods used are described in detail and all input data and intermediate output data used to derive the DPUR factors are listed.

Contents

1 Introduction

Organisations that discharge radioactive waste to the environment in England must apply to the Environment Agency for a permit under the Environmental Permitting (England and Wales) Regulations (2016) (EPR 2016). The Environment Agency is required to ensure that doses from discharges do not exceed the Euratom Basic Safety Standards directive public dose limit of 1 mSv/y [1] and have regard for a maximum dose constraint of 0.3 mSv/y for any source from which radioactive discharges are first made after May 2000 [2]. Therefore, as part of the application, each organisation applying for a discharge permit is required to submit an assessment of the radiological impact of their discharges. The Euratom Basic Safety Standards Directive requires that assessments of doses from practices are made as realistic as possible for the population as a whole and for reference groups of the population [1].

Many of the organisations applying for discharge permits are ‘small users’ of radioactive materials (also referred to as ‘non-nuclear sites’), including hospitals, universities and commercial research centres. The radionuclides discharged by many small users have short half-lives and are often released in low quantities. Effective doses from these discharges can vary depending on the radionuclide, the half life and the quantity discharged. Undertaking a detailed assessment of the radiological impact of a release of radionuclides into the environment can involve significant effort, which may not be proportionate if the assessed doses are low or very low. A method for making an initial radiological assessment on a cautious and simplified basis allows for a quick assessment of the likely impact with a proportionate amount of effort.

The Environment Agencies, in collaboration with the Food Standards Agency and the Health Protection Agency (now UK Health Security Agency), published ‘Principles for the Assessment of Prospective Public Doses’ [3], defining a set of principles and providing guidance on the assessment of public doses for the purpose of authorising planned discharges of radioactive waste to the environment. A staged approach to the assessment of doses for permitting purposes is recommended, as shown in Figure 1. The first stage consists of a simple and cautious assessment of the dose to a representative person (an initial radiological assessment). If the resulting effective dose rate is less than 0.02 mSv/y then no further assessment would be needed for the purpose of permitting the discharge of radioactive waste to the environment. Further investigation using more realistic data may be undertaken when the effective dose exceeds 0.02 mSv/y [3], in particular if a regulatory decision is dependent on the outcome of the assessment.

The initial assessment needs to be simple and straightforward, cautious (but not unrealistic), consistent and supported by the most appropriate data. This will provide a robust and acceptable test to identify where further resource should be expended on the radiological assessment, such as including detailed source and site data, short-term release assessment, collective dose assessment and variability and uncertainty assessments.

The Environment Agency first developed an initial radiological assessment system in 2005 [4]. This was reviewed, further developed, updated and published as the 'Initial Radiological Assessment Methodology' in 2006 [5, 6].

Two reports were produced: a 'User Report' presenting the information needed to carry out initial assessments [5] and a report describing the methodology in detail with all of the relevant input data, intermediate data and data sources [6]. The initial radiological assessment system has been widely used since its publication and has become the default system to use for initial radiological assessments at the Environment Agency.

Some of the underlying models and data have been refined, and the Environment Agency has gained experience of using the initial radiological assessment tool (IRAT). IRAT has now been updated to IRAT2, to include the most up to date information, several additional radionuclides, and additional exposure pathways. It also includes an assessment of the dose rates to wildlife, based on an internationally recommended methodology.

This report presents the models and data used in IRAT2 and accompanies an updated User Guide [7].

2 Methods for deriving environmental radionuclide concentrations

In assessing the radiological impact of discharges of radionuclides to the environment, the methodology must consider the scenarios for release, the pathways for transport through the environment and the modes of exposure of the receptor (humans or wildlife). Thus, a source–pathway–receptor analysis is appropriate. For IRAT2, the sources are radioactive gaseous and liquid discharges.

The IRAT system uses pre-calculated dose per unit release (DPUR) factors to humans and wildlife. The derivation of the DPUR factors was carried out in 2 steps. The first step was to calculate the environmental activity concentrations[1] arising from a unit release to the environment, calculated using dispersion and transfer models. The second step was to calculate the doses to humans and dose rates to wildlife from exposure to those environmental activity concentrations. The outcomes are DPUR factors, which form the basis of the IRAT system.

2.1 Environmental Modelling

During the development of IRAT in 2005/6, a review of available methodologies, approaches and data was carried out [6]. Although some models and data have been updated since the publication of IRAT, no new approaches or systems have been developed to undertake initial radiological assessment which meet our needs. Therefore, the general approaches used in IRAT have been retained for IRAT2, with underpinning data being updated and extended as appropriate.

For IRAT2, the discharges considered are gaseous releases to atmosphere and liquid releases to streams and rivers, sewage treatment works, or to estuarine and coastal environments. All these routes of discharge have been extensively studied over many years. Thus, the dominant pathways of radionuclide transport through the environment for each of these sources have been well characterised, as have the modes of exposure of humans and wildlife.

Numerical dispersion models were used to calculate concentrations in environmental media. IRAT2 does not include these models within it but contains pre-calculated data which was derived by using them.

To calculate the dispersion of radionuclides for most of the discharge scenarios and pathways, the most recent release of the Public Health England (now UK Health Secutiry Agency) modelling tool PC-CREAM 08 was used (an updated version of PC-CREAM 98). It is based on a methodology for assessing the radiological consequences of routine releases to the environment originally

[1] In this report the term concentration(s) is used as shorthand for radioactivity concentration(s)

developed for the European Commission [8]. The modules PLUME, FARMLAND, DORIS and GRANIS are contained within PC-CREAM 08 and were used to calculate the transfers of radionuclides through the atmospheric and coastal environments and the foodchain. PC-CREAM 08 and its underlying dispersion models are seen to be robust, fit for the purpose and have been verified against environmental data [9, 10, 11]. The outputs of the model (environmental concentrations per unit release) were used to derive dose per unit release (DPUR) factors for use in IRAT2.

The only aspects of environmental dispersion not covered by PC-CREAM 08 were the river dispersion modelling, sewage dispersion modelling and the child in a brook/stream exposure scenario. A simple sewage works model, used in the original version of IRAT, was retained and used to derive activity concentrations in liquids and solid sludges, taking into account volumes of materials and residence times.

All discharges were assumed to be continuous, uniform, routine releases. This is consistent with the requirements of discharge permits. To allow for build-up of concentrations of radionuclides in the environment, it was assumed that discharges continued for 50 years. The effective dose in the 50th year of discharges, representing the maximum annual dose, was assessed.

The basis of the approach used in this report was to abstract information from existing data compilations and to use the information as input to the environmental models. Where available, input data were taken from the most recent published compilations of nuclide specific parameters such as IAEA’s handbook on modelling in terrestrial and freshwater environments [12] or taken from PC-CREAM 08 [8].

2.2 Atmospheric dispersion and calculation of air concentrations

Radionuclides released to atmosphere are dispersed as they travel downwind. Numerous atmospheric dispersion models are available, and they differ predominantly by their descriptions of the atmospheric boundary layer and atmospheric stability. The simplest types of dispersion models are based on Gaussian plume dispersion. A widely used Gaussian plume model, suitable for generic assessments, is described in a report of the UK Atmospheric Dispersion Working Group known as ‘R91’ [13]. The new generation Gaussian plume dispersion model, ADMS [14], is a potential alternative model that has been widely applied, but this is most suited to more complex site-specific assessments and therefore was not used for IRAT2.

For IRAT2, the PLUME atmospheric dispersion model in PC-CREAM 08 was used to predict air concentrations at ground level from continuous releases. PLUME is based on the R91 model [13]. It is designed for the assessment of continuous releases, is established and widely used, and has the advantage that it is integrated with other models such as the FARMLAND foodchain model.

Atmospheric conditions have been simplified into a series of stability categories and the frequency of each category – depending on the position in the UK – can be applied. It allows a significant amount of flexibility for predicting air concentrations at a range of distances and stack (release) heights. Moreover, it can model a wide range of radionuclides and ground deposition rates. For the calculation of DPUR factors, two set distances and one stack height were used. Atmospheric conditions and stability category combinations that lead to high ground level air concentrations (for dicharges averaged over a year) were adopted. This is described in more detail in Appendix D.

Atmospheric modelling is based on assumptions and a generalisation of environmental and atmospheric conditions. Gaussian plume models have been validated and found to perform well in assessment of long term averages. The models peform less well over short distances from the source and over shorter timescales. Around 100 m may be regarded as the lower limit of the range where Gaussian plume models such as R-91 are applicable.

2.3 Transfers from atmosphere through the terrestrial environment and calculation of concentrations in terrestrial foodstuffs

Most radiological assessment models use very similar approaches to estimating the radiological impacts of continuous releases of radionuclides to terrestrial environments. Radionuclides released to and dispersed in the atmosphere enter the terrestrial environment because of dry and wet deposition on soils and vegetation, and uptake into plants. With both dry and wet deposition, the initial deposit is partitioned into that which is deposited on plants (leaves) and that which is deposited directly on soil. Once deposited on vegetation, radionuclides are lost from plants due to removal by wind and rain, either through leaching or by cuticular abrasion and may be taken up into plants by translocation or photosynthesis. Plant growth can also lead to a reduction in radionuclide concentrations, termed ‘growth dilution’. Weathering losses and growth dilution effects are often estimated in models using a weathering half-life, typically in the range of 5 to 30 days. Translocation from foliage to edible parts of plants is generally represented using an empirical scaling factor.

The model used to predict concentrations in the terrestrial foodchain is FARMLAND in the PC-CREAM 08 model. FARMLAND is designed to predict concentrations of radionuclides in food from continuous releases to the atmosphere.

The FARMLAND model in PC CREAM has a compartmental model of soil - either several well mixed compartments representing the soil underneath undisturbed pasture or one well-mixed compartment representing ploughed soil in arable land. Radionuclide sorption in soils use a distribution co-efficient (K_d value) and plant uptake using a plant–soil concentration ratio. The assessment model for transfer to animals in the human foodchain use transfer factors that relate concentrations of radionuclides in meat, offal and cow’s milk to daily rates of intake in the diet of animals. The FARMLAND model is appropriate for radiological assessment purposes when considering annual doses from continuous releases.

External dose rates above soil and inhalation of resuspended material containing radionuclides are included. Resuspended material refers to the movement of material from the ground surface to the atmosphere as a result of wind and mechanical activities.

The transfer of radionuclides in the terrestrial environment and into foods is described in more detail in Appendix D.

2.4 Dispersion in estuarine and coastal water

A major factor in modelling estuarine and coastal environments is the degree of dispersion that occurs due to factors such as the tidal exchange of water and local currents. The main solution available for transport modelling involves the use of single and multiple uniformly mixed compartments or ‘box-models’ which can be used to represent areas and regions of coastal or esturine waters.

Estuaries represent a particularly complex aquatic environment. Discharges of radionuclides are more likely to occur to estuaries than directly to the coastal environment, and the initial degree of dilution will often be less. Discharges into well-mixed estuaries are often modelled in a similar way to discharges to coastal environments. For stratified estuaries, it is necessary to employ more than one compartment in the vertical dimension. Due to large differences in the characteristics between individual estuaries, it is difficult to apply generic methods.

For the marine dispersion modelling in IRAT2, the DORIS model in PC-CREAM 08 was used. The DORIS model is a compartment model that has been configured for coastal discharges of radionuclides to UK and other European coastlines. It is widely used in the UK, both by the nuclear industry and by the regulators, to assess the impact of continuous discharges of radionuclides to the sea. Discharges occur into a local marine compartment, which can be configured by the user to represent the area of the coast immediately surrounding the point of discharge. From the local marine compartment, an exchange of water and sediments takes place with the adjacent regional compartment and from there into other European waters. As the highest exposures arise from the local compartment, it is important that its configuration is conservative, or representative of the local conditions. This is described in more detail in Appendix E.

2.5 Modelling of freshwater rivers and streams

Rivers are complex and dynamic systems. Simplifying assumptions can be made when modelling river geometry and processes and this approach has been adopted for initial assessment purposes. In the UK, freshwater environments receiving radioactive discharges vary greatly in size, from small streams less than 1 m across to large rivers receiving discharges from multiple sources, like the Thames.

The highest radiological impact can normally be expected immediately downstream of the discharge point depending upon the habit data, where the activity concentrations of the radionuclides are highest. At such short distances downstream, it is unlikely that much can be gained from a detailed dispersion model. Common to all models, there is an initial phase of mixing as the plume disperses across the river. However, thereafter, the concentration in water can be calculated by considering the volumetric flow rate leading to dilution, and allowing for depletion by radioactive decay and deposition to bottom sediments. Partitioning between solution and suspended sediments in such models almost always uses an equilibrium K_d-based approach.

For IRAT2 a simple river model was adopted and implemented in a spreadsheet to calculate radionuclide concentrations in river environments along with the DPUR factors. This is described in more detail in Appendix F.

2.6 Sewage treatment works

PC-CREAM 08 does not include a sewer model. Therefore, the sewer model in the original version of IRAT was retained and used in IRAT2. The sewer model effectively calculates radionuclide concentration in raw sewage and in treated efflluents and sludges from the sewage works. The model is a simple representation of the dilution of radionuclides in water, and the distribution of radionuclides between liquid and sediment phases using partitioning factors. A simple model, such as that adopted by Titley *et al*. [15], is appropriate for initial assessment purposes. This model is characterised in terms of the time taken for each stage of the sewage treatment process. It relies on radionuclide-specific or element-specific removal coefficients which define the partitioning of radionuclides between the effluent and the solids which are separated during treatment. Removal coefficients provide information on the ultimate fate of radionuclides, and can usually be defined from empirical observations [16]. Removal co-efficients are not available for all the radionuclides in IRAT2. In order to achieve a comprehensive set of values for all the radionuclides and treatment processes of interest in IRAT2, removal coefficients were derived from supporting data such as K_d values. Some of the partitioning data has been updated for IRAT2.

Particular issues arise with tritium (H-3) and carbon-14 (C-14) because of the wide range of chemical forms that may be present. However, some empirical data are available that allow a commentary to be developed on the degree to which different chemical forms of these elements will be associated with different forms of sewage sludge.

In IRAT2, treated effluent is assumed to be discharged to a small stream or brook that is accessible to children before joining the main river or estuary. Treated sludge is assumed to be applied to agricultural land or incinerated.

Spreadsheets were used to implement the main parts of the sewer model and calculate the DPUR factors for discharges to sewer.

Sewage sludges are treated for long enough to make them suitable for application to land. This may be of the order of 20-30 days or more. Many radionuclides will have decayed to reduced levels during this time. Transfers of radionuclides present in sewage sludge to agricultural land can occur in the liquid phase of a slurry, or in interstitial water of sludge 'cake', as well as bound to the solid phase. In principle, radionuclide transfers from soils to plants could differ between sludge-conditioned and unconditioned soils. However, in practice, the information that is available suggests only very limited distinctions [17]. This means that the models and data used to characterise these transfers in other contexts can be used also in the context of sewage sludge amended systems. IRAT2 makes use of the FARMLAND model in PC-CREAM 08 for modelling the transfer of radionuclides from sewage sludge applied to land into the foodchain. The FARMLAND model was adapted to allow calculations of sludge to land, as described in Appendix G.

Around 15 – 20% of sewage sludge is incinerated as a method for recovery of energy and as a means of volume reduction of solid waste for ultimate disposal. Sludges from sewage may be available for incineration relatively quickly (a few days) once dewatered. Details of radionuclide behaviour during incineration of such material are limited but studies have examined the behaviour of metals [18]. These show that, while some elements are either substantially retained (e.g. chromium) or essentially entirely released (e.g. carbon), some depend on factors such as incineration temperature, feedstock composition and the abatement systems in place. The conservative approach taken for IRAT2 is to assume that all radionuclides in incinerated sludge are released to air. The assessment can then be refined using incineration partitioning factors. Incineration of sewage sludge is described in more detail in Appendix H.

2.7 Input data

Locating suitable and complete data to support the generation of DPUR factors for a large number of radionuclides, discharge scenarios and exposure paths was challenging. There are gaps in data for element specific environmental transfers. The data gaps have been filled using a range of sources and methods. We have chosen the best available radionuclide specific data wherever possible rather than selecting a uniform set of data for all elements. In addition, as new and better data are published, they can easily be included in future. The approach taken to fill data gaps is described in more detail in Appendix C.

2.8 Ingrowth of progeny

For some pathways and some radionuclides, the ingrowth of progeny can be important for the radiological assessment. In IRAT2, progeny were considered if significant ingrowth is likely to occur in the 50-year discharge period. Ingrowth during transfer through the environment was calculated using PC-CREAM 08 where appropriate. Where PC-CREAM 08 was not used, the ingrowth of progeny was considered separately (e.g. for radionuclides in riverbank sediments). More details are given in Appendices D to G.

3 Dose assessment method

3.1 Introduction to dose per unit release factors

IRAT2 has been developed for the purpose of assessing the impact of planned, or prospective, discharges of radioactivity into the environment. IRAT2 is a screening tool to be used as part of a staged approach to radiological impact assessment. IRAT2 can be used to undertake an initial conservative 'screening' assessment (stage 1) and, if necessary, a more refined assessment (stage 2). The initial 'screening' assessment should include sufficient caution in the assumptions and modelling to ensure that the calculated doses are unlikely to be underestimated.

In this report, dose to humans refers to effective dose which takes account of the effect of ionising radiation on different organs and tissues of the human body[2]. Dose rate to wildlife refers to absorbed dose rate[3].

In IRAT2, dose per unit release (DPUR) factors for continuous releases are used to assess doses associated with proposed annual discharges. This is a simple and straightforward way of undertaking an initial assessment. Generic (non site-specific), cautious DPUR factors have been used in IRAT2. A single DPUR factor is provided for each radionuclide, exposed group and discharge scenario. An advantage of pre-calculated DPUR factors is that a first cautious assessment can be carried out to provide a quick and simple scoping calculation. Pre-calculated DPUR factors can also be useful where site-specific data are not readily available. The DPUR factors have been calculated based on cautious assumptions to ensure that doses are not underestimated but without being overly conservative and unrealistic.

An assessment using IRAT2 may be refined with the inclusion of some site-specific factors. A refined assessment can be achieved by adjusting the environmental dispersion and dilution of the discharged radionuclides using a very simple modelling step. For example, for discharges to a river, linear, scaling factors representing different river flow rates can be applied.

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[2] Effective dose is calculated for the whole body and is the addition of equivalent doses to all organs, each adjusted to account for the sensitivity of the organ to radiation. Equivalent dose to an organ is based on the absorbed dose (see footnote 3) to an organ, adjusted to account for the effectiveness of the type of radiation. Expressed in sieverts, Sv, or multiples thereof e.g. millisiverts, mSv. In the context of radiological assessments for humans usually expressed as an annual dose rate in mSv/y.

[3] Absorbed dose is the amount of energy deposited by radiation in a mass – in this case the body mass of an organism. Expressed in grays (Gy) or multiples thereof e.g. µGy. Normally expressed as absorbed dose rate in the context of wildlife exposure e.g. µGy/hour.

A stage 2 refined IRAT2 assessment can be performed if the initial screening assessment results in an annual effective dose which exceeds 0.02 mSv/y to members of the public or a dose rate which exceeds 1 µGy/h to wildlife. A detailed site-specific assessment may need to follow if the result of the refined IRAT2 assessment is greater than 0.02 mSv/y or 1 µGy/h. This is illustrated in Figure 1.

3.2 Release scenarios

The following release scenarios may be specified in discharge permits and therefore need to be included:

- release of radionuclides to air;
- release of radionuclides in liquids direct to estuary/coastal water;
- release of radionuclides in liquids direct to river;
- release of radionuclides in liquids to public sewer with ongoing transfer into treated liquids and solids.

There are a number of exposure pathways for members of the public from these releases. These releases may also result in doses to wildlife. Dose per unit release (DPUR) factors have been calculated. The DPUR factors are derived from a combination of doses from the various exposure pathways arising from each release route.

3.3 Doses to the public

The dose assessment is based on doses to members of the public exposed to radionuclides in the environment. IRAT2 has been developed to assess the impact of planned not historic releases of radioactivity into the environment, therefore radionuclide concentrations in the environment must be calculated using models (as outlined in section 2).

Since it is not feasible to assess the dose rate to every individual exposed to the discharges, the DPUR factors are calculated for reference groups of people whose location and habits will make them potentially the most exposed. In assessments of doses to the public, the concept of 'representative person' is used[4]. The representative person is 'an individual receiving a dose that is representative of the more highly exposed individuals in the population' [3]. ICRP has recommended that the dose rate to the representative person can be compared with the public dose limit and with the public dose constraint [19]. The doses calculated with DPUR factors are cautious and will not be directly equivalent to the dose to the representative person. The doses calculated using the DPUR factors should only be used for initial screening assessment purposes.

[4] ICRP and the HPA (now UK HSA) have stated that this term is the equivalent of and replaces the average member of the critical group [19, 20] which was the term used in the first version of the initial radiological assessment methodology.

DPUR factors are generated for four age groups: fetus (or ‘offspring’), 1-year-old infants, 10-year-old children and adults. PHE (now UK HSA) has recommended that the concept of the representative person includes the developing fetus. For some radionuclides (phosphorus-32 (P-32), phosphorus-33 (P-33) and calcium-45 (Ca-45)), the fetus may receive the highest dose following the releases of radionuclides to the environment [21]. As these radionuclides may be discharged by non-nuclear users of radioactive substances, the dose to the fetus is included as one of the age groups in the assessments of dose for those users. The term offspring has been used to denote collectively the embryo, fetus and newborn child [22].

DPUR factors have been calculated for exposed groups potentially affected by the discharges. The assessment includes the most exposed age group for each of the exposed groups.

The assessment of dose to members of the public may include those exposed as a result of their work but who are not employed by the organisation making the radioactive discharges. The workers considered in IRAT2 are farmers, fishermen and workers at sewage treatment works.

In calculation of DPUR factors, assumptions were made about the habits and locations of exposed groups. The assumptions about habits are based on UK habits data published by PHE (now UK HSA). The habits data used are taken from the higher end of the range, including high food consumption rates and high occupancy (time spent in the areas where people may be exposed.

It is assumed for a stage 1 screening assessment that all the groups are present, and the exposures can occur. This is a comprehensive assessment which includes potential future exposures.

It may not be known whether doses from a combination of habits would occur. However, to cover that situation an initial assessment could be made by summing the estimated doses calculated for the groups in question.

3.4 Dose rates to wildlife

There is a need to demonstrate that wildlife is adequately protected from permitted radiological discharges. The ‘Principles for the Assessment of Prospective Public Doses’ document [3] does not provide guidance on methods for the assessment of doses to animals and plants, but refers to the ERICA[5] tool, developed internationally with support from the European Union. This has been developed to support decisions about radiological protection of the environment [23]. The ERICA tool evaluates the potential exposure of a variety of reference organisms on the basis of specified radionuclide concentrations in the soil or water they may live on or in. The ERICA integrated approach and tool is an accepted methodology for assessing the exposure of wildlife in European

[5]Environmental Risk from Ionising Contaminants: Assessment and Management (ERICA) http://www.erica-tool.com/

ecosystems. The concentrations of radionuclides in soil or water were calculated using models described in section 2.

IRAT2 uses Dose rate Per Unit Release (DPUR) factors for wildlife for each of the exposure scenarios. The DPUR factors for wildlife were calculated using Dose rate Per Unit Concentration (DPUC) factors generated using the ERICA tool (v1.2) following the same approach used in the habitats assessments for radioactive substances carried out to assess the impact of permitted radioactive discharges on designated wildlife sites [24, 25].

The ERICA tool does not incorporate assessment methods and tools for noble gases, but these are available in the Ar-Kr-Xe dose calculator, a spreadsheet-based tool [26]. This tool was used to derive DPUC factors for noble gas radionuclides used in IRAT2.

3.5 List of radionuclides considered

The list of radionuclides for which DPUR factors were developed was comprehensive in order to allow for initial assessments of discharges from a wide range of sources, including small users and the nuclear industry.

The list of radionuclides included in IRAT2 is presented in Table 1. The list of radionuclides has been extended since the publication of the original version of IRAT to include radionuclides more recently identified as being used in industry, mainly in medical applications.

4 Derivation of dose per unit release (DPUR) factors

4.1 Discharge scenarios and exposure groups

Radioactive discharges to air have been assessed by calculating the doses to one exposure group - a 'local resident family'. Members of this group have been assumed to be exposed to a plume of radionuclides discharged to the atmosphere and the deposition of part of that discharge on the ground, resulting in exposure by external radiation and the consumption of foodstuffs. For the base case (the stage 1 assessment), releases have been assumed to be from a ground level source. It has been further assumed that the group live 100 m from the source and have been exposed to inhalation and external radiation at this distance and consume contaminated food grown at a distance of 500 m from the source. Results can be scaled by a stack height of up to 100 m for the stage 2 assessment. More details are given in Appendix D.

Discharges to air may arise from incineration of radioactive wastes. Radionuclides may partition between flue gases and solid and liquid residues during incineration of radioactive wastes. The partitioning is affected by the incineration processes and abatement employed. A compilation of data for partitioning during incineration is presented in Appendix H which can then be used with the information in Appendix D to refine doses from radioactive discharges to air which occur via incineration.

Radioactive discharges to estuary and coastal water have been assessed by calculating the dose rate to one exposure group – a 'fishing family'. Members of this group were assumed to be exposed to radioactivity in coastal discharges by consumption of seafood contaminated by radionuclides in seawater and by spending time on local beaches. For the base case (the stage 1 assessment) releases were assumed to take place into a local marine compartment with relatively low dispersion, characterised by a volumetric water exchange rate of 100 m^3/s with the neighbouring regional compartment. Results can be scaled by larger volumetric water exchange rates for the stage 2 assessment. More details are given in Appendix E.

Radioactive discharges to a river have been assessed by calculating the doses to two exposure groups. One group is an 'angler family' who were assumed to consume fish, drink water from the river and spend some time on the riverbanks. The second group is an 'irrigated food family' who were assumed to grow and consume terrestrial foodstuffs irrigated with water from the river, as well as drink water from the river. For the base case (the stage 1 assessment) releases were assumed to take place into a small river with a water flow rate of 1 m^3/s. Results can be scaled by a larger volumetric flow for the stage 2 assessment. More details are given in Appendix F.

For releases to sewer 7 exposure groups were considered:

- ‘Sewage treatment workers’ exposed to radionuclides in raw sewage and sewage sludge at the sewage treatment works
- Members of a ‘farming family’ exposed to soil conditioned with treated sewage sludge and consume foodstuffs produced in that soil
- Members of a ‘farming family’ exposed to soil and foods that have become contaminated as a result of incineration of sludge and subsequent deposition of radionuclides onto the ground
- ‘Children playing in brook’ exposed to liquid effluent from the sewage treatment works which had been discharged into a small brook with a base case flow rate of 0.1 m^3/s
- Members of a ‘fishing family’ exposed to discharges from sewer to estuary and coastal water (see Appendix E).
- Members of an ‘angler family’ family exspoed to discharges from sewer to a river (see Appendix F).
- An irrigated food consumer exposed to discharges from sewer to a river (see Appendix F).

The fifth, sixth and seventh groups were considered in the same way as in the coastal/estuary and river release scenarios but additional factors were applied to account for partitioning of radionuclides at the sewage treatment works.

For all sewer exposure groups it was assumed that in the stage 1 initial assessment the volumetric flow rate through the sewage treatment works was 60 $m^{3/}$d, cautiously representative of a small facility with little dilution. Results can be scaled by flow rates specific to particular sewage treatment works. More details on assessment of disposals of radioactive waste with sewage are given in Appendix G.

If sewage sludge is incinerated, further assessment may be required. Information on possible assessment approaches is presented in Appendix H.

The potential exposure of wildlife is also considered in IRAT2 for all release routes – to air, estuary/coastal water, river and sewer. All of the reference organisms included in the ERICA assessment tool (version 1.2) were considered. The ERICA tool was used to calculate dose per unit concentration (DPUC) factors, as described in Appendix A. DPUR factors were then calculated using spreadsheets.

4.2 Basis for dose per unit release (DPUR) factors

DPUR factors were calculated for each release scenario, exposure group, pathway (p), radionuclide (r) and age group (a) as follows:

$$DPUR_{p,r,a} = CPUR_r \times H_{p,a} \times DF_{r,a}$$

where $DPUR_{p,r,a}$ is the dose per unit release factor for a specific pathway, radionuclide and age group (μSv/y per unit release of 1 Bq/y)

$CPUR_r$	is the activity concentration [of a radionuclide, r] per unit release in a relevant material (Bq/kg or /l or /m^3 per unit release of 1 Bq/y)
$H_{p,a}$	is the habit data relevant to the pathway and age group considered, either ingestion rate (kg or l/y) or inhalation rate (m^3/y) or occupancy time (h/y)
$DF_{r,a}$	is the dose per unit intake (or dose coefficient) by ingestion or inhalation (μSv/Bq) or external dose factor (μSv/h per Bq/kg)

The same approach was taken when calculating DPUR factors for wildlife, with the exception that the habit data are implicit in the wildlife DPUC factors.

Full details of the approach and formulae used to calculate individual DPUR factors for members of the public and wildlife are given in Appendices D, E, F and G for discharges to air, coastal water, river and sewer respectively, together with the relevant habit data.

For each exposure group the DPUR factors for all relevant pathways for each of the releases were summed. The summed DPUR factors for each release for the worst affected age group was selected.

$$DPUR_{r,a} = DPUR_{p1,r,a} + DPUR_{p2,r,a} + \ldots DPUR_{pn,r,a}$$

Where:-

$DPUR_{r,a}$	= Total dose per unit release from all exposure pathways for each radionuclide and each age group
$DPUR_{p1,r,a}$	= Dose per unit release from exposure pathway 1 for each radionuclide and each age group
$DPUR_{p2,r,a}$	= Dose per unit release from exposure pathway 2 for each radionuclide and each age group
$DPUR_{pn,r,a}$	= Dose per unit release from exposure pathway n for each radionuclide and each age group

The total DPUR factors ($DPUR_{r,a}$) were used to derive the total dose summed over radionuclides for each discharge scenario and exposure group as follows:

$$D_{tot} = \sum [DPUR_{r,a} \times Q_r]$$

where

D_{tot}	is the total dose for the exposure group under consideration (μSv/y)
Q_r	is the discharge rate of the discharge scenario and radionuclide under consideration (Bq/y)

The total dose for the exposure group under consideration (D_{tot}) may be for a mix of age groups (depending on the radionuclides being discharged).

The highest total dose for each exposure group and from each exposure scenario (the dose to the representative person) can then be compared with

0.02 mSv/y (see Section 1.1) to determine if further, more site-specific assessments are needed.

For wildlife, DPUR factors were calculated for each reference organism and radionuclide combination for each release scenario. The DPUR factors for each radionuclide within each release scenario were then compared, and the worst affected reference organism was identified. The highest dose rate to the worst affected reference organism can then be compared against the 1 µGy/h dose rate (see Section 1.1) to determine in further, more site-specific assessments are needed.

The initial assessment can be adapted to reflect more site-specific conditions to enable a stage 2 dose assessment [3] to be undertaken. The accompanying report 'Initial Radiological Assessment Tool 2 – Part 1 User Report' [7] provides details on how the initial assessment can be changed by applying simple 'step two' scaling factors and guidance on how to refine the assessment further.

DPUR factors are shown in Tables 2-36.

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List of abbreviations

Bq	Becquerel
CR	Concentration ratio
DPUC	Dose per unit concentration (for wildlife)
DPUR	Dose per unit release (for people) or dose rate per unit release (for wildlife)
EPR 2016	Environmental Permitting (England and Wales) Regulations 2016
GDC	Generalised derived constraints
GDL	Generalised derived limits
Gy	Gray
HPA	Heath Protection Agency (now UK HSA)
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IRAT	Initial radiological assessment tool
IRAT2	Initial radiological assessment tool version 2
NDAWG	National Dose Assessment Working Group (this group is no longer active)
NRPB	National Radiological Protection Board (now UK HSA)
OBT	Organically bound tritium
PHE	Public Health England (previously NRPB, then HPA, now UK HSA).
RAPs	Reference animal and plants
STW	sewage treatment works
Sv	Sievert
UK HSA	UK Health Security Agency

List of Tables

Table 1. Radionuclides considered in the initial assessment methodology

Radionuclide	Half-life^	Release to air	Release to estuary/coastal water	Release to river	Release to public sewer
H-3	12.32 y	✓	✓	✓	✓
H-3 organic	12.32 y	✓	✓	✓	✓
C-11	20.39 m	✓	not considered	not considered	✓
C-14	5,730 y	✓	✓	✓	✓
N-13	9.965 m	✓	gas	gas	gas
O-15	2.04 m	✓	gas	gas	gas
F-18	1.83 h	✓	not considered	not considered	✓
Na-22	2.602 y	✓	✓	✓	✓
Na-24	14.96 h	✓	✓	✓	✓
P-32	14.263 d	✓	✓	✓	✓
P-33	25.34 d	✓	✓	✓	✓
S-35	87.51 d	✓	✓	✓	✓
Cl-36	301,000 y	✓	✓	✓	✓
Ar-41	1.827 h	✓	gas	gas	gas
Ca-45	162.67 d	✓	✓	✓	✓
Ca-47	4.536 d	✓	✓	✓	✓
V-48	15.974 d	✓	✓	✓	✓
Cr-51	27.703 d	✓	✓	✓	✓
Mn-52	5.591 d	✓	✓	✓	✓
Mn-54	312.12 d	✓	✓	✓	✓
Mn-56	2.5789 h	✓	not considered	not considered	✓
Fe-55	2.737 y	✓	✓	✓	✓
Fe-59	44.495 d	✓	✓	✓	✓
Co-56	77.23 d	✓	✓	✓	✓
Co-57	271.74 d	✓	✓	✓	✓
Co-58	70.86 d	✓	✓	✓	✓
Co-60	5.271 y	✓	✓	✓	✓
Ni-63	100.1 y	✓	✓	✓	✓
Cu-61*	3.333 h	✓	✓	✓	✓
Cu-64*	12.701 h	✓	✓	✓	✓
Zn-62*	9.186 h	✓	✓	✓	✓
Zn-65	243.9 d	✓	✓	✓	✓
Ga-67	3.26 d	✓	✓	✓	✓
Ga-68*	1.129 h	✓	not considered	not considered	✓
Se-75	119.8 d	✓	✓	✓	✓
Br-76*	16.2 h	✓	✓	✓	✓
Br-77*	57 h	✓	✓	✓	✓
Br-82	35.3 h	✓	✓	✓	✓
Kr-79	35.04 h	✓	gas	gas	gas
Kr-81m	13.1 s	✓	gas	gas	gas

Radionuclide	Half-life^	Release to air	Release to estuary/coastal water	Release to river	Release to public sewer
Kr-85	10.756 y	✓	gas	gas	gas
Kr-85m	4.48 h	✓	gas	gas	gas
Rb-81*	4.576 h	✓	✓	✓	✓
Rb-82	1.273 m	✓	not considered	not considered	✓
Rb-83	86.2 d	✓	✓	✓	✓
Sr-83*	32.41 h	✓	✓	✓	✓
Sr-85*	64.84 d	✓	✓	✓	✓
Sr-89	50.53 d	✓	✓	✓	✓
Sr-90	28.79 y	✓	✓	✓	✓
Y-90	64.1 h	✓	✓	✓	✓
Zr-89*	3.27 d	✓	✓	✓	✓
Zr-95	64.032 d	✓	✓	✓	✓
Nb-95	34.991 d	✓	✓	✓	✓
Mo-99	65.94 h	✓	✓	✓	✓
Tc-94m*	52 m	✓	not considered	not considered	✓
Tc-99	211,100 y	✓	✓	✓	✓
Tc-99m	6.015 h	✓	✓	✓	✓
Ru-103	39.26 d	✓	✓	✓	✓
Ru-106	373.59 d	✓	✓	✓	✓
Ag-110m	249.76 d	✓	✓	✓	✓
In-111	67.32 h	✓	✓	✓	✓
In-113m	1.658 h	✓	not considered	not considered	✓
Sb-125	2.76 y	✓	✓	✓	✓
I-123	13.27 h	✓	✓	✓	✓
I-124*	4.176 d	✓	✓	✓	✓
I-125	59.4 d	✓	✓	✓	✓
I-129	1.57E+07 y	✓	✓	✓	✓
I-131	8.02 d	✓	✓	✓	✓
I-132	2.3 h	✓	not considered	not considered	✓
I-133	20.8 h	✓	✓	✓	✓
I-134	52.5 m	✓	not considered	not considered	✓
I-135	6.57 h	✓	✓	✓	✓
Xe-133	5.243 d	✓	gas	gas	gas
Cs-134	2.065 y	✓	✓	✓	✓
Cs-136	13.16 d	✓	✓	✓	✓
Cs-137	30.167 y	✓	✓	✓	✓
Ba-140	12.752 d	✓	✓	✓	✓
La-140	40.274 h	✓	✓	✓	✓
Ce-141	32.508 d	✓	✓	✓	✓
Ce-144	284.91 d	✓	✓	✓	✓
Pm-147	2.6234 y	✓	✓	✓	✓
Sm-153	46.5 h	✓	✓	✓	✓
Eu-152	13.537 y	✓	✓	✓	✓

Radionuclide	Half-life^	Release to air	Release to estuary/coastal water	Release to river	Release to public sewer
Eu-154	8.593 y	✓	✓	✓	✓
Eu-155	4.7611 y	✓	✓	✓	✓
Er-169	9.4 d	✓	✓	✓	✓
Lu-177	6.647 d	✓	✓	✓	✓
Re-188*	17.004 h	✓	✓	✓	✓
Au-198	64.68 h	✓	✓	✓	✓
Tl-201	3.038 d	✓	✓	✓	✓
Pb-210	22.2 y	✓	✓	✓	✓
Pb-212*	10.64 h	✓	✓	✓	✓
Bi-213*	45.59 m	✓	not considered	not considered	✓
Po-210	138.38 d	✓	✓	✓	✓
At-211*	7.214 h	✓	✓	✓	✓
Rn-222	3.8235 d	✓	gas	gas	gas
Ra-223	11.43 d	✓	✓	✓	✓
Ra-226	1,600 y	✓	✓	✓	✓
Ac-225*	10 d	✓	✓	✓	✓
Th-227*	18.68 d	✓	✓	✓	✓
Th-230	75,380 y	✓	✓	✓	✓
Th-232	1.405E+10 y	✓	✓	✓	✓
Th-234	24.1 d	✓	✓	✓	✓
U-234	244,500 y	✓	✓	✓	✓
U-235	7.04E+08 y	✓	✓	✓	✓
U-238	4.468E+09 y	✓	✓	✓	✓
Np-237	2.144E+06 y	✓	✓	✓	✓
Pu-238	87.7 y	✓	✓	✓	✓
Pu-239	24,110 y	✓	✓	✓	✓
Pu-240	6,564 y	✓	✓	✓	✓
Pu-241	14.35 y	✓	✓	✓	✓
Pu-242	375,000 y	✓	✓	✓	✓
Am-241	432.2 y	✓	✓	✓	✓
Am-242	16.02 h	✓	✓	✓	✓
Am-243	7,370 y	✓	✓	✓	✓
Cm-242	162.8 d	✓	✓	✓	✓
Cm-243	29.1 y	✓	✓	✓	✓
Cm-244	18.1 y	✓	✓	✓	✓

* Radionuclide added for IRAT2 (radionuclide was not included in the original version of IRAT).
^ Half lives taken from ICRP recommended nuclear data [27], y=years, d=days, h=hours, m=minutes, s=seconds.
not considered: Radionuclides are ‘not considered’ where their half-life is sufficiently short that they have decayed to insignificant concentrations during their release to environmental media. Further information is provided in the appendices of this report.
gas: Radionuclides are released in gaseous form only and therefore not included in the aquatic assessments.

Table 2. Dose per unit release factors for worst age group local resident family – atmospheric release scenario

Radionuclide	Worst total DPUR (µSv/y per Bq/y)	Worst age group
H-3	9.8E-13	Offspring
H-3 organic	2.0E-12	Offspring
C-11	2.8E-12	Adult
C-14	7.0E-11	Infant
N-13	2.4E-12	Adult
O-15	2.0E-12	Adult
F-18	4.1E-12	Adult
Na-22	6.2E-09	Offspring
Na-24	2.6E-11	Adult
P-32	3.6E-10	Offspring
P-33	8.9E-11	Offspring
S-35	5.7E-11	Infant
Cl-36	2.1E-09	Infant
Ar-41	3.3E-12	Adult
Ca-45	3.4E-10	Offspring
Ca-47	9.9E-11	Infant
V-48	2.5E-10	Adult
Cr-51	4.5E-12	Adult
Mn-52	1.2E-10	Adult
Mn-54	9.8E-10	Adult
Mn-56	7.7E-12	Adult
Fe-55	3.8E-11	Infant
Fe-59	3.0E-10	Adult
Co-56	1.2E-09	Adult
Co-57	1.2E-10	Adult
Co-58	3.1E-10	Adult
Co-60	1.2E-08	Adult
Ni-63	1.5E-11	Infant
Cu-61	4.2E-12	Adult
Cu-64	3.6E-12	Child
Zn-62	2.1E-11	Infant
Zn-65	6.8E-10	Adult
Ga-67	7.7E-12	Adult
Ga-68	3.5E-12	Adult
Se-75	1.2E-09	Infant
Br-76	2.3E-11	Adult
Br-77	6.6E-12	Infant
Br-82	3.8E-11	Adult
Kr-79	6.0E-13	Adult
Kr-81m	5.8E-14	Adult
Kr-85	1.3E-14	Adult
Kr-85m	3.7E-13	Adult
Rb-81	3.0E-12	Adult
Rb-82	2.0E-12	Adult

Radionuclide	Worst total DPUR (µSv/y per Bq/y)	Worst age group
Rb-83	2.2E-10	Infant
Sr-83	1.8E-10	Adult
Sr-85	1.4E-10	Adult
Sr-89	1.5E-10	Infant
Sr-90	2.0E-09	Infant
Y-90	4.9E-11	Infant
Zr-89	3.0E-11	Adult
Zr-95	6.0E-10	Adult
Nb-95	1.4E-10	Adult
Mo-99	2.7E-11	Infant
Tc-94m	5.8E-12	Adult
Tc-99	1.2E-08	Infant
Tc-99m	8.4E-13	Adult
Ru-103	1.3E-10	Adult
Ru-106	9.1E-10	Adult
Ag-110m	3.0E-09	Adult
In-111	1.0E-11	Adult
In-113m	1.1E-12	Adult
Sb-125	1.4E-09	Adult
I-123	1.9E-10	Adult
I-124	1.7E-09	Infant
I-125	3.3E-09	Infant
I-129	2.0E-08	Child
I-131	4.4E-09	Infant
I-132	1.5E-11	Adult
I-133	1.6E-10	Infant
I-134	1.0E-11	Adult
I-135	2.8E-11	Adult
Xe-133	7.1E-14	Adult
Cs-134	4.3E-09	Adult
Cs-136	1.6E-10	Adult
Cs-137	7.1E-09	Adult
Ba-140	2.5E-10	Adult
La-140	4.6E-11	Adult
Ce-141	8.2E-11	Adult
Ce-144	9.1E-10	Infant
Pm-147	1.1E-10	Adult
Sm-153	1.6E-11	Child
Eu-152	1.0E-08	Adult
Eu-154	9.0E-09	Adult
Eu-155	3.4E-10	Adult
Er-169	2.4E-11	Child
Lu-177	2.8E-11	Adult
Re-188	5.1E-11	Infant
Au-198	2.6E-11	Infant
Tl-201	2.8E-12	Infant
Pb-210	2.8E-08	Child
Pb-212	3.8E-09	Adult

Radionuclide	Worst total DPUR (µSv/y per Bq/y)	Worst age group
Bi-213	6.8E-10	Child
Po-210	1.0E-07	Infant
As-211	2.0E-08	Adult
Rn-222	3.8E-10	Infant
Ra-223	1.7E-07	Adult
Ra-226	1.1E-07	Adult
Ac-225	1.9E-07	Adult
Th-227	2.3E-07	Adult
Th-230	3.4E-07	Adult
Th-232	5.8E-07	Adult
Th-234	1.8E-10	Adult
U-234	7.9E-08	Adult
U-235	7.2E-08	Adult
U-238	6.6E-08	Adult
Np-237	5.2E-07	Adult
Pu-238	1.0E-06	Adult
Pu-239	1.1E-06	Adult
Pu-240	1.1E-06	Adult
Pu-241	2.0E-08	Adult
Pu-242	1.1E-06	Adult
Am-241	9.5E-07	Adult
Am-242	3.9E-10	Adult
Am-243	9.3E-07	Adult
Cm-242	1.2E-07	Adult
Cm-243	7.0E-07	Adult
Cm-244	6.1E-07	Adult

Table 3. Dose per unit release factors for offspring in a local resident family – atmospheric release scenario

Radionuclide	DPURs for offspring in a local resident family (µSv/y per Bq/y)											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External from air	External from deposited	Inhalation	Total
H-3	3.5E-14	5.6E-14	3.3E-14	9.5E-15	3.8E-15	1.7E-14	3.8E-15	1.2E-13	0.0E+00	0.0E+00	7.1E-13	9.8E-13
H-3 organic	7.1E-14	1.1E-13	6.6E-14	1.9E-14	7.7E-15	3.5E-14	7.7E-15	2.4E-13	0.0E+00	0.0E+00	1.4E-12	2.0E-12
C-11	<p	<p	<p	<p	<p	<p	<p	<p	2.4E-12	0.0E+00	<p	2.4E-12
C-14	4.8E-12	7.8E-12	4.5E-12	2.2E-12	9.0E-13	4.0E-12	9.0E-13	7.2E-12	1.4E-16	0.0E+00	1.5E-12	3.4E-11
N-13	<p	<p	<p	<p	<p	<p	<p	<p	2.3E-12	2.8E-14	<p	2.4E-12
O-15	<p	<p	<p	<p	<p	<p	<p	<p	2.0E-12	4.9E-15	<p	2.0E-12
F-18	<p	<p	<p	<p	<p	<p	<p	<p	2.4E-12	3.2E-13	<p	2.7E-12
Na-22	5.7E-12	8.4E-12	1.4E-11	2.6E-11	1.0E-11	2.7E-11	5.9E-12	2.7E-11	5.4E-12	6.0E-09	2.7E-11	6.2E-09
Na-24	<p	<p	<p	<p	<p	<p	<p	<p	1.1E-11	9.2E-12	<p	2.0E-11
P-32	1.8E-11	1.1E-11	1.9E-11	8.8E-12	1.4E-12	1.2E-10	1.4E-12	4.1E-11	2.8E-14	0.0E+00	1.5E-10	3.6E-10
P-33	4.5E-12	3.9E-12	6.8E-12	2.8E-12	4.5E-13	3.6E-11	4.3E-13	7.2E-12	7.7E-16	0.0E+00	2.7E-11	8.9E-11
S-35	3.0E-13	3.8E-13	5.9E-13	3.8E-12	1.8E-12	8.6E-12	1.9E-12	2.8E-12	1.6E-16	0.0E+00	3.4E-13	2.1E-11
Cl-36	<p	<p	<p	<p	<p	<p	<p	<p	8.8E-15	2.3E-12	<p	2.3E-12
Ar-41	<p	<p	<p	<p	<p	<p	<p	<p	3.3E-12	0.0E+00	<p	3.3E-12
Ca-45	1.9E-11	4.9E-13	2.1E-12	4.7E-11	1.9E-11	3.7E-11	1.3E-12	1.8E-10	8.1E-16	2.5E-19	3.8E-11	3.4E-10
Ca-47	2.6E-12	9.5E-15	1.7E-13	1.2E-12	5.0E-13	1.1E-12	3.7E-14	2.9E-11	2.7E-12	2.2E-11	2.3E-11	8.2E-11
V-48	<p	<p	<p	<p	<p	<p	<p	<p	7.2E-12	1.8E-10	<p	1.9E-10
Cr-51	<p	<p	<p	<p	<p	<p	<p	<p	7.3E-14	3.5E-12	<p	3.5E-12
Mn-52	<p	<p	<p	<p	<p	<p	<p	<p	8.6E-12	7.6E-11	<p	8.4E-11
Mn-54	<p	<p	<p	<p	<p	<p	<p	<p	2.0E-12	9.2E-10	<p	9.2E-10
Mn-56	<p	<p	<p	<p	<p	<p	<p	<p	4.3E-12	6.9E-13	<p	5.0E-12
Fe-55	<p	<p	<p	<p	<p	<p	<p	<p	0.0E+00	7.8E-15	<p	7.8E-15
Fe-59	<p	<p	<p	<p	<p	<p	<p	<p	3.0E-12	2.0E-10	<p	2.0E-10
Co-56	<p	<p	<p	<p	<p	<p	<p	<p	9.2E-12	1.0E-09	<p	1.0E-09
Co-57	<p	<p	<p	<p	<p	<p	<p	<p	2.6E-13	1.1E-10	<p	1.1E-10
Co-58	<p	<p	<p	<p	<p	<p	<p	<p	2.4E-12	2.7E-10	<p	2.7E-10
Co-60	<p	<p	<p	<p	<p	<p	<p	<p	6.3E-12	1.1E-08	<p	1.1E-08

Radionuclide	DPURs for offspring in a local resident family (µSv/y per Bq/y)											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External from air	External from deposited	Inhalation	Total
Ni-63	<p	<p	<p	<p	<p	<p	<p	<p	0.0E+00	0.0E+00	<p	0.0E+00
Cu-61	<p	<p	<p	<p	<p	<p	<p	<p	2.0E-12	4.8E-13	<p	2.4E-12
Cu-64	<p	<p	<p	<p	<p	<p	<p	<p	4.5E-13	4.1E-13	<p	8.6E-13
Zn-62	<p	<p	<p	<p	<p	<p	<p	<p	1.0E-12	2.3E-12	<p	3.3E-12
Zn-65	<p	<p	<p	<p	<p	<p	<p	<p	1.4E-12	5.0E-10	<p	5.0E-10
Ga-67	<p	<p	<p	<p	<p	<p	<p	<p	3.4E-13	1.9E-12	<p	2.3E-12
Ga-68	<p	<p	<p	<p	<p	<p	<p	<p	2.3E-12	1.8E-13	<p	2.4E-12
Se-75	4.7E-12	6.4E-12	9.1E-12	4.6E-11	3.6E-10	4.8E-11	2.7E-10	3.2E-11	8.9E-13	1.7E-10	2.5E-11	9.8E-10
Br-76	<p	<p	<p	<p	<p	<p	<p	<p	6.7E-12	6.7E-12	<p	1.3E-11
Br-77	<p	<p	<p	<p	<p	<p	<p	<p	7.4E-13	3.0E-12	<p	3.7E-12
Br-82	<p	<p	<p	<p	<p	<p	<p	<p	6.4E-12	1.5E-11	<p	2.2E-11
Kr-79	<p	<p	<p	<p	<p	<p	<p	<p	6.0E-13	0.0E+00	<p	6.0E-13
Kr-81m	<p	<p	<p	<p	<p	<p	<p	<p	5.8E-14	0.0E+00	<p	5.8E-14
Kr-85	<p	<p	<p	<p	<p	<p	<p	<p	1.3E-14	0.0E+00	<p	1.3E-14
Kr-85m	<p	<p	<p	<p	<p	<p	<p	<p	3.7E-13	0.0E+00	<p	3.7E-13
Rb-81	<p	<p	<p	<p	<p	<p	<p	<p	1.7E-12	4.8E-13	<p	2.2E-12
Rb-82	<p	<p	<p	<p	<p	<p	<p	<p	1.9E-12	3.0E-15	<p	1.9E-12
Rb-83	<p	<p	<p	<p	<p	<p	<p	<p	1.2E-12	1.7E-10	<p	1.7E-10
Sr-83	<p	<p	<p	<p	<p	<p	<p	<p	1.9E-12	1.7E-10	<p	1.8E-10
Sr-85	<p	<p	<p	<p	<p	<p	<p	<p	1.2E-12	1.3E-10	<p	1.3E-10
Sr-89	1.2E-11	2.8E-13	1.7E-12	2.6E-13	1.0E-13	3.3E-13	7.2E-14	8.6E-12	2.3E-14	1.6E-14	4.7E-11	7.1E-11
Sr-90	1.3E-10	1.3E-10	1.4E-11	7.3E-12	2.9E-12	2.2E-11	4.8E-12	5.4E-10	5.2E-15	1.2E-16	2.0E-10	1.0E-09
Y-90	<p	<p	<p	<p	<p	<p	<p	<p	4.2E-14	6.3E-19	<p	4.2E-14
Zr-89	<p	<p	<p	<p	<p	<p	<p	<p	2.8E-12	1.5E-11	<p	1.8E-11
Zr-95	<p	<p	<p	<p	<p	<p	<p	<p	1.8E-12	4.9E-10	<p	4.9E-10
Nb-95	<p	<p	<p	<p	<p	<p	<p	<p	1.8E-12	1.1E-10	<p	1.1E-10
Mo-99	<p	<p	<p	<p	<p	<p	<p	<p	3.7E-13	3.1E-12	<p	3.4E-12
Tc-94m	<p	<p	<p	<p	<p	<p	<p	<p	4.5E-12	2.6E-13	<p	4.8E-12
Tc-99	<p	<p	<p	<p	<p	<p	<p	<p	1.5E-15	0.0E+00	<p	1.5E-15
Tc-99m	<p	<p	<p	<p	<p	<p	<p	<p	2.8E-13	1.2E-13	<p	4.0E-13
Ru-103	<p	<p	<p	<p	<p	<p	<p	<p	1.1E-12	7.4E-11	<p	7.5E-11

Radionuclide	DPURs for offspring in a local resident family (µSv/y per Bq/y)											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External from air	External from deposited	Inhalation	Total
Ru-106	<p	<p	<p	<p	<p	<p	<p	<p	5.6E-13	2.6E-10	<p	2.6E-10
Ag-110m	<p	<p	<p	<p	<p	<p	<p	<p	6.7E-12	2.5E-09	<p	2.5E-09
In-111	<p	<p	<p	<p	<p	<p	<p	<p	8.9E-13	4.3E-12	<p	5.2E-12
In-113m	<p	<p	<p	<p	<p	<p	<p	<p	5.9E-13	7.1E-14	<p	6.6E-13
Sb-125	<p	<p	<p	<p	<p	<p	<p	<p	9.9E-13	1.2E-09	<p	1.2E-09
I-123	<p	<p	<p	<p	<p	<p	<p	<p	3.1E-13	1.8E-10	<p	1.8E-10
I-124	<p	<p	<p	<p	<p	<p	<p	<p	2.4E-12	1.6E-10	<p	1.6E-10
I-125	<p	<p	<p	<p	<p	<p	<p	<p	1.8E-14	2.1E-11	<p	2.1E-11
I-129	<p	<p	<p	<p	<p	<p	<p	<p	1.4E-14	3.6E-10	<p	3.6E-10
I-131	8.1E-11	2.8E-11	5.4E-11	1.9E-11	7.8E-12	2.7E-11	6.1E-12	3.4E-10	8.2E-13	1.1E-10	1.7E-10	8.4E-10
I-132	<p	<p	<p	<p	<p	<p	<p	<p	5.0E-12	7.7E-12	<p	1.3E-11
I-133	<p	<p	<p	<p	<p	<p	<p	<p	1.3E-12	2.0E-11	<p	2.1E-11
I-134	<p	<p	<p	<p	<p	<p	<p	<p	5.8E-12	3.4E-12	<p	9.2E-12
I-135	<p	<p	<p	<p	<p	<p	<p	<p	3.6E-12	1.7E-11	<p	2.1E-11
Xe-133	<p	<p	<p	<p	<p	<p	<p	<p	7.1E-14	0.0E+00	<p	7.1E-14
Cs-134	<p	<p	<p	<p	<p	<p	<p	<p	3.7E-12	3.6E-09	<p	3.6E-09
Cs-136	<p	<p	<p	<p	<p	<p	<p	<p	5.3E-12	1.1E-10	<p	1.2E-10
Cs-137	<p	<p	<p	<p	<p	<p	<p	<p	1.4E-12	6.6E-09	<p	6.6E-09
Ba-140	<p	<p	<p	<p	<p	<p	<p	<p	4.3E-13	1.4E-10	<p	1.4E-10
La-140	<p	<p	<p	<p	<p	<p	<p	<p	5.9E-12	1.5E-11	<p	2.1E-11
Ce-141	<p	<p	<p	<p	<p	<p	<p	<p	1.6E-13	8.8E-12	<p	9.0E-12
Ce-144	<p	<p	<p	<p	<p	<p	<p	<p	4.0E-14	4.7E-11	<p	4.7E-11
Pm-147	<p	<p	<p	<p	<p	<p	<p	<p	4.6E-16	9.4E-15	<p	9.9E-15
Sm-153	<p	<p	<p	<p	<p	<p	<p	<p	1.1E-13	3.5E-13	<p	4.6E-13
Eu-152	<p	<p	<p	<p	<p	<p	<p	<p	2.8E-12	9.0E-09	<p	9.0E-09
Eu-154	<p	<p	<p	<p	<p	<p	<p	<p	3.0E-12	7.8E-09	<p	7.8E-09
Eu-155	<p	<p	<p	<p	<p	<p	<p	<p	1.1E-13	1.9E-10	<p	1.9E-10
Er-169	<p	<p	<p	<p	<p	<p	<p	<p	1.6E-15	8.0E-19	<p	1.6E-15
Lu-177	<p	<p	<p	<p	<p	<p	<p	<p	7.9E-14	8.8E-13	<p	9.6E-13
Re-188	<p	<p	<p	<p	<p	<p	<p	<p	1.7E-13	1.6E-13	<p	3.2E-13

Radionuclide	DPURs for offspring in a local resident family (µSv/y per Bq/y)											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External from air	External from deposited	Inhalation	Total
Au-198	<p	<p	<p	<p	<p	<p	<p	<p	9.6E-13	4.4E-12	<p	5.4E-12
Tl-201	<p	<p	<p	<p	<p	<p	<p	<p	1.7E-13	8.9E-13	<p	1.1E-12
Pb-210	<p	<p	<p	<p	<p	<p	<p	<p	2.4E-15	6.3E-12	<p	6.3E-12
Pb-212	<p	<p	<p	<p	<p	<p	<p	<p	3.3E-13	6.0E-13	<p	9.3E-13
Bi-213	<p	<p	<p	<p	<p	<p	<p	<p	3.2E-13	2.9E-14	<p	3.5E-13
Po-210	<p	<p	<p	<p	<p	<p	<p	<p	2.1E-17	4.4E-15	<p	4.4E-15
As-211	<p	<p	<p	<p	<p	<p	<p	<p	9.1E-14	1.8E-08	<p	1.8E-08
Rn-222	<p	<p	<p	<p	<p	<p	<p	<p	9.6E-16	0.0E+00	<p	9.6E-16
Ra-223	<p	<p	<p	<p	<p	<p	<p	<p	4.2E-13	1.3E-11	<p	1.3E-11
Ra-226	5.3E-10	2.5E-10	1.9E-10	7.7E-11	3.1E-11	3.1E-10	2.0E-11	3.8E-10	1.5E-14	2.7E-08	2.2E-09	3.1E-08
Ac-225	<p	<p	<p	<p	<p	<p	<p	<p	3.4E-14	7.1E-12	<p	7.2E-12
Th-227	<p	<p	<p	<p	<p	<p	<p	<p	2.3E-13	4.1E-11	<p	4.1E-11
Th-230	<p	<p	<p	<p	<p	<p	<p	<p	7.8E-16	2.7E-08	<p	2.7E-08
Th-232	<p	<p	<p	<p	<p	<p	<p	<p	3.8E-16	1.9E-08	<p	1.9E-08
Th-234	<p	<p	<p	<p	<p	<p	<p	<p	8.0E-14	3.8E-12	<p	3.9E-12
U-234	<p	<p	<p	<p	<p	<p	<p	<p	3.2E-16	2.0E-10	<p	2.0E-10
U-235	<p	<p	<p	<p	<p	<p	<p	<p	3.4E-13	2.0E-09	<p	2.0E-09
U-238	<p	<p	<p	<p	<p	<p	<p	<p	1.3E-16	3.2E-10	<p	3.2E-10
Np-237	<p	<p	<p	<p	<p	<p	<p	<p	4.7E-14	2.9E-09	<p	2.9E-09
Pu-238	<p	<p	<p	<p	<p	<p	<p	<p	1.9E-16	1.6E-12	<p	1.6E-12
Pu-239	<p	<p	<p	<p	<p	<p	<p	<p	1.8E-16	2.0E-09	<p	2.0E-09
Pu-240	<p	<p	<p	<p	<p	<p	<p	<p	1.8E-16	1.2E-12	<p	1.2E-12
Pu-241	<p	<p	<p	<p	<p	<p	<p	<p	3.4E-18	1.4E-10	<p	1.4E-10
Pu-242	<p	<p	<p	<p	<p	<p	<p	<p	1.5E-16	3.3E-10	<p	3.3E-10
Am-241	<p	<p	<p	<p	<p	<p	<p	<p	3.6E-14	3.0E-09	<p	3.0E-09
Am-242	<p	<p	<p	<p	<p	<p	<p	<p	3.2E-14	8.9E-12	<p	8.9E-12
Am-243	<p	<p	<p	<p	<p	<p	<p	<p	9.8E-14	2.4E-09	<p	2.4E-09
Cm-242	<p	<p	<p	<p	<p	<p	<p	<p	2.1E-16	5.1E-13	<p	5.1E-13
Cm-243	<p	<p	<p	<p	<p	<p	<p	<p	2.8E-13	3.6E-09	<p	3.6E-09
Cm-244	<p	<p	<p	<p	<p	<p	<p	<p	1.8E-16	2.4E-12	<p	2.4E-12

<p: not calculated as dose rate to parent greater than dose rate to offspring

Table 4. Dose per unit release factors for infant in a local resident family – atmospheric release scenario

Radionuclide	DPURs for infant in a local resident family (µSv/y per Bq/y)											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External from air	External from deposited	Inhalation	Total
H-3	1.0E-14	3.0E-14	2.4E-14	1.8E-15	1.6E-15	5.9E-15	1.6E-15	2.4E-13	0.0E+00	0.0E+00	2.6E-13	5.8E-13
H-3 organic	2.5E-14	7.6E-14	5.9E-14	4.4E-15	4.0E-15	1.5E-14	4.0E-15	6.1E-13	0.0E+00	0.0E+00	6.0E-13	1.4E-12
C-11	nc	nc	nc	nc	nc	nc	nc	nc	1.1E-12	0.0E+00	5.9E-13	1.7E-12
C-14	1.8E-12	5.4E-12	4.2E-12	5.4E-13	4.9E-13	1.8E-12	4.9E-13	1.9E-11	6.5E-17	0.0E+00	3.6E-11	7.0E-11
N-13	nc	nc	nc	nc	nc	nc	nc	nc	1.1E-12	9.6E-15	0.0E+00	1.1E-12
O-15	nc	nc	nc	nc	nc	nc	nc	nc	9.3E-13	1.7E-15	0.0E+00	9.3E-13
F-18	nc	nc	nc	nc	nc	nc	nc	nc	1.1E-12	1.1E-13	1.7E-12	2.9E-12
Na-22	4.4E-12	1.2E-11	2.7E-11	1.3E-11	1.2E-11	2.5E-11	6.8E-12	1.5E-10	2.5E-12	2.1E-09	3.9E-11	2.4E-09
Na-24	2.3E-14	2.8E-16	4.5E-15	2.4E-15	2.2E-15	1.4E-15	3.9E-16	1.2E-13	5.1E-12	3.2E-12	9.7E-12	1.8E-11
P-32	2.5E-12	2.8E-12	6.7E-12	8.1E-13	3.0E-13	2.0E-11	3.0E-13	4.1E-11	1.3E-14	0.0E+00	8.1E-11	1.6E-10
P-33	3.2E-13	5.0E-13	1.2E-12	1.3E-13	4.6E-14	3.0E-12	4.5E-14	3.6E-12	3.6E-16	0.0E+00	2.5E-11	3.4E-11
S-35	2.4E-13	5.7E-13	1.2E-12	2.0E-12	2.1E-12	8.3E-12	2.3E-12	1.6E-11	7.7E-17	0.0E+00	2.4E-11	5.7E-11
Cl-36	8.4E-11	2.1E-10	3.1E-10	6.0E-11	5.5E-11	1.7E-10	4.7E-11	1.1E-09	4.1E-15	8.0E-13	1.4E-10	2.1E-09
Ar-41	nc	nc	nc	nc	nc	nc	nc	nc	1.5E-12	0.0E+00	0.0E+00	1.5E-12
Ca-45	2.0E-12	9.5E-14	5.5E-13	3.2E-12	2.9E-12	4.6E-12	1.9E-13	1.3E-10	3.8E-16	8.8E-20	4.7E-11	1.9E-10
Ca-47	5.8E-13	4.0E-15	9.8E-14	1.8E-13	1.7E-13	2.9E-13	1.2E-14	4.7E-11	1.3E-12	7.6E-12	4.2E-11	9.9E-11
V-48	1.4E-12	1.7E-15	3.5E-13	1.9E-16	1.8E-16	1.0E-17	1.1E-16	4.1E-15	3.4E-12	6.4E-11	5.9E-11	1.3E-10
Cr-51	3.6E-14	2.2E-18	5.8E-15	8.8E-15	8.0E-15	1.7E-14	4.7E-15	1.0E-13	3.4E-14	1.2E-12	1.1E-12	2.6E-12
Mn-52	6.0E-13	5.7E-15	1.2E-13	1.2E-14	2.1E-12	1.9E-14	1.5E-12	2.0E-13	4.0E-12	2.6E-11	3.7E-11	7.2E-11
Mn-54	7.6E-13	1.4E-13	8.4E-13	9.8E-14	2.0E-11	1.4E-13	1.3E-11	3.3E-13	9.5E-13	3.2E-10	3.3E-11	3.9E-10
Mn-56	nc	nc	nc	nc	nc	nc	nc	nc	2.0E-12	2.4E-13	4.2E-12	6.4E-12
Fe-55	6.4E-13	3.5E-15	2.7E-13	7.4E-15	2.0E-13	3.7E-13	2.9E-11	1.2E-13	0.0E+00	2.7E-15	7.6E-12	3.8E-11
Fe-59	2.4E-12	4.8E-15	8.2E-13	5.3E-15	1.5E-13	1.5E-13	1.2E-11	5.2E-13	1.4E-12	7.0E-11	7.0E-11	1.6E-10
Co-56	3.1E-12	5.2E-14	1.2E-12	1.0E-13	7.9E-12	7.4E-14	4.8E-12	2.1E-12	4.3E-12	3.5E-10	1.1E-10	4.9E-10
Co-57	3.8E-13	1.7E-14	1.7E-13	2.3E-14	1.7E-12	1.8E-14	1.1E-12	2.6E-13	1.2E-13	3.6E-11	1.2E-11	5.2E-11
Co-58	9.1E-13	1.4E-14	3.4E-13	2.8E-14	2.1E-12	2.0E-14	1.3E-12	6.1E-13	1.1E-12	9.2E-11	3.5E-11	1.3E-10
Co-60	7.2E-12	2.0E-12	3.2E-12	6.9E-13	5.3E-11	6.0E-13	3.9E-11	6.0E-12	2.9E-12	4.0E-09	1.8E-10	4.3E-09

Radionuclide	DPURs for infant in a local resident family (µSv/y per Bq/y)											
	Green veg	**Root veg**	**Fruit**	**Sheep meat**	**Sheep liver**	**Cow meat**	**Cow liver**	**Cow milk**	**External from air**	**External from deposited**	**Inhalation**	**Total**
Ni-63	3.9E-13	1.4E-13	2.1E-13	3.3E-17	3.0E-16	4.0E-16	1.1E-15	3.7E-12	0.0E+00	0.0E+00	1.0E-11	1.5E-11
Cu-61	1.8E-15	1.9E-17	2.8E-16	9.2E-20	3.7E-20	1.0E-17	3.5E-20	1.1E-14	9.2E-13	1.6E-13	2.4E-12	3.5E-12
Cu-64	7.1E-15	8.1E-17	1.2E-15	3.4E-18	1.4E-18	3.6E-16	1.2E-18	1.1E-13	2.1E-13	1.4E-13	3.1E-12	3.5E-12
Zn-62	4.1E-14	1.7E-16	7.6E-15	1.2E-17	4.8E-18	1.3E-15	4.4E-18	5.3E-13	4.7E-13	7.9E-13	1.9E-11	2.1E-11
Zn-65	4.3E-12	4.0E-13	6.8E-12	9.4E-13	3.8E-13	9.7E-11	3.3E-13	1.3E-10	6.7E-13	1.7E-10	3.5E-11	4.4E-10
Ga-67	5.4E-14	1.7E-18	9.2E-15	7.8E-17	7.2E-17	3.9E-16	2.2E-14	8.7E-15	1.6E-13	6.6E-13	5.4E-12	6.3E-12
Ga-68	5.2E-16	2.8E-21	8.3E-17	9.8E-22	9.0E-22	5.7E-21	3.1E-19	8.5E-18	1.1E-12	6.3E-14	1.7E-12	2.8E-12
Se-75	4.2E-12	1.1E-11	2.1E-11	2.6E-11	4.8E-10	5.1E-11	3.5E-10	2.0E-10	4.2E-13	6.0E-11	3.2E-11	1.2E-09
Br-76	3.0E-14	4.4E-16	5.9E-15	8.7E-18	8.0E-17	2.7E-17	7.4E-17	3.7E-12	3.1E-12	2.3E-12	1.2E-11	2.2E-11
Br-77	1.5E-14	1.8E-15	7.3E-15	2.3E-17	2.1E-16	6.1E-17	1.7E-16	2.5E-12	3.5E-13	1.0E-12	2.8E-12	6.6E-12
Br-82	5.9E-14	3.3E-15	1.9E-14	5.1E-17	4.6E-16	1.4E-16	4.0E-16	9.2E-12	3.0E-12	5.3E-12	1.6E-11	3.4E-11
Kr-79	nc	nc	nc	nc	nc	nc	nc	nc	2.8E-13	0.0E+00	0.0E+00	2.8E-13
Kr-81m	nc	nc	nc	nc	nc	nc	nc	nc	2.7E-14	0.0E+00	0.0E+00	2.7E-14
Kr-85	nc	nc	nc	nc	nc	nc	nc	nc	6.0E-15	0.0E+00	0.0E+00	6.0E-15
Kr-85m	nc	nc	nc	nc	nc	nc	nc	nc	1.7E-13	0.0E+00	0.0E+00	1.7E-13
Rb-81	1.0E-15	1.4E-17	1.7E-16	1.6E-18	1.5E-18	5.0E-18	1.4E-18	3.1E-14	8.1E-13	1.6E-13	1.3E-12	2.4E-12
Rb-82	nc	nc	nc	nc	nc	nc	nc	nc	9.1E-13	1.0E-15	5.9E-14	9.7E-13
Rb-83	2.1E-12	5.0E-12	1.1E-11	1.4E-12	1.2E-12	2.6E-12	7.2E-13	1.2E-10	5.5E-13	5.8E-11	2.1E-11	2.2E-10
Sr-83	5.6E-14	3.8E-16	9.2E-15	1.2E-16	1.1E-16	2.8E-16	7.6E-17	1.2E-13	8.9E-13	6.0E-11	1.0E-11	7.1E-11
Sr-85	6.4E-13	3.1E-14	2.3E-13	8.9E-15	8.1E-15	2.1E-14	5.8E-15	3.3E-12	5.5E-13	4.4E-11	1.7E-11	6.5E-11
Sr-89	3.5E-12	1.4E-13	1.2E-12	4.6E-14	4.2E-14	1.1E-13	3.0E-14	1.7E-11	1.1E-14	5.6E-15	1.3E-10	1.5E-10
Sr-90	4.2E-11	7.6E-11	1.1E-11	1.5E-12	1.4E-12	8.1E-12	2.2E-12	1.2E-09	2.4E-15	4.3E-17	5.9E-10	2.0E-09
Y-90	7.6E-13	3.9E-17	1.3E-13	1.4E-17	1.2E-16	3.5E-17	9.5E-17	1.2E-13	2.0E-14	2.2E-19	4.7E-11	4.9E-11
Zr-89	2.0E-13	2.0E-17	3.4E-14	6.3E-17	5.8E-17	1.9E-17	4.3E-17	5.9E-15	1.3E-12	5.2E-12	1.5E-11	2.2E-11
Zr-95	1.1E-12	3.3E-15	4.2E-13	1.1E-15	9.8E-16	2.3E-16	5.2E-16	2.4E-14	8.3E-13	1.7E-10	8.6E-11	2.6E-10
Nb-95	5.6E-13	1.5E-15	1.8E-13	1.3E-16	1.2E-16	6.9E-18	7.2E-17	1.4E-15	8.6E-13	3.7E-11	2.8E-11	6.6E-11
Mo-99	1.4E-13	7.8E-16	2.4E-14	4.8E-15	8.7E-14	2.4E-15	6.7E-14	1.2E-12	1.7E-13	1.1E-12	2.4E-11	2.7E-11
Tc-94m	nc	nc	nc	nc	nc	nc	nc	nc	2.1E-12	9.0E-14	1.6E-12	3.8E-12
Tc-99	1.5E-10	2.9E-10	2.4E-10	1.5E-09	4.1E-09	1.5E-10	1.7E-10	4.9E-09	7.1E-16	0.0E+00	7.0E-11	1.2E-08
Tc-99m	7.8E-16	3.2E-16	1.5E-16	5.4E-17	1.5E-16	2.0E-16	2.2E-16	8.2E-14	1.3E-13	4.1E-14	5.3E-13	7.9E-13
Ru-103	8.0E-13	6.3E-16	1.3E-13	2.2E-15	9.7E-15	7.0E-14	5.8E-15	4.9E-14	5.1E-13	2.6E-11	4.5E-11	7.2E-11

Radionuclide	DPURs for infant in a local resident family (µSv/y per Bq/y)											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External from air	External from deposited	Inhalation	Total
Ru-106	1.1E-11	6.1E-14	1.8E-12	1.1E-13	4.7E-13	3.9E-12	3.2E-13	6.6E-13	2.6E-13	9.0E-11	5.9E-10	7.0E-10
Ag-110m	3.3E-12	1.5E-14	2.4E-12	2.0E-14	1.1E-10	8.8E-13	9.6E-11	9.9E-10	3.1E-12	8.6E-10	1.5E-10	2.2E-09
In-111	6.8E-14	1.7E-18	1.1E-14	4.1E-17	3.8E-17	1.1E-16	2.9E-17	1.1E-13	4.2E-13	1.5E-12	6.5E-12	8.6E-12
In-113m	nc	nc	nc	nc	nc	nc	nc	nc	2.8E-13	2.4E-14	5.9E-13	8.9E-13
Sb-125	1.5E-12	8.1E-15	7.8E-13	1.8E-13	1.7E-11	3.5E-13	8.1E-12	3.7E-13	4.6E-13	4.3E-10	8.6E-11	5.5E-10
I-123	1.2E-13	1.3E-15	2.3E-14	1.4E-15	1.3E-15	8.6E-15	2.4E-15	1.0E-12	1.5E-13	6.4E-11	3.9E-12	6.9E-11
I-124	4.4E-11	1.3E-11	3.9E-11	4.5E-12	4.1E-12	1.5E-11	4.0E-12	1.3E-09	1.1E-12	5.5E-11	2.2E-10	1.7E-09
I-125	9.4E-11	2.0E-10	4.5E-10	3.1E-11	2.8E-11	4.4E-11	1.2E-11	2.3E-09	8.4E-15	7.1E-12	1.1E-10	3.3E-09
I-129	6.7E-10	1.9E-09	3.0E-09	2.8E-10	2.5E-10	2.7E-10	7.3E-11	1.3E-08	6.3E-15	1.2E-10	4.2E-10	2.0E-08
I-131	1.2E-10	7.5E-11	2.0E-10	1.8E-11	1.7E-11	4.7E-11	1.3E-11	3.6E-09	3.8E-13	3.9E-11	3.5E-10	4.4E-09
I-132	nc	nc	nc	nc	nc	nc	nc	nc	2.4E-12	2.7E-12	4.7E-12	9.7E-12
I-133	4.4E-12	9.9E-14	9.7E-13	9.6E-14	8.8E-14	5.2E-13	1.4E-13	5.7E-11	6.2E-13	6.9E-12	8.8E-11	1.6E-10
I-134	nc	nc	nc	nc	nc	nc	nc	nc	2.7E-12	1.2E-12	1.8E-12	5.7E-12
I-135	2.9E-13	1.1E-15	4.9E-14	1.1E-15	1.0E-15	7.4E-15	2.0E-15	9.4E-13	1.7E-12	6.0E-12	1.8E-11	2.7E-11
Xe-133	nc	nc	nc	nc	nc	nc	nc	nc	3.3E-14	0.0E+00	0.0E+00	3.3E-14
Cs-134	4.7E-12	1.3E-11	2.9E-11	1.2E-11	1.1E-11	2.2E-11	6.0E-12	1.4E-10	1.7E-12	1.2E-09	3.9E-11	1.5E-09
Cs-136	1.2E-12	1.2E-12	2.9E-12	1.2E-12	1.1E-12	2.0E-12	5.5E-13	2.9E-11	2.5E-12	3.8E-11	2.8E-11	1.1E-10
Cs-137	3.9E-12	1.2E-11	2.3E-11	1.1E-11	1.0E-11	1.9E-11	5.3E-12	1.2E-10	6.3E-13	2.3E-09	2.9E-11	2.5E-09
Ba-140	2.1E-12	1.1E-15	4.7E-13	3.1E-14	2.8E-14	1.8E-14	1.8E-14	2.4E-12	2.0E-13	4.7E-11	1.1E-10	1.6E-10
La-140	3.3E-13	1.1E-17	5.4E-14	6.7E-17	2.5E-15	4.6E-18	2.0E-15	5.0E-14	2.7E-12	5.1E-12	3.4E-11	4.2E-11
Ce-141	8.4E-13	3.4E-16	1.4E-13	1.9E-17	1.4E-13	1.6E-15	8.8E-14	1.2E-13	7.7E-14	3.0E-12	5.9E-11	6.4E-11
Ce-144	8.8E-12	2.2E-14	1.4E-12	1.2E-15	8.6E-12	1.5E-13	8.3E-12	1.6E-12	1.9E-14	1.6E-11	8.6E-10	9.1E-10
Pm-147	4.6E-13	2.7E-14	1.5E-13	1.5E-14	8.5E-14	6.0E-14	1.3E-13	5.6E-14	2.1E-16	3.3E-15	9.7E-11	9.8E-11
Sm-153	1.6E-13	1.5E-17	2.5E-14	1.9E-19	1.4E-15	2.0E-17	1.1E-15	2.4E-14	5.0E-14	1.2E-13	1.6E-11	1.6E-11
Eu-152	1.8E-12	1.7E-13	4.2E-13	8.3E-14	4.6E-13	4.5E-13	9.9E-13	2.4E-13	1.3E-12	3.1E-09	5.4E-10	3.7E-09
Eu-154	2.9E-12	1.9E-13	6.1E-13	1.3E-13	7.0E-13	6.5E-13	1.4E-12	3.8E-13	1.4E-12	2.7E-09	8.1E-10	3.5E-09
Eu-155	5.2E-13	2.1E-14	1.0E-13	2.1E-14	1.2E-13	9.7E-14	2.1E-13	6.7E-14	5.3E-14	6.5E-11	1.2E-10	1.9E-10
Er-169	2.6E-13	4.6E-17	4.2E-14	1.8E-18	1.3E-14	1.6E-16	9.0E-15	4.2E-14	7.3E-16	2.8E-19	1.9E-11	1.9E-11
Lu-177	3.0E-13	4.4E-17	4.8E-14	1.5E-18	1.1E-14	1.4E-16	7.6E-15	4.8E-14	3.7E-14	3.0E-13	2.2E-11	2.3E-11
Re-188	1.9E-13	8.0E-14	4.2E-14	5.0E-14	1.4E-13	1.6E-13	1.8E-13	2.7E-11	7.7E-14	5.4E-14	2.4E-11	5.1E-11

Radionuclide	DPURs for infant in a local resident family (µSv/y per Bq/y)											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External from air	External from deposited	Inhalation	Total
Au-198	2.7E-13	8.8E-17	4.4E-14	6.6E-15	6.0E-15	1.8E-13	4.8E-14	1.3E-14	4.5E-13	1.5E-12	2.4E-11	2.6E-11
Tl-201	2.4E-14	4.2E-15	1.5E-14	2.4E-14	2.2E-14	6.3E-14	1.7E-14	4.3E-13	8.0E-14	3.1E-13	1.8E-12	2.8E-12
Pb-210	1.0E-09	1.2E-10	7.2E-10	1.0E-10	2.6E-10	4.0E-10	3.1E-10	4.1E-09	1.1E-15	2.2E-12	2.0E-08	2.7E-08
Pb-212	4.6E-13	9.7E-17	7.4E-14	2.9E-17	7.6E-17	8.1E-17	6.4E-17	4.1E-13	1.5E-13	2.1E-13	2.5E-09	2.5E-09
Bi-213	nc	nc	nc	nc	nc	nc	nc	nc	1.5E-13	9.9E-15	6.4E-10	6.4E-10
Po-210	2.3E-09	5.8E-09	1.3E-08	8.1E-10	8.9E-09	9.0E-10	6.6E-09	2.6E-09	9.6E-18	1.5E-15	5.9E-08	1.0E-07
As-211	3.9E-13	1.6E-15	6.5E-14	3.8E-18	5.9E-18	2.5E-17	2.1E-18	7.9E-12	4.3E-14	6.2E-09	2.0E-09	8.2E-09
Rn-222	nc	nc	nc	nc	nc	nc	nc	nc	4.5E-16	0.0E+00	3.8E-10	3.8E-10
Ra-223	1.2E-10	3.0E-13	2.6E-11	2.0E-12	1.8E-12	1.4E-11	1.2E-12	3.3E-10	2.0E-13	4.4E-12	1.1E-07	1.1E-07
Ra-226	3.0E-10	2.6E-10	2.6E-10	2.8E-11	2.6E-11	2.1E-10	1.7E-11	1.5E-09	7.0E-15	9.3E-09	5.9E-08	7.1E-08
Ac-225	1.8E-11	2.7E-15	2.8E-12	5.2E-16	9.5E-14	1.1E-15	6.3E-14	4.0E-13	1.6E-14	2.5E-12	1.2E-07	1.2E-07
Th-227	9.4E-12	3.5E-16	1.5E-12	2.5E-15	2.3E-14	1.2E-14	1.4E-14	3.3E-13	1.1E-13	1.4E-11	1.6E-07	1.6E-07
Th-230	9.7E-11	1.3E-12	2.0E-11	6.1E-13	5.6E-12	7.0E-12	8.4E-12	7.2E-12	3.7E-16	9.3E-09	1.9E-07	2.0E-07
Th-232	1.1E-10	1.4E-12	2.2E-11	6.7E-13	6.1E-12	7.7E-12	9.2E-12	7.9E-12	1.8E-16	6.6E-09	2.7E-07	2.8E-07
Th-234	3.7E-12	1.7E-16	6.0E-13	1.2E-15	1.1E-14	5.8E-15	7.0E-15	1.3E-13	3.7E-14	1.3E-12	1.7E-10	1.7E-10
U-234	3.2E-11	4.4E-12	7.2E-12	1.2E-12	1.1E-12	3.8E-12	5.4E-13	5.7E-10	1.5E-16	6.9E-11	5.9E-08	6.0E-08
U-235	3.2E-11	4.4E-12	7.2E-12	1.2E-12	1.1E-12	3.8E-12	5.4E-13	5.7E-10	1.6E-13	7.0E-10	5.4E-08	5.5E-08
U-238	3.0E-11	4.0E-12	6.7E-12	1.1E-12	9.9E-13	3.5E-12	5.0E-13	5.3E-10	6.2E-17	1.1E-10	5.1E-08	5.1E-08
Np-237	5.3E-11	1.8E-11	1.5E-11	4.6E-13	3.0E-11	2.5E-12	8.4E-11	1.4E-12	2.2E-14	1.0E-09	2.2E-07	2.2E-07
Pu-238	9.5E-11	5.2E-13	1.6E-11	6.5E-13	4.3E-11	2.6E-12	8.9E-11	1.5E-12	8.7E-17	5.6E-13	4.0E-07	4.0E-07
Pu-239	9.9E-11	6.5E-13	1.7E-11	7.0E-13	4.6E-11	2.9E-12	9.7E-11	1.7E-12	8.6E-17	7.0E-10	4.2E-07	4.2E-07
Pu-240	9.9E-11	6.4E-13	1.7E-11	6.9E-13	4.6E-11	2.9E-12	9.7E-11	1.7E-12	8.5E-17	4.1E-13	4.2E-07	4.2E-07
Pu-241	1.3E-12	3.5E-15	2.2E-13	8.5E-15	5.6E-13	3.2E-14	1.1E-12	1.8E-14	1.6E-18	4.7E-11	5.2E-09	5.3E-09
Pu-242	9.5E-11	6.2E-13	1.6E-11	6.6E-13	4.3E-11	2.7E-12	9.2E-11	1.6E-12	7.2E-17	1.1E-10	3.9E-07	3.9E-07
Am-241	8.7E-11	9.1E-13	1.5E-11	7.2E-13	4.7E-11	3.5E-12	1.2E-10	2.0E-12	1.7E-14	1.0E-09	3.7E-07	3.7E-07
Am-242	2.4E-14	2.2E-19	3.8E-15	9.0E-19	2.4E-17	2.0E-18	2.6E-17	2.7E-18	1.5E-14	3.1E-12	3.2E-10	3.2E-10
Am-243	8.7E-11	9.5E-13	1.5E-11	7.2E-13	4.7E-11	3.5E-12	1.2E-10	2.0E-12	4.6E-14	8.4E-10	3.7E-07	3.7E-07
Cm-242	1.6E-11	3.4E-15	2.7E-12	3.8E-14	2.4E-12	6.5E-14	2.2E-12	3.8E-14	9.9E-17	1.8E-13	9.7E-08	9.7E-08
Cm-243	7.8E-11	6.6E-13	1.3E-11	5.2E-13	3.4E-11	2.0E-12	6.8E-11	1.2E-12	1.3E-13	1.2E-09	3.3E-07	3.3E-07
Cm-244	6.9E-11	4.6E-13	1.1E-11	4.4E-13	2.9E-11	1.7E-12	5.7E-11	9.7E-13	8.4E-17	8.3E-13	3.1E-07	3.1E-07

nc: not considered as half-life less than 3 hours

Table 5. Dose per unit release factors for child in a local resident family – atmospheric release scenario

Radionuclide	DPURs for child in a local resident family (µSv/y per Bq/y)											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External from air	External from deposited	Inhalation	Total
H-3	1.1E-14	3.1E-14	1.6E-14	2.8E-15	1.4E-15	8.5E-15	1.4E-15	8.7E-14	0.0E+00	0.0E+00	3.6E-13	5.2E-13
H-3 organic	2.8E-14	7.6E-14	4.0E-14	7.0E-15	3.5E-15	2.1E-14	3.5E-15	2.2E-13	0.0E+00	0.0E+00	8.7E-13	1.3E-12
C-11	nc	nc	nc	nc	nc	nc	nc	nc	1.4E-12	0.0E+00	5.0E-13	1.9E-12
C-14	2.1E-12	5.7E-12	3.0E-12	9.0E-13	4.5E-13	2.7E-12	4.5E-13	7.2E-12	8.4E-17	0.0E+00	4.4E-11	6.7E-11
N-13	nc	nc	nc	nc	nc	nc	nc	nc	1.4E-12	1.4E-14	0.0E+00	1.4E-12
O-15	nc	nc	nc	nc	nc	nc	nc	nc	1.2E-12	2.5E-15	0.0E+00	1.2E-12
F-18	nc	nc	nc	nc	nc	nc	nc	nc	1.4E-12	1.6E-13	1.6E-12	3.2E-12
Na-22	3.8E-12	9.4E-12	1.4E-11	1.6E-11	7.8E-12	2.7E-11	4.5E-12	4.2E-11	3.2E-12	3.1E-09	3.8E-11	3.2E-09
Na-24	1.8E-14	2.0E-16	2.2E-15	2.7E-15	1.3E-15	1.4E-15	2.4E-16	3.0E-14	6.6E-12	4.7E-12	8.9E-12	2.0E-11
P-32	1.7E-12	1.6E-12	2.7E-12	7.5E-13	1.5E-13	1.7E-11	1.5E-13	8.6E-12	1.7E-14	0.0E+00	8.3E-11	1.2E-10
P-33	2.2E-13	3.1E-13	5.0E-13	1.2E-13	2.5E-14	2.6E-12	2.4E-14	7.9E-13	4.6E-16	0.0E+00	3.3E-11	3.8E-11
S-35	1.7E-13	3.8E-13	5.3E-13	2.1E-12	1.2E-12	7.8E-12	1.3E-12	3.8E-12	9.9E-17	0.0E+00	3.1E-11	4.9E-11
Cl-36	5.9E-11	1.3E-10	1.3E-10	6.0E-11	3.0E-11	1.5E-10	2.6E-11	2.4E-10	5.3E-15	1.2E-12	1.6E-10	1.0E-09
Ar-41	nc	nc	nc	nc	nc	nc	nc	nc	2.0E-12	0.0E+00	0.0E+00	2.0E-12
Ca-45	1.7E-12	7.4E-14	2.9E-13	3.9E-12	1.9E-12	5.1E-12	1.3E-13	3.6E-11	4.9E-16	1.3E-19	6.1E-11	1.1E-10
Ca-47	4.4E-13	2.7E-15	4.5E-14	1.9E-13	9.7E-14	2.8E-13	7.2E-15	1.1E-11	1.6E-12	1.1E-11	4.6E-11	7.1E-11
V-48	1.2E-12	1.3E-15	1.8E-13	2.3E-16	1.1E-16	1.1E-17	7.0E-17	1.1E-15	4.3E-12	9.4E-11	6.8E-11	1.7E-10
Cr-51	2.9E-14	1.6E-18	2.8E-15	9.9E-15	4.9E-15	1.7E-14	2.9E-15	2.6E-14	4.4E-14	1.8E-12	1.0E-12	2.9E-12
Mn-52	5.4E-13	4.7E-15	6.8E-14	1.5E-14	1.5E-12	2.2E-14	1.1E-12	5.9E-14	5.1E-12	3.9E-11	3.8E-11	8.5E-11
Mn-54	7.4E-13	1.2E-13	5.0E-13	1.4E-13	1.5E-11	1.8E-13	9.6E-12	1.0E-13	1.2E-12	4.7E-10	3.8E-11	5.3E-10
Mn-56	nc	nc	nc	nc	nc	nc	nc	nc	2.6E-12	3.5E-13	3.8E-12	6.7E-12
Fe-55	6.9E-13	3.4E-15	1.8E-13	1.1E-14	1.7E-13	5.1E-13	2.4E-11	4.1E-14	0.0E+00	4.0E-15	9.7E-12	3.6E-11
Fe-59	2.0E-12	3.6E-15	4.2E-13	6.4E-15	9.7E-14	1.6E-13	7.8E-12	1.4E-13	1.8E-12	1.0E-10	8.6E-11	2.0E-10
Co-56	2.8E-12	4.2E-14	6.7E-13	1.3E-13	5.6E-12	8.6E-14	3.3E-12	6.1E-13	5.5E-12	5.2E-10	1.2E-10	6.6E-10
Co-57	3.2E-13	1.3E-14	8.7E-14	2.7E-14	1.1E-12	1.9E-14	7.4E-13	7.0E-14	1.6E-13	5.4E-11	1.3E-11	7.0E-11
Co-58	8.2E-13	1.1E-14	1.9E-13	3.6E-14	1.5E-12	2.3E-14	9.0E-13	1.8E-13	1.4E-12	1.4E-10	3.8E-11	1.8E-10
Co-60	6.8E-12	1.7E-12	1.8E-12	9.4E-13	3.9E-11	7.4E-13	2.9E-11	1.8E-12	3.8E-12	5.8E-09	2.4E-10	6.2E-09
Ni-63	3.1E-13	1.0E-13	1.0E-13	3.7E-17	1.8E-16	4.0E-16	6.6E-16	9.3E-13	0.0E+00	0.0E+00	1.1E-11	1.2E-11

Radionuclide	DPURs for child in a local resident family (µSv/y per Bq/y)											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External from air	External from deposited	Inhalation	Total
Cu-61	1.3E-15	1.2E-17	1.2E-16	9.4E-20	2.1E-20	9.4E-18	2.0E-20	2.6E-15	1.2E-12	2.4E-13	2.2E-12	3.6E-12
Cu-64	5.0E-15	5.1E-17	5.0E-16	3.4E-18	7.6E-19	3.3E-16	6.8E-19	2.4E-14	2.7E-13	2.1E-13	3.1E-12	3.6E-12
Zn-62	3.0E-14	1.1E-16	3.3E-15	1.2E-17	2.7E-18	1.2E-15	2.5E-18	1.2E-13	6.1E-13	1.2E-12	1.6E-11	1.8E-11
Zn-65	4.0E-12	3.4E-13	3.9E-12	1.2E-12	2.8E-13	1.2E-10	2.4E-13	3.8E-11	8.6E-13	2.6E-10	3.8E-11	4.6E-10
Ga-67	4.2E-14	1.2E-18	4.4E-15	8.7E-17	4.4E-17	3.9E-16	1.3E-14	2.2E-15	2.1E-13	9.8E-13	5.7E-12	6.9E-12
Ga-68	3.6E-16	1.7E-21	3.5E-17	9.8E-22	4.9E-22	5.1E-21	1.7E-19	1.9E-18	1.4E-12	9.3E-14	1.4E-12	2.9E-12
Se-75	4.6E-12	1.0E-11	1.4E-11	4.1E-11	4.1E-10	7.1E-11	3.0E-10	7.0E-11	5.3E-13	8.8E-11	3.9E-11	1.0E-09
Br-76	2.2E-14	3.0E-16	2.7E-15	9.4E-18	4.7E-17	2.6E-17	4.3E-17	9.0E-13	4.0E-12	3.4E-12	1.2E-11	2.0E-11
Br-77	1.4E-14	1.5E-15	4.0E-15	2.9E-17	1.5E-16	7.1E-17	1.2E-16	7.2E-13	4.5E-13	1.5E-12	2.5E-12	5.2E-12
Br-82	5.0E-14	2.6E-15	9.7E-15	6.2E-17	3.1E-16	1.6E-16	2.6E-16	2.5E-12	3.8E-12	7.9E-12	1.7E-11	3.2E-11
Kr-79	nc	nc	nc	nc	nc	nc	nc	nc	3.6E-13	0.0E+00	0.0E+00	3.6E-13
Kr-81m	nc	nc	nc	nc	nc	nc	nc	nc	3.5E-14	0.0E+00	0.0E+00	3.5E-14
Kr-85	nc	nc	nc	nc	nc	nc	nc	nc	7.7E-15	0.0E+00	0.0E+00	7.7E-15
Kr-85m	nc	nc	nc	nc	nc	nc	nc	nc	2.2E-13	0.0E+00	0.0E+00	2.2E-13
Rb-81	7.4E-16	8.9E-18	7.5E-17	1.7E-18	8.3E-19	4.6E-18	7.7E-19	7.2E-15	1.0E-12	2.4E-13	1.1E-12	2.4E-12
Rb-82	nc	nc	nc	nc	nc	nc	nc	nc	1.2E-12	1.5E-15	4.6E-14	1.2E-12
Rb-83	1.9E-12	4.0E-12	6.0E-12	1.7E-12	8.6E-13	3.0E-12	5.0E-13	3.5E-11	7.0E-13	8.5E-11	2.0E-11	1.6E-10
Sr-83	4.4E-14	2.7E-16	4.4E-15	1.3E-16	6.6E-17	2.8E-16	4.7E-17	3.0E-14	1.1E-12	8.9E-11	9.4E-12	9.9E-11
Sr-85	7.2E-13	3.2E-14	1.6E-13	1.4E-14	7.2E-15	3.0E-14	5.1E-15	1.2E-12	7.1E-13	6.4E-11	1.9E-11	8.6E-11
Sr-89	2.6E-12	9.8E-14	5.6E-13	5.0E-14	2.5E-14	1.0E-13	1.7E-14	4.1E-12	1.4E-14	8.3E-15	1.4E-10	1.5E-10
Sr-90	8.1E-11	1.3E-10	1.3E-11	4.1E-12	2.0E-12	2.0E-11	3.3E-12	7.5E-10	3.1E-15	6.4E-17	8.0E-10	1.8E-09
Y-90	5.2E-13	2.4E-17	5.4E-14	1.3E-17	6.6E-17	3.1E-17	5.1E-17	2.7E-14	2.5E-14	3.2E-19	4.2E-11	4.3E-11
Zr-89	1.7E-13	1.5E-17	1.8E-14	7.5E-17	3.7E-17	2.0E-17	2.8E-17	1.6E-15	1.7E-12	7.7E-12	1.5E-11	2.5E-11
Zr-95	8.9E-13	2.3E-15	2.0E-13	1.2E-15	6.1E-16	2.3E-16	3.2E-16	6.2E-15	1.1E-12	2.5E-10	1.1E-10	3.6E-10
Nb-95	4.5E-13	1.1E-15	8.7E-14	1.5E-16	7.7E-17	7.1E-18	4.5E-17	3.7E-16	1.1E-12	5.4E-11	3.5E-11	9.0E-11
Mo-99	1.0E-13	5.2E-16	1.1E-14	5.0E-15	5.0E-14	2.3E-15	3.8E-14	2.9E-13	2.2E-13	1.6E-12	2.4E-11	2.6E-11
Tc-94m	nc	nc	nc	nc	nc	nc	nc	nc	2.7E-12	1.3E-13	1.4E-12	4.2E-12
Tc-99	9.8E-11	1.7E-10	9.2E-11	1.4E-09	2.0E-09	1.2E-10	8.3E-11	1.0E-09	9.1E-16	0.0E+00	8.9E-11	5.0E-09
Tc-99m	6.1E-16	2.2E-16	7.1E-17	6.0E-17	8.9E-17	2.0E-16	1.3E-16	2.0E-14	1.7E-13	6.0E-14	5.3E-13	7.8E-13
Ru-103	6.1E-13	4.3E-16	6.0E-14	2.4E-15	5.8E-15	6.8E-14	3.5E-15	1.2E-14	6.6E-13	3.8E-11	5.5E-11	9.4E-11

Radionuclide	DPURs for child in a local resident family (µSv/y per Bq/y)											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External from air	External from deposited	Inhalation	Total
Ru-106	8.0E-12	3.9E-14	7.9E-13	1.1E-13	2.6E-13	3.6E-12	1.8E-13	1.5E-13	3.4E-13	1.3E-10	6.4E-10	7.9E-10
Ag-110m	2.9E-12	1.1E-14	1.3E-12	2.5E-14	7.7E-11	9.8E-13	6.5E-11	2.8E-10	4.0E-12	1.3E-09	1.9E-10	1.9E-09
In-111	5.5E-14	1.3E-18	5.7E-15	4.8E-17	2.4E-17	1.1E-16	1.8E-17	2.8E-14	5.3E-13	2.2E-12	6.4E-12	9.3E-12
In-113m	nc	nc	nc	nc	nc	nc	nc	nc	3.5E-13	3.6E-14	5.6E-13	9.5E-13
Sb-125	1.2E-12	5.9E-15	3.8E-13	2.1E-13	1.0E-11	3.6E-13	5.1E-12	9.5E-14	5.9E-13	6.3E-10	1.1E-10	7.6E-10
I-123	7.3E-14	7.0E-16	8.4E-15	1.2E-15	6.1E-16	6.7E-15	1.1E-15	1.9E-13	1.9E-13	9.4E-11	2.6E-12	9.7E-11
I-124	2.9E-11	7.5E-12	1.6E-11	4.2E-12	2.1E-12	1.2E-11	2.1E-12	2.7E-10	1.5E-12	8.1E-11	1.6E-10	5.8E-10
I-125	1.2E-10	2.3E-10	3.5E-10	5.6E-11	2.8E-11	7.2E-11	1.2E-11	9.6E-10	1.1E-14	1.0E-11	1.6E-10	2.0E-09
I-129	1.4E-09	3.5E-09	3.7E-09	7.9E-10	4.0E-10	6.9E-10	1.1E-10	8.1E-09	8.1E-15	1.8E-10	9.6E-10	2.0E-08
I-131	8.0E-11	4.6E-11	8.1E-11	1.8E-11	8.8E-12	4.1E-11	6.8E-12	7.7E-10	4.9E-13	5.7E-11	2.7E-10	1.4E-09
I-132	nc	nc	nc	nc	nc	nc	nc	nc	3.0E-12	3.9E-12	3.1E-12	1.0E-11
I-133	2.3E-12	4.7E-14	3.1E-13	7.3E-14	3.6E-14	3.5E-13	5.9E-14	9.7E-12	8.0E-13	1.0E-11	5.4E-11	7.8E-11
I-134	nc	nc	nc	nc	nc	nc	nc	nc	3.5E-12	1.7E-12	1.4E-12	6.6E-12
I-135	1.7E-13	5.7E-16	1.7E-14	9.0E-16	4.5E-16	5.5E-15	9.2E-16	1.7E-13	2.2E-12	8.8E-12	1.1E-11	2.3E-11
Xe-133	nc	nc	nc	nc	nc	nc	nc	nc	4.3E-14	0.0E+00	0.0E+00	4.3E-14
Cs-134	9.6E-12	2.4E-11	3.6E-11	3.5E-11	1.7E-11	5.7E-11	9.5E-12	9.2E-11	2.2E-12	1.8E-09	8.3E-11	2.2E-09
Cs-136	1.3E-12	1.2E-12	1.9E-12	1.9E-12	9.4E-13	2.8E-12	4.7E-13	1.0E-11	3.2E-12	5.7E-11	3.1E-11	1.1E-10
Cs-137	7.5E-12	2.0E-11	2.7E-11	3.1E-11	1.6E-11	4.9E-11	8.1E-12	7.6E-11	8.1E-13	3.3E-09	5.8E-11	3.6E-09
Ba-140	1.5E-12	7.2E-16	2.2E-13	3.3E-14	1.6E-14	1.8E-14	1.0E-14	5.8E-13	2.6E-13	6.9E-11	1.2E-10	1.9E-10
La-140	2.5E-13	7.2E-18	2.5E-14	7.2E-17	1.4E-15	4.5E-18	1.2E-15	1.2E-14	3.5E-12	7.6E-12	3.1E-11	4.3E-11
Ce-141	5.8E-13	2.1E-16	5.7E-14	1.9E-17	7.6E-14	1.4E-15	4.7E-14	2.6E-14	9.9E-14	4.5E-12	7.2E-11	7.8E-11
Ce-144	5.8E-12	1.3E-14	5.7E-13	1.1E-15	4.4E-12	1.3E-13	4.3E-12	3.3E-13	2.4E-14	2.4E-11	8.6E-10	9.0E-10
Pm-147	3.2E-13	1.7E-14	6.3E-14	1.5E-14	4.6E-14	5.4E-14	7.2E-14	1.3E-14	2.8E-16	4.8E-15	1.1E-10	1.1E-10
Sm-153	1.1E-13	9.7E-18	1.1E-14	1.9E-19	7.7E-16	1.8E-17	6.0E-16	5.4E-15	6.5E-14	1.8E-13	1.6E-11	1.6E-11
Eu-152	1.5E-12	1.2E-13	2.1E-13	9.7E-14	2.9E-13	4.8E-13	6.3E-13	6.3E-14	1.7E-12	4.6E-09	7.7E-10	5.4E-09
Eu-154	2.3E-12	1.4E-13	3.0E-13	1.5E-13	4.4E-13	6.7E-13	8.9E-13	9.7E-14	1.8E-12	4.0E-09	1.0E-09	5.0E-09
Eu-155	3.7E-13	1.3E-14	4.4E-14	2.2E-14	6.5E-14	9.0E-14	1.2E-13	1.6E-14	6.8E-14	9.6E-11	1.4E-10	2.4E-10
Er-169	1.8E-13	2.9E-17	1.8E-14	1.8E-18	7.1E-15	1.4E-16	4.8E-15	9.1E-15	9.4E-16	4.1E-19	2.4E-11	2.4E-11
Lu-177	2.1E-13	2.9E-17	2.1E-14	1.5E-18	6.1E-15	1.3E-16	4.2E-15	1.1E-14	4.8E-14	4.5E-13	2.7E-11	2.7E-11
Re-188	1.1E-13	4.5E-14	1.6E-14	4.4E-14	6.5E-14	1.3E-13	8.5E-14	5.3E-12	9.9E-14	8.0E-14	1.6E-11	2.2E-11
Au-198	2.0E-13	5.7E-17	1.9E-14	6.7E-15	3.3E-15	1.6E-13	2.7E-14	3.0E-15	5.8E-13	2.3E-12	2.2E-11	2.5E-11

Radionuclide	DPURs for child in a local resident family (µSv/y per Bq/y)											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External from air	External from deposited	Inhalation	Total
Tl-201	1.8E-14	2.9E-15	7.0E-15	2.6E-14	1.3E-14	6.1E-14	1.0E-14	1.0E-13	1.0E-13	4.6E-13	1.5E-12	2.3E-12
Pb-210	1.2E-09	1.3E-10	5.4E-10	1.8E-10	2.5E-10	6.3E-10	3.0E-10	1.6E-09	1.4E-15	3.2E-12	2.4E-08	2.8E-08
Pb-212	3.4E-13	6.5E-17	3.3E-14	3.1E-17	4.4E-17	7.7E-17	3.7E-17	9.7E-14	2.0E-13	3.1E-13	3.5E-09	3.5E-09
Bi-213	nc	nc	nc	nc	nc	nc	nc	nc	1.9E-13	1.5E-14	6.8E-10	6.8E-10
Po-210	1.6E-09	3.6E-09	5.5E-09	8.0E-10	4.8E-09	8.0E-10	3.5E-09	5.7E-10	1.2E-17	2.2E-15	7.2E-08	9.3E-08
As-211	2.7E-13	1.0E-15	2.7E-14	3.8E-18	3.2E-18	2.2E-17	1.1E-18	1.8E-12	5.5E-14	9.1E-09	2.2E-09	1.1E-08
Rn-222	nc	nc	nc	nc	nc	nc	nc	nc	5.8E-16	0.0E+00	3.6E-10	3.6E-10
Ra-223	1.1E-10	2.6E-13	1.5E-11	2.7E-12	1.3E-12	1.8E-11	8.6E-13	1.0E-10	2.5E-13	6.5E-12	1.6E-07	1.6E-07
Ra-226	5.8E-10	4.6E-10	3.1E-10	7.7E-11	3.9E-11	5.2E-10	2.5E-11	9.4E-10	9.0E-15	1.4E-08	7.7E-08	9.4E-08
Ac-225	1.2E-11	1.7E-15	1.2E-12	5.2E-16	5.2E-14	1.0E-15	3.4E-14	9.0E-14	2.0E-14	3.6E-12	1.7E-07	1.7E-07
Th-227	7.2E-12	2.4E-16	7.1E-13	2.7E-15	1.4E-14	1.2E-14	8.5E-15	8.3E-14	1.4E-13	2.1E-11	2.2E-07	2.2E-07
Th-230	1.3E-10	1.6E-12	1.6E-11	1.2E-12	5.9E-12	1.2E-11	8.9E-12	3.2E-12	4.7E-16	1.4E-08	2.5E-07	2.7E-07
Th-232	1.6E-10	1.9E-12	2.0E-11	1.4E-12	7.2E-12	1.5E-11	1.1E-11	3.8E-12	2.3E-16	9.7E-09	4.1E-07	4.2E-07
Th-234	2.6E-12	1.0E-16	2.5E-13	1.2E-15	6.1E-15	5.2E-15	3.7E-15	2.9E-14	4.8E-14	1.9E-12	1.7E-10	1.8E-10
U-234	4.3E-11	5.2E-12	5.9E-12	2.2E-12	1.1E-12	6.6E-12	5.6E-13	2.4E-10	1.9E-16	1.0E-10	7.5E-08	7.6E-08
U-235	4.1E-11	5.0E-12	5.6E-12	2.1E-12	1.1E-12	6.3E-12	5.4E-13	2.3E-10	2.1E-13	1.0E-09	6.8E-08	6.9E-08
U-238	3.9E-11	4.8E-12	5.4E-12	2.0E-12	1.0E-12	6.0E-12	5.2E-13	2.2E-10	7.9E-17	1.6E-10	6.3E-08	6.3E-08
Np-237	6.5E-11	2.0E-11	1.1E-11	8.0E-13	2.9E-11	3.9E-12	8.0E-11	5.6E-13	2.8E-14	1.5E-09	3.5E-07	3.5E-07
Pu-238	1.3E-10	6.5E-13	1.4E-11	1.3E-12	4.6E-11	4.7E-12	9.7E-11	6.9E-13	1.1E-16	8.3E-13	6.9E-07	6.9E-07
Pu-239	1.5E-10	8.8E-13	1.6E-11	1.5E-12	5.3E-11	5.5E-12	1.1E-10	8.0E-13	1.1E-16	1.0E-09	7.5E-07	7.5E-07
Pu-240	1.5E-10	8.7E-13	1.6E-11	1.5E-12	5.3E-11	5.5E-12	1.1E-10	8.0E-13	1.1E-16	6.0E-13	7.5E-07	7.5E-07
Pu-241	2.8E-12	6.7E-15	2.8E-13	2.5E-14	9.1E-13	8.5E-14	1.7E-12	1.2E-14	2.0E-18	7.0E-11	1.3E-08	1.3E-08
Pu-242	1.4E-10	8.4E-13	1.5E-11	1.4E-12	5.1E-11	5.3E-12	1.1E-10	7.7E-13	9.2E-17	1.7E-10	7.1E-07	7.1E-07
Am-241	1.2E-10	1.1E-12	1.3E-11	1.4E-12	5.1E-11	6.2E-12	1.3E-10	8.9E-13	2.1E-14	1.5E-09	6.3E-07	6.3E-07
Am-242	1.6E-14	1.4E-19	1.6E-15	8.8E-19	1.3E-17	1.7E-18	1.4E-17	5.9E-19	1.9E-14	4.5E-12	3.8E-10	3.8E-10
Am-243	1.2E-10	1.2E-12	1.3E-11	1.4E-12	5.1E-11	6.3E-12	1.3E-10	9.1E-13	5.9E-14	1.2E-09	6.3E-07	6.3E-07
Cm-242	1.2E-11	2.3E-15	1.2E-12	4.0E-14	1.4E-12	6.2E-14	1.2E-12	9.0E-15	1.3E-16	2.6E-13	1.1E-07	1.1E-07
Cm-243	8.8E-11	6.8E-13	9.1E-12	8.4E-13	3.0E-11	3.0E-12	6.0E-11	4.3E-13	1.7E-13	1.8E-09	4.9E-07	4.9E-07
Cm-244	7.7E-11	4.6E-13	7.9E-12	7.1E-13	2.6E-11	2.4E-12	5.0E-11	3.5E-13	1.1E-16	1.2E-12	4.2E-07	4.2E-07

nc: not considered as half-life less than 3 hours

Table 6. Dose per unit release factors for adult in a local resident family – atmospheric release scenario

Radionuclide	DPURs for adult in a local resident family (µSv/y per Bq/y)											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External from air	External from deposited	Inhalation	Total
H-3	2.0E-14	3.3E-14	1.9E-14	5.5E-15	2.2E-15	9.9E-15	2.2E-15	6.8E-14	0.0E+00	0.0E+00	4.1E-13	5.7E-13
H-3 organic	4.7E-14	7.6E-14	4.4E-14	1.3E-14	5.1E-15	2.3E-14	5.1E-15	1.6E-13	0.0E+00	0.0E+00	9.4E-13	1.3E-12
C-11	nc	nc	nc	nc	nc	nc	nc	nc	2.4E-12	0.0E+00	4.0E-13	2.8E-12
C-14	3.5E-12	5.6E-12	3.2E-12	1.6E-12	6.5E-13	2.9E-12	6.5E-13	5.2E-12	1.4E-16	0.0E+00	4.6E-11	6.9E-11
N-13	nc	nc	nc	nc	nc	nc	nc	nc	2.3E-12	2.8E-14	0.0E+00	2.4E-12
O-15	nc	nc	nc	nc	nc	nc	nc	nc	2.0E-12	4.9E-15	0.0E+00	2.0E-12
F-18	nc	nc	nc	nc	nc	nc	nc	nc	2.4E-12	3.2E-13	1.3E-12	4.1E-12
Na-22	5.0E-12	7.5E-12	1.3E-11	2.3E-11	9.1E-12	2.4E-11	5.3E-12	2.4E-11	5.4E-12	6.0E-09	2.9E-11	6.2E-09
Na-24	2.3E-14	1.5E-16	1.8E-15	3.7E-15	1.5E-15	1.2E-15	2.6E-16	1.7E-14	1.1E-11	9.2E-12	6.1E-12	2.6E-11
P-32	1.7E-12	1.0E-12	1.8E-12	8.5E-13	1.4E-13	1.1E-11	1.4E-13	3.9E-12	2.8E-14	0.0E+00	7.7E-11	9.8E-11
P-33	2.3E-13	1.9E-13	3.4E-13	1.4E-13	2.3E-14	1.8E-12	2.2E-14	3.6E-13	7.7E-16	0.0E+00	3.4E-11	3.7E-11
S-35	1.9E-13	2.5E-13	3.8E-13	2.5E-12	1.2E-12	5.6E-12	1.2E-12	1.8E-12	1.6E-16	0.0E+00	3.2E-11	4.5E-11
Cl-36	6.6E-11	9.0E-11	9.9E-11	7.3E-11	2.9E-11	1.1E-10	2.5E-11	1.2E-10	8.8E-15	2.3E-12	1.6E-10	7.8E-10
Ar-41	nc	nc	nc	nc	nc	nc	nc	nc	3.3E-12	0.0E+00	0.0E+00	3.3E-12
Ca-45	1.5E-12	4.0E-14	1.7E-13	3.8E-12	1.5E-12	3.0E-12	1.0E-13	1.4E-11	8.1E-16	2.5E-19	6.1E-11	8.6E-11
Ca-47	5.3E-13	2.0E-15	3.6E-14	2.6E-13	1.0E-13	2.2E-13	7.7E-15	6.1E-12	2.7E-12	2.2E-11	4.3E-11	7.5E-11
V-48	1.4E-12	9.1E-16	1.4E-13	2.9E-16	1.2E-16	8.5E-18	7.2E-17	5.6E-16	7.2E-12	1.8E-10	5.4E-11	2.5E-10
Cr-51	3.2E-14	1.1E-18	2.1E-15	1.2E-14	4.8E-15	1.3E-14	2.8E-15	1.3E-14	7.3E-14	3.5E-12	8.3E-13	4.5E-12
Mn-52	6.5E-13	3.4E-15	5.4E-14	2.0E-14	1.6E-12	1.7E-14	1.1E-12	3.1E-14	8.6E-12	7.6E-11	3.2E-11	1.2E-10
Mn-54	9.3E-13	9.2E-14	4.1E-13	1.9E-13	1.6E-11	1.4E-13	1.1E-11	5.7E-14	2.0E-12	9.2E-10	3.4E-11	9.8E-10
Mn-56	nc	nc	nc	nc	nc	nc	nc	nc	4.3E-12	6.9E-13	2.7E-12	7.7E-12
Fe-55	4.7E-13	1.4E-15	8.1E-14	8.5E-15	1.0E-13	2.3E-13	1.5E-11	1.2E-14	0.0E+00	7.8E-15	8.6E-12	2.4E-11
Fe-59	1.8E-12	1.9E-15	2.4E-13	6.2E-15	7.4E-14	9.4E-14	6.0E-12	5.4E-14	3.0E-12	2.0E-10	8.3E-11	3.0E-10
Co-56	2.8E-12	2.5E-14	4.3E-13	1.4E-13	4.8E-12	5.6E-14	2.9E-12	2.6E-13	9.2E-12	1.0E-09	1.1E-10	1.2E-09
Co-57	2.7E-13	6.6E-15	4.7E-14	2.5E-14	8.3E-13	1.0E-14	5.4E-13	2.5E-14	2.6E-13	1.1E-10	1.2E-11	1.2E-10
Co-58	8.1E-13	6.7E-15	1.2E-13	3.9E-14	1.3E-12	1.5E-14	7.8E-13	7.6E-14	2.4E-12	2.7E-10	3.6E-11	3.1E-10
Co-60	4.8E-12	7.3E-13	8.5E-13	7.3E-13	2.4E-11	3.4E-13	1.8E-11	5.7E-13	6.3E-12	1.1E-08	2.3E-10	1.2E-08
Ni-63	3.7E-13	7.3E-14	8.0E-14	4.9E-17	2.0E-16	3.2E-16	7.1E-16	5.0E-13	0.0E+00	0.0E+00	1.1E-11	1.2E-11

Radionuclide	DPURs for adult in a local resident family (µSv/y per Bq/y)											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External from air	External from deposited	Inhalation	Total
Cu-61	1.5E-15	8.8E-18	9.7E-17	1.2E-19	2.2E-20	7.4E-18	2.1E-20	1.4E-15	2.0E-12	4.8E-13	1.8E-12	4.2E-12
Cu-64	5.5E-15	3.4E-17	3.6E-16	4.1E-18	7.3E-19	2.3E-16	6.5E-19	1.2E-14	4.5E-13	4.1E-13	2.7E-12	3.6E-12
Zn-62	3.2E-14	7.2E-17	2.3E-15	1.4E-17	2.5E-18	8.4E-16	2.3E-18	5.7E-14	1.0E-12	2.3E-12	1.1E-11	1.5E-11
Zn-65	5.6E-12	2.8E-13	3.6E-12	1.9E-12	3.4E-13	1.1E-10	3.0E-13	2.3E-11	1.4E-12	5.0E-10	3.6E-11	6.8E-10
Ga-67	4.5E-14	7.7E-19	3.1E-15	1.0E-16	4.1E-17	2.8E-16	1.2E-14	1.0E-15	3.4E-13	1.9E-12	5.4E-12	7.7E-12
Ga-68	4.1E-16	1.2E-21	2.7E-17	1.2E-21	4.9E-22	3.8E-21	1.7E-19	9.5E-19	2.3E-12	1.8E-13	1.1E-12	3.5E-12
Se-75	4.5E-12	6.2E-12	8.8E-12	4.4E-11	3.5E-10	4.6E-11	2.6E-10	3.0E-11	8.9E-13	1.7E-10	2.3E-11	9.5E-10
Br-76	2.7E-14	2.2E-16	2.2E-15	1.2E-17	5.0E-17	2.1E-17	4.6E-17	4.8E-13	6.7E-12	6.7E-12	9.3E-12	2.3E-11
Br-77	1.8E-14	1.1E-15	3.4E-15	4.1E-17	1.7E-16	6.0E-17	1.3E-16	4.0E-13	7.4E-13	3.0E-12	1.9E-12	6.0E-12
Br-82	6.5E-14	2.0E-15	8.3E-15	8.8E-17	3.5E-16	1.3E-16	3.0E-16	1.4E-12	6.4E-12	1.5E-11	1.4E-11	3.8E-11
Kr-79	nc	nc	nc	nc	nc	nc	nc	nc	6.0E-13	0.0E+00	0.0E+00	6.0E-13
Kr-81m	nc	nc	nc	nc	nc	nc	nc	nc	5.8E-14	0.0E+00	0.0E+00	5.8E-14
Kr-85	nc	nc	nc	nc	nc	nc	nc	nc	1.3E-14	0.0E+00	0.0E+00	1.3E-14
Kr-85m	nc	nc	nc	nc	nc	nc	nc	nc	3.7E-13	0.0E+00	0.0E+00	3.7E-13
Rb-81	9.1E-16	6.6E-18	6.1E-17	2.2E-18	8.9E-19	3.8E-18	8.4E-19	3.9E-15	1.7E-12	4.8E-13	7.7E-13	3.0E-12
Rb-82	nc	nc	nc	nc	nc	nc	nc	nc	1.9E-12	3.0E-15	3.3E-14	2.0E-12
Rb-83	2.5E-12	3.3E-12	5.3E-12	2.6E-12	1.0E-12	2.7E-12	5.9E-13	2.1E-11	1.2E-12	1.7E-10	1.6E-11	2.2E-10
Sr-83	5.4E-14	2.0E-16	3.6E-15	1.8E-16	7.1E-17	2.3E-16	5.0E-17	1.6E-14	1.9E-12	1.7E-10	7.0E-12	1.8E-10
Sr-85	6.1E-13	1.6E-14	9.0E-14	1.3E-14	5.4E-15	1.7E-14	3.8E-15	4.4E-13	1.2E-12	1.3E-10	1.4E-11	1.4E-10
Sr-89	2.7E-12	6.0E-14	3.7E-13	5.5E-14	2.2E-14	7.1E-14	1.6E-14	1.9E-12	2.3E-14	1.6E-14	1.4E-10	1.4E-10
Sr-90	8.6E-11	8.4E-11	8.9E-12	4.8E-12	1.9E-12	1.4E-11	3.1E-12	3.5E-10	5.2E-15	1.2E-16	8.1E-10	1.4E-09
Y-90	5.4E-13	1.5E-17	3.7E-14	1.5E-17	6.1E-17	2.1E-17	4.7E-17	1.2E-14	4.2E-14	6.3E-19	3.4E-11	3.4E-11
Zr-89	1.9E-13	1.0E-17	1.3E-14	9.2E-17	3.7E-17	1.5E-17	2.7E-17	7.7E-16	2.8E-12	1.5E-11	1.2E-11	3.0E-11
Zr-95	1.0E-12	1.6E-15	1.5E-13	1.5E-15	6.1E-16	1.7E-16	3.2E-16	3.1E-15	1.8E-12	4.9E-10	1.1E-10	6.0E-10
Nb-95	5.4E-13	7.9E-16	6.9E-14	2.0E-16	8.1E-17	5.6E-18	4.8E-17	2.0E-16	1.8E-12	1.1E-10	3.4E-11	1.4E-10
Mo-99	1.2E-13	3.9E-16	8.6E-15	6.8E-15	5.5E-14	1.9E-15	4.2E-14	1.6E-13	3.7E-13	3.1E-12	2.0E-11	2.4E-11
Tc-94m	nc	nc	nc	nc	nc	nc	nc	nc	4.5E-12	2.6E-13	1.0E-12	5.8E-12
Tc-99	1.1E-10	1.1E-10	6.8E-11	1.7E-09	2.0E-09	9.2E-11	8.2E-11	4.9E-10	1.5E-15	0.0E+00	9.0E-11	4.7E-09
Tc-99m	7.1E-16	1.6E-16	5.5E-17	7.6E-17	9.1E-17	1.5E-16	1.4E-16	1.0E-14	2.8E-13	1.2E-13	4.3E-13	8.4E-13
Ru-103	6.8E-13	2.9E-16	4.4E-14	3.0E-15	5.6E-15	5.0E-14	3.4E-15	5.8E-15	1.1E-12	7.4E-11	5.4E-11	1.3E-10

Radionuclide	DPURs for adult in a local resident family (µSv/y per Bq/y)										
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External from air	External from deposited	Inhalation	Total
Ru-106	8.6E-12	2.5E-14	5.5E-13	1.3E-13	2.5E-13	2.5E-12	1.7E-13	7.1E-14	5.6E-13	2.6E-10	6.3E-10	9.1E-10
Ag-110m	3.5E-12	8.5E-15	1.0E-12	3.3E-14	8.3E-11	7.9E-13	7.0E-11	1.5E-10	6.7E-12	2.5E-09	1.7E-10	3.0E-09
In-111	6.2E-14	8.4E-19	4.2E-15	5.9E-17	2.4E-17	8.1E-17	1.8E-17	1.4E-14	8.9E-13	4.3E-12	5.2E-12	1.0E-11
In-113m	nc	nc	nc	nc	nc	nc	nc	nc	5.9E-13	7.1E-14	4.5E-13	1.1E-12
Sb-125	1.4E-12	4.2E-15	3.0E-13	2.7E-13	1.1E-11	2.9E-13	5.3E-12	5.0E-14	9.9E-13	1.2E-09	1.1E-10	1.4E-09
I-123	7.2E-14	4.1E-16	5.4E-15	1.3E-15	5.2E-16	4.3E-15	9.5E-16	8.3E-14	3.1E-13	1.8E-10	1.5E-12	1.9E-10
I-124	2.8E-11	4.3E-12	9.9E-12	4.4E-12	1.8E-12	7.8E-12	1.7E-12	1.1E-10	2.4E-12	1.6E-10	9.0E-11	4.2E-10
I-125	1.3E-10	1.5E-10	2.6E-10	6.8E-11	2.7E-11	5.3E-11	1.2E-11	4.6E-10	1.8E-14	2.1E-11	1.0E-10	1.3E-09
I-129	1.8E-09	2.8E-09	3.2E-09	1.1E-09	4.6E-10	6.0E-10	1.3E-10	4.7E-09	1.4E-14	3.6E-10	7.4E-10	1.6E-08
I-131	7.8E-11	2.6E-11	5.2E-11	1.9E-11	7.4E-12	2.6E-11	5.8E-12	3.3E-10	8.2E-13	1.1E-10	1.5E-10	8.1E-10
I-132	nc	nc	nc	nc	nc	nc	nc	nc	5.0E-12	7.7E-12	1.9E-12	1.5E-11
I-133	2.3E-12	2.8E-14	2.0E-13	7.8E-14	3.1E-14	2.3E-13	5.1E-14	4.2E-12	1.3E-12	2.0E-11	3.1E-11	5.9E-11
I-134	nc	nc	nc	nc	nc	nc	nc	nc	5.8E-12	3.4E-12	9.2E-13	1.0E-11
I-135	1.6E-13	3.3E-16	1.1E-14	9.5E-16	3.8E-16	3.5E-15	7.8E-16	7.4E-14	3.6E-12	1.7E-11	6.6E-12	2.8E-11
Xe-133	nc	nc	nc	nc	nc	nc	nc	nc	7.1E-14	0.0E+00	0.0E+00	7.1E-14
Cs-134	3.0E-11	4.4E-11	7.4E-11	1.2E-10	4.7E-11	1.2E-10	2.6E-11	1.2E-10	3.7E-12	3.6E-09	1.5E-10	4.3E-09
Cs-136	2.0E-12	1.1E-12	2.0E-12	3.2E-12	1.3E-12	2.9E-12	6.3E-13	6.9E-12	5.3E-12	1.1E-10	2.7E-11	1.6E-10
Cs-137	2.2E-11	3.6E-11	5.3E-11	1.0E-10	4.1E-11	9.5E-11	2.1E-11	9.8E-11	1.4E-12	6.6E-09	1.0E-10	7.1E-09
Ba-140	1.6E-12	4.4E-16	1.5E-13	3.7E-14	1.5E-14	1.2E-14	9.4E-15	2.6E-13	4.3E-13	1.4E-10	1.2E-10	2.5E-10
La-140	2.7E-13	4.7E-18	1.8E-14	8.6E-17	1.4E-15	3.2E-18	1.1E-15	5.7E-15	5.9E-12	1.5E-11	2.5E-11	4.6E-11
Ce-141	6.2E-13	1.4E-16	4.0E-14	2.2E-17	7.2E-14	1.0E-15	4.5E-14	1.2E-14	1.6E-13	8.8E-12	7.2E-11	8.2E-11
Ce-144	6.2E-12	8.5E-15	4.0E-13	1.3E-15	4.2E-12	9.1E-14	4.0E-12	1.6E-13	4.0E-14	4.7E-11	8.1E-10	8.7E-10
Pm-147	3.3E-13	1.0E-14	4.3E-14	1.8E-14	4.2E-14	3.7E-14	6.6E-14	5.7E-15	4.6E-16	9.4E-15	1.1E-10	1.1E-10
Sm-153	1.1E-13	6.1E-18	7.3E-15	2.2E-19	7.1E-16	1.3E-17	5.6E-16	2.5E-15	1.1E-13	3.5E-13	1.4E-11	1.5E-11
Eu-152	1.8E-12	9.1E-14	1.7E-13	1.3E-13	3.2E-13	3.8E-13	6.8E-13	3.4E-14	2.8E-12	9.0E-09	9.5E-10	1.0E-08
Eu-154	2.5E-12	9.3E-14	2.2E-13	1.8E-13	4.3E-13	4.9E-13	8.7E-13	4.8E-14	3.0E-12	7.8E-09	1.2E-09	9.0E-09
Eu-155	4.0E-13	8.7E-15	3.1E-14	2.6E-14	6.1E-14	6.4E-14	1.1E-13	7.3E-15	1.1E-13	1.9E-10	1.6E-10	3.4E-10
Er-169	1.9E-13	1.8E-17	1.2E-14	2.0E-18	6.4E-15	9.7E-17	4.3E-15	4.1E-15	1.6E-15	8.0E-19	2.3E-11	2.3E-11
Lu-177	2.2E-13	1.7E-17	1.4E-14	1.7E-18	5.4E-15	8.4E-17	3.7E-15	4.9E-15	7.9E-14	8.8E-13	2.7E-11	2.8E-11
Re-188	1.3E-13	2.9E-14	1.1E-14	5.3E-14	6.3E-14	9.3E-14	8.2E-14	2.5E-12	1.7E-13	1.6E-13	1.0E-11	1.4E-11
Au-198	2.0E-13	3.5E-17	1.3E-14	7.6E-15	3.0E-15	1.1E-13	2.4E-14	1.3E-15	9.6E-13	4.4E-12	1.9E-11	2.5E-11

Radionuclide	DPURs for adult in a local resident family (µSv/y per Bq/y)											
	Green veg	**Root veg**	**Fruit**	**Sheep meat**	**Sheep liver**	**Cow meat**	**Cow liver**	**Cow milk**	**External from air**	**External from deposited**	**Inhalation**	**Total**
Tl-201	2.2E-14	2.1E-15	5.6E-15	3.5E-14	1.4E-14	4.9E-14	1.1E-14	5.5E-14	1.7E-13	8.9E-13	9.9E-13	2.3E-12
Pb-210	1.0E-09	6.5E-11	3.0E-10	1.6E-10	1.8E-10	3.4E-10	2.2E-10	5.9E-10	2.4E-15	6.3E-12	2.5E-08	2.8E-08
Pb-212	2.3E-13	2.7E-17	1.5E-14	2.3E-17	2.6E-17	3.5E-17	2.2E-17	2.9E-14	3.3E-13	6.0E-13	3.8E-09	3.8E-09
Bi-213	nc	nc	nc	nc	nc	nc	nc	nc	3.2E-13	2.9E-14	6.7E-10	6.7E-10
Po-210	1.7E-09	2.3E-09	3.8E-09	9.2E-10	4.4E-09	5.5E-10	3.3E-09	2.6E-10	2.1E-17	4.4E-15	7.4E-08	9.2E-08
As-211	2.9E-13	6.6E-16	2.0E-14	4.5E-18	3.0E-18	1.6E-17	1.1E-18	8.4E-13	9.1E-14	1.8E-08	2.5E-09	2.0E-08
Rn-222	nc	nc	nc	nc	nc	nc	nc	nc	9.6E-16	0.0E+00	2.7E-10	2.7E-10
Ra-223	5.7E-11	8.0E-14	5.1E-12	1.5E-12	6.0E-13	5.9E-12	3.8E-13	2.3E-11	4.2E-13	1.3E-11	1.7E-07	1.7E-07
Ra-226	4.6E-10	2.2E-10	1.6E-10	6.8E-11	2.7E-11	2.7E-10	1.8E-11	3.3E-10	1.5E-14	2.7E-08	7.9E-08	1.1E-07
Ac-225	1.3E-11	1.0E-15	8.1E-13	5.7E-16	4.6E-14	6.8E-16	3.0E-14	4.0E-14	3.4E-14	7.1E-12	1.9E-07	1.9E-07
Th-227	6.3E-12	1.3E-16	4.1E-13	2.6E-15	1.0E-14	6.7E-15	6.5E-15	3.2E-14	2.3E-13	4.1E-11	2.3E-07	2.3E-07
Th-230	2.6E-10	1.9E-12	2.2E-11	2.6E-12	1.0E-11	1.6E-11	1.6E-11	2.8E-12	7.8E-16	2.7E-08	3.2E-07	3.4E-07
Th-232	2.9E-10	2.1E-12	2.4E-11	2.8E-12	1.1E-11	1.8E-11	1.7E-11	3.0E-12	3.8E-16	1.9E-08	5.6E-07	5.8E-07
Th-234	2.7E-12	6.5E-17	1.8E-13	1.4E-15	5.6E-15	3.6E-15	3.4E-15	1.3E-14	8.0E-14	3.8E-12	1.7E-10	1.8E-10
U-234	6.5E-11	4.7E-12	5.8E-12	3.7E-12	1.5E-12	6.5E-12	7.4E-13	1.6E-10	3.2E-16	2.0E-10	7.9E-08	7.9E-08
U-235	6.2E-11	4.6E-12	5.6E-12	3.5E-12	1.4E-12	6.2E-12	7.1E-13	1.6E-10	3.4E-13	2.0E-09	7.0E-08	7.2E-08
U-238	5.9E-11	4.4E-12	5.4E-12	3.4E-12	1.3E-12	6.0E-12	6.8E-13	1.5E-10	1.3E-16	3.2E-10	6.5E-08	6.6E-08
Np-237	1.5E-10	2.8E-11	1.7E-11	2.0E-12	5.7E-11	5.8E-12	1.6E-10	5.6E-13	4.7E-14	2.9E-09	5.2E-07	5.2E-07
Pu-238	2.9E-10	8.6E-13	2.0E-11	3.1E-12	8.9E-11	6.8E-12	1.9E-10	6.6E-13	1.9E-16	1.6E-12	1.0E-06	1.0E-06
Pu-239	3.2E-10	1.1E-12	2.2E-11	3.5E-12	9.9E-11	7.7E-12	2.1E-10	7.4E-13	1.8E-16	2.0E-09	1.1E-06	1.1E-06
Pu-240	3.2E-10	1.1E-12	2.2E-11	3.4E-12	9.9E-11	7.7E-12	2.1E-10	7.4E-13	1.8E-16	1.2E-12	1.1E-06	1.1E-06
Pu-241	6.0E-12	8.6E-15	4.0E-13	6.0E-14	1.7E-12	1.2E-13	3.3E-12	1.2E-14	3.4E-18	1.4E-10	2.0E-08	2.0E-08
Pu-242	3.0E-10	1.1E-12	2.1E-11	3.3E-12	9.5E-11	7.4E-12	2.0E-10	7.1E-13	1.5E-16	3.3E-10	1.1E-06	1.1E-06
Am-241	2.5E-10	1.4E-12	1.7E-11	3.2E-12	9.2E-11	8.5E-12	2.3E-10	8.1E-13	3.6E-14	3.0E-09	9.5E-07	9.5E-07
Am-242	1.7E-14	8.7E-20	1.1E-15	1.0E-18	1.2E-17	1.2E-18	1.3E-17	2.8E-19	3.2E-14	8.9E-12	3.8E-10	3.9E-10
Am-243	2.5E-10	1.5E-12	1.7E-11	3.2E-12	9.3E-11	8.6E-12	2.3E-10	8.3E-13	9.8E-14	2.4E-09	9.3E-07	9.3E-07
Cm-242	1.4E-11	1.6E-15	9.0E-13	5.0E-14	1.4E-12	4.6E-14	1.2E-12	4.5E-15	2.1E-16	5.1E-13	1.2E-07	1.2E-07
Cm-243	1.9E-10	8.7E-13	1.3E-11	2.0E-12	5.6E-11	4.2E-12	1.1E-10	4.0E-13	2.8E-13	3.6E-09	7.0E-07	7.0E-07
Cm-244	1.5E-10	5.5E-13	1.0E-11	1.5E-12	4.4E-11	3.1E-12	8.5E-11	3.0E-13	1.8E-16	2.4E-12	6.1E-07	6.1E-07

nc: not considered as half-life less than 3 hours

Table 7. Dose rate per unit release factors for worst affected terrestrial reference organism – atmospheric release scenario

Radionuclide	Worst total DPUR (µGy/h per Bq/y)	Worst affected reference organism
H-3	3.5E-15	Amphibian, Annelid, Arthropod - detritivorous, Bird, Grasses & Herbs, Mammal - large, Mammal - small-burrowing, Mollusc - gastropod, Reptile, Shrub, Tree
H-3 organic	3.1E-14	Amphibian, Bird, Mammal - large, Mammal - small-burrowing, Reptile
C-11	2.2E-12	Mammal - large
C-14	1.1E-13	Bird, Mammal - large, Mammal - small-burrowing, Reptile
N-13	4.6E-15	Mammal – large
O-15	1.1E-16	Tree
F-18	2.2E-16	Mammal – large
Na-22	2.5E-12	Mammal – large
Na-24	2.7E-15	Mammal – large
P-32	1.5E-12	Mammal – large
P-33	1.7E-13	Amphibian, Bird, Mammal - large, Mammal - small-burrowing, Reptile
S-35	1.2E-14	Grasses & Herbs, Shrub, Tree
Cl-36	1.9E-11	Grasses & Herbs
Ar-41	1.8E-15	Grasses & Herbs
Ca-45	6.4E-14	Mammal – large
Ca-47	3.4E-14	Mammal – large
V-48	2.1E-14	Annelid
Cr-51	3.8E-16	Annelid
Mn-52	8.3E-15	Arthropod – detritivorous
Mn-54	1.4E-13	Arthropod – detritivorous
Mn-56	1.6E-16	Shrub
Fe-55	3.0E-14	Shrub
Fe-59	2.6E-14	Arthropod – detritivorous
Co-56	1.5E-13	Arthropod – detritivorous
Co-57	1.2E-14	Amphibian
Co-58	3.6E-14	Annelid
Co-60	2.0E-12	Amphibian
Ni-63	2.7E-14	Reptile
Cu-61	1.7E-16	Mammal – large
Cu-64	1.9E-16	Mammal – large
Zn-62	1.2E-15	Mammal – large
Zn-65	1.6E-13	Mammal – large
Ga-67	1.8E-16	Annelid
Ga-68	2.1E-17	Annelid
Se-75	2.8E-14	Annelid
Br-76	8.1E-16	Amphibian

Radionuclide	Worst total DPUR (µGy/h per Bq/y)	Worst affected reference organism
Br-77	3.1E-16	Amphibian
Br-82	1.7E-15	Amphibian
Kr-79^	5.4E-17	Shrub
Kr-81m^	5.4E-17	Shrub
Kr-85	5.4E-17	Shrub
Kr-85m^	5.4E-17	Shrub
Rb-81	1.9E-16	Mammal – large
Rb-82	2.2E-18	Mammal – large
Rb-83	7.2E-14	Mammal – large
Sr-83	7.5E-16	Mammal – large
Sr-85	2.4E-14	Mammal – large
Sr-89	4.3E-14	Lichen & Bryophytes
Sr-90	7.6E-12	Lichen & Bryophytes
Y-90	1.5E-16	Bird
Zr-89	1.6E-15	Arthropod – detritivorous
Zr-95	2.5E-14	Amphibian
Nb-95	1.3E-14	Annelid
Mo-99	3.4E-16	Annelid
Tc-94m	1.4E-16	Grasses & Herbs
Tc-99	2.4E-12	Grasses & Herbs
Tc-99m	4.2E-17	Grasses & Herbs
Ru-103	1.9E-14	Lichen & Bryophytes
Ru-106	5.5E-13	Lichen & Bryophytes
Ag-110m	3.9E-13	Annelid
In-111	4.0E-16	Arthropod – detritivorous
In-113m	7.1E-18	Arthropod – detritivorous
Sb-125	1.9E-13	Annelid
I-123	2.9E-16	Amphibian
I-124	1.9E-14	Amphibian
I-125	9.6E-15	Mammal – large
I-129	1.8E-12	Mammal – large
I-131	1.4E-14	Amphibian
I-132	9.0E-16	Amphibian
I-133	2.6E-15	Amphibian
I-134	3.9E-16	Amphibian
I-135	1.8E-15	Amphibian
Xe-133	6.2E-17	Grasses & Herbs
Cs-134	1.5E-12	Mammal – large
Cs-136	3.3E-14	Mammal – large
Cs-137	6.4E-12	Mammal – large
Ba-140	1.0E-13	Bird
La-140	1.8E-15	Amphibian
Ce-141	8.0E-16	Amphibian
Ce-144	1.7E-14	Bird
Pm-147	2.1E-15	Bird
Sm-153	2.8E-17	Bird

Radionuclide	Worst total DPUR (µGy/h per Bq/y)	Worst affected reference organism
Eu-152	1.9E-12	Annelid
Eu-154	1.5E-12	Arthropod – detritivorous
Eu-155	5.1E-14	Bird
Er-169	3.4E-17	Bird
Lu-177	7.8E-17	Annelid
Re-188	2.8E-15	Grasses & Herbs
Au-198	5.6E-15	Grasses & Herbs
Tl-201	6.6E-16	Mammal – large
Pb-210	2.3E-12	Lichen & Bryophytes
Pb-212	4.6E-14	Lichen & Bryophytes
Bi-213	3.1E-15	Lichen & Bryophytes
Po-210	1.1E-11	Lichen & Bryophytes
As-211	3.8E-15	Mammal - small-burrowing
Rn-222	2.6E-15	Arthropod – detritivorous
Ra-223	1.0E-12	Lichen & Bryophytes
Ra-226	8.3E-10	Lichen & Bryophytes
Ac-225	5.0E-13	Lichen & Bryophytes
Th-227	2.1E-13	Lichen & Bryophytes
Th-230	8.7E-11	Lichen & Bryophytes
Th-232	7.5E-11	Lichen & Bryophytes
Th-234	2.1E-15	Lichen & Bryophytes
U-234	2.1E-10	Lichen & Bryophytes
U-235	2.0E-10	Lichen & Bryophytes
U-238	1.9E-10	Lichen & Bryophytes
Np-237	2.3E-10	Lichen & Bryophytes
Pu-238	2.9E-11	Lichen & Bryophytes
Pu-239	3.3E-11	Lichen & Bryophytes
Pu-240	3.3E-11	Lichen & Bryophytes
Pu-241	3.7E-15	Lichen & Bryophytes
Pu-242	3.1E-11	Lichen & Bryophytes
Am-241	2.6E-10	Lichen & Bryophytes
Am-242	5.2E-17	Lichen & Bryophytes
Am-243	2.6E-10	Lichen & Bryophytes
Cm-242	5.8E-12	Lichen & Bryophytes
Cm-243	1.7E-10	Lichen & Bryophytes
Cm-244	1.3E-10	Lichen & Bryophytes

^dose factors not available for this radioactive noble gas so used DPUR for krypton-85 for which dose factors were derived.

Table 8. Dose rate per unit release factors for terrestrial reference organisms (µGy/h per Bq/y) – atmospheric release scenario

Radio-nuclide	Amphibian	Annelid	Arthropo, detriti-vorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryo-phytes	Mammal - large	Mammal - small-burrowing	Mollusc, gastro-pod	Reptile	Shrub	Tree
H-3	3.5E-15	3.5E-15	3.5E-15	3.5E-15	3.3E-15	3.5E-15	3.5E-15	3.5E-15	3.5E-15	3.5E-15	3.5E-15	3.5E-15	3.5E-15
H-3 organic	3.1E-14	1.0E-14	1.0E-14	3.1E-14	9.4E-15	2.1E-14	2.1E-14	3.1E-14	3.1E-14	1.0E-14	3.1E-14	2.1E-14	3.0E-14
C-11	8.9E-13	2.6E-13	2.1E-13	1.1E-12	2.4E-13	5.2E-13	4.1E-13	2.2E-12	1.0E-12	2.5E-13	9.8E-13	5.2E-13	2.0E-12
C-14	1.1E-13	3.5E-14	3.5E-14	1.1E-13	3.5E-14	7.2E-14	7.3E-14	1.1E-13	1.1E-13	3.5E-14	1.1E-13	7.2E-14	1.1E-13
N-13	2.1E-15	6.0E-16	4.8E-16	2.6E-15	5.5E-16	1.2E-15	9.1E-16	4.6E-15	2.4E-15	5.8E-16	2.3E-15	1.2E-15	4.3E-15
O-15	2.0E-17	1.7E-17	1.2E-17	2.3E-17	1.5E-17	4.9E-17	3.1E-17	3.7E-17	2.2E-17	1.6E-17	2.1E-17	4.9E-17	1.1E-16
F-18	1.0E-16	3.4E-17	3.5E-17	1.1E-16	1.5E-17	2.0E-16	2.0E-17	2.2E-16	1.1E-16	1.4E-17	1.1E-16	2.1E-17	5.2E-17
Na-22	9.8E-13	9.4E-13	9.4E-13	4.6E-13	3.7E-13	4.6E-13	6.7E-13	2.5E-12	1.5E-12	3.6E-13	9.4E-13	5.3E-13	3.7E-13
Na-24	1.1E-15	1.1E-15	1.1E-15	5.2E-16	3.9E-16	5.3E-16	7.6E-16	2.7E-15	1.8E-15	3.8E-16	1.1E-15	6.3E-16	3.8E-16
P-32	1.4E-12	4.0E-13	2.9E-13	1.5E-12	3.4E-13	8.2E-13	5.4E-13	1.5E-12	1.5E-12	3.9E-13	1.4E-12	8.2E-13	1.5E-12
P-33	1.7E-13	5.4E-14	5.3E-14	1.7E-13	5.3E-14	1.1E-13	1.1E-13	1.7E-13	1.7E-13	5.4E-14	1.7E-13	1.1E-13	1.6E-13
S-35	4.1E-15	4.1E-15	4.1E-15	4.1E-15	4.0E-15	1.2E-14	1.2E-14	4.1E-15	4.1E-15	4.1E-15	4.1E-15	1.2E-14	1.2E-14
Cl-36	6.7E-12	1.6E-13	2.5E-13	6.7E-12	2.5E-13	1.9E-11	7.3E-13	6.7E-12	6.7E-12	1.5E-13	6.7E-12	9.2E-13	1.3E-12
Ar-41	8.6E-16	2.2E-19	9.7E-16	7.8E-16	9.3E-16	1.8E-15	1.0E-15	4.5E-16	2.0E-19	9.0E-16	8.4E-16	1.0E-15	1.2E-15
Ca-45	6.4E-14	1.4E-15	7.4E-16	4.3E-16	7.5E-16	2.2E-15	1.5E-14	6.4E-14	6.4E-14	3.6E-16	6.4E-14	1.4E-15	5.6E-15
Ca-47	2.1E-14	3.0E-15	2.8E-15	1.1E-15	1.2E-15	1.6E-15	4.5E-15	3.4E-14	2.2E-14	1.1E-15	2.2E-14	1.3E-15	3.6E-15
V-48	2.1E-14	2.1E-14	2.1E-14	8.2E-15	8.0E-15	7.8E-15	8.1E-15	4.7E-15	2.0E-14	8.2E-15	1.9E-14	7.3E-15	6.4E-15
Cr-51	3.7E-16	3.8E-16	3.8E-16	1.6E-16	1.6E-16	1.6E-16	1.7E-16	7.6E-17	3.5E-16	1.6E-16	3.4E-16	1.5E-16	1.3E-16
Mn-52	8.1E-15	8.2E-15	8.3E-15	2.9E-15	3.2E-15	3.1E-15	3.3E-15	1.6E-15	7.7E-15	3.1E-15	7.5E-15	4.3E-15	2.8E-15
Mn-54	1.3E-13	1.3E-13	1.4E-13	5.2E-14	5.2E-14	4.9E-14	5.4E-14	2.6E-14	1.3E-13	5.2E-14	1.2E-13	7.0E-14	4.5E-14
Mn-56	7.4E-17	7.5E-17	7.7E-17	2.7E-17	3.1E-17	3.0E-17	3.8E-17	1.5E-17	7.1E-17	2.9E-17	6.9E-17	1.6E-16	2.7E-17
Fe-55	1.2E-16	1.7E-16	7.1E-16	7.3E-17	6.7E-16	7.0E-16	4.2E-15	1.7E-17	5.9E-17	3.2E-16	1.1E-16	3.0E-14	4.4E-16
Fe-59	2.5E-14	2.5E-14	2.6E-14	9.1E-15	1.0E-14	9.7E-15	1.1E-14	5.1E-15	2.4E-14	9.9E-15	2.3E-14	2.3E-14	8.7E-15
Co-56	1.5E-13	1.5E-13	1.5E-13	5.1E-14	5.4E-14	5.3E-14	5.5E-14	4.7E-14	1.4E-13	5.4E-14	1.4E-13	5.0E-14	4.3E-14
Co-57	1.2E-14	1.1E-14	1.1E-14	5.2E-15	5.4E-15	5.8E-15	5.9E-15	6.2E-15	1.2E-14	5.5E-15	1.2E-14	5.2E-15	4.4E-15
Co-58	3.6E-14	3.6E-14	3.6E-14	1.4E-14	1.4E-14	1.3E-14	1.4E-14	1.2E-14	3.5E-14	1.4E-14	3.4E-14	1.3E-14	1.1E-14
Co-60	2.0E-12	2.0E-12	2.0E-12	7.6E-13	7.7E-13	7.4E-13	7.7E-13	6.5E-13	1.9E-12	7.7E-13	1.9E-12	7.0E-13	6.1E-13

Radio-nuclide	Amphibian	Annelid	Arthropo, detriti-vorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryo-phytes	Mammal - large	Mammal - small-burrowing	Mollusc, gastro-pod	Reptile	Shrub	Tree
Ni-63	9.6E-15	6.4E-15	1.5E-15	9.6E-15	1.5E-15	1.2E-14	2.1E-14	9.6E-15	9.6E-15	1.6E-15	2.7E-14	8.8E-15	1.9E-15
Cu-61	1.1E-16	1.3E-16	6.6E-17	1.0E-16	3.8E-17	2.1E-17	2.9E-17	1.7E-16	1.2E-16	9.3E-17	4.9E-17	3.5E-17	2.1E-17
Cu-64	1.4E-16	1.6E-16	7.3E-17	1.3E-16	4.8E-17	1.9E-17	3.4E-17	1.9E-16	1.4E-16	1.4E-16	4.5E-17	4.4E-17	1.9E-17
Zn-62	8.8E-16	9.2E-16	3.3E-16	9.0E-16	2.3E-16	1.1E-16	1.4E-16	1.2E-15	9.6E-16	7.0E-16	2.6E-16	2.4E-16	1.2E-16
Zn-65	9.0E-14	8.9E-14	7.7E-14	6.7E-14	3.2E-14	2.8E-14	3.0E-14	1.6E-13	9.8E-14	4.3E-14	6.9E-14	2.9E-14	2.7E-14
Ga-67	1.7E-16	1.8E-16	1.7E-16	8.7E-17	7.3E-17	7.5E-17	7.5E-17	4.3E-17	1.6E-16	8.6E-17	1.6E-16	7.0E-17	6.2E-17
Ga-68	1.9E-17	2.1E-17	1.9E-17	9.9E-18	7.3E-18	7.2E-18	7.5E-18	4.7E-18	1.8E-17	9.2E-18	1.8E-17	6.8E-18	6.1E-18
Se-75	2.1E-14	2.8E-14	2.1E-14	1.1E-14	9.3E-15	1.1E-14	9.3E-15	7.9E-15	2.0E-14	9.1E-15	1.9E-14	1.2E-14	9.4E-15
Br-76	8.1E-16	7.6E-16	7.6E-16	3.8E-16	3.1E-16	2.9E-16	2.8E-16	4.1E-16	8.0E-16	3.0E-16	7.6E-16	2.5E-16	3.0E-16
Br-77	3.1E-16	3.1E-16	3.1E-16	1.4E-16	1.3E-16	1.2E-16	1.2E-16	1.5E-16	3.0E-16	1.2E-16	2.9E-16	1.1E-16	1.3E-16
Br-82	1.7E-15	1.7E-15	1.7E-15	7.2E-16	6.6E-16	6.3E-16	6.4E-16	7.7E-16	1.6E-15	6.5E-16	1.6E-15	5.8E-16	6.4E-16
Kr-79^	4.7E-18	2.8E-21	2.8E-17	2.4E-18	1.6E-17	2.4E-17	5.0E-17	8.3E-19	6.9E-22	1.0E-17	3.9E-18	5.4E-17	2.5E-18
Kr-81m^	4.7E-18	2.8E-21	2.8E-17	2.4E-18	1.6E-17	2.4E-17	5.0E-17	8.3E-19	6.9E-22	1.0E-17	3.9E-18	5.4E-17	2.5E-18
Kr-85	4.7E-18	2.8E-21	2.8E-17	2.4E-18	1.6E-17	2.4E-17	5.0E-17	8.3E-19	6.9E-22	1.0E-17	3.9E-18	5.4E-17	2.5E-18
Kr-85m^	4.7E-18	2.8E-21	2.8E-17	2.4E-18	1.6E-17	2.4E-17	5.0E-17	8.3E-19	6.9E-22	1.0E-17	3.9E-18	5.4E-17	2.5E-18
Rb-81	5.6E-17	4.9E-17	4.9E-17	3.2E-17	2.1E-17	3.8E-17	7.3E-17	1.9E-16	1.2E-16	2.0E-17	5.5E-17	5.2E-17	2.2E-17
Rb-82	4.7E-19	3.3E-19	3.2E-19	3.6E-19	1.4E-19	4.2E-19	5.7E-19	2.2E-18	1.7E-18	1.3E-19	5.0E-19	6.4E-19	1.8E-19
Rb-83	2.5E-14	2.3E-14	2.3E-14	1.3E-14	9.4E-15	1.4E-14	2.5E-14	7.2E-14	4.4E-14	9.1E-15	2.4E-14	1.8E-14	9.5E-15
Sr-83	6.0E-16	4.6E-16	4.8E-16	3.7E-16	2.1E-16	2.5E-16	5.2E-16	7.5E-16	6.6E-16	1.8E-16	4.6E-16	1.8E-16	3.1E-16
Sr-85	1.9E-14	1.7E-14	1.7E-14	1.0E-14	6.9E-15	7.2E-15	9.4E-15	2.4E-14	2.0E-14	6.7E-15	1.6E-14	6.3E-15	1.1E-14
Sr-89	1.9E-14	9.2E-16	3.4E-15	1.9E-14	4.1E-15	1.0E-14	4.3E-14	2.6E-14	2.6E-14	1.2E-15	6.2E-15	2.4E-15	7.7E-15
Sr-90	4.0E-12	1.8E-13	6.2E-13	4.0E-12	7.4E-13	2.1E-12	7.6E-12	5.6E-12	5.3E-12	2.3E-13	1.3E-12	4.7E-13	1.6E-12
Y-90	1.3E-16	8.4E-18	4.0E-18	1.5E-16	5.4E-18	3.3E-17	8.5E-17	2.9E-19	2.8E-19	7.8E-18	1.4E-16	4.6E-18	1.3E-17
Zr-89	1.6E-15	1.6E-15	1.6E-15	6.3E-16	6.2E-16	6.1E-16	6.5E-16	3.1E-16	1.5E-15	6.2E-16	1.5E-15	5.7E-16	5.0E-16
Zr-95	2.5E-14	2.5E-14	2.5E-14	1.0E-14	9.4E-15	9.5E-15	1.0E-14	4.6E-15	2.3E-14	9.4E-15	2.3E-14	8.7E-15	7.7E-15
Nb-95	1.3E-14	1.3E-14	1.3E-14	5.3E-15	5.1E-15	4.8E-15	5.0E-15	2.8E-15	1.3E-14	5.3E-15	1.2E-14	4.5E-15	3.9E-15
Mo-99	2.9E-16	3.4E-16	2.7E-16	2.0E-16	1.1E-16	1.1E-16	1.2E-16	8.3E-17	2.8E-16	1.8E-16	2.7E-16	1.1E-16	9.8E-17
Tc-94m	3.2E-17	3.2E-17	3.0E-17	1.3E-17	1.4E-17	1.4E-16	7.9E-17	1.7E-17	3.2E-17	1.4E-17	3.0E-17	9.9E-18	8.7E-18
Tc-99	6.7E-14	6.7E-14	6.4E-14	2.8E-14	6.6E-14	2.4E-12	2.2E-12	6.7E-14	6.7E-14	6.6E-14	6.7E-14	2.0E-15	2.0E-15

Radio-nuclide	Amphibian	Annelid	Arthropo, detriti-vorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryo-phytes	Mammal - large	Mammal - small-burrowing	Mollusc, gastro-pod	Reptile	Shrub	Tree
Tc-99m	1.0E-17	1.0E-17	1.0E-17	4.7E-18	5.3E-18	4.2E-17	3.8E-17	6.7E-18	1.0E-17	5.3E-18	9.8E-18	4.2E-18	3.6E-18
Ru-103	9.0E-15	9.0E-15	9.0E-15	3.9E-15	3.5E-15	3.5E-15	1.9E-14	2.7E-15	8.7E-15	3.5E-15	8.3E-15	4.3E-15	6.0E-15
Ru-106	6.8E-14	4.0E-14	3.9E-14	4.8E-14	1.6E-14	1.8E-14	5.5E-13	4.5E-14	6.7E-14	1.6E-14	6.5E-14	8.7E-14	1.4E-13
Ag-110m	3.7E-13	3.9E-13	3.8E-13	1.7E-13	1.4E-13	1.8E-13	1.4E-13	2.0E-13	3.7E-13	1.5E-13	3.5E-13	1.3E-13	2.0E-13
In-111	3.9E-16	3.9E-16	4.0E-16	1.6E-16	1.7E-16	1.7E-16	1.7E-16	7.8E-17	3.7E-16	1.7E-16	3.5E-16	1.6E-16	1.4E-16
In-113m	7.0E-18	7.1E-18	7.1E-18	3.0E-18	2.9E-18	2.9E-18	2.9E-18	1.4E-18	6.6E-18	3.1E-18	6.4E-18	2.7E-18	2.3E-18
Sb-125	1.9E-13	1.9E-13	1.9E-13	7.4E-14	7.5E-14	7.6E-14	9.0E-14	3.6E-14	1.8E-13	7.7E-14	1.7E-13	7.2E-14	6.5E-14
I-123	2.9E-16	2.6E-16	2.8E-16	1.7E-16	1.4E-16	1.3E-16	1.2E-16	1.9E-16	2.9E-16	1.3E-16	2.8E-16	1.1E-16	1.4E-16
I-124	1.9E-14	1.8E-14	1.8E-14	8.5E-15	7.4E-15	6.8E-15	6.8E-15	9.2E-15	1.8E-14	7.1E-15	1.7E-14	6.1E-15	7.0E-15
I-125	8.8E-15	5.0E-15	6.6E-15	8.6E-15	5.0E-15	3.6E-15	2.8E-15	9.6E-15	9.2E-15	3.3E-15	8.8E-15	1.3E-15	4.0E-15
I-129	1.7E-12	8.2E-13	1.3E-12	1.7E-12	1.1E-12	6.5E-13	5.8E-13	1.8E-12	1.8E-12	7.3E-13	1.7E-12	1.2E-13	7.0E-13
I-131	1.4E-14	1.2E-14	1.3E-14	7.8E-15	6.4E-15	5.4E-15	5.4E-15	8.1E-15	1.4E-14	5.8E-15	1.3E-14	4.2E-15	5.7E-15
I-132	9.0E-16	8.4E-16	8.5E-16	4.4E-16	3.6E-16	3.3E-16	3.3E-16	4.5E-16	8.5E-16	3.4E-16	8.5E-16	2.9E-16	3.4E-16
I-133	2.6E-15	2.2E-15	2.3E-15	1.4E-15	1.1E-15	9.3E-16	9.1E-16	1.5E-15	2.5E-15	9.7E-16	2.4E-15	7.4E-16	9.8E-16
I-134	3.9E-16	3.7E-16	3.7E-16	1.8E-16	1.6E-16	1.4E-16	1.4E-16	1.9E-16	3.8E-16	1.5E-16	3.7E-16	1.2E-16	1.5E-16
I-135	1.8E-15	1.7E-15	1.8E-15	8.5E-16	7.4E-16	6.6E-16	6.7E-16	9.1E-16	1.8E-15	7.0E-16	1.7E-15	5.8E-16	6.8E-16
Xe-133	2.8E-17	7.4E-21	3.4E-17	2.3E-17	3.1E-17	6.2E-17	3.7E-17	7.4E-18	6.2E-21	3.1E-17	2.7E-17	4.0E-17	2.7E-17
Cs-134	5.8E-13	5.5E-13	5.6E-13	2.9E-13	2.2E-13	2.8E-13	4.2E-13	1.5E-12	9.0E-13	2.1E-13	5.6E-13	3.2E-13	2.2E-13
Cs-136	1.3E-14	1.2E-14	1.2E-14	6.3E-15	4.9E-15	5.8E-15	8.1E-15	3.3E-14	1.9E-14	4.9E-15	1.2E-14	6.5E-15	4.8E-15
Cs-137	1.9E-12	1.6E-12	1.7E-12	1.1E-12	7.0E-13	1.4E-12	2.9E-12	6.4E-12	4.5E-12	6.6E-13	1.9E-12	2.0E-12	7.0E-13
Ba-140	1.6E-14	1.6E-14	1.6E-14	1.0E-13	6.0E-15	5.9E-15	6.3E-15	3.6E-15	1.5E-14	6.2E-15	1.4E-14	8.3E-15	6.1E-15
La-140	1.8E-15	1.6E-15	1.6E-15	9.3E-16	6.1E-16	5.9E-16	6.1E-16	3.7E-16	1.5E-15	6.1E-16	1.8E-15	5.6E-16	4.8E-16
Ce-141	8.0E-16	8.0E-16	7.9E-16	5.7E-16	3.5E-16	4.2E-16	4.0E-16	1.7E-16	7.7E-16	5.4E-16	7.4E-16	3.7E-16	3.0E-16
Ce-144	7.4E-15	7.2E-15	6.6E-15	1.7E-14	2.8E-15	4.6E-15	3.8E-15	2.3E-15	7.1E-15	1.2E-14	6.8E-15	3.8E-15	2.4E-15
Pm-147	1.5E-16	1.5E-16	6.5E-17	2.1E-15	6.5E-17	4.1E-16	4.8E-16	1.5E-16	1.5E-16	2.1E-15	1.5E-16	2.7E-16	5.2E-17
Sm-153	2.5E-17	2.5E-17	2.5E-17	2.8E-17	1.1E-17	1.6E-17	1.4E-17	5.7E-18	2.4E-17	2.8E-17	2.2E-17	1.4E-17	9.8E-18
Eu-152	1.9E-12	1.9E-12	1.9E-12	1.0E-12	7.7E-13	7.4E-13	7.5E-13	4.2E-13	1.8E-12	7.7E-13	1.8E-12	7.0E-13	6.0E-13
Eu-154	1.5E-12	1.5E-12	1.5E-12	9.4E-13	6.0E-13	5.8E-13	6.0E-13	3.4E-13	1.5E-12	6.0E-13	1.4E-12	5.3E-13	4.6E-13
Eu-155	2.5E-14	2.3E-14	2.3E-14	5.1E-14	1.1E-14	1.3E-14	1.2E-14	7.8E-15	2.4E-14	1.2E-14	2.3E-14	1.2E-14	9.9E-15
Er-169	2.4E-18	2.4E-18	1.0E-18	3.4E-17	1.0E-18	6.7E-18	7.7E-18	2.4E-18	2.4E-18	3.4E-17	2.4E-18	4.5E-18	8.5E-19

Radio-nuclide	Amphibian	Annelid	Arthropo, detriti-vorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryo-phytes	Mammal - large	Mammal - small-burrowing	Mollusc, gastro-pod	Reptile	Shrub	Tree
Lu-177	7.7E-17	7.8E-17	7.7E-17	6.5E-17	3.4E-17	4.0E-17	4.0E-17	1.7E-17	7.3E-17	6.5E-17	7.1E-17	3.6E-17	2.8E-17
Re-188	1.1E-16	9.6E-17	6.9E-17	4.7E-17	7.5E-17	2.8E-15	1.7E-15	1.1E-16	1.1E-16	8.2E-17	1.1E-16	8.1E-18	7.9E-18
Au-198	6.1E-16	6.0E-16	5.8E-16	2.5E-16	3.3E-16	5.6E-15	4.6E-15	3.7E-16	6.0E-16	3.3E-16	5.8E-16	1.7E-16	1.5E-16
Tl-201	1.1E-16	7.1E-17	7.3E-17	9.5E-17	3.9E-17	1.4E-16	3.9E-16	6.6E-16	4.4E-16	3.3E-17	1.2E-16	2.2E-16	5.0E-17
Pb-210	1.4E-13	5.3E-13	3.7E-13	7.4E-14	4.0E-13	1.3E-13	2.3E-12	4.5E-14	4.5E-14	9.0E-15	4.7E-14	3.4E-13	8.4E-14
Pb-212	2.4E-15	8.8E-15	7.4E-15	1.2E-15	7.2E-15	2.2E-15	4.6E-14	7.3E-16	9.5E-16	2.4E-16	9.7E-16	5.8E-15	1.3E-15
Bi-213	1.5E-16	5.8E-16	4.8E-16	7.4E-17	4.8E-16	1.5E-16	3.1E-15	4.6E-17	4.7E-17	9.7E-18	5.0E-17	3.9E-16	8.5E-17
Po-210	4.5E-13	4.4E-14	4.4E-14	4.5E-14	4.4E-14	1.2E-12	1.1E-11	3.9E-13	3.9E-13	4.4E-14	5.6E-13	1.4E-12	3.2E-13
At-211	3.8E-15	1.5E-15	2.8E-15	3.7E-15	2.8E-15	1.3E-15	1.3E-15	3.7E-15	3.8E-15	1.7E-15	3.8E-15	8.0E-18	1.3E-15
Rn-222	2.5E-15	2.5E-15	2.6E-15	9.0E-16	9.7E-16	9.4E-16	9.7E-16	5.1E-16	2.4E-15	9.7E-16	2.3E-15	8.9E-16	7.7E-16
Ra-223	6.6E-14	6.4E-14	6.4E-14	5.3E-14	6.3E-14	2.6E-13	1.0E-12	6.5E-14	6.5E-14	7.0E-14	6.5E-14	4.8E-13	1.7E-14
Ra-226	5.8E-11	5.7E-11	5.7E-11	4.7E-11	5.3E-11	2.1E-10	8.3E-10	5.4E-11	5.8E-11	5.8E-11	5.7E-11	3.8E-10	1.6E-11
Ac-225	1.4E-15	1.3E-14	7.6E-15	8.5E-16	7.0E-15	2.1E-13	5.0E-13	3.5E-16	1.0E-15	1.2E-14	3.7E-15	8.1E-14	2.0E-15
Th-227	9.4E-16	5.7E-15	3.5E-15	5.1E-16	3.1E-15	8.7E-14	2.1E-13	2.2E-16	7.6E-16	5.3E-15	1.8E-15	3.3E-14	9.5E-16
Th-230	9.1E-14	2.1E-12	1.2E-12	9.0E-14	1.2E-12	3.7E-11	8.7E-11	3.1E-14	3.3E-14	2.1E-12	5.0E-13	1.4E-11	2.9E-13
Th-232	7.7E-14	1.8E-12	1.0E-12	7.7E-14	9.9E-13	3.1E-11	7.5E-11	2.7E-14	2.8E-14	1.8E-12	4.3E-13	1.2E-11	2.5E-13
Th-234	2.3E-16	3.1E-16	2.6E-16	1.0E-16	1.3E-16	1.4E-15	2.1E-15	4.8E-17	2.3E-16	1.7E-16	2.3E-16	6.0E-16	9.1E-17
U-234	1.3E-12	8.0E-12	2.5E-12	3.0E-13	2.5E-12	3.1E-11	2.1E-10	1.3E-12	1.3E-12	8.0E-12	1.2E-12	1.5E-11	1.6E-12
U-235	1.8E-12	8.0E-12	2.9E-12	5.2E-13	2.5E-12	2.8E-11	2.0E-10	1.3E-12	1.7E-12	7.7E-12	1.7E-12	1.4E-11	1.6E-12
U-238	1.1E-12	6.9E-12	2.1E-12	2.6E-13	2.1E-12	2.6E-11	1.9E-10	1.1E-12	1.1E-12	6.9E-12	1.1E-12	1.2E-11	1.4E-12
Np-237	3.2E-11	4.2E-11	2.4E-11	7.3E-12	2.3E-11	3.9E-11	2.3E-10	1.3E-10	1.3E-10	1.3E-10	1.3E-10	5.3E-11	1.6E-12
Pu-238	3.2E-12	7.0E-12	5.9E-12	5.2E-13	5.9E-12	3.7E-12	2.9E-11	3.2E-12	3.2E-12	2.7E-11	2.6E-12	1.6E-11	1.6E-11
Pu-239	3.6E-12	7.8E-12	6.6E-12	5.8E-13	6.6E-12	4.2E-12	3.3E-11	3.6E-12	3.6E-12	3.1E-11	2.9E-12	1.8E-11	1.8E-11
Pu-240	3.6E-12	7.8E-12	6.5E-12	5.8E-13	6.5E-12	4.1E-12	3.3E-11	3.6E-12	3.6E-12	3.1E-11	2.9E-12	1.8E-11	1.8E-11
Pu-241	4.0E-16	8.7E-16	7.3E-16	6.5E-17	6.9E-16	4.6E-16	3.7E-15	4.0E-16	4.0E-16	3.4E-15	3.3E-16	2.0E-15	2.0E-15
Pu-242	3.4E-12	7.4E-12	6.2E-12	5.5E-13	6.2E-12	3.9E-12	3.1E-11	3.4E-12	3.4E-12	2.9E-11	2.8E-12	1.7E-11	1.7E-11
Am-241	3.5E-11	4.6E-11	2.6E-11	8.1E-12	2.6E-11	2.7E-11	2.6E-10	6.3E-12	6.3E-12	3.8E-11	1.7E-11	7.1E-12	7.1E-12
Am-242	1.0E-17	1.2E-17	7.7E-18	2.9E-18	6.6E-18	7.1E-18	5.2E-17	1.9E-18	3.6E-18	9.2E-18	5.9E-18	2.7E-18	2.6E-18
Am-243	3.6E-11	4.7E-11	2.7E-11	8.3E-12	2.6E-11	2.7E-11	2.6E-10	6.4E-12	6.9E-12	3.8E-11	1.7E-11	7.3E-12	7.3E-12

Radio-nuclide	Amphibian	Annelid	Arthropo, detriti-vorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryo-phytes	Mammal - large	Mammal - small-burrowing	Mollusc, gastro-pod	Reptile	Shrub	Tree
Cm-242	7.9E-13	1.0E-12	8.0E-13	1.8E-13	8.0E-13	2.9E-15	5.8E-12	3.2E-12	3.2E-12	3.2E-12	3.2E-12	1.3E-12	5.5E-14
Cm-243	2.3E-11	3.1E-11	2.4E-11	5.4E-12	2.4E-11	2.1E-13	1.7E-10	9.4E-11	9.3E-11	9.3E-11	9.3E-11	3.9E-11	1.7E-12
Cm-244	1.8E-11	2.4E-11	1.8E-11	4.2E-12	1.8E-11	6.8E-14	1.3E-10	7.3E-11	7.3E-11	7.3E-11	7.3E-11	3.0E-11	1.3E-12

^dose factors not available for this radioactive noble gas so used DPUR for krypton-85 for which dose factors were derived.

Table 9. Dose per unit release factors for worst age group fishing family – coastal release scenario

These DPURs are multiplied by the factor Q_{eff} (see Table G.10) when assessing exposure of the fishing family via the sewer release scenario.

Radionuclide*	Worst total DPUR (µSv/y per Bq/y)	Worst age group
H-3	9.0E-16	Offspring
H-3 organic	3.6E-11	Offspring
C-14	4.5E-10	Offspring
Na-22	2.5E-13	Offspring
Na-24	1.0E-15	Adult
P-32	1.2E-08	Offspring
P-33	2.7E-09	Offspring
S-35	7.6E-15	Offspring
Cl-36	1.6E-15	Adult
Ca-45	6.8E-13	Offspring
Ca-47	4.8E-13	Offspring
V-48	5.5E-11	Adult
Cr-51	8.2E-13	Adult
Mn-52	2.5E-11	Adult
Mn-54	3.2E-10	Adult
Fe-55	2.3E-13	Adult
Fe-59	7.0E-11	Adult
Co-56	3.7E-10	Adult
Co-57	3.1E-11	Adult
Co-58	9.1E-11	Adult
Co-60	3.7E-09	Adult
Ni-63	3.4E-12	Adult
Cu-61	2.9E-12	Adult
Cu-64	9.9E-12	Adult
Zn-62	5.9E-11	Adult
Zn-65	2.8E-09	Adult
Ga-67	1.1E-12	Adult
Se-75	6.5E-10	Offspring
Br-76	6.5E-15	Adult
Br-77	4.1E-15	Adult
Br-82	1.6E-14	Adult
Rb-81	2.7E-15	Adult
Rb-83	9.3E-12	Adult
Sr-83	1.0E-13	Adult
Sr-85	1.3E-13	Adult
Sr-89	1.5E-12	Offspring
Sr-90	6.2E-12	Offspring
Y-90	5.7E-13	Adult
Zr-89	3.2E-12	Adult
Zr-95	1.3E-10	Adult
Nb-95	3.3E-11	Adult

Radionuclide*	Worst total DPUR (µSv/y per Bq/y)	Worst age group
Mo-99	2.4E-13	Adult
Tc-99	7.0E-12	Adult
Tc-99m	7.2E-15	Adult
Ru-103	1.4E-11	Adult
Ru-106	6.6E-11	Adult
Ag-110m	3.9E-09	Adult
In-111	5.9E-12	Adult
Sb-125	4.1E-11	Adult
I-123	3.1E-15	Adult
I-124	1.0E-12	Adult
I-125	3.0E-12	Adult
I-129	2.5E-11	Adult
I-131	2.6E-12	Offspring
I-133	9.4E-14	Adult
I-135	7.0E-15	Adult
Cs-134	1.8E-10	Adult
Cs-136	7.0E-12	Adult
Cs-137	2.0E-10	Adult
Ba-140	8.5E-12	Adult
La-140	2.6E-12	Adult
Ce-141	2.4E-12	Adult
Ce-144	2.1E-11	Adult
Pm-147	3.0E-13	Adult
Sm-153	2.7E-13	Adult
Eu-152	2.8E-09	Adult
Eu-154	2.5E-09	Adult
Eu-155	4.8E-11	Adult
Er-169	5.4E-14	Adult
Lu-177	2.6E-13	Adult
Re-188	1.2E-12	Adult
Au-198	3.2E-12	Adult
Tl-201	2.4E-12	Adult
Pb-210	1.6E-07	Adult
Pb-212	1.4E-10	Adult
Po-210	4.8E-10	Adult
At-211	8.9E-14	Adult
Ra-223	1.6E-10	Adult
Ra-226	1.2E-09	Offspring
Ac-225	6.1E-12	Adult
Th-227	2.3E-10	Adult
Th-230	9.1E-11	Adult
Th-232	7.6E-09	Adult
Th-234	1.3E-12	Adult
U-234	1.3E-11	Adult
U-235	2.5E-11	Adult
U-238	1.4E-11	Adult
Np-237	3.6E-10	Adult

Radionuclide*	Worst total DPUR (µSv/y per Bq/y)	Worst age group
Pu-238	1.4E-09	Adult
Pu-239	1.5E-09	Adult
Pu-240	1.5E-09	Adult
Pu-241	2.8E-11	Adult
Pu-242	1.5E-09	Adult
Am-241	6.6E-11	Adult
Am-242	1.7E-14	Adult
Am-243	6.2E-10	Adult
Cm-242	2.6E-12	Adult
Cm-243	3.3E-10	Adult
Cm-244	2.2E-11	Adult

*radionuclides with a half-life of less than 3 hours were not considered.

Table 10. Dose per unit release factors for offspring in a fishing family – coastal release scenario

Radionuclide*	DPURs for offspring in a fishing family (µSv/y per Bq/y)				
	Fish	Crustacea	Molluscs	External	Total
H-3	5.1E-16	2.0E-16	2.0E-16	0.0E+00	9.0E-16
H-3 organic	2.0E-11	7.8E-12	7.8E-12	0.0E+00	3.6E-11
C-14	2.5E-10	1.0E-10	1.0E-10	2.1E-16	4.5E-10
Na-22	5.8E-14	1.6E-15	6.8E-15	1.9E-13	2.5E-13
Na-24	<p	<p	<p	4.4E-16	4.4E-16
P-32	7.6E-09	2.0E-09	2.0E-09	2.5E-16	1.2E-08
P-33	1.7E-09	4.6E-10	4.6E-10	1.3E-18	2.7E-09
S-35	2.9E-15	1.2E-15	3.5E-15	1.5E-19	7.6E-15
Cl-36	<p	<p	<p	5.6E-17	5.6E-17
Ca-45	2.6E-13	2.6E-13	1.6E-13	3.8E-17	6.8E-13
Ca-47	8.7E-14	8.7E-14	5.2E-14	2.6E-13	4.8E-13
V-48	<p	<p	<p	5.4E-11	5.4E-11
Cr-51	<p	<p	<p	6.2E-13	6.2E-13
Mn-52	<p	<p	<p	1.9E-11	1.9E-11
Mn-54	<p	<p	<p	3.1E-10	3.1E-10
Fe-55	<p	<p	<p	0.0E+00	0.0E+00
Fe-59	<p	<p	<p	6.9E-11	6.9E-11
Co-56	<p	<p	<p	3.4E-10	3.4E-10
Co-57	<p	<p	<p	2.7E-11	2.7E-11
Co-58	<p	<p	<p	8.0E-11	8.0E-11
Co-60	<p	<p	<p	3.6E-09	3.6E-09
Ni-63	<p	<p	<p	0.0E+00	0.0E+00
Cu-61	<p	<p	<p	4.1E-15	4.1E-15
Cu-64	<p	<p	<p	1.2E-14	1.2E-14
Zn-62	<p	<p	<p	4.9E-14	4.9E-14
Zn-65	<p	<p	<p	1.3E-10	1.3E-10
Ga-67	<p	<p	<p	2.0E-15	2.0E-15
Se-75	3.7E-10	1.5E-10	1.3E-10	5.0E-12	6.5E-10
Br-76	<p	<p	<p	3.2E-16	3.2E-16
Br-77	<p	<p	<p	3.5E-16	3.5E-16
Br-82	<p	<p	<p	1.3E-15	1.3E-15
Rb-81	<p	<p	<p	5.0E-16	5.0E-16
Rb-83	<p	<p	<p	6.5E-12	6.5E-12
Sr-83	<p	<p	<p	8.8E-14	8.8E-14
Sr-85	<p	<p	<p	6.0E-14	6.0E-14
Sr-89	4.9E-13	3.3E-13	6.5E-13	2.8E-16	1.5E-12
Sr-90	2.1E-12	1.4E-12	2.8E-12	5.3E-15	6.2E-12
Y-90	<p	<p	<p	1.4E-14	1.4E-14
Zr-89	<p	<p	<p	3.0E-12	3.0E-12
Zr-95	<p	<p	<p	1.3E-10	1.3E-10
Nb-95	<p	<p	<p	3.3E-11	3.3E-11
Mo-99	<p	<p	<p	1.9E-14	1.9E-14
Tc-99	<p	<p	<p	1.8E-16	1.8E-16
Tc-99m	<p	<p	<p	5.3E-18	5.3E-18
Ru-103	<p	<p	<p	1.3E-11	1.3E-11

Radionuclide*	DPURs for offspring in a fishing family (µSv/y per Bq/y)				
	Fish	Crustacea	Molluscs	External	Total
Ru-106	<p	<p	<p	5.5E-11	5.5E-11
Ag-110m	<p	<p	<p	2.2E-10	2.2E-10
In-111	<p	<p	<p	3.4E-13	3.4E-13
Sb-125	<p	<p	<p	2.6E-11	2.6E-11
I-123	<p	<p	<p	2.5E-17	2.5E-17
I-124	<p	<p	<p	8.9E-15	8.9E-15
I-125	<p	<p	<p	6.8E-16	6.8E-16
I-129	<p	<p	<p	1.1E-14	1.1E-14
I-131	1.6E-12	2.2E-13	7.2E-13	8.4E-15	2.6E-12
I-133	<p	<p	<p	3.1E-16	3.1E-16
I-135	<p	<p	<p	1.0E-16	1.0E-16
Cs-134	<p	<p	<p	1.5E-10	1.5E-10
Cs-136	<p	<p	<p	3.1E-12	3.1E-12
Cs-137	<p	<p	<p	1.7E-10	1.7E-10
Ba-140	<p	<p	<p	8.1E-12	8.1E-12
La-140	<p	<p	<p	2.2E-12	2.2E-12
Ce-141	<p	<p	<p	2.3E-12	2.3E-12
Ce-144	<p	<p	<p	2.0E-11	2.0E-11
Pm-147	<p	<p	<p	8.0E-15	8.0E-15
Sm-153	<p	<p	<p	3.3E-14	3.3E-14
Eu-152	<p	<p	<p	2.8E-09	2.8E-09
Eu-154	<p	<p	<p	2.5E-09	2.5E-09
Eu-155	<p	<p	<p	4.7E-11	4.7E-11
Er-169	<p	<p	<p	2.4E-16	2.4E-16
Lu-177	<p	<p	<p	1.9E-13	1.9E-13
Re-188	<p	<p	<p	2.5E-17	2.5E-17
Au-198	<p	<p	<p	1.1E-13	1.1E-13
Tl-201	<p	<p	<p	2.9E-14	2.9E-14
Pb-210	<p	<p	<p	3.1E-12	3.1E-12
Pb-212	<p	<p	<p	1.7E-14	1.7E-14
Po-210	<p	<p	<p	1.5E-15	1.5E-15
At-211	<p	<p	<p	1.3E-18	1.3E-18
Ra-223	<p	<p	<p	1.6E-13	1.6E-13
Ra-226	4.9E-10	1.9E-10	1.9E-10	3.3E-10	1.2E-09
Ac-225	<p	<p	<p	1.8E-12	1.8E-12
Th-227	<p	<p	<p	7.8E-12	7.8E-12
Th-230	<p	<p	<p	2.3E-11	2.3E-11
Th-232	<p	<p	<p	4.5E-09	4.5E-09
Th-234	<p	<p	<p	6.4E-13	6.4E-13
U-234	<p	<p	<p	6.7E-15	6.7E-15
U-235	<p	<p	<p	1.3E-11	1.3E-11
U-238	<p	<p	<p	2.3E-12	2.3E-12
Np-237	<p	<p	<p	1.8E-11	1.8E-11
Pu-238	<p	<p	<p	5.9E-14	5.9E-14
Pu-239	<p	<p	<p	1.4E-13	1.4E-13
Pu-240	<p	<p	<p	6.1E-14	6.1E-14
Pu-241	<p	<p	<p	2.2E-13	2.2E-13

Radionuclide*	DPURs for offspring in a fishing family (µSv/y per Bq/y)				
	Fish	Crustacea	Molluscs	External	Total
Pu-242	<p	<p	<p	5.4E-14	5.4E-14
Am-241	<p	<p	<p	2.6E-11	2.6E-11
Am-242	<p	<p	<p	1.8E-15	1.8E-15
Am-243	<p	<p	<p	5.8E-10	5.8E-10
Cm-242	<p	<p	<p	5.4E-15	5.4E-15
Cm-243	<p	<p	<p	3.0E-10	3.0E-10
Cm-244	<p	<p	<p	4.8E-14	4.8E-14

<p: not calculated as dose rate to parent greater than dose rate to offspring
*radionuclides with a half-life of less than 3 hours were not considered.

Table 11. Dose per unit release factors for infant in a fishing family – coastal release scenario

Radionuclide*	DPURs for infant in a fishing family (µSv/y per Bq/y)				
	Fish	Crustacea^	Molluscs^	External	Total
H-3	3.9E-17	0.0E+00	0.0E+00	0.0E+00	3.9E-17
H-3 organic	1.9E-12	0.0E+00	0.0E+00	0.0E+00	1.9E-12
C-14	2.5E-11	0.0E+00	0.0E+00	3.1E-18	2.5E-11
Na-22	1.2E-14	0.0E+00	0.0E+00	2.8E-15	1.5E-14
Na-24	1.3E-16	0.0E+00	0.0E+00	6.6E-18	1.4E-16
P-32	2.9E-10	0.0E+00	0.0E+00	3.8E-18	2.9E-10
P-33	3.2E-11	0.0E+00	0.0E+00	2.0E-20	3.2E-11
S-35	6.4E-16	0.0E+00	0.0E+00	2.3E-21	6.4E-16
Cl-36	3.1E-16	0.0E+00	0.0E+00	8.4E-19	3.1E-16
Ca-45	7.4E-15	0.0E+00	0.0E+00	5.8E-19	7.4E-15
Ca-47	5.3E-15	0.0E+00	0.0E+00	3.9E-15	9.2E-15
V-48	7.7E-15	0.0E+00	0.0E+00	8.2E-13	8.2E-13
Cr-51	1.1E-14	0.0E+00	0.0E+00	9.4E-15	2.1E-14
Mn-52	6.8E-14	0.0E+00	0.0E+00	2.8E-13	3.5E-13
Mn-54	3.5E-14	0.0E+00	0.0E+00	4.7E-12	4.7E-12
Fe-55	5.8E-15	0.0E+00	0.0E+00	0.0E+00	5.8E-15
Fe-59	2.7E-14	0.0E+00	0.0E+00	1.0E-12	1.1E-12
Co-56	6.9E-13	0.0E+00	0.0E+00	5.0E-12	5.7E-12
Co-57	7.7E-14	0.0E+00	0.0E+00	4.1E-13	4.9E-13
Co-58	2.0E-13	0.0E+00	0.0E+00	1.2E-12	1.4E-12
Co-60	1.5E-12	0.0E+00	0.0E+00	5.4E-11	5.5E-11
Ni-63	4.4E-13	0.0E+00	0.0E+00	0.0E+00	4.4E-13
Cu-61	6.0E-15	0.0E+00	0.0E+00	6.1E-17	6.0E-15
Cu-64	2.2E-14	0.0E+00	0.0E+00	1.7E-16	2.3E-14
Zn-62	1.3E-13	0.0E+00	0.0E+00	7.4E-16	1.3E-13
Zn-65	3.6E-12	0.0E+00	0.0E+00	1.9E-12	5.5E-12
Ga-67	1.9E-13	0.0E+00	0.0E+00	3.1E-17	1.9E-13
Se-75	8.8E-11	0.0E+00	0.0E+00	7.4E-14	8.9E-11
Br-76	5.0E-16	0.0E+00	0.0E+00	4.7E-18	5.0E-16
Br-77	2.4E-16	0.0E+00	0.0E+00	5.3E-18	2.4E-16
Br-82	9.6E-16	0.0E+00	0.0E+00	2.0E-17	9.8E-16
Rb-81	5.7E-16	0.0E+00	0.0E+00	7.5E-18	5.7E-16
Rb-83	5.4E-13	0.0E+00	0.0E+00	9.7E-14	6.4E-13
Sr-83	1.1E-15	0.0E+00	0.0E+00	1.3E-15	2.5E-15
Sr-85	6.6E-15	0.0E+00	0.0E+00	9.0E-16	7.5E-15
Sr-89	3.7E-14	0.0E+00	0.0E+00	4.2E-18	3.7E-14
Sr-90	1.8E-13	0.0E+00	0.0E+00	8.0E-17	1.8E-13
Y-90	5.0E-15	0.0E+00	0.0E+00	2.1E-16	5.2E-15
Zr-89	5.7E-16	0.0E+00	0.0E+00	4.4E-14	4.5E-14
Zr-95	1.3E-15	0.0E+00	0.0E+00	1.9E-12	1.9E-12
Nb-95	2.4E-15	0.0E+00	0.0E+00	4.9E-13	5.0E-13
Mo-99	7.1E-15	0.0E+00	0.0E+00	2.8E-16	7.3E-15
Tc-99	3.1E-13	0.0E+00	0.0E+00	2.8E-18	3.1E-13
Tc-99m	2.5E-16	0.0E+00	0.0E+00	7.9E-20	2.5E-16

Radionuclide*	DPURs for infant in a fishing family (µSv/y per Bq/y)				
	Fish	Crustacea^	Molluscs^	External	Total
Ru-103	2.7E-15	0.0E+00	0.0E+00	1.9E-13	1.9E-13
Ru-106	3.2E-14	0.0E+00	0.0E+00	8.3E-13	8.6E-13
Ag-110m	8.0E-11	0.0E+00	0.0E+00	3.3E-12	8.4E-11
In-111	9.6E-14	0.0E+00	0.0E+00	5.1E-15	1.0E-13
Sb-125	3.2E-12	0.0E+00	0.0E+00	3.9E-13	3.5E-12
I-123	8.7E-16	0.0E+00	0.0E+00	3.7E-19	8.7E-16
I-124	2.7E-13	0.0E+00	0.0E+00	1.3E-16	2.7E-13
I-125	3.6E-13	0.0E+00	0.0E+00	1.0E-17	3.6E-13
I-129	1.6E-12	0.0E+00	0.0E+00	1.7E-16	1.6E-12
I-131	6.4E-13	0.0E+00	0.0E+00	1.3E-16	6.4E-13
I-133	3.1E-14	0.0E+00	0.0E+00	4.7E-18	3.1E-14
I-135	2.1E-15	0.0E+00	0.0E+00	1.5E-18	2.1E-15
Cs-134	1.1E-12	0.0E+00	0.0E+00	2.2E-12	3.3E-12
Cs-136	4.2E-13	0.0E+00	0.0E+00	4.7E-14	4.7E-13
Cs-137	8.7E-13	0.0E+00	0.0E+00	2.5E-12	3.4E-12
Ba-140	8.6E-14	0.0E+00	0.0E+00	1.2E-13	2.1E-13
La-140	4.8E-15	0.0E+00	0.0E+00	3.3E-14	3.8E-14
Ce-141	1.7E-15	0.0E+00	0.0E+00	3.4E-14	3.6E-14
Ce-144	1.5E-14	0.0E+00	0.0E+00	3.0E-13	3.1E-13
Pm-147	6.8E-15	0.0E+00	0.0E+00	1.2E-16	6.9E-15
Sm-153	5.4E-15	0.0E+00	0.0E+00	5.0E-16	5.9E-15
Eu-152	3.0E-14	0.0E+00	0.0E+00	4.1E-11	4.1E-11
Eu-154	4.7E-14	0.0E+00	0.0E+00	3.7E-11	3.7E-11
Eu-155	8.3E-15	0.0E+00	0.0E+00	7.1E-13	7.2E-13
Er-169	8.2E-16	0.0E+00	0.0E+00	3.6E-18	8.2E-16
Lu-177	1.1E-15	0.0E+00	0.0E+00	2.8E-15	3.8E-15
Re-188	5.6E-14	0.0E+00	0.0E+00	3.7E-19	5.6E-14
Au-198	1.2E-13	0.0E+00	0.0E+00	1.7E-15	1.2E-13
Tl-201	4.5E-13	0.0E+00	0.0E+00	4.4E-16	4.5E-13
Pb-210	1.5E-10	0.0E+00	0.0E+00	4.6E-14	1.5E-10
Pb-212	2.6E-13	0.0E+00	0.0E+00	2.5E-16	2.6E-13
Po-210	1.9E-11	0.0E+00	0.0E+00	2.2E-17	1.9E-11
At-211	2.0E-14	0.0E+00	0.0E+00	1.9E-20	2.0E-14
Ra-223	4.9E-11	0.0E+00	0.0E+00	2.4E-15	4.9E-11
Ra-226	7.4E-11	0.0E+00	0.0E+00	5.0E-12	7.9E-11
Ac-225	9.2E-14	0.0E+00	0.0E+00	2.7E-14	1.2E-13
Th-227	5.3E-11	0.0E+00	0.0E+00	1.2E-13	5.3E-11
Th-230	3.1E-12	0.0E+00	0.0E+00	3.5E-13	3.5E-12
Th-232	5.3E-10	0.0E+00	0.0E+00	6.8E-11	6.0E-10
Th-234	1.0E-13	0.0E+00	0.0E+00	9.6E-15	1.1E-13
U-234	1.0E-13	0.0E+00	0.0E+00	1.0E-16	1.0E-13
U-235	1.0E-13	0.0E+00	0.0E+00	1.9E-13	2.9E-13
U-238	9.5E-14	0.0E+00	0.0E+00	3.5E-14	1.3E-13
Np-237	1.7E-13	0.0E+00	0.0E+00	2.7E-13	4.4E-13
Pu-238	8.7E-12	0.0E+00	0.0E+00	8.8E-16	8.7E-12
Pu-239	9.3E-12	0.0E+00	0.0E+00	2.1E-15	9.3E-12
Pu-240	9.3E-12	0.0E+00	0.0E+00	9.2E-16	9.3E-12

Radionuclide*	DPURs for infant in a fishing family (µSv/y per Bq/y)				
	Fish	Crustacea^	Molluscs^	External	Total
Pu-241	1.2E-13	0.0E+00	0.0E+00	3.4E-15	1.2E-13
Pu-242	8.9E-12	0.0E+00	0.0E+00	8.2E-16	8.9E-12
Am-241	5.6E-13	0.0E+00	0.0E+00	3.9E-13	9.5E-13
Am-242	8.0E-16	0.0E+00	0.0E+00	2.7E-17	8.3E-16
Am-243	5.6E-13	0.0E+00	0.0E+00	8.6E-12	9.2E-12
Cm-242	9.5E-14	0.0E+00	0.0E+00	8.2E-17	9.5E-14
Cm-243	4.7E-13	0.0E+00	0.0E+00	4.6E-12	5.0E-12
Cm-244	4.0E-13	0.0E+00	0.0E+00	7.1E-16	4.1E-13

*radionuclides with a half-life of less than 3 hours were not considered. ^assumed none ingested

Table 12. Dose per unit release factors for child in a fishing family – coastal release scenario

Radionuclide*	DPURs for child in a fishing family (µSv/y per Bq/y)				
	Fish	Crustacea	Molluscs	External	Total
H-3	7.5E-17	3.7E-17	3.7E-17	0.0E+00	1.5E-16
H-3 organic	3.6E-12	1.8E-12	1.8E-12	0.0E+00	7.2E-12
C-14	5.1E-11	2.5E-11	2.5E-11	3.1E-17	1.0E-10
Na-22	1.8E-14	6.1E-16	2.6E-15	2.8E-14	4.9E-14
Na-24	1.8E-16	6.2E-18	2.6E-17	6.6E-17	2.8E-16
P-32	3.2E-10	1.1E-10	1.1E-10	3.8E-17	5.3E-10
P-33	3.8E-11	1.3E-11	1.3E-11	2.0E-19	6.4E-11
S-35	7.9E-16	3.9E-16	1.2E-15	2.3E-20	2.4E-15
Cl-36	3.7E-16	1.8E-16	1.5E-16	8.4E-18	7.2E-16
Ca-45	1.1E-14	1.3E-14	8.0E-15	5.8E-18	3.2E-14
Ca-47	6.8E-15	8.5E-15	5.1E-15	3.9E-14	5.9E-14
V-48	1.1E-14	3.6E-14	1.8E-13	8.2E-12	8.4E-12
Cr-51	1.5E-14	3.8E-15	7.6E-14	9.4E-14	1.9E-13
Mn-52	1.0E-13	2.6E-13	2.6E-12	2.8E-12	5.8E-12
Mn-54	5.8E-14	1.5E-13	1.5E-12	4.7E-11	4.8E-11
Fe-55	1.1E-14	8.9E-14	8.9E-14	0.0E+00	1.9E-13
Fe-59	4.0E-14	3.3E-13	3.3E-13	1.0E-11	1.1E-11
Co-56	1.1E-12	5.3E-12	1.5E-11	5.0E-11	7.2E-11
Co-57	1.1E-13	5.6E-13	1.6E-12	4.1E-12	6.3E-12
Co-58	3.1E-13	1.6E-12	4.4E-12	1.2E-11	1.8E-11
Co-60	2.4E-12	1.2E-11	3.4E-11	5.4E-10	5.9E-10
Ni-63	5.8E-13	2.9E-13	5.8E-13	0.0E+00	1.5E-12
Cu-61	7.3E-15	1.1E-12	2.9E-13	6.1E-16	1.4E-12
Cu-64	2.7E-14	4.1E-12	1.1E-12	1.7E-15	5.2E-12
Zn-62	1.6E-13	2.4E-11	6.5E-12	7.4E-15	3.1E-11
Zn-65	5.8E-12	8.7E-10	2.3E-10	1.9E-11	1.1E-09
Ga-67	2.5E-13	1.3E-13	1.3E-13	3.1E-16	5.1E-13
Se-75	1.6E-10	8.1E-11	7.3E-11	7.4E-13	3.2E-10
Br-76	6.4E-16	1.1E-15	1.1E-15	4.7E-17	2.8E-15
Br-77	3.6E-16	6.1E-16	6.1E-16	5.3E-17	1.6E-15
Br-82	1.4E-15	2.3E-15	2.3E-15	2.0E-16	6.3E-15
Rb-81	7.1E-16	7.1E-17	7.1E-17	7.5E-17	9.2E-16
Rb-83	8.2E-13	8.2E-14	8.2E-14	9.7E-13	2.0E-12
Sr-83	1.6E-15	1.3E-15	2.6E-15	1.3E-14	1.9E-14
Sr-85	1.3E-14	1.1E-14	2.1E-14	9.0E-15	5.3E-14
Sr-89	4.8E-14	3.9E-14	7.9E-14	4.2E-17	1.7E-13
Sr-90	5.9E-13	4.8E-13	9.6E-13	8.0E-16	2.0E-12
Y-90	5.9E-15	1.5E-13	1.5E-13	2.1E-15	3.0E-13
Zr-89	8.2E-16	4.1E-15	1.0E-13	4.4E-13	5.5E-13
Zr-95	1.8E-15	8.8E-15	2.2E-13	1.9E-11	1.9E-11
Nb-95	3.3E-15	1.1E-14	5.5E-14	4.9E-12	5.0E-12
Mo-99	8.9E-15	4.4E-14	4.4E-14	2.8E-15	1.0E-13
Tc-99	3.4E-13	2.1E-12	1.0E-12	2.8E-17	3.4E-12
Tc-99m	3.3E-16	2.1E-15	1.0E-15	7.9E-19	3.4E-15
Ru-103	3.5E-15	8.7E-14	4.4E-13	1.9E-12	2.4E-12

Radionuclide*	DPURs for child in a fishing family (µSv/y per Bq/y)				
	Fish	Crustacea	Molluscs	External	Total
Ru-106	3.9E-14	9.8E-13	4.9E-12	8.3E-12	1.4E-11
Ag-110m	1.2E-10	1.2E-09	3.6E-10	3.3E-11	1.7E-09
In-111	1.3E-13	1.3E-12	1.3E-12	5.1E-14	2.8E-12
Sb-125	4.3E-12	1.0E-12	1.0E-12	3.9E-12	1.0E-11
I-123	9.0E-16	1.5E-16	5.0E-16	3.7E-18	1.5E-15
I-124	3.0E-13	5.0E-14	1.7E-13	1.3E-15	5.2E-13
I-125	7.8E-13	1.3E-13	4.3E-13	1.0E-16	1.3E-12
I-129	5.6E-12	9.1E-13	3.0E-12	1.7E-15	9.6E-12
I-131	7.4E-13	1.2E-13	4.1E-13	1.3E-15	1.3E-12
I-133	2.8E-14	4.6E-15	1.5E-14	4.7E-17	4.8E-14
I-135	2.1E-15	3.5E-16	1.2E-15	1.5E-17	3.6E-15
Cs-134	3.9E-12	9.7E-13	1.2E-12	2.2E-11	2.8E-11
Cs-136	7.8E-13	1.9E-13	2.3E-13	4.7E-13	1.7E-12
Cs-137	2.9E-12	7.2E-13	8.6E-13	2.5E-11	3.0E-11
Ba-140	1.1E-13	3.9E-15	5.5E-14	1.2E-12	1.4E-12
La-140	6.3E-15	6.3E-14	1.3E-13	3.3E-13	5.2E-13
Ce-141	2.1E-15	2.0E-14	4.1E-14	3.4E-13	4.1E-13
Ce-144	1.6E-14	1.6E-13	3.3E-13	3.0E-12	3.5E-12
Pm-147	8.2E-15	5.4E-14	9.5E-14	1.2E-15	1.6E-13
Sm-153	6.4E-15	4.3E-14	7.5E-14	5.0E-15	1.3E-13
Eu-152	4.2E-14	2.8E-13	4.9E-13	4.1E-10	4.1E-10
Eu-154	6.5E-14	4.3E-13	7.5E-13	3.7E-10	3.7E-10
Eu-155	1.0E-14	6.8E-14	1.2E-13	7.1E-12	7.3E-12
Er-169	9.6E-16	9.6E-15	1.9E-14	3.6E-17	3.0E-14
Lu-177	1.3E-15	1.3E-14	2.6E-14	2.8E-14	6.8E-14
Re-188	5.9E-14	3.7E-13	1.9E-13	3.7E-18	6.2E-13
Au-198	1.5E-13	7.5E-13	7.5E-13	1.7E-14	1.7E-12
Tl-201	5.8E-13	5.8E-14	3.5E-13	4.4E-15	1.0E-12
Pb-210	3.2E-10	7.2E-08	4.0E-08	4.6E-13	1.1E-07
Pb-212	3.3E-13	7.3E-11	4.1E-11	2.5E-15	1.1E-10
Po-210	2.3E-11	1.1E-10	1.1E-10	2.2E-16	2.5E-10
At-211	2.4E-14	3.9E-15	1.3E-14	1.9E-19	4.1E-14
Ra-223	8.0E-11	4.0E-11	4.0E-11	2.4E-14	1.6E-10
Ra-226	2.5E-10	1.2E-10	1.2E-10	5.0E-11	5.4E-10
Ac-225	1.1E-13	1.1E-12	1.1E-12	2.7E-13	2.6E-12
Th-227	8.7E-11	7.2E-11	7.2E-11	1.2E-12	2.3E-10
Th-230	7.9E-12	6.5E-12	6.5E-12	3.5E-12	2.4E-11
Th-232	1.5E-09	1.2E-09	1.2E-09	6.8E-10	4.5E-09
Th-234	1.2E-13	9.9E-14	9.9E-14	9.6E-14	4.1E-13
U-234	2.4E-13	1.2E-12	3.5E-12	1.0E-15	4.8E-12
U-235	2.3E-13	1.1E-12	3.3E-12	1.9E-12	6.6E-12
U-238	2.2E-13	1.1E-12	3.2E-12	3.5E-13	4.8E-12
Np-237	3.5E-13	1.7E-11	6.8E-11	2.7E-12	8.9E-11
Pu-238	2.1E-11	2.1E-11	3.1E-10	8.8E-15	3.6E-10
Pu-239	2.4E-11	2.4E-11	3.6E-10	2.1E-14	4.1E-10
Pu-240	2.4E-11	2.4E-11	3.6E-10	9.2E-15	4.1E-10
Pu-241	4.2E-13	4.2E-13	6.3E-12	3.4E-14	7.2E-12

Radionuclide*	DPURs for child in a fishing family (µSv/y per Bq/y)				
	Fish	Crustacea	Molluscs	External	Total
Pu-242	2.3E-11	2.3E-11	3.5E-10	8.2E-15	3.9E-10
Am-241	1.3E-12	2.6E-12	6.6E-12	3.9E-12	1.4E-11
Am-242	9.6E-16	1.9E-15	4.8E-15	2.7E-16	8.0E-15
Am-243	1.3E-12	2.7E-12	6.6E-12	8.6E-11	9.7E-11
Cm-242	1.3E-13	2.6E-13	6.6E-13	8.2E-16	1.1E-12
Cm-243	9.1E-13	1.8E-12	4.6E-12	4.6E-11	5.3E-11
Cm-244	7.8E-13	1.6E-12	3.9E-12	7.1E-15	6.3E-12

*radionuclides with a half-life of less than 3 hours were not considered.

Table 13. Dose per unit release factors for adult in a fishing family – coastal release scenario

Radionuclide*	DPURs for adult in a fishing family (µSv/y per Bq/y)				
	Fish	Crustacea	Molluscs	External	Total
H-3	2.9E-16	1.1E-16	1.1E-16	0.0E+00	5.2E-16
H-3 organic	1.3E-11	5.2E-12	5.2E-12	0.0E+00	2.4E-11
C-14	1.8E-10	7.2E-11	7.2E-11	2.1E-16	3.3E-10
Na-22	5.2E-14	1.4E-15	6.1E-15	1.9E-13	2.5E-13
Na-24	4.9E-16	1.4E-17	5.9E-17	4.4E-16	1.0E-15
P-32	7.3E-10	1.9E-10	1.9E-10	2.5E-16	1.1E-09
P-33	8.7E-11	2.3E-11	2.3E-11	1.3E-18	1.3E-10
S-35	1.9E-15	7.5E-16	2.3E-15	1.5E-19	4.9E-15
Cl-36	9.1E-16	3.6E-16	3.0E-16	5.6E-17	1.6E-15
Ca-45	2.1E-14	2.1E-14	1.3E-14	3.8E-17	5.5E-14
Ca-47	1.8E-14	1.8E-14	1.1E-14	2.6E-13	3.0E-13
V-48	2.8E-14	7.4E-14	3.7E-13	5.4E-11	5.5E-11
Cr-51	3.7E-14	7.4E-15	1.5E-13	6.2E-13	8.2E-13
Mn-52	2.8E-13	5.5E-13	5.5E-12	1.9E-11	2.5E-11
Mn-54	1.6E-13	3.2E-13	3.2E-12	3.1E-10	3.2E-10
Fe-55	1.6E-14	1.1E-13	1.1E-13	0.0E+00	2.3E-13
Fe-59	7.6E-14	5.1E-13	5.1E-13	6.9E-11	7.0E-11
Co-56	2.3E-12	9.2E-12	2.6E-11	3.4E-10	3.7E-10
Co-57	2.0E-13	8.1E-13	2.3E-12	2.7E-11	3.1E-11
Co-58	6.8E-13	2.7E-12	7.7E-12	8.0E-11	9.1E-11
Co-60	3.7E-12	1.5E-11	4.2E-11	3.6E-09	3.7E-09
Ni-63	1.6E-12	6.2E-13	1.2E-12	0.0E+00	3.4E-12
Cu-61	1.9E-14	2.3E-12	6.1E-13	4.1E-15	2.9E-12
Cu-64	6.5E-14	7.8E-12	2.1E-12	1.2E-14	9.9E-12
Zn-62	3.8E-13	4.6E-11	1.2E-11	4.9E-14	5.9E-11
Zn-65	1.8E-11	2.1E-09	5.6E-10	1.3E-10	2.8E-09
Ga-67	6.0E-13	2.4E-13	2.4E-13	2.0E-15	1.1E-12
Se-75	3.5E-10	1.4E-10	1.3E-10	5.0E-12	6.2E-10
Br-76	1.7E-15	2.3E-15	2.3E-15	3.2E-16	6.5E-15
Br-77	1.0E-15	1.4E-15	1.4E-15	3.5E-16	4.1E-15
Br-82	4.0E-15	5.3E-15	5.3E-15	1.3E-15	1.6E-14
Rb-81	1.9E-15	1.5E-16	1.5E-16	5.0E-16	2.7E-15
Rb-83	2.4E-12	1.9E-13	1.9E-13	6.5E-12	9.3E-12
Sr-83	4.3E-15	2.9E-15	5.8E-15	8.8E-14	1.0E-13
Sr-85	2.4E-14	1.6E-14	3.1E-14	6.0E-14	1.3E-13
Sr-89	1.1E-13	7.1E-14	1.4E-13	2.8E-16	3.2E-13
Sr-90	1.4E-12	9.0E-13	1.8E-12	5.3E-15	4.1E-12
Y-90	1.4E-14	2.7E-13	2.7E-13	1.4E-14	5.7E-13
Zr-89	2.0E-15	8.1E-15	2.0E-13	3.0E-12	3.2E-12
Zr-95	4.4E-15	1.8E-14	4.4E-13	1.3E-10	1.3E-10
Nb-95	8.7E-15	2.3E-14	1.2E-13	3.3E-11	3.3E-11
Mo-99	2.4E-14	9.7E-14	9.7E-14	1.9E-14	2.4E-13
Tc-99	8.4E-13	4.1E-12	2.0E-12	1.8E-16	7.0E-12
Tc-99m	8.4E-16	4.2E-15	2.1E-15	5.3E-18	7.2E-15

Radionuclide*	DPURs for adult in a fishing family (µSv/y per Bq/y)				
	Fish	Crustacea	Molluscs	External	Total
Ru-103	8.5E-15	1.7E-13	8.5E-13	1.3E-11	1.4E-11
Ru-106	9.2E-14	1.8E-12	9.2E-12	5.5E-11	6.6E-11
Ag-110m	3.2E-10	2.6E-09	7.7E-10	2.2E-10	3.9E-09
In-111	3.3E-13	2.6E-12	2.6E-12	3.4E-13	5.9E-12
Sb-125	1.1E-11	2.2E-12	2.2E-12	2.6E-11	4.1E-11
I-123	1.9E-15	2.6E-16	8.5E-16	2.5E-17	3.1E-15
I-124	6.3E-13	8.4E-14	2.8E-13	8.9E-15	1.0E-12
I-125	1.9E-12	2.5E-13	8.3E-13	6.8E-16	3.0E-12
I-129	1.6E-11	2.1E-12	7.0E-12	1.1E-14	2.5E-11
I-131	1.6E-12	2.1E-13	6.9E-13	8.4E-15	2.5E-12
I-133	6.0E-14	7.9E-15	2.6E-14	3.1E-16	9.4E-14
I-135	4.4E-15	5.9E-16	2.0E-15	1.0E-16	7.0E-15
Cs-134	2.7E-11	5.3E-12	6.3E-12	1.5E-10	1.8E-10
Cs-136	2.7E-12	5.3E-13	6.4E-13	3.1E-12	7.0E-12
Cs-137	1.9E-11	3.7E-12	4.5E-12	1.7E-10	2.0E-10
Ba-140	2.5E-13	6.9E-15	9.9E-14	8.1E-12	8.5E-12
La-140	1.5E-14	1.2E-13	2.4E-13	2.2E-12	2.6E-12
Ce-141	4.9E-15	3.9E-14	7.8E-14	2.3E-12	2.4E-12
Ce-144	3.9E-14	3.1E-13	6.2E-13	2.0E-11	2.1E-11
Pm-147	1.9E-14	9.9E-14	1.7E-13	8.0E-15	3.0E-13
Sm-153	1.5E-14	7.9E-14	1.4E-13	3.3E-14	2.7E-13
Eu-152	1.1E-13	6.1E-13	1.1E-12	2.8E-09	2.8E-09
Eu-154	1.6E-13	8.4E-13	1.5E-12	2.5E-09	2.5E-09
Eu-155	2.4E-14	1.3E-13	2.2E-13	4.7E-11	4.8E-11
Er-169	2.2E-15	1.7E-14	3.5E-14	2.4E-16	5.4E-14
Lu-177	2.9E-15	2.3E-14	4.6E-14	1.9E-13	2.6E-13
Re-188	1.4E-13	7.2E-13	3.6E-13	2.5E-17	1.2E-12
Au-198	3.4E-13	1.4E-12	1.4E-12	1.1E-13	3.2E-12
Tl-201	1.5E-12	1.2E-13	7.4E-13	2.9E-14	2.4E-12
Pb-210	5.8E-10	1.0E-07	5.8E-08	3.1E-12	1.6E-07
Pb-212	5.1E-13	9.1E-11	5.1E-11	1.7E-14	1.4E-10
Po-210	5.3E-11	2.1E-10	2.1E-10	1.5E-15	4.8E-10
At-211	5.6E-14	7.5E-15	2.5E-14	1.3E-18	8.9E-14
Ra-223	8.8E-11	3.5E-11	3.5E-11	1.6E-13	1.6E-10
Ra-226	4.3E-10	1.7E-10	1.7E-10	3.3E-10	1.1E-09
Ac-225	2.5E-13	2.0E-12	2.0E-12	1.8E-12	6.1E-12
Th-227	9.7E-11	6.4E-11	6.4E-11	7.8E-12	2.3E-10
Th-230	2.9E-11	1.9E-11	1.9E-11	2.3E-11	9.1E-11
Th-232	1.3E-09	8.5E-10	8.5E-10	4.5E-09	7.6E-09
Th-234	2.7E-13	1.8E-13	1.8E-13	6.4E-13	1.3E-12
U-234	7.8E-13	3.0E-12	9.1E-12	6.7E-15	1.3E-11
U-235	7.5E-13	2.9E-12	8.8E-12	1.3E-11	2.5E-11
U-238	7.2E-13	2.8E-12	8.4E-12	2.3E-12	1.4E-11
Np-237	1.7E-12	6.8E-11	2.7E-10	1.8E-11	3.6E-10
Pu-238	1.0E-10	8.0E-11	1.2E-09	5.9E-14	1.4E-09
Pu-239	1.1E-10	8.9E-11	1.3E-09	1.4E-13	1.5E-09
Pu-240	1.1E-10	8.8E-11	1.3E-09	6.1E-14	1.5E-09

Radionuclide*	DPURs for adult in a fishing family (µSv/y per Bq/y)				
	Fish	Crustacea	Molluscs	External	Total
Pu-241	2.0E-12	1.6E-12	2.4E-11	2.2E-13	2.8E-11
Pu-242	1.1E-10	8.5E-11	1.3E-09	5.4E-14	1.5E-09
Am-241	6.0E-12	9.6E-12	2.4E-11	2.6E-11	6.6E-11
Am-242	2.3E-15	3.7E-15	9.2E-15	1.8E-15	1.7E-14
Am-243	6.1E-12	9.7E-12	2.4E-11	5.8E-10	6.2E-10
Cm-242	4.0E-13	6.3E-13	1.6E-12	5.4E-15	2.6E-12
Cm-243	4.3E-12	6.8E-12	1.7E-11	3.0E-10	3.3E-10
Cm-244	3.4E-12	5.4E-12	1.3E-11	4.8E-14	2.2E-11

*radionuclides with a half-life of less than 3 hours were not considered.

Table 14. Dose rate per unit release factors for worst affected marine reference organism – coastal release scenario

These DPURs are multiplied by the factor Q_{eff} (see Table G.10) when assessing exposure of coastal wildlife via the sewer release scenario.

Radionuclide*	Worst total DPUR (µGy/h per Bq/y)	Worst affected reference organism
H-3	2.6E-18	Mollusc - bivalve, Polychaete worm
H-3 organic	2.6E-14	Polychaete worm
C-14	8.9E-14	Polychaete worm
Na-22	1.2E-13	Reptile
Na-24	1.5E-14	Reptile
P-32	7.8E-12	Crustacean
P-33	1.1E-12	Sea anemones & True coral
S-35	2.7E-17	Sea anemones & True coral
Cl-36	4.7E-17	Phytoplankton
Ca-45	2.2E-15	Mammal
Ca-47	5.2E-13	Polychaete worm
V-48	1.2E-11	Polychaete worm
Cr-51	8.8E-14	Polychaete worm
Mn-52	1.2E-11	Polychaete worm
Mn-54	4.2E-12	Polychaete worm
Fe-55	7.2E-16	Polychaete worm
Fe-59	5.7E-12	Polychaete worm
Co-56	1.6E-11	Polychaete worm
Co-57	5.7E-13	Polychaete worm
Co-58	4.3E-12	Polychaete worm
Co-60	1.3E-11	Polychaete worm
Ni-63	1.6E-14	Sea anemones & True coral
Cu-61	2.7E-13	Crustacean
Cu-64	3.2E-13	Crustacean
Zn-62	4.3E-12	Crustacean
Zn-65	2.2E-12	Crustacean
Ga-67	5.4E-14	Zooplankton

Radionuclide*	Worst total DPUR (µGy/h per Bq/y)	Worst affected reference organism
Se-75	3.5E-13	Reptile
Br-76	8.0E-14	Mollusc – bivalve
Br-77	1.2E-14	Mollusc – bivalve
Br-82	5.6E-14	Mollusc – bivalve
Rb-81	1.0E-14	Polychaete worm
Rb-83	2.9E-13	Polychaete worm
Sr-83	4.0E-15	Polychaete worm
Sr-85	8.3E-15	Mammal
Sr-89	1.5E-14	Bird
Sr-90	3.4E-14	Reptile
Y-90	4.9E-13	Polychaete worm
Zr-89	3.4E-12	Polychaete worm
Zr-95	3.8E-12	Polychaete worm
Nb-95	3.4E-12	Polychaete worm
Mo-99	2.6E-13	Zooplankton
Tc-99	9.9E-13	Vascular plant
Tc-99m	9.9E-15	Mammal
Ru-103	1.2E-12	Polychaete worm
Ru-106	1.9E-12	Polychaete worm
Ag-110m	4.5E-12	Mammal
In-111	5.1E-13	Polychaete worm
Sb-125	5.3E-13	Mammal
I-123	4.9E-15	Mollusc - bivalve
I-124	1.2E-13	Mollusc – bivalve
I-125	6.9E-14	Mollusc – bivalve
I-129	1.4E-13	Mollusc – bivalve
I-131	1.7E-13	Mollusc – bivalve
I-133	6.5E-14	Mollusc – bivalve
I-135	2.2E-14	Mollusc – bivalve
Cs-134	9.8E-13	Polychaete worm
Cs-136	8.5E-13	Polychaete worm
Cs-137	3.8E-13	Polychaete worm
Ba-140	1.4E-11	Polychaete worm
La-140	4.8E-12	Polychaete worm
Ce-141	3.7E-13	Mammal, Polychaete worm
Ce-144	1.8E-12	Polychaete worm
Pm-147	2.4E-15	Macroalgae
Sm-153	1.6E-13	Polychaete worm
Eu-152	7.1E-12	Polychaete worm
Eu-154	7.5E-12	Polychaete worm
Eu-155	3.4E-13	Polychaete worm
Er-169	5.3E-15	Macroalgae
Lu-177	1.4E-13	Polychaete worm
Re-188	5.6E-13	Vascular plant
Au-198	7.8E-13	Vascular plant
Tl-201	6.6E-14	Polychaete worm

Radionuclide*	Worst total DPUR (µGy/h per Bq/y)	Worst affected reference organism
Pb-210	3.9E-12	Phytoplankton
Pb-212	5.2E-10	Phytoplankton
Po-210	6.3E-12	Polychaete worm
At-211	3.9E-12	Mollusc – bivalve
Ra-223	9.9E-12	Phytoplankton
Ra-226	4.8E-11	Phytoplankton
Ac-225	2.1E-09	Phytoplankton
Th-227	6.6E-11	Phytoplankton
Th-230	8.0E-11	Phytoplankton
Th-232	6.9E-11	Phytoplankton
Th-234	8.0E-13	Polychaete worm
U-234	8.6E-12	Polychaete worm
U-235	8.0E-12	Polychaete worm
U-238	7.4E-12	Polychaete worm
Np-237	3.3E-12	Polychaete worm
Pu-238	3.5E-10	Phytoplankton
Pu-239	3.3E-10	Phytoplankton
Pu-240	3.3E-10	Phytoplankton
Pu-241	1.8E-13	Phytoplankton
Pu-242	3.2E-10	Phytoplankton
Am-241	4.0E-11	Phytoplankton
Am-242	1.5E-13	Phytoplankton
Am-243	3.9E-11	Phytoplankton
Cm-242	4.2E-11	Phytoplankton
Cm-243	5.2E-11	Phytoplankton
Cm-244	5.0E-11	Phytoplankton

*radionuclides with a half-life of less than 3 hours were not considered.

Table 15. Dose rate per unit release factors for marine reference organisms (µGy/h per Bq/y) – coastal release scenario

Radio-nuclide*	Benthic fish	Bird	Crust-acean	Macro-algae	Mammal	Mollusc - bivalve	Pelagic fish	Phyto-plankton	Poly-chaete worm	Reptile	Sea anemone & True coral	Vascular plant	Zoo-plankton
H-3	2.6E-18	2.6E-18	2.6E-18	2.6E-18	2.6E-18	2.6E-18	2.6E-18	2.6E-18	2.6E-18	2.6E-18	2.6E-18	2.6E-18	2.6E-18
H-3 org.	4.4E-15	4.4E-15	3.6E-15	3.3E-15	4.4E-15	1.7E-15	4.4E-15	6.4E-16	2.6E-14	4.4E-15	4.4E-15	3.3E-15	2.6E-14
C-14	1.6E-14	1.6E-14	1.3E-14	1.2E-14	1.6E-14	5.8E-15	1.6E-14	2.1E-15	8.9E-14	1.6E-14	1.5E-14	1.2E-14	8.9E-14
Na-22	5.9E-15	4.3E-14	4.5E-15	4.4E-15	5.5E-14	2.6E-15	6.6E-15	5.9E-16	7.9E-15	1.2E-13	9.4E-15	7.0E-16	4.6E-15
Na-24	9.1E-16	6.2E-15	6.6E-16	6.9E-16	6.8E-15	4.3E-16	9.9E-16	7.2E-17	1.3E-15	1.5E-14	1.6E-15	1.1E-16	6.2E-16
P-32	7.6E-12	3.0E-12	7.8E-12	5.9E-13	3.1E-12	1.4E-12	7.8E-12	3.7E-13	1.8E-12	3.1E-12	6.4E-12	7.3E-13	9.2E-13
P-33	1.1E-12	4.1E-13	1.1E-12	1.0E-13	4.1E-13	2.1E-13	1.1E-12	3.1E-13	2.8E-13	4.1E-13	1.1E-12	1.1E-13	2.4E-13
S-35	8.4E-18	1.3E-17	1.7E-17	2.5E-17	1.3E-17	2.7E-17	8.5E-18	7.6E-18	1.5E-17	1.3E-17	2.7E-17	2.6E-17	8.6E-18
Cl-36	3.2E-18	3.3E-18	3.1E-18	4.0E-17	3.0E-18	3.2E-18	3.4E-18	4.7E-17	2.8E-18	3.0E-18	4.3E-18	4.3E-17	1.2E-17
Ca-45	1.2E-16	2.2E-15	1.4E-16	1.0E-16	2.2E-15	4.7E-17	1.1E-16	2.2E-15	4.5E-17	2.2E-15	1.3E-15	5.6E-17	8.8E-16
Ca-47	2.3E-13	1.2E-14	2.3E-13	2.7E-13	1.9E-14	2.5E-13	6.9E-16	9.3E-15	5.2E-13	1.9E-14	2.7E-13	2.5E-13	6.4E-15
V-48	5.7E-12	2.5E-15	5.5E-12	6.1E-12	7.8E-15	6.1E-12	8.3E-17	3.9E-16	1.2E-11	7.7E-15	6.2E-12	6.0E-12	1.4E-14
Cr-51	4.0E-14	2.0E-15	3.9E-14	4.8E-14	3.6E-15	4.4E-14	1.8E-16	3.4E-15	8.8E-14	3.5E-15	4.5E-14	4.7E-14	7.1E-16
Mn-52	5.7E-12	4.3E-15	5.5E-12	6.0E-12	1.5E-14	6.0E-12	1.9E-15	3.0E-16	1.2E-11	1.5E-14	6.1E-12	5.9E-12	3.7E-16
Mn-54	2.0E-12	1.5E-15	1.9E-12	2.1E-12	5.3E-15	2.1E-12	6.6E-16	1.2E-16	4.2E-12	5.3E-15	2.1E-12	2.1E-12	1.1E-16
Fe-55	7.3E-17	1.2E-18	9.6E-17	2.4E-16	1.2E-18	3.0E-16	6.9E-19	8.8E-19	7.2E-16	1.2E-18	6.1E-16	2.7E-16	6.4E-19
Fe-59	2.7E-12	2.0E-17	2.6E-12	2.8E-12	5.2E-17	2.8E-12	9.6E-18	4.9E-18	5.7E-12	5.2E-17	2.9E-12	2.8E-12	4.6E-18
Co-56	7.6E-12	4.3E-15	7.3E-12	8.0E-12	1.4E-14	7.9E-12	3.5E-14	1.6E-15	1.6E-11	1.4E-14	8.1E-12	7.9E-12	6.3E-15
Co-57	2.6E-13	5.3E-16	2.5E-13	2.8E-13	1.0E-15	2.8E-13	5.2E-15	2.3E-15	5.7E-13	1.0E-15	2.8E-13	2.8E-13	3.8E-15
Co-58	2.0E-12	1.4E-15	2.0E-12	2.1E-12	4.4E-15	2.1E-12	1.1E-14	1.5E-15	4.3E-12	4.3E-15	2.2E-12	2.1E-12	3.2E-15
Co-60	6.0E-12	3.7E-15	6.0E-12	6.5E-12	1.2E-14	6.5E-12	3.1E-14	4.4E-15	1.3E-11	1.2E-14	6.4E-12	6.4E-12	8.3E-15
Ni-63	6.4E-16	1.3E-15	3.2E-15	2.5E-15	1.3E-15	1.6E-14	6.4E-16	1.4E-15	1.1E-14	1.3E-15	1.6E-14	2.4E-15	1.3E-15
Cu-61	6.6E-14	2.0E-14	2.7E-13	5.6E-14	3.6E-14	1.0E-13	1.8E-14	1.4E-15	1.2E-13	3.6E-14	6.8E-14	5.3E-14	3.8E-14
Cu-64	6.0E-14	2.4E-14	3.2E-13	4.3E-14	3.7E-14	1.1E-13	2.3E-14	4.4E-15	1.0E-13	3.7E-14	6.1E-14	4.2E-14	7.0E-14
Zn-62	7.2E-13	3.4E-13	4.3E-12	5.8E-13	4.7E-13	1.3E-12	3.2E-13	9.6E-15	1.2E-12	4.7E-13	7.6E-13	4.8E-13	3.5E-13
Zn-65	1.1E-12	1.2E-13	2.2E-12	1.0E-12	4.1E-13	1.2E-12	9.7E-14	8.8E-15	2.1E-12	4.1E-13	1.1E-12	1.0E-12	1.0E-13
Ga-67	1.2E-15	3.6E-15	1.4E-15	2.6E-15	6.9E-15	3.9E-15	1.2E-16	2.5E-15	5.0E-15	6.8E-15	3.7E-15	2.7E-15	5.4E-14

Radio-nuclide*	Benthic fish	Bird	Crust-acean	Macro-algae	Mammal	Mollusc - bivalve	Pelagic fish	Phyto-plankton	Poly-chaete worm	Reptile	Sea anemone & True coral	Vascular plant	Zoo-plankton
Se-75	8.8E-14	1.2E-13	2.0E-13	9.1E-14	3.5E-13	9.9E-14	7.7E-15	1.3E-14	2.0E-13	3.5E-13	8.9E-14	8.9E-14	4.4E-15
Br-76	1.2E-16	4.3E-17	5.4E-16	2.9E-14	3.8E-17	8.0E-14	1.5E-16	8.7E-16	7.1E-14	3.8E-17	5.8E-14	2.4E-16	9.0E-15
Br-77	2.5E-17	1.3E-17	1.1E-16	5.4E-15	1.1E-17	1.2E-14	3.3E-17	7.0E-16	1.1E-14	1.1E-17	9.7E-15	4.1E-17	2.7E-15
Br-82	1.3E-16	7.4E-17	5.3E-16	2.4E-14	6.5E-17	5.6E-14	1.7E-16	2.7E-15	4.9E-14	6.5E-17	4.4E-14	2.0E-16	1.2E-14
Rb-81	4.7E-15	5.8E-16	4.5E-15	5.1E-15	5.1E-16	5.0E-15	9.5E-17	6.0E-18	1.0E-14	1.1E-15	5.3E-15	4.9E-15	8.8E-17
Rb-83	1.3E-13	1.2E-14	1.3E-13	1.4E-13	1.2E-14	1.4E-13	1.8E-15	1.8E-16	2.9E-13	2.6E-14	1.5E-13	1.4E-13	1.7E-15
Sr-83	2.0E-15	1.4E-15	2.1E-15	2.1E-15	2.8E-15	2.7E-15	2.0E-16	3.2E-16	4.0E-15	2.9E-15	2.5E-15	2.0E-15	2.5E-16
Sr-85	6.0E-16	2.6E-15	9.9E-16	5.1E-16	8.3E-15	1.2E-15	3.7E-16	4.3E-16	6.4E-16	8.2E-15	7.6E-16	3.7E-16	2.6E-16
Sr-89	2.2E-15	1.5E-14	4.5E-15	2.2E-15	1.5E-14	1.3E-14	2.2E-15	3.0E-15	1.3E-16	1.5E-14	7.3E-15	2.8E-16	3.4E-15
Sr-90	4.9E-15	3.3E-14	1.0E-14	4.6E-15	3.4E-14	2.8E-14	5.0E-15	7.2E-15	3.6E-16	3.4E-14	1.5E-14	6.6E-16	6.4E-15
Y-90	1.1E-13	2.2E-16	5.1E-14	4.1E-13	2.3E-16	1.8E-13	2.2E-16	8.7E-15	4.9E-13	2.3E-16	3.3E-13	1.5E-13	2.1E-14
Zr-89	1.6E-12	3.5E-17	1.5E-12	1.7E-12	9.3E-17	1.7E-12	3.0E-17	1.8E-15	3.4E-12	9.2E-17	1.7E-12	1.7E-12	2.6E-15
Zr-95	1.8E-12	1.1E-16	1.7E-12	1.9E-12	2.8E-16	1.9E-12	4.3E-17	7.2E-15	3.8E-12	2.7E-16	1.9E-12	1.9E-12	6.4E-15
Nb-95	1.6E-12	7.8E-16	1.6E-12	1.7E-12	2.4E-15	1.7E-12	2.6E-17	2.5E-16	3.4E-12	2.3E-15	1.7E-12	1.7E-12	5.6E-15
Mo-99	1.4E-14	5.0E-14	4.4E-14	8.4E-14	1.0E-13	4.0E-14	7.3E-16	5.7E-15	6.6E-14	1.0E-13	4.9E-14	8.6E-14	2.6E-13
Tc-99	1.5E-15	3.2E-13	3.2E-13	9.8E-13	3.2E-13	1.5E-13	1.5E-15	7.9E-17	3.2E-13	3.2E-13	3.1E-13	9.9E-13	1.8E-15
Tc-99m	4.7E-17	4.0E-15	3.7E-15	7.5E-15	9.9E-15	1.2E-15	1.6E-17	1.2E-18	2.4E-15	9.7E-15	2.3E-15	7.8E-15	1.3E-17
Ru-103	5.8E-13	2.2E-14	5.6E-13	6.2E-13	4.2E-14	6.2E-13	3.6E-16	4.6E-14	1.2E-12	4.2E-14	6.3E-13	6.1E-13	2.4E-13
Ru-106	5.8E-13	1.7E-13	4.3E-13	1.2E-12	1.9E-13	8.7E-13	3.0E-15	5.2E-14	1.9E-12	1.9E-13	1.2E-12	8.1E-13	8.0E-13
Ag-110m	2.2E-12	1.3E-12	3.5E-12	1.8E-12	4.5E-12	2.5E-12	5.3E-13	4.8E-13	4.2E-12	4.4E-12	1.8E-12	1.8E-12	6.6E-14
In-111	2.3E-13	6.5E-15	2.2E-13	2.6E-13	1.7E-14	2.5E-13	9.8E-16	1.0E-14	5.1E-13	1.7E-14	2.6E-13	2.5E-13	6.8E-15
Sb-125	8.4E-14	2.8E-13	7.4E-14	7.8E-14	5.3E-13	8.6E-14	1.9E-14	5.1E-14	2.5E-13	5.3E-13	7.3E-14	7.8E-14	2.7E-14
I-123	6.8E-17	2.2E-18	9.0E-17	2.3E-15	1.9E-18	4.9E-15	8.5E-18	3.9E-16	4.7E-15	1.9E-18	4.4E-15	8.0E-17	1.4E-15
I-124	2.4E-15	7.4E-17	2.9E-15	4.8E-14	6.5E-17	1.2E-13	2.3E-16	2.1E-15	1.1E-13	6.5E-17	9.8E-14	2.7E-15	1.9E-14
I-125	2.2E-16	9.8E-18	5.2E-16	3.2E-14	9.1E-18	6.9E-14	8.8E-17	6.2E-15	6.7E-14	9.2E-18	6.5E-14	3.7E-16	2.1E-14
I-129	2.5E-16	1.4E-17	7.5E-16	6.5E-14	1.3E-17	1.4E-13	1.5E-16	1.4E-14	1.4E-13	1.3E-17	1.3E-13	5.1E-16	4.6E-14
I-131	1.3E-15	4.5E-17	1.9E-15	7.5E-14	4.0E-17	1.7E-13	2.2E-16	9.6E-15	1.5E-13	4.0E-17	1.5E-13	1.6E-15	4.8E-14
I-133	4.3E-16	1.5E-17	6.8E-16	2.7E-14	1.4E-17	6.5E-14	8.5E-17	1.8E-15	6.0E-14	1.4E-17	6.0E-14	5.6E-16	1.5E-14
I-135	3.6E-16	1.1E-17	4.5E-16	9.6E-15	1.0E-17	2.2E-14	3.8E-17	6.4E-16	2.1E-14	1.0E-17	2.0E-14	4.1E-16	4.9E-15
Cs-134	4.6E-13	2.9E-14	4.4E-13	4.9E-13	3.6E-14	4.8E-13	4.6E-15	3.8E-16	9.8E-13	7.7E-14	5.0E-13	4.8E-13	3.3E-15

Radio-nuclide*	Benthic fish	Bird	Crust-acean	Macro-algae	Mammal	Mollusc - bivalve	Pelagic fish	Phyto-plankton	Poly-chaete worm	Reptile	Sea anemone & True coral	Vascular plant	Zoo-plankton
Cs-136	3.9E-13	2.1E-14	3.9E-13	4.3E-13	2.9E-14	4.3E-13	3.2E-15	3.2E-16	8.5E-13	6.3E-14	4.3E-13	4.3E-13	2.1E-15
Cs-137	1.8E-13	2.6E-14	1.7E-13	1.9E-13	2.1E-14	1.9E-13	4.4E-15	2.8E-16	3.8E-13	4.4E-14	2.0E-13	1.8E-13	4.6E-15
Ba-140	6.6E-12	6.7E-14	6.4E-12	7.3E-12	1.3E-13	7.0E-12	4.4E-14	1.2E-14	1.4E-11	1.3E-13	7.3E-12	7.0E-12	2.2E-14
La-140	2.2E-12	1.6E-14	2.2E-12	2.5E-12	3.3E-14	2.4E-12	1.4E-14	2.0E-15	4.8E-12	3.2E-14	2.5E-12	2.4E-12	6.1E-15
Ce-141	1.6E-13	1.6E-13	8.0E-16	1.1E-16	3.7E-13	1.9E-13	1.1E-16	2.1E-15	3.7E-13	8.0E-16	1.9E-13	1.8E-13	1.5E-15
Ce-144	4.9E-13	4.7E-15	2.9E-13	1.3E-12	5.0E-15	6.8E-13	8.3E-16	3.2E-15	1.8E-12	5.0E-15	1.2E-12	6.3E-13	4.5E-15
Pm-147	2.6E-16	3.8E-16	2.4E-16	2.4E-15	3.8E-16	1.1E-15	6.8E-17	1.7E-15	1.9E-15	3.8E-16	1.5E-15	6.6E-16	1.0E-15
Sm-153	6.3E-14	5.0E-16	6.0E-14	8.8E-14	5.6E-16	7.5E-14	8.8E-17	1.4E-15	1.6E-13	5.5E-16	8.4E-14	7.4E-14	1.1E-15
Eu-152	3.3E-12	2.0E-14	3.2E-12	3.5E-12	5.3E-14	3.5E-12	5.5E-16	2.7E-15	7.1E-12	5.3E-14	3.6E-12	3.5E-12	1.4E-15
Eu-154	3.5E-12	3.2E-14	3.4E-12	3.8E-12	6.5E-14	3.7E-12	9.4E-16	4.9E-15	7.5E-12	6.4E-14	3.8E-12	3.7E-12	2.8E-15
Eu-155	1.5E-13	5.5E-15	1.5E-13	1.7E-13	7.6E-15	1.7E-13	1.7E-16	2.2E-15	3.4E-13	7.5E-15	1.8E-13	1.7E-13	8.4E-16
Er-169	5.5E-16	3.3E-16	5.5E-16	5.3E-15	3.3E-16	2.1E-15	5.9E-17	1.4E-15	4.3E-15	3.3E-16	3.5E-15	1.5E-15	8.7E-16
Lu-177	6.0E-14	4.3E-16	5.8E-14	7.4E-14	4.8E-16	6.7E-14	7.5E-17	1.5E-15	1.4E-13	4.8E-16	7.2E-14	6.6E-14	1.0E-15
Re-188	9.5E-16	2.0E-13	1.9E-13	4.4E-13	2.1E-13	8.5E-14	9.0E-16	1.9E-17	1.7E-13	2.1E-13	1.6E-13	5.6E-13	5.2E-16
Au-198	7.4E-14	2.6E-13	3.3E-13	7.2E-13	3.9E-13	1.9E-13	1.2E-15	4.7E-17	3.8E-13	3.8E-13	2.9E-13	7.8E-13	1.0E-15
Tl-201	3.0E-14	1.6E-15	2.9E-14	3.3E-14	1.1E-15	3.3E-14	2.6E-16	2.4E-17	6.6E-14	2.3E-15	3.4E-14	3.2E-14	3.3E-16
Pb-210	9.7E-13	6.6E-13	1.1E-12	1.7E-13	6.6E-13	3.9E-13	9.4E-13	3.9E-12	2.5E-12	6.6E-13	1.4E-12	8.0E-14	5.9E-13
Pb-212	3.7E-11	2.1E-11	2.4E-11	2.2E-12	2.1E-11	7.9E-12	3.6E-11	5.2E-10	4.6E-11	2.1E-11	3.7E-11	2.1E-12	1.8E-11
Po-210	1.1E-12	1.1E-12	2.9E-12	3.8E-14	1.1E-12	8.7E-13	1.1E-12	7.1E-13	6.3E-12	1.1E-12	2.9E-12	3.8E-14	1.4E-12
At-211	4.0E-15	3.0E-16	1.7E-14	1.9E-12	3.0E-16	3.9E-12	4.0E-15	4.2E-13	3.9E-12	3.0E-16	3.9E-12	1.1E-14	1.4E-12
Ra-223	1.5E-12	1.3E-12	1.0E-12	1.5E-12	1.3E-12	9.8E-13	1.1E-12	9.9E-12	2.4E-12	1.3E-12	1.8E-12	1.1E-12	6.5E-13
Ra-226	6.0E-12	7.1E-12	4.0E-12	4.1E-12	7.0E-12	3.0E-12	5.7E-12	4.8E-11	6.4E-12	7.0E-12	6.1E-12	4.0E-12	3.3E-12
Ac-225	1.2E-10	6.8E-11	9.6E-11	7.2E-12	6.8E-11	2.4E-11	1.2E-10	2.1E-09	1.4E-10	6.8E-11	1.2E-10	7.0E-12	6.4E-11
Th-227	5.2E-13	3.7E-13	3.7E-12	7.6E-13	3.7E-13	4.7E-13	3.0E-13	6.6E-11	8.2E-13	3.7E-13	5.8E-13	7.6E-13	7.4E-13
Th-230	1.5E-13	2.0E-13	4.2E-12	5.1E-13	2.0E-13	1.9E-13	1.5E-13	8.0E-11	2.0E-13	2.0E-13	2.0E-13	5.1E-13	7.9E-13
Th-232	1.6E-13	1.6E-13	3.6E-12	4.6E-13	1.6E-13	2.0E-13	1.2E-13	6.9E-11	2.3E-13	1.6E-13	2.0E-13	4.6E-13	6.7E-13
Th-234	2.1E-13	2.3E-15	1.7E-13	6.4E-13	2.4E-15	2.9E-13	1.7E-15	1.8E-13	8.0E-13	2.4E-15	5.2E-13	2.7E-13	4.5E-15
U-234	7.7E-14	7.7E-14	3.1E-14	7.1E-13	7.7E-14	2.8E-13	7.7E-14	1.9E-12	8.6E-12	7.7E-14	8.6E-12	2.0E-12	3.2E-14
U-235	8.4E-14	7.1E-14	4.2E-14	6.8E-13	6.9E-14	2.7E-13	7.1E-14	1.7E-12	8.0E-12	6.9E-14	8.0E-12	1.9E-12	3.0E-14
U-238	6.6E-14	6.6E-14	2.7E-14	6.2E-13	6.6E-14	2.4E-13	6.6E-14	1.6E-12	7.4E-12	6.6E-14	7.4E-12	1.8E-12	2.8E-14

Radio-nuclide*	Benthic fish	Bird	Crust-acean	Macro-algae	Mammal	Mollusc - bivalve	Pelagic fish	Phyto-plankton	Poly-chaete worm	Reptile	Sea anemone & True coral	Vascular plant	Zoo-plankton
Np-237	7.7E-14	7.5E-14	3.3E-14	4.5E-13	7.5E-14	3.2E-12	7.5E-14	1.2E-12	3.3E-12	7.5E-14	3.3E-14	4.5E-13	1.5E-13
Pu-238	3.9E-12	1.1E-12	3.2E-13	1.1E-11	3.8E-12	3.1E-12	3.9E-12	3.5E-10	4.3E-12	3.8E-12	1.4E-12	1.1E-11	1.8E-11
Pu-239	3.7E-12	1.1E-12	3.1E-13	1.1E-11	3.6E-12	2.9E-12	3.7E-12	3.3E-10	4.1E-12	3.6E-12	1.3E-12	1.1E-11	1.7E-11
Pu-240	3.7E-12	1.1E-12	3.1E-13	1.1E-11	3.6E-12	2.9E-12	3.7E-12	3.3E-10	4.1E-12	3.6E-12	1.3E-12	1.1E-11	1.7E-11
Pu-241	1.3E-15	4.6E-16	4.7E-16	3.1E-15	1.5E-15	4.6E-14	1.1E-15	1.8E-13	4.7E-14	1.5E-15	5.8E-16	3.1E-15	6.0E-15
Pu-242	3.5E-12	1.0E-12	2.9E-13	1.0E-11	3.4E-12	2.7E-12	3.5E-12	3.2E-10	3.8E-12	3.4E-12	1.2E-12	1.0E-11	1.6E-11
Am-241	1.5E-13	7.8E-14	1.6E-13	1.7E-13	2.6E-13	1.9E-11	8.0E-14	4.0E-11	1.9E-11	2.6E-13	1.0E-13	1.7E-13	7.6E-13
Am-242	8.6E-15	2.5E-16	7.8E-15	2.0E-14	8.1E-16	3.7E-14	7.3E-16	1.5E-13	5.0E-14	8.1E-16	1.3E-14	1.6E-14	3.5E-15
Am-243	7.6E-13	7.6E-14	7.5E-13	8.5E-13	2.5E-13	1.9E-11	7.8E-14	3.9E-11	2.0E-11	2.5E-13	7.9E-13	8.3E-13	7.4E-13
Cm-242	2.2E-13	6.4E-14	7.8E-14	1.9E-12	2.1E-13	4.9E-12	2.2E-13	4.2E-11	4.9E-12	2.1E-13	1.2E-14	1.9E-12	9.9E-13
Cm-243	6.4E-13	7.7E-14	4.6E-13	2.7E-12	2.6E-13	6.5E-12	2.6E-13	5.2E-11	6.9E-12	2.6E-13	4.4E-13	2.7E-12	1.2E-12
Cm-244	2.6E-13	7.5E-14	9.2E-14	2.2E-12	2.5E-13	5.9E-12	2.6E-13	5.0E-11	5.9E-12	2.5E-13	1.2E-14	2.2E-12	1.2E-12

*radionuclides with a half-life of less than 3 hours were not considered.

Table 16. Dose per unit release factors for worst age group angler family – river release scenario

These DPURs are multiplied by the factor Q_{eff} (see Table G.10) when assessing exposure of angler family via the sewer release scenario.

Radionuclide*	Worst total DPUR (µSv/y per Bq/y)	Worst age group
H-3	6.1E-13	Offspring
H-3 organic	1.5E-08	Offspring
C-14	1.9E-07	Offspring
Na-22	2.4E-10	Offspring
Na-24	2.9E-11	Adult
P-32	2.2E-06	Offspring
P-33	4.3E-07	Offspring
S-35	1.0E-10	Offspring
Cl-36	6.1E-11	Infant
Ca-45	2.2E-10	Offspring
Ca-47	4.6E-10	Offspring
V-48	2.2E-10	Adult
Cr-51	3.5E-10	Adult
Mn-52	1.4E-08	Adult
Mn-54	1.8E-08	Adult
Fe-55	3.5E-11	Adult
Fe-59	6.1E-09	Adult
Co-56	7.0E-08	Adult
Co-57	1.4E-09	Adult
Co-58	1.7E-08	Adult
Co-60	4.8E-08	Adult
Ni-63	5.3E-12	Infant
Cu-61	1.1E-10	Adult
Cu-64	4.0E-11	Adult
Zn-62	2.2E-09	Adult
Zn-65	8.6E-09	Adult
Ga-67	6.1E-11	Adult
Se-75	1.0E-08	Offspring
Br-76	1.2E-09	Adult
Br-77	1.5E-10	Adult
Br-82	1.3E-09	Adult
Rb-81	1.9E-09	Adult
Rb-83	1.0E-08	Adult
Sr-83	2.1E-10	Adult
Sr-85	6.3E-10	Adult
Sr-89	2.4E-10	Offspring
Sr-90	8.6E-10	Offspring
Y-90	1.8E-10	Infant
Zr-89	2.7E-10	Adult
Zr-95	1.7E-09	Adult
Nb-95	2.1E-10	Adult
Mo-99	4.7E-10	Adult
Tc-99	4.3E-11	Infant

Radionuclide*	Worst total DPUR (µSv/y per Bq/y)	Worst age group
Tc-99m	1.2E-12	Infant
Ru-103	7.1E-09	Adult
Ru-106	3.6E-09	Adult
Ag-110m	7.2E-08	Adult
In-111	2.0E-09	Adult
Sb-125	1.9E-09	Adult
I-123	1.3E-10	Adult
I-124	1.3E-09	Adult
I-125	4.9E-10	Adult
I-129	3.6E-09	Adult
I-131	1.4E-09	Infant
I-133	6.4E-10	Adult
I-135	1.3E-09	Adult
Cs-134	3.7E-08	Adult
Cs-136	8.5E-09	Adult
Cs-137	1.8E-08	Adult
Ba-140	1.0E-09	Adult
La-140	8.8E-09	Adult
Ce-141	1.3E-09	Adult
Ce-144	1.5E-09	Adult
Pm-147	1.5E-11	Infant
Sm-153	2.0E-10	Adult
Eu-152	7.7E-10	Adult
Eu-154	8.9E-10	Adult
Eu-155	4.7E-11	Adult
Er-169	2.6E-12	Infant
Lu-177	1.7E-10	Adult
Re-188	9.6E-11	Infant
Au-198	2.1E-09	Adult
Tl-201	2.2E-10	Adult
Pb-210	2.3E-08	Infant
Pb-212	2.5E-09	Adult
Po-210	3.2E-08	Infant
At-211	5.8E-10	Infant
Ra-223	7.1E-09	Infant
Ra-226	1.7E-08	Offspring
Ac-225	1.1E-09	Adult
Th-227	1.9E-09	Adult
Th-230	5.6E-10	Adult
Th-232	6.7E-08	Adult
Th-234	6.0E-10	Adult
U-234	1.1E-09	Infant
U-235	1.1E-09	Infant
U-238	9.9E-10	Infant
Np-237	4.2E-09	Adult
Pu-238	2.9E-07	Adult
Pu-239	3.1E-07	Adult
Pu-240	3.1E-07	Adult

Radionuclide*	Worst total DPUR (µSv/y per Bq/y)	Worst age group
Pu-241	6.0E-09	Adult
Pu-242	3.0E-07	Adult
Am-241	6.1E-09	Adult
Am-242	6.6E-11	Adult
Am-243	9.2E-09	Adult
Cm-242	5.8E-10	Infant
Cm-243	5.2E-09	Adult
Cm-244	3.8E-09	Adult

*radionuclides with a half-life of less than 3 hours were not considered.

Table 17. Dose per unit release factors for offspring in an angler family – river release scenario

Radionuclide*	DPURs for offspring in an angler family (µSv/y per Bq/y)			
	Fish	External	Drinking water	Total
H-3	2.0E-14	0.0E+00	5.9E-13	6.1E-13
H-3 organic	1.5E-08	0.0E+00	1.1E-12	1.5E-08
C-14	1.9E-07	4.0E-15	1.4E-11	1.9E-07
Na-22	1.7E-10	2.5E-13	6.8E-11	2.4E-10
Na-24	<p	8.5E-14	<p	8.5E-14
P-32	2.2E-06	1.2E-13	4.7E-10	2.2E-06
P-33	4.3E-07	4.9E-16	9.1E-11	4.3E-07
S-35	1.0E-10	4.7E-16	3.8E-12	1.0E-10
Cl-36	<p	4.7E-14	<p	4.7E-14
Ca-45	6.3E-11	1.1E-14	1.6E-10	2.2E-10
Ca-47	5.6E-11	2.7E-10	1.4E-10	4.6E-10
V-48	<p	6.3E-11	<p	6.3E-11
Cr-51	<p	3.5E-10	<p	3.5E-10
Mn-52	<p	1.4E-08	<p	1.4E-08
Mn-54	<p	1.8E-08	<p	1.8E-08
Fe-55	<p	0.0E+00	<p	0.0E+00
Fe-59	<p	5.9E-09	<p	5.9E-09
Co-56	<p	7.0E-08	<p	7.0E-08
Co-57	<p	1.4E-09	<p	1.4E-09
Co-58	<p	1.7E-08	<p	1.7E-08
Co-60	<p	4.8E-08	<p	4.8E-08
Ni-63	<p	0.0E+00	<p	0.0E+00
Cu-61	<p	9.0E-11	<p	9.0E-11
Cu-64	<p	2.1E-11	<p	2.1E-11
Zn-62	<p	1.6E-10	<p	1.6E-10
Zn-65	<p	3.4E-10	<p	3.4E-10
Ga-67	<p	9.7E-12	<p	9.7E-12
Se-75	8.9E-09	1.2E-09	4.4E-11	1.0E-08
Br-76	<p	1.2E-09	<p	1.2E-09
Br-77	<p	1.5E-10	<p	1.5E-10
Br-82	<p	1.2E-09	<p	1.2E-09
Rb-81	<p	1.8E-09	<p	1.8E-09
Rb-83	<p	7.2E-09	<p	7.2E-09
Sr-83	<p	2.0E-10	<p	2.0E-10
Sr-85	<p	6.2E-10	<p	6.2E-10
Sr-89	2.1E-11	3.4E-12	2.2E-10	2.4E-10
Sr-90	7.5E-11	9.1E-12	7.8E-10	8.6E-10
Y-90	<p	4.4E-12	<p	4.4E-12
Zr-89	<p	2.4E-10	<p	2.4E-10
Zr-95	<p	1.6E-09	<p	1.6E-09
Nb-95	<p	8.6E-11	<p	8.6E-11
Mo-99	<p	4.6E-10	<p	4.6E-10
Tc-99	<p	1.1E-16	<p	1.1E-16

Radionuclide*	DPURs for offspring in an angler family (µSv/y per Bq/y)			
	Fish	External	Drinking water	Total
Tc-99m	<p	1.3E-13	<p	1.3E-13
Ru-103	<p	7.1E-09	<p	7.1E-09
Ru-106	<p	3.4E-09	<p	3.4E-09
Ag-110m	<p	7.2E-08	<p	7.2E-08
In-111	<p	1.4E-09	<p	1.4E-09
Sb-125	<p	1.9E-09	<p	1.9E-09
I-123	<p	1.2E-10	<p	1.2E-10
I-124	<p	8.8E-10	<p	8.8E-10
I-125	<p	8.7E-12	<p	8.7E-12
I-129	<p	7.0E-12	<p	7.0E-12
I-131	3.7E-10	3.2E-10	3.7E-10	1.1E-09
I-133	<p	5.1E-10	<p	5.1E-10
I-135	<p	1.3E-09	<p	1.3E-09
Cs-134	<p	2.3E-08	<p	2.3E-08
Cs-136	<p	6.3E-09	<p	6.3E-09
Cs-137	<p	8.4E-09	<p	8.4E-09
Ba-140	<p	9.9E-10	<p	9.9E-10
La-140	<p	8.8E-09	<p	8.8E-09
Ce-141	<p	1.3E-09	<p	1.3E-09
Ce-144	<p	1.5E-09	<p	1.5E-09
Pm-147	<p	3.5E-14	<p	3.5E-14
Sm-153	<p	2.0E-10	<p	2.0E-10
Eu-152	<p	6.3E-10	<p	6.3E-10
Eu-154	<p	7.0E-10	<p	7.0E-10
Eu-155	<p	1.5E-11	<p	1.5E-11
Er-169	<p	2.2E-13	<p	2.2E-13
Lu-177	<p	1.6E-10	<p	1.6E-10
Re-188	<p	6.5E-12	<p	6.5E-12
Au-198	<p	2.1E-09	<p	2.1E-09
Tl-201	<p	1.9E-10	<p	1.9E-10
Pb-210	<p	1.0E-11	<p	1.0E-11
Pb-212	<p	2.3E-09	<p	2.3E-09
Po-210	<p	1.5E-13	<p	1.5E-13
At-211	<p	3.0E-11	<p	3.0E-11
Ra-223	<p	3.6E-10	<p	3.6E-10
Ra-226	6.3E-10	1.2E-08	4.7E-09	1.7E-08
Ac-225	<p	9.6E-10	<p	9.6E-10
Th-227	<p	1.9E-09	<p	1.9E-09
Th-230	<p	4.6E-12	<p	4.6E-12
Th-232	<p	6.6E-08	<p	6.6E-08
Th-234	<p	5.9E-10	<p	5.9E-10
U-234	<p	3.4E-15	<p	3.4E-15
U-235	<p	6.7E-12	<p	6.7E-12
U-238	<p	1.3E-12	<p	1.3E-12
Np-237	<p	2.0E-12	<p	2.0E-12
Pu-238	<p	5.2E-13	<p	5.2E-13

Radionuclide*	DPURs for offspring in an angler family (µSv/y per Bq/y)			
	Fish	External	Drinking water	Total
Pu-239	<p	1.2E-12	<p	1.2E-12
Pu-240	<p	5.0E-13	<p	5.0E-13
Pu-241	<p	2.3E-14	<p	2.3E-14
Pu-242	<p	4.4E-13	<p	4.4E-13
Am-241	<p	1.5E-10	<p	1.5E-10
Am-242	<p	5.7E-11	<p	5.7E-11
Am-243	<p	3.3E-09	<p	3.3E-09
Cm-242	<p	1.0E-13	<p	1.0E-13
Cm-243	<p	4.4E-10	<p	4.4E-10
Cm-244	<p	7.3E-14	<p	7.3E-14

<p: not calculated as dose rate to parent greater than dose rate to offspring
*radionuclides with a half-life of less than 3 hours were not considered.

Table 18. Dose per unit release factors for infant in an angler family – river release scenario

Radionuclide*	DPURs for infant in an angler family (µSv/y per Bq/y)			
	Fish	External	Drinking water	Total
H-3	1.5E-15	0.0E+00	4.0E-13	4.0E-13
H-3 organic	1.4E-09	0.0E+00	9.2E-13	1.4E-09
C-14	1.9E-08	1.2E-16	1.2E-11	1.9E-08
Na-22	3.6E-11	7.6E-15	1.2E-10	1.6E-10
Na-24	5.5E-12	2.5E-15	1.9E-11	2.4E-11
P-32	8.4E-08	3.6E-15	1.6E-10	8.4E-08
P-33	8.0E-09	1.5E-17	1.5E-11	8.0E-09
S-35	2.2E-11	1.4E-17	7.1E-12	2.9E-11
Cl-36	9.3E-12	1.4E-15	5.2E-11	6.1E-11
Ca-45	1.8E-12	3.3E-16	3.9E-11	4.0E-11
Ca-47	3.4E-12	8.0E-12	7.3E-11	8.5E-11
V-48	3.4E-11	1.9E-12	9.0E-11	1.3E-10
Cr-51	1.6E-13	1.1E-11	1.1E-12	1.2E-11
Mn-52	1.6E-11	4.3E-10	1.7E-11	4.6E-10
Mn-54	5.7E-12	5.4E-10	6.1E-12	5.5E-10
Fe-55	1.1E-11	0.0E+00	1.6E-11	2.7E-11
Fe-59	5.8E-11	1.8E-10	8.9E-11	3.2E-10
Co-56	1.3E-11	2.1E-09	4.5E-11	2.2E-09
Co-57	1.4E-12	4.3E-11	4.8E-12	4.9E-11
Co-58	3.8E-12	5.2E-10	1.3E-11	5.4E-10
Co-60	2.4E-11	1.4E-09	8.1E-11	1.5E-09
Ni-63	4.0E-13	0.0E+00	4.9E-12	5.3E-12
Cu-61	5.4E-12	2.7E-12	6.1E-12	1.4E-11
Cu-64	5.9E-12	6.2E-13	6.7E-12	1.3E-11
Zn-62	6.9E-10	4.8E-12	5.3E-11	7.4E-10
Zn-65	1.7E-09	1.0E-11	1.3E-10	1.8E-09
Ga-67	1.5E-11	2.9E-13	9.8E-12	2.5E-11
Se-75	2.1E-09	3.7E-11	9.2E-11	2.3E-09
Br-76	7.1E-12	3.6E-11	2.0E-11	6.3E-11
Br-77	1.2E-12	4.4E-12	3.3E-12	8.9E-12
Br-82	6.9E-12	3.6E-11	2.0E-11	6.3E-11
Rb-81	2.3E-11	5.5E-11	1.2E-12	7.9E-11
Rb-83	6.0E-10	2.2E-10	3.2E-11	8.5E-10
Sr-83	2.4E-13	6.0E-12	2.1E-11	2.7E-11
Sr-85	2.7E-13	1.9E-11	2.4E-11	4.3E-11
Sr-89	1.6E-12	1.0E-13	1.4E-10	1.4E-10
Sr-90	6.4E-12	2.7E-13	5.7E-10	5.8E-10
Y-90	2.4E-11	1.3E-13	1.6E-10	1.8E-10
Zr-89	3.0E-12	7.3E-12	3.6E-11	4.6E-11
Zr-95	3.8E-12	4.9E-11	4.4E-11	9.7E-11
Nb-95	3.0E-11	2.6E-12	2.6E-11	5.9E-11
Mo-99	1.4E-13	1.4E-11	1.9E-11	3.3E-11
Tc-99	3.0E-12	3.2E-18	4.0E-11	4.3E-11
Tc-99m	8.2E-14	4.0E-15	1.1E-12	1.2E-12

Radionuclide*	DPURs for infant in an angler family (µSv/y per Bq/y)			
	Fish	**External**	**Drinking water**	**Total**
Ru-103	3.5E-12	2.1E-10	1.7E-11	2.3E-10
Ru-106	3.7E-11	1.0E-10	1.8E-10	3.2E-10
Ag-110m	4.1E-12	2.2E-09	9.8E-12	2.2E-09
In-111	1.8E-10	4.2E-11	4.7E-12	2.3E-10
Sb-125	6.0E-12	5.6E-11	4.2E-11	1.0E-10
I-123	1.5E-12	3.7E-12	1.3E-11	1.9E-11
I-124	8.9E-11	2.7E-11	7.7E-10	8.9E-10
I-125	4.6E-11	2.6E-13	4.0E-10	4.5E-10
I-129	1.8E-10	2.1E-13	1.5E-09	1.7E-09
I-131	1.5E-10	9.5E-12	1.3E-09	1.4E-09
I-133	3.6E-11	1.5E-11	3.1E-10	3.6E-10
I-135	7.2E-12	3.8E-11	6.2E-11	1.1E-10
Cs-134	5.9E-10	7.0E-10	6.1E-11	1.3E-09
Cs-136	3.5E-10	1.9E-10	3.6E-11	5.7E-10
Cs-137	4.4E-10	2.5E-10	4.6E-11	7.4E-10
Ba-140	6.3E-13	3.0E-11	1.4E-10	1.7E-10
La-140	4.5E-12	2.6E-10	3.2E-11	3.0E-10
Ce-141	4.1E-13	3.8E-11	4.3E-12	4.3E-11
Ce-144	3.2E-12	4.4E-11	3.3E-11	8.0E-11
Pm-147	1.5E-12	1.0E-15	1.3E-11	1.5E-11
Sm-153	1.1E-12	6.0E-12	9.6E-12	1.7E-11
Eu-152	3.0E-11	1.9E-11	6.0E-11	1.1E-10
Eu-154	4.8E-11	2.1E-11	9.7E-11	1.7E-10
Eu-155	8.9E-12	4.6E-13	1.8E-11	2.7E-11
Er-169	2.3E-13	6.6E-15	2.4E-12	2.6E-12
Lu-177	3.8E-13	4.9E-12	3.3E-12	8.6E-12
Re-188	6.9E-12	2.0E-13	8.9E-11	9.6E-11
Au-198	4.6E-12	6.2E-11	5.0E-12	7.1E-11
Tl-201	8.7E-12	5.6E-12	2.5E-12	1.7E-11
Pb-210	2.0E-09	3.1E-13	2.1E-08	2.3E-08
Pb-212	3.6E-11	6.9E-11	3.7E-10	4.8E-10
Po-210	3.9E-09	4.4E-15	2.8E-08	3.2E-08
At-211	3.2E-11	9.0E-13	5.5E-10	5.8E-10
Ra-223	1.1E-10	1.1E-11	7.0E-09	7.1E-09
Ra-226	9.4E-11	3.6E-10	6.1E-09	6.6E-09
Ac-225	1.8E-11	2.9E-11	3.2E-10	3.7E-10
Th-227	1.5E-12	5.7E-11	6.7E-11	1.3E-10
Th-230	9.1E-12	1.4E-13	3.9E-10	4.0E-10
Th-232	9.9E-12	2.0E-09	4.3E-10	2.4E-09
Th-234	5.5E-13	1.8E-11	2.4E-11	4.2E-11
U-234	3.9E-12	1.0E-16	1.1E-09	1.1E-09
U-235	3.9E-12	2.0E-13	1.1E-09	1.1E-09
U-238	3.6E-12	4.0E-14	9.9E-10	9.9E-10
Np-237	2.0E-10	5.9E-14	1.7E-09	1.9E-09
Pu-238	2.5E-08	1.5E-14	3.1E-10	2.5E-08
Pu-239	2.6E-08	3.5E-14	3.3E-10	2.7E-08

Radionuclide*	DPURs for infant in an angler family (µSv/y per Bq/y)			
	Fish	**External**	**Drinking water**	**Total**
Pu-240	2.6E-08	1.5E-14	3.3E-10	2.7E-08
Pu-241	3.6E-10	7.0E-16	4.4E-12	3.6E-10
Pu-242	2.5E-08	1.3E-14	3.1E-10	2.5E-08
Am-241	4.9E-10	4.5E-12	5.3E-10	1.0E-09
Am-242	2.9E-12	1.7E-12	3.1E-12	7.7E-12
Am-243	4.9E-10	9.9E-11	5.3E-10	1.1E-09
Cm-242	6.0E-11	3.1E-15	5.2E-10	5.8E-10
Cm-243	2.6E-10	1.3E-11	2.3E-09	2.5E-09
Cm-244	2.3E-10	2.2E-15	2.0E-09	2.2E-09

*radionuclides with a half-life of less than 3 hours were not considered.

Table 19. Dose per unit release factors for child in an angler family – river release scenario

Radionuclide*	DPURs for child in an angler family (µSv/y per Bq/y)			
	Fish	External	Drinking water	Total
H-3	3.6E-15	0.0E+00	2.6E-13	2.6E-13
H-3 organic	3.3E-09	0.0E+00	5.9E-13	3.3E-09
C-14	4.7E-08	2.0E-15	8.2E-12	4.7E-08
Na-22	6.6E-11	1.3E-13	6.1E-11	1.3E-10
Na-24	9.3E-12	4.2E-14	8.5E-12	1.8E-11
P-32	1.2E-07	6.0E-14	5.9E-11	1.2E-07
P-33	1.2E-08	2.5E-16	5.9E-12	1.2E-08
S-35	3.4E-11	2.4E-16	3.0E-12	3.7E-11
Cl-36	1.4E-11	2.4E-14	2.1E-11	3.5E-11
Ca-45	3.3E-12	5.5E-15	1.9E-11	2.2E-11
Ca-47	5.5E-12	1.3E-10	3.2E-11	1.7E-10
V-48	6.0E-11	3.1E-11	4.3E-11	1.3E-10
Cr-51	2.7E-13	1.8E-10	4.8E-13	1.8E-10
Mn-52	3.1E-11	7.1E-09	9.1E-12	7.1E-09
Mn-54	1.2E-11	9.0E-09	3.5E-12	9.0E-09
Fe-55	2.5E-11	0.0E+00	1.0E-11	3.5E-11
Fe-59	1.1E-10	3.0E-09	4.3E-11	3.1E-09
Co-56	2.5E-11	3.5E-08	2.3E-11	3.5E-08
Co-57	2.5E-12	7.1E-10	2.3E-12	7.1E-10
Co-58	7.4E-12	8.7E-09	6.8E-12	8.7E-09
Co-60	4.8E-11	2.4E-08	4.4E-11	2.4E-08
Ni-63	6.7E-13	0.0E+00	2.2E-12	2.9E-12
Cu-61	8.2E-12	4.5E-11	2.5E-12	5.6E-11
Cu-64	8.9E-12	1.0E-11	2.7E-12	2.2E-11
Zn-62	1.1E-09	8.0E-11	2.2E-11	1.2E-09
Zn-65	3.4E-09	1.7E-10	7.0E-11	3.6E-09
Ga-67	2.5E-11	4.8E-12	4.4E-12	3.4E-11
Se-75	4.9E-09	6.2E-10	5.7E-11	5.6E-09
Br-76	1.1E-11	5.9E-10	8.8E-12	6.1E-10
Br-77	2.2E-12	7.3E-11	1.7E-12	7.7E-11
Br-82	1.3E-11	6.1E-10	9.6E-12	6.3E-10
Rb-81	3.6E-11	9.1E-10	5.1E-13	9.5E-10
Rb-83	1.2E-09	3.6E-09	1.6E-11	4.8E-09
Sr-83	4.0E-13	9.9E-11	9.6E-12	1.1E-10
Sr-85	6.6E-13	3.1E-10	1.6E-11	3.3E-10
Sr-89	2.5E-12	1.7E-12	6.1E-11	6.6E-11
Sr-90	2.6E-11	4.6E-12	6.3E-10	6.7E-10
Y-90	3.6E-11	2.2E-12	6.3E-11	1.0E-10
Zr-89	5.4E-12	1.2E-10	1.7E-11	1.4E-10
Zr-95	6.4E-12	8.1E-10	2.0E-11	8.4E-10
Nb-95	5.2E-11	4.3E-11	1.2E-11	1.1E-10
Mo-99	2.2E-13	2.3E-10	8.2E-12	2.4E-10
Tc-99	4.1E-12	5.3E-17	1.4E-11	1.9E-11

Radionuclide*	DPURs for child in an angler family (µSv/y per Bq/y)			
	Fish	External	Drinking water	Total
Tc-99m	1.4E-13	6.6E-14	4.8E-13	6.8E-13
Ru-103	5.7E-12	3.5E-09	7.3E-12	3.5E-09
Ru-106	5.7E-11	1.7E-09	7.3E-11	1.8E-09
Ag-110m	7.7E-12	3.6E-08	4.9E-12	3.6E-08
In-111	3.1E-10	7.0E-10	2.2E-12	1.0E-09
Sb-125	1.0E-11	9.3E-10	1.9E-11	9.6E-10
I-123	2.0E-12	6.1E-11	4.6E-12	6.8E-11
I-124	1.3E-10	4.4E-10	2.9E-10	8.6E-10
I-125	1.3E-10	4.3E-12	2.9E-10	4.2E-10
I-129	7.7E-10	3.5E-12	1.8E-09	2.6E-09
I-131	2.1E-10	1.6E-10	4.9E-10	8.6E-10
I-133	4.0E-11	2.5E-10	9.4E-11	3.9E-10
I-135	8.9E-12	6.3E-10	2.1E-11	6.6E-10
Cs-134	2.6E-09	1.2E-08	7.2E-11	1.4E-08
Cs-136	8.1E-10	3.2E-09	2.3E-11	4.0E-09
Cs-137	1.8E-09	4.2E-09	5.1E-11	6.1E-09
Ba-140	1.0E-12	5.0E-10	6.0E-11	5.6E-10
La-140	7.2E-12	4.4E-09	1.4E-11	4.4E-09
Ce-141	6.1E-13	6.4E-10	1.7E-12	6.4E-10
Ce-144	4.4E-12	7.3E-10	1.2E-11	7.4E-10
Pm-147	2.3E-12	1.7E-14	5.3E-12	7.5E-12
Sm-153	1.6E-12	9.9E-11	3.8E-12	1.0E-10
Eu-152	5.3E-11	3.2E-10	2.8E-11	4.0E-10
Eu-154	8.3E-11	3.5E-10	4.5E-11	4.8E-10
Eu-155	1.4E-11	7.7E-12	7.4E-12	2.9E-11
Er-169	3.3E-13	1.1E-13	9.3E-13	1.4E-12
Lu-177	5.8E-13	8.2E-11	1.4E-12	8.4E-11
Re-188	9.0E-12	3.3E-12	3.2E-11	4.4E-11
Au-198	7.1E-12	1.0E-09	2.1E-12	1.0E-09
Tl-201	1.4E-11	9.3E-11	1.1E-12	1.1E-10
Pb-210	5.4E-09	5.2E-12	1.5E-08	2.0E-08
Pb-212	5.7E-11	1.2E-09	1.6E-10	1.4E-09
Po-210	5.7E-09	7.4E-14	1.1E-08	1.7E-08
At-211	4.6E-11	1.5E-11	2.2E-10	2.8E-10
Ra-223	2.2E-10	1.8E-10	3.9E-09	4.3E-09
Ra-226	3.9E-10	5.9E-09	6.8E-09	1.3E-08
Ac-225	2.8E-11	4.8E-10	1.3E-10	6.4E-10
Th-227	2.5E-12	9.5E-10	3.0E-11	9.8E-10
Th-230	2.7E-11	2.3E-12	3.1E-10	3.4E-10
Th-232	3.2E-11	3.3E-08	3.7E-10	3.4E-08
Th-234	8.2E-13	2.9E-10	9.5E-12	3.1E-10
U-234	1.1E-11	1.7E-15	8.2E-10	8.3E-10
U-235	1.1E-11	3.4E-12	7.9E-10	8.0E-10
U-238	1.0E-11	6.7E-13	7.5E-10	7.6E-10
Np-237	5.2E-10	9.9E-13	1.2E-09	1.7E-09
Pu-238	7.5E-08	2.6E-13	2.5E-10	7.6E-08

Radionuclide*	DPURs for child in an angler family (µSv/y per Bq/y)			
	Fish	External	Drinking water	Total
Pu-239	8.5E-08	5.8E-13	2.8E-10	8.5E-08
Pu-240	8.5E-08	2.5E-13	2.8E-10	8.5E-08
Pu-241	1.6E-09	1.2E-14	5.3E-12	1.6E-09
Pu-242	8.2E-08	2.2E-13	2.7E-10	8.2E-08
Am-241	1.4E-09	7.5E-11	4.2E-10	1.9E-09
Am-242	4.2E-12	2.8E-11	1.2E-12	3.4E-11
Am-243	1.4E-09	1.6E-09	4.2E-10	3.5E-09
Cm-242	9.5E-11	5.2E-14	2.2E-10	3.2E-10
Cm-243	6.3E-10	2.2E-10	1.5E-09	2.3E-09
Cm-244	5.5E-10	3.6E-14	1.3E-09	1.8E-09

*radionuclides with a half-life of less than 3 hours were not considered.

Table 20. Dose per unit release factors for adult in an angler family – river release scenario

Radionuclide*	DPURs for adult angler family (µSv/y per Bq/y)			
	Fish	External	Drinking water	Total
H-3	1.1E-14	0.0E+00	3.4E-13	3.5E-13
H-3 organic	9.9E-09	0.0E+00	7.4E-13	9.9E-09
C-14	1.4E-07	4.0E-15	1.0E-11	1.4E-07
Na-22	1.5E-10	2.5E-13	6.1E-11	2.2E-10
Na-24	2.1E-11	8.5E-14	8.2E-12	2.9E-11
P-32	2.1E-07	1.2E-13	4.6E-11	2.1E-07
P-33	2.1E-08	4.9E-16	4.6E-12	2.1E-08
S-35	6.5E-11	4.7E-16	2.5E-12	6.8E-11
Cl-36	2.8E-11	4.7E-14	1.8E-11	4.5E-11
Ca-45	5.2E-12	1.1E-14	1.3E-11	1.8E-11
Ca-47	1.2E-11	2.7E-10	2.9E-11	3.1E-10
V-48	1.2E-10	6.3E-11	3.8E-11	2.2E-10
Cr-51	5.4E-13	3.5E-10	4.0E-13	3.5E-10
Mn-52	6.6E-11	1.4E-08	8.2E-12	1.4E-08
Mn-54	2.6E-11	1.8E-08	3.2E-12	1.8E-08
Fe-55	3.0E-11	0.0E+00	5.2E-12	3.5E-11
Fe-59	1.6E-10	5.9E-09	2.9E-11	6.1E-09
Co-56	4.4E-11	7.0E-08	1.7E-11	7.0E-08
Co-57	3.7E-12	1.4E-09	1.4E-12	1.4E-09
Co-58	1.3E-11	1.7E-08	5.1E-12	1.7E-08
Co-60	5.9E-11	4.8E-08	2.3E-11	4.8E-08
Ni-63	1.4E-12	0.0E+00	2.0E-12	3.5E-12
Cu-61	1.7E-11	9.0E-11	2.2E-12	1.1E-10
Cu-64	1.7E-11	2.1E-11	2.2E-12	4.0E-11
Zn-62	2.0E-09	1.6E-10	1.8E-11	2.2E-09
Zn-65	8.2E-09	3.4E-10	7.3E-11	8.6E-09
Ga-67	4.8E-11	9.7E-12	3.6E-12	6.1E-11
Se-75	8.5E-09	1.2E-09	4.3E-11	9.8E-09
Br-76	2.4E-11	1.2E-09	8.0E-12	1.2E-09
Br-77	5.1E-12	1.5E-10	1.7E-12	1.5E-10
Br-82	2.9E-11	1.2E-09	9.4E-12	1.3E-09
Rb-81	7.8E-11	1.8E-09	4.8E-13	1.9E-09
Rb-83	2.7E-09	7.2E-09	1.7E-11	1.0E-08
Sr-83	8.6E-13	2.0E-10	8.9E-12	2.1E-10
Sr-85	9.8E-13	6.2E-10	1.0E-11	6.3E-10
Sr-89	4.6E-12	3.4E-12	4.7E-11	5.5E-11
Sr-90	4.9E-11	9.1E-12	5.1E-10	5.7E-10
Y-90	6.6E-11	4.4E-12	4.9E-11	1.2E-10
Zr-89	1.1E-11	2.4E-10	1.4E-11	2.7E-10
Zr-95	1.3E-11	1.6E-09	1.7E-11	1.7E-09
Nb-95	1.1E-10	8.6E-11	1.1E-11	2.1E-10
Mo-99	4.9E-13	4.6E-10	7.7E-12	4.7E-10
Tc-99	8.1E-12	1.1E-16	1.2E-11	2.0E-11
Tc-99m	2.8E-13	1.3E-13	4.2E-13	8.3E-13
Ru-103	1.1E-11	7.1E-09	6.1E-12	7.1E-09

Radionuclide*	DPURs for adult angler family (µSv/y per Bq/y)			
	Fish	External	Drinking water	Total
Ru-106	1.1E-10	3.4E-09	5.8E-11	3.6E-09
Ag-110m	1.7E-11	7.2E-08	4.5E-12	7.2E-08
In-111	6.1E-10	1.4E-09	1.8E-12	2.0E-09
Sb-125	2.1E-11	1.9E-09	1.7E-11	1.9E-09
I-123	3.4E-12	1.2E-10	3.4E-12	1.3E-10
I-124	2.1E-10	8.8E-10	2.1E-10	1.3E-09
I-125	2.4E-10	8.7E-12	2.4E-10	4.9E-10
I-129	1.8E-09	7.0E-12	1.8E-09	3.6E-09
I-131	3.6E-10	3.2E-10	3.6E-10	1.0E-09
I-133	7.0E-11	5.1E-10	7.0E-11	6.4E-10
I-135	1.5E-11	1.3E-09	1.5E-11	1.3E-09
Cs-134	1.4E-08	2.3E-08	1.7E-10	3.7E-08
Cs-136	2.2E-09	6.3E-09	2.6E-11	8.5E-09
Cs-137	9.5E-09	8.4E-09	1.1E-10	1.8E-08
Ba-140	1.8E-12	9.9E-10	4.6E-11	1.0E-09
La-140	1.4E-11	8.8E-09	1.1E-11	8.8E-09
Ce-141	1.1E-12	1.3E-09	1.4E-12	1.3E-09
Ce-144	8.4E-12	1.5E-09	1.0E-11	1.5E-09
Pm-147	4.1E-12	3.5E-14	4.1E-12	8.3E-12
Sm-153	3.0E-12	2.0E-10	3.0E-12	2.0E-10
Eu-152	1.1E-10	6.3E-10	2.6E-11	7.7E-10
Eu-154	1.6E-10	7.0E-10	3.7E-11	8.9E-10
Eu-155	2.6E-11	1.5E-11	6.0E-12	4.7E-11
Er-169	6.0E-13	2.2E-13	7.2E-13	1.5E-12
Lu-177	1.0E-12	1.6E-10	1.0E-12	1.7E-10
Re-188	1.7E-11	6.5E-12	2.6E-11	5.0E-11
Au-198	1.3E-11	2.1E-09	1.6E-12	2.1E-09
Tl-201	3.0E-11	1.9E-10	1.0E-12	2.2E-10
Pb-210	7.8E-09	1.0E-11	9.4E-09	1.7E-08
Pb-212	6.8E-11	2.3E-09	8.1E-11	2.5E-09
Po-210	1.1E-08	1.5E-13	8.8E-09	1.9E-08
At-211	8.9E-11	3.0E-11	1.8E-10	3.0E-10
Ra-223	2.0E-10	3.6E-10	1.5E-09	2.0E-09
Ra-226	5.5E-10	1.2E-08	4.1E-09	1.7E-08
Ac-225	4.9E-11	9.6E-10	9.8E-11	1.1E-09
Th-227	3.9E-12	1.9E-09	1.9E-11	1.9E-09
Th-230	9.3E-11	4.6E-12	4.6E-10	5.6E-10
Th-232	1.0E-10	6.6E-08	5.1E-10	6.7E-08
Th-234	1.5E-12	5.9E-10	7.5E-12	6.0E-10
U-234	3.0E-11	3.4E-15	9.3E-10	9.6E-10
U-235	2.9E-11	6.7E-12	8.9E-10	9.3E-10
U-238	2.7E-11	1.3E-12	8.5E-10	8.8E-10
Np-237	2.1E-09	2.0E-12	2.1E-09	4.2E-09
Pu-238	2.9E-07	5.2E-13	4.1E-10	2.9E-07
Pu-239	3.1E-07	1.2E-12	4.5E-10	3.1E-07
Pu-240	3.1E-07	5.0E-13	4.5E-10	3.1E-07
Pu-241	6.0E-09	2.3E-14	8.6E-12	6.0E-09

Radionuclide*	DPURs for adult angler family (µSv/y per Bq/y)			
	Fish	External	Drinking water	Total
Pu-242	3.0E-07	4.4E-13	4.3E-10	3.0E-07
Am-241	5.2E-09	1.5E-10	6.6E-10	6.1E-09
Am-242	7.9E-12	5.7E-11	9.8E-13	6.6E-11
Am-243	5.2E-09	3.3E-09	6.6E-10	9.2E-09
Cm-242	1.9E-10	1.0E-13	1.9E-10	3.8E-10
Cm-243	2.4E-09	4.4E-10	2.4E-09	5.2E-09
Cm-244	1.9E-09	7.3E-14	1.9E-09	3.8E-09

*radionuclides with a half-life of less than 3 hours were not considered.

Table 21. Dose per unit release factors for worst age group, irrigated food consumer family – river release scenario

These DPURs are multiplied by the factor Q_{eff} (see Table G.10) when assessing exposure of irrigated food consumer family via the sewer release scenario.

Radionuclide*	Worst total DPUR (µSv/y per Bq/y)	Worst age group
H-3	7.3E-13	Offspring
H-3 organic	1.2E-12	Offspring
C-14	1.6E-10	Offspring
Na-22	8.5E-10	Infant
Na-24	2.0E-11	Infant
P-32	5.7E-10	Offspring
P-33	1.2E-10	Offspring
S-35	1.1E-11	Infant
Cl-36	1.3E-09	Infant
Ca-45	2.0E-10	Offspring
Ca-47	1.5E-10	Offspring
V-48	1.1E-10	Infant
Cr-51	1.5E-12	Infant
Mn-52	2.7E-11	Infant
Mn-54	1.1E-10	Infant
Fe-55	1.8E-11	Infant
Fe-59	1.2E-10	Infant
Co-56	1.6E-10	Infant
Co-57	1.7E-11	Infant
Co-58	4.4E-11	Infant
Co-60	1.3E-09	Infant
Ni-63	6.4E-12	Infant
Cu-61	6.1E-12	Infant
Cu-64	6.8E-12	Infant
Zn-62	5.3E-11	Infant
Zn-65	2.1E-10	Infant
Ga-67	1.0E-11	Infant
Se-75	1.8E-10	Infant
Br-76	2.1E-11	Infant
Br-77	3.7E-12	Infant
Br-82	2.1E-11	Infant
Rb-81	1.3E-12	Infant
Rb-83	8.6E-11	Infant
Sr-83	4.0E-11	Infant
Sr-85	3.9E-11	Infant
Sr-89	2.5E-10	Offspring
Sr-90	1.3E-09	Offspring
Y-90	1.6E-10	Infant
Zr-89	3.8E-11	Infant
Zr-95	9.9E-11	Infant
Nb-95	3.9E-11	Infant

Radionuclide*	Worst total DPUR (µSv/y per Bq/y)	Worst age group
Mo-99	2.0E-11	Infant
Tc-99	1.4E-09	Infant
Tc-99m	1.1E-12	Infant
Ru-103	2.6E-11	Infant
Ru-106	2.3E-10	Infant
Ag-110m	2.8E-10	Infant
In-111	5.3E-12	Infant
Sb-125	1.8E-10	Infant
I-123	1.6E-11	Infant
I-124	8.0E-10	Infant
I-125	6.1E-10	Infant
I-129	4.2E-09	Child
I-131	1.4E-09	Infant
I-133	3.1E-10	Infant
I-135	6.3E-11	Infant
Cs-134	8.4E-10	Adult
Cs-136	5.9E-11	Infant
Cs-137	1.0E-09	Adult
Ba-140	1.6E-10	Infant
La-140	3.4E-11	Infant
Ce-141	7.2E-12	Infant
Ce-144	5.8E-11	Infant
Pm-147	1.4E-11	Infant
Sm-153	1.0E-11	Infant
Eu-152	1.0E-09	Infant
Eu-154	9.3E-10	Infant
Eu-155	3.9E-11	Infant
Er-169	3.0E-12	Infant
Lu-177	4.1E-12	Infant
Re-188	9.0E-11	Infant
Au-198	6.1E-12	Infant
Tl-201	2.7E-12	Infant
Pb-210	2.5E-08	Infant
Pb-212	3.7E-10	Infant
Po-210	7.0E-08	Infant
At-211	2.4E-09	Infant
Ra-223	7.3E-09	Infant
Ra-226	1.2E-08	Child
Ac-225	3.6E-10	Infant
Th-227	9.3E-11	Infant
Th-230	3.9E-09	Adult
Th-232	3.1E-09	Adult
Th-234	3.3E-11	Infant
U-234	1.2E-09	Infant
U-235	1.4E-09	Infant
U-238	1.1E-09	Infant
Np-237	2.8E-09	Adult

Radionuclide*	Worst total DPUR (µSv/y per Bq/y)	Worst age group
Pu-238	1.0E-09	Adult
Pu-239	1.3E-09	Adult
Pu-240	1.1E-09	Adult
Pu-241	3.6E-11	Adult
Pu-242	1.1E-09	Adult
Am-241	1.5E-09	Adult
Am-242	4.1E-12	Infant
Am-243	1.5E-09	Adult
Cm-242	5.6E-10	Infant
Cm-243	3.2E-09	Adult
Cm-244	2.2E-09	Adult

*radionuclides with a half-life of less than 3 hours were not considered.

Table 22. Dose per unit release factors for offspring irrigated food consumer family – river release scenario

Radio-nuclide*	DPURs for offspring irrigated food consumer family (µSv/y per Bq/y)					
	Green veg	Root veg	Fruit	External, soil	Ingestion, water	Total
H-3	3.8E-14	6.2E-14	3.6E-14	0.0E+00	5.9E-13	7.3E-13
H-3 organic	1.7E-14	2.7E-14	1.6E-14	0.0E+00	1.1E-12	1.2E-12
C-14	4.4E-11	5.6E-11	4.2E-11	0.0E+00	1.4E-11	1.6E-10
Na-22	1.1E-11	1.7E-11	2.8E-11	6.3E-10	6.8E-11	7.6E-10
Na-24	<p	<p	<p	9.6E-13	<p	9.6E-13
P-32	3.6E-11	2.1E-11	3.8E-11	0.0E+00	4.7E-10	5.7E-10
P-33	9.1E-12	7.8E-12	1.4E-11	0.0E+00	9.1E-11	1.2E-10
S-35	5.9E-13	7.6E-13	1.2E-12	0.0E+00	3.8E-12	6.3E-12
Cl-36	<p	<p	<p	2.4E-13	<p	2.4E-13
Ca-45	3.8E-11	9.8E-13	4.2E-12	2.7E-20	1.6E-10	2.0E-10
Ca-47	5.1E-12	1.9E-14	3.5E-13	2.3E-12	1.4E-10	1.5E-10
V-48	<p	<p	<p	1.9E-11	<p	1.9E-11
Cr-51	<p	<p	<p	3.6E-13	<p	3.6E-13
Mn-52	<p	<p	<p	8.0E-12	<p	8.0E-12
Mn-54	<p	<p	<p	9.6E-11	<p	9.6E-11
Fe-55	<p	<p	<p	8.2E-16	<p	8.2E-16
Fe-59	<p	<p	<p	2.1E-11	<p	2.1E-11
Co-56	<p	<p	<p	1.1E-10	<p	1.1E-10
Co-57	<p	<p	<p	1.1E-11	<p	1.1E-11
Co-58	<p	<p	<p	2.8E-11	<p	2.8E-11
Co-60	<p	<p	<p	1.2E-09	<p	1.2E-09
Ni-63	<p	<p	<p	0.0E+00	<p	0.0E+00
Cu-61	<p	<p	<p	5.0E-14	<p	5.0E-14
Cu-64	<p	<p	<p	4.3E-14	<p	4.3E-14
Zn-62	<p	<p	<p	2.4E-13	<p	2.4E-13
Zn-65	<p	<p	<p	5.3E-11	<p	5.3E-11
Ga-67	<p	<p	<p	2.0E-13	<p	2.0E-13
Se-75	9.4E-12	1.3E-11	1.8E-11	1.8E-11	4.4E-11	1.0E-10
Br-76	<p	<p	<p	7.1E-13	<p	7.1E-13
Br-77	<p	<p	<p	3.1E-13	<p	3.1E-13
Br-82	<p	<p	<p	1.6E-12	<p	1.6E-12
Rb-81	<p	<p	<p	5.0E-14	<p	5.0E-14
Rb-83	<p	<p	<p	1.8E-11	<p	1.8E-11
Sr-83	<p	<p	<p	1.8E-11	<p	1.8E-11
Sr-85	<p	<p	<p	1.3E-11	<p	1.3E-11
Sr-89	2.5E-11	5.6E-13	3.5E-12	1.7E-15	2.2E-10	2.5E-10
Sr-90	2.7E-10	2.6E-10	2.7E-11	1.3E-17	7.8E-10	1.3E-09
Y-90	<p	<p	<p	6.6E-20	<p	6.6E-20
Zr-89	<p	<p	<p	1.6E-12	<p	1.6E-12
Zr-95	<p	<p	<p	5.1E-11	<p	5.1E-11
Nb-95	<p	<p	<p	1.1E-11	<p	1.1E-11
Mo-99	<p	<p	<p	3.2E-13	<p	3.2E-13
Tc-99	<p	<p	<p	0.0E+00	<p	0.0E+00
Tc-99m	<p	<p	<p	1.2E-14	<p	1.2E-14
Ru-103	<p	<p	<p	7.7E-12	<p	7.7E-12

Radio-nuclide*	DPURs for offspring irrigated food consumer family (µSv/y per Bq/y)					
	Green veg	Root veg	Fruit	External, soil	Ingestion, water	Total
Ru-106	<p	<p	<p	2.7E-11	<p	2.7E-11
Ag-110m	<p	<p	<p	2.6E-10	<p	2.6E-10
In-111	<p	<p	<p	4.5E-13	<p	4.5E-13
Sb-125	<p	<p	<p	1.3E-10	<p	1.3E-10
I-123	<p	<p	<p	2.2E-12	<p	2.2E-12
I-124	<p	<p	<p	1.9E-12	<p	1.9E-12
I-125	<p	<p	<p	2.4E-13	<p	2.4E-13
I-129	<p	<p	<p	4.2E-12	<p	4.2E-12
I-131	2.3E-11	7.8E-12	1.5E-11	1.3E-12	3.7E-10	4.2E-10
I-133	<p	<p	<p	2.3E-13	<p	2.3E-13
I-135	<p	<p	<p	2.0E-13	<p	2.0E-13
Cs-134	<p	<p	<p	3.8E-10	<p	3.8E-10
Cs-136	<p	<p	<p	1.2E-11	<p	1.2E-11
Cs-137	<p	<p	<p	6.9E-10	<p	6.9E-10
Ba-140	<p	<p	<p	1.4E-11	<p	1.4E-11
La-140	<p	<p	<p	1.6E-12	<p	1.6E-12
Ce-141	<p	<p	<p	9.2E-13	<p	9.2E-13
Ce-144	<p	<p	<p	4.9E-12	<p	4.9E-12
Pm-147	<p	<p	<p	9.9E-16	<p	9.9E-16
Sm-153	<p	<p	<p	3.7E-14	<p	3.7E-14
Eu-152	<p	<p	<p	9.5E-10	<p	9.5E-10
Eu-154	<p	<p	<p	8.2E-10	<p	8.2E-10
Eu-155	<p	<p	<p	2.0E-11	<p	2.0E-11
Er-169	<p	<p	<p	8.4E-20	<p	8.4E-20
Lu-177	<p	<p	<p	9.3E-14	<p	9.3E-14
Re-188	<p	<p	<p	1.6E-14	<p	1.6E-14
Au-198	<p	<p	<p	4.7E-13	<p	4.7E-13
Tl-201	<p	<p	<p	9.4E-14	<p	9.4E-14
Pb-210	<p	<p	<p	6.7E-13	<p	6.7E-13
Pb-212	<p	<p	<p	6.3E-14	<p	6.3E-14
Po-210	<p	<p	<p	4.6E-16	<p	4.6E-16
At-211	<p	<p	<p	1.9E-09	<p	1.9E-09
Ra-223	<p	<p	<p	1.3E-12	<p	1.3E-12
Ra-226	1.1E-09	5.1E-10	3.7E-10	2.8E-09	4.7E-09	9.4E-09
Ac-225	<p	<p	<p	7.5E-13	<p	7.5E-13
Th-227	<p	<p	<p	4.3E-12	<p	4.3E-12
Th-230	<p	<p	<p	2.8E-09	<p	2.8E-09
Th-232	<p	<p	<p	2.0E-09	<p	2.0E-09
Th-234	<p	<p	<p	4.0E-13	<p	4.0E-13
U-234	<p	<p	<p	2.1E-11	<p	2.1E-11
U-235	<p	<p	<p	2.1E-10	<p	2.1E-10
U-238	<p	<p	<p	3.4E-11	<p	3.4E-11
Np-237	<p	<p	<p	3.1E-10	<p	3.1E-10
Pu-238	<p	<p	<p	1.7E-13	<p	1.7E-13
Pu-239	<p	<p	<p	2.1E-10	<p	2.1E-10
Pu-240	<p	<p	<p	1.2E-13	<p	1.2E-13
Pu-241	<p	<p	<p	1.4E-11	<p	1.4E-11

Radio-nuclide*	DPURs for offspring irrigated food consumer family (µSv/y per Bq/y)					
	Green veg	Root veg	Fruit	External, soil	Ingestion, water	Total
Pu-242	<p	<p	<p	3.5E-11	<p	3.5E-11
Am-241	<p	<p	<p	3.2E-10	<p	3.2E-10
Am-242	<p	<p	<p	9.3E-13	<p	9.3E-13
Am-243	<p	<p	<p	2.6E-10	<p	2.6E-10
Cm-242	<p	<p	<p	5.3E-14	<p	5.3E-14
Cm-243	<p	<p	<p	3.7E-10	<p	3.7E-10
Cm-244	<p	<p	<p	2.5E-13	<p	2.5E-13

<p: not calculated as dose rate to parent greater than dose rate to offspring
*radionuclides with a half-life of less than 3 hours were not considered.

Table 23. Dose per unit release factors for infant irrigated food consumer family – river release scenario

Radio-nuclide*	DPURs for infant irrigated food consumer family (µSv/y per Bq/y)					
	Green veg	Root veg	Fruit	External, soil	Ingestion, water	Total
H-3	1.1E-14	3.3E-14	2.6E-14	0.0E+00	4.0E-13	4.7E-13
H-3 organic	6.0E-15	1.8E-14	1.4E-14	0.0E+00	9.2E-13	9.5E-13
C-14	1.7E-11	3.9E-11	3.9E-11	0.0E+00	1.2E-11	1.1E-10
Na-22	8.9E-12	2.4E-11	5.5E-11	6.3E-10	1.2E-10	8.5E-10
Na-24	4.7E-14	5.6E-16	9.1E-15	9.6E-13	1.9E-11	2.0E-11
P-32	5.1E-12	5.6E-12	1.4E-11	0.0E+00	1.6E-10	1.8E-10
P-33	6.4E-13	1.0E-12	2.4E-12	0.0E+00	1.5E-11	1.9E-11
S-35	4.8E-13	1.2E-12	2.4E-12	0.0E+00	7.1E-12	1.1E-11
Cl-36	1.7E-10	4.3E-10	6.3E-10	2.4E-13	5.2E-11	1.3E-09
Ca-45	4.0E-12	1.9E-13	1.1E-12	2.7E-20	3.9E-11	4.4E-11
Ca-47	1.2E-12	8.0E-15	2.0E-13	2.3E-12	7.3E-11	7.7E-11
V-48	2.8E-12	3.5E-15	7.1E-13	1.9E-11	9.0E-11	1.1E-10
Cr-51	7.2E-14	4.4E-18	1.2E-14	3.6E-13	1.1E-12	1.5E-12
Mn-52	1.2E-12	1.1E-14	2.5E-13	8.0E-12	1.7E-11	2.7E-11
Mn-54	1.5E-12	2.8E-13	1.7E-12	9.6E-11	6.1E-12	1.1E-10
Fe-55	1.3E-12	7.1E-15	5.5E-13	8.2E-16	1.6E-11	1.8E-11
Fe-59	4.9E-12	9.6E-15	1.6E-12	2.1E-11	8.9E-11	1.2E-10
Co-56	6.3E-12	1.0E-13	2.4E-12	1.1E-10	4.5E-11	1.6E-10
Co-57	7.7E-13	3.5E-14	3.4E-13	1.1E-11	4.8E-12	1.7E-11
Co-58	1.8E-12	2.8E-14	6.8E-13	2.8E-11	1.3E-11	4.4E-11
Co-60	1.4E-11	4.0E-12	6.3E-12	1.2E-09	8.1E-11	1.3E-09
Ni-63	7.9E-13	2.8E-13	4.2E-13	0.0E+00	4.9E-12	6.4E-12
Cu-61	3.6E-15	3.9E-17	5.7E-16	5.0E-14	6.1E-12	6.1E-12
Cu-64	1.4E-14	1.6E-16	2.3E-15	4.3E-14	6.7E-12	6.8E-12
Zn-62	8.3E-14	3.5E-16	1.5E-14	2.4E-13	5.3E-11	5.3E-11
Zn-65	8.6E-12	8.1E-13	1.4E-11	5.3E-11	1.3E-10	2.1E-10
Ga-67	1.1E-13	3.4E-18	1.8E-14	2.0E-13	9.8E-12	1.0E-11
Se-75	8.5E-12	2.1E-11	4.1E-11	1.8E-11	9.2E-11	1.8E-10
Br-76	5.9E-14	8.8E-16	1.2E-14	7.1E-13	2.0E-11	2.1E-11
Br-77	3.1E-14	3.6E-15	1.5E-14	3.1E-13	3.3E-12	3.7E-12
Br-82	1.2E-13	6.7E-15	3.7E-14	1.6E-12	2.0E-11	2.1E-11
Rb-81	2.0E-15	2.7E-17	3.4E-16	5.0E-14	1.2E-12	1.3E-12
Rb-83	4.2E-12	1.0E-11	2.2E-11	1.8E-11	3.2E-11	8.6E-11
Sr-83	1.1E-13	7.7E-16	1.8E-14	1.8E-11	2.1E-11	4.0E-11
Sr-85	1.3E-12	6.3E-14	4.7E-13	1.3E-11	2.4E-11	3.9E-11
Sr-89	7.0E-12	2.9E-13	2.4E-12	1.7E-15	1.4E-10	1.5E-10
Sr-90	8.4E-11	1.5E-10	2.2E-11	1.3E-17	5.7E-10	8.3E-10
Y-90	1.5E-12	7.9E-17	2.6E-13	6.6E-20	1.6E-10	1.6E-10
Zr-89	4.0E-13	4.0E-17	6.9E-14	1.6E-12	3.6E-11	3.8E-11
Zr-95	2.3E-12	6.6E-15	8.4E-13	5.1E-11	4.4E-11	9.9E-11
Nb-95	1.1E-12	3.0E-15	3.6E-13	1.1E-11	2.6E-11	3.9E-11
Mo-99	2.7E-13	1.6E-15	4.7E-14	3.2E-13	1.9E-11	2.0E-11
Tc-99	3.1E-10	5.9E-10	4.8E-10	0.0E+00	4.0E-11	1.4E-09
Tc-99m	1.6E-15	6.5E-16	3.1E-16	1.2E-14	1.1E-12	1.1E-12

Radio-nuclide*	DPURs for infant irrigated food consumer family (µSv/y per Bq/y)					
	Green veg	Root veg	Fruit	External, soil	Ingestion, water	Total
Ru-103	1.6E-12	1.3E-15	2.6E-13	7.7E-12	1.7E-11	2.6E-11
Ru-106	2.3E-11	1.2E-13	3.6E-12	2.7E-11	1.8E-10	2.3E-10
Ag-110m	6.6E-12	2.9E-14	4.8E-12	2.6E-10	9.8E-12	2.8E-10
In-111	1.4E-13	3.4E-18	2.3E-14	4.5E-13	4.7E-12	5.3E-12
Sb-125	3.0E-12	1.6E-14	1.6E-12	1.3E-10	4.2E-11	1.8E-10
I-123	3.4E-14	3.6E-16	6.4E-15	2.2E-12	1.3E-11	1.6E-11
I-124	1.3E-11	3.5E-12	1.1E-11	1.9E-12	7.7E-10	8.0E-10
I-125	2.7E-11	5.7E-11	1.3E-10	2.4E-13	4.0E-10	6.1E-10
I-129	1.9E-10	5.4E-10	8.4E-10	4.2E-12	1.5E-09	3.1E-09
I-131	3.4E-11	2.1E-11	5.5E-11	1.3E-12	1.3E-09	1.4E-09
I-133	1.2E-12	2.8E-14	2.7E-13	2.3E-13	3.1E-10	3.1E-10
I-135	8.2E-14	3.1E-16	1.4E-14	2.0E-13	6.2E-11	6.3E-11
Cs-134	9.5E-12	2.6E-11	5.8E-11	3.8E-10	6.1E-11	5.3E-10
Cs-136	2.4E-12	2.4E-12	5.9E-12	1.2E-11	3.6E-11	5.9E-11
Cs-137	7.8E-12	2.3E-11	4.6E-11	6.9E-10	4.6E-11	8.1E-10
Ba-140	4.1E-12	2.1E-15	9.5E-13	1.4E-11	1.4E-10	1.6E-10
La-140	6.6E-13	2.1E-17	1.1E-13	1.6E-12	3.2E-11	3.4E-11
Ce-141	1.7E-12	6.9E-16	2.7E-13	9.2E-13	4.3E-12	7.2E-12
Ce-144	1.8E-11	4.4E-14	2.8E-12	4.9E-12	3.3E-11	5.8E-11
Pm-147	9.2E-13	5.3E-14	2.9E-13	9.9E-16	1.3E-11	1.4E-11
Sm-153	3.1E-13	3.1E-17	5.0E-14	3.7E-14	9.6E-12	1.0E-11
Eu-152	3.6E-12	3.3E-13	8.3E-13	9.5E-10	6.0E-11	1.0E-09
Eu-154	5.7E-12	3.9E-13	1.2E-12	8.2E-10	9.7E-11	9.3E-10
Eu-155	1.0E-12	4.1E-14	2.0E-13	2.0E-11	1.8E-11	3.9E-11
Er-169	5.3E-13	9.3E-17	8.5E-14	8.4E-20	2.4E-12	3.0E-12
Lu-177	6.0E-13	8.9E-17	9.6E-14	9.3E-14	3.3E-12	4.1E-12
Re-188	3.7E-13	1.6E-13	8.4E-14	1.6E-14	8.9E-11	9.0E-11
Au-198	5.5E-13	1.8E-16	8.9E-14	4.7E-13	5.0E-12	6.1E-12
Tl-201	4.8E-14	8.5E-15	3.0E-14	9.4E-14	2.5E-12	2.7E-12
Pb-210	2.0E-09	2.4E-10	1.4E-09	6.7E-13	2.1E-08	2.5E-08
Pb-212	9.2E-13	1.9E-16	1.5E-13	6.3E-14	3.7E-10	3.7E-10
Po-210	4.7E-09	1.2E-08	2.6E-08	4.6E-16	2.8E-08	7.0E-08
At-211	7.8E-13	3.3E-15	1.3E-13	1.9E-09	5.5E-10	2.4E-09
Ra-223	2.4E-10	6.1E-13	5.3E-11	1.3E-12	7.0E-09	7.3E-09
Ra-226	5.9E-10	5.3E-10	5.2E-10	2.8E-09	6.1E-09	1.1E-08
Ac-225	3.5E-11	5.4E-15	5.7E-12	7.5E-13	3.2E-10	3.6E-10
Th-227	1.9E-11	7.0E-16	3.1E-12	4.3E-12	6.7E-11	9.3E-11
Th-230	1.9E-10	2.6E-12	4.0E-11	2.8E-09	3.9E-10	3.5E-09
Th-232	2.1E-10	2.9E-12	4.3E-11	2.0E-09	4.3E-10	2.7E-09
Th-234	7.5E-12	3.3E-16	1.2E-12	4.0E-13	2.4E-11	3.3E-11
U-234	6.5E-11	8.8E-12	1.5E-11	2.1E-11	1.1E-09	1.2E-09
U-235	6.5E-11	8.8E-12	1.5E-11	2.1E-10	1.1E-09	1.4E-09
U-238	6.0E-11	8.1E-12	1.3E-11	3.4E-11	9.9E-10	1.1E-09
Np-237	1.1E-10	3.7E-11	3.0E-11	3.1E-10	1.7E-09	2.2E-09
Pu-238	1.9E-10	1.0E-12	3.2E-11	1.7E-13	3.1E-10	5.3E-10
Pu-239	2.0E-10	1.3E-12	3.4E-11	2.1E-10	3.3E-10	7.7E-10
Pu-240	2.0E-10	1.3E-12	3.4E-11	1.2E-13	3.3E-10	5.6E-10

Radio-nuclide*	DPURs for infant irrigated food consumer family (µSv/y per Bq/y)					
	Green veg	Root veg	Fruit	External, soil	Ingestion, water	Total
Pu-241	2.7E-12	7.1E-15	4.5E-13	1.4E-11	4.4E-12	2.2E-11
Pu-242	1.9E-10	1.2E-12	3.3E-11	3.5E-11	3.1E-10	5.7E-10
Am-241	1.8E-10	1.8E-12	3.0E-11	3.2E-10	5.3E-10	1.1E-09
Am-242	4.7E-14	4.4E-19	7.6E-15	9.3E-13	3.1E-12	4.1E-12
Am-243	1.8E-10	1.9E-12	3.0E-11	2.6E-10	5.3E-10	9.9E-10
Cm-242	3.3E-11	6.9E-15	5.3E-12	5.3E-14	5.2E-10	5.6E-10
Cm-243	1.6E-10	1.3E-12	2.6E-11	3.7E-10	2.3E-09	2.8E-09
Cm-244	1.4E-10	9.2E-13	2.3E-11	2.5E-13	2.0E-09	2.2E-09

*radionuclides with a half-life of less than 3 hours were not considered.

Table 24. Dose per unit release factors for child irrigated food consumer family – river release scenario

Radio-nuclide*	DPURs for child irrigated food consumer family (µSv/y per Bq/y)					
	Green veg	Root veg	Fruit	External, soil	Ingestion, water	Total
H-3	1.2E-14	3.4E-14	1.8E-14	0.0E+00	2.6E-13	3.2E-13
H-3 organic	6.6E-15	1.8E-14	9.4E-15	0.0E+00	5.9E-13	6.2E-13
C-14	1.9E-11	4.1E-11	2.8E-11	0.0E+00	8.2E-12	9.7E-11
Na-22	7.6E-12	1.9E-11	2.9E-11	6.3E-10	6.1E-11	7.5E-10
Na-24	3.7E-14	4.0E-16	4.4E-15	9.6E-13	8.5E-12	9.5E-12
P-32	3.3E-12	3.3E-12	5.4E-12	0.0E+00	5.9E-11	7.1E-11
P-33	4.4E-13	6.3E-13	1.0E-12	0.0E+00	5.9E-12	7.9E-12
S-35	3.5E-13	7.5E-13	1.1E-12	0.0E+00	3.0E-12	5.1E-12
Cl-36	1.2E-10	2.7E-10	2.7E-10	2.4E-13	2.1E-11	6.8E-10
Ca-45	3.4E-12	1.5E-13	5.8E-13	2.7E-20	1.9E-11	2.3E-11
Ca-47	8.8E-13	5.4E-15	9.1E-14	2.3E-12	3.2E-11	3.5E-11
V-48	2.4E-12	2.6E-15	3.6E-13	1.9E-11	4.3E-11	6.5E-11
Cr-51	5.7E-14	3.2E-18	5.7E-15	3.6E-13	4.8E-13	9.1E-13
Mn-52	1.1E-12	9.4E-15	1.4E-13	8.0E-12	9.1E-12	1.8E-11
Mn-54	1.5E-12	2.5E-13	1.0E-12	9.6E-11	3.5E-12	1.0E-10
Fe-55	1.4E-12	6.8E-15	3.6E-13	8.2E-16	1.0E-11	1.2E-11
Fe-59	4.1E-12	7.3E-15	8.5E-13	2.1E-11	4.3E-11	7.0E-11
Co-56	5.7E-12	8.5E-14	1.3E-12	1.1E-10	2.3E-11	1.4E-10
Co-57	6.5E-13	2.7E-14	1.7E-13	1.1E-11	2.3E-12	1.4E-11
Co-58	1.6E-12	2.3E-14	3.8E-13	2.8E-11	6.8E-12	3.7E-11
Co-60	1.4E-11	3.5E-12	3.7E-12	1.2E-09	4.4E-11	1.3E-09
Ni-63	6.1E-13	2.0E-13	2.0E-13	0.0E+00	2.2E-12	3.2E-12
Cu-61	2.5E-15	2.5E-17	2.5E-16	5.0E-14	2.5E-12	2.6E-12
Cu-64	1.0E-14	1.0E-16	9.9E-16	4.3E-14	2.7E-12	2.8E-12
Zn-62	6.0E-14	2.2E-16	6.7E-15	2.4E-13	2.2E-11	2.2E-11
Zn-65	8.0E-12	6.8E-13	7.8E-12	5.3E-11	7.0E-11	1.4E-10
Ga-67	8.4E-14	2.4E-18	8.8E-15	2.0E-13	4.4E-12	4.7E-12
Se-75	9.2E-12	2.1E-11	2.7E-11	1.8E-11	5.7E-11	1.3E-10
Br-76	4.5E-14	6.0E-16	5.5E-15	7.1E-13	8.8E-12	9.6E-12
Br-77	2.8E-14	3.0E-15	8.1E-15	3.1E-13	1.7E-12	2.1E-12
Br-82	1.0E-13	5.1E-15	1.9E-14	1.6E-12	9.6E-12	1.1E-11
Rb-81	1.5E-15	1.8E-17	1.5E-16	5.0E-14	5.1E-13	5.7E-13
Rb-83	3.7E-12	8.1E-12	1.2E-11	1.8E-11	1.6E-11	5.8E-11
Sr-83	8.9E-14	5.5E-16	8.9E-15	1.8E-11	9.6E-12	2.8E-11
Sr-85	1.4E-12	6.4E-14	3.2E-13	1.3E-11	1.6E-11	3.1E-11
Sr-89	5.3E-12	2.0E-13	1.1E-12	1.7E-15	6.1E-11	6.8E-11
Sr-90	1.6E-10	2.6E-10	2.5E-11	1.3E-17	6.3E-10	1.1E-09
Y-90	1.0E-12	4.9E-17	1.1E-13	6.6E-20	6.3E-11	6.4E-11
Zr-89	3.4E-13	3.0E-17	3.5E-14	1.6E-12	1.7E-11	1.9E-11
Zr-95	1.8E-12	4.7E-15	4.1E-13	5.1E-11	2.0E-11	7.4E-11
Nb-95	9.0E-13	2.2E-15	1.8E-13	1.1E-11	1.2E-11	2.4E-11
Mo-99	2.0E-13	1.0E-15	2.1E-14	3.2E-13	8.2E-12	8.8E-12
Tc-99	2.0E-10	3.4E-10	1.8E-10	0.0E+00	1.4E-11	7.3E-10
Tc-99m	1.2E-15	4.5E-16	1.4E-16	1.2E-14	4.8E-13	4.9E-13
Ru-103	1.2E-12	8.7E-16	1.2E-13	7.7E-12	7.3E-12	1.6E-11

Radio-nuclide*	DPURs for child irrigated food consumer family (µSv/y per Bq/y)					
	Green veg	Root veg	Fruit	External, soil	Ingestion, water	Total
Ru-106	1.6E-11	7.9E-14	1.6E-12	2.7E-11	7.3E-11	1.2E-10
Ag-110m	5.8E-12	2.3E-14	2.5E-12	2.6E-10	4.9E-12	2.7E-10
In-111	1.1E-13	2.5E-18	1.1E-14	4.5E-13	2.2E-12	2.8E-12
Sb-125	2.4E-12	1.2E-14	7.7E-13	1.3E-10	1.9E-11	1.5E-10
I-123	2.1E-14	2.0E-16	2.4E-15	2.2E-12	4.6E-12	6.8E-12
I-124	8.2E-12	2.1E-12	4.4E-12	1.9E-12	2.9E-10	3.1E-10
I-125	3.4E-11	6.5E-11	9.9E-11	2.4E-13	2.9E-10	4.9E-10
I-129	3.8E-10	9.8E-10	1.0E-09	4.2E-12	1.8E-09	4.2E-09
I-131	2.3E-11	1.3E-11	2.3E-11	1.3E-12	4.9E-10	5.5E-10
I-133	6.5E-13	1.3E-14	8.8E-14	2.3E-13	9.4E-11	9.5E-11
I-135	4.7E-14	1.6E-16	4.8E-15	2.0E-13	2.1E-11	2.1E-11
Cs-134	1.9E-11	4.8E-11	7.3E-11	3.8E-10	7.2E-11	5.9E-10
Cs-136	2.6E-12	2.3E-12	3.9E-12	1.2E-11	2.3E-11	4.3E-11
Cs-137	1.5E-11	4.1E-11	5.4E-11	6.9E-10	5.1E-11	8.5E-10
Ba-140	3.1E-12	1.4E-15	4.4E-13	1.4E-11	6.0E-11	7.7E-11
La-140	5.0E-13	1.5E-17	5.0E-14	1.6E-12	1.4E-11	1.6E-11
Ce-141	1.2E-12	4.3E-16	1.1E-13	9.2E-13	1.7E-12	3.9E-12
Ce-144	1.2E-11	2.6E-14	1.1E-12	4.9E-12	1.2E-11	3.0E-11
Pm-147	6.4E-13	3.4E-14	1.3E-13	9.9E-16	5.3E-12	6.1E-12
Sm-153	2.2E-13	1.9E-17	2.1E-14	3.7E-14	3.8E-12	4.1E-12
Eu-152	3.0E-12	2.5E-13	4.2E-13	9.5E-10	2.8E-11	9.8E-10
Eu-154	4.6E-12	2.8E-13	6.0E-13	8.2E-10	4.5E-11	8.7E-10
Eu-155	7.5E-13	2.7E-14	8.9E-14	2.0E-11	7.4E-12	2.8E-11
Er-169	3.6E-13	5.8E-17	3.6E-14	8.4E-20	9.3E-13	1.3E-12
Lu-177	4.3E-13	5.8E-17	4.2E-14	9.3E-14	1.4E-12	1.9E-12
Re-188	2.3E-13	9.0E-14	3.1E-14	1.6E-14	3.2E-11	3.2E-11
Au-198	3.9E-13	1.1E-16	3.9E-14	4.7E-13	2.1E-12	3.0E-12
Tl-201	3.7E-14	5.9E-15	1.4E-14	9.4E-14	1.1E-12	1.3E-12
Pb-210	2.5E-09	2.6E-10	1.1E-09	6.7E-13	1.5E-08	1.9E-08
Pb-212	6.8E-13	1.3E-16	6.7E-14	6.3E-14	1.6E-10	1.6E-10
Po-210	3.2E-09	7.2E-09	1.1E-08	4.6E-16	1.1E-08	3.3E-08
At-211	5.4E-13	2.1E-15	5.5E-14	1.9E-09	2.2E-10	2.1E-09
Ra-223	2.3E-10	5.3E-13	3.1E-11	1.3E-12	3.9E-09	4.1E-09
Ra-226	1.2E-09	9.3E-10	6.2E-10	2.8E-09	6.8E-09	1.2E-08
Ac-225	2.5E-11	3.4E-15	2.4E-12	7.5E-13	1.3E-10	1.6E-10
Th-227	1.5E-11	4.9E-16	1.4E-12	4.3E-12	3.0E-11	5.0E-11
Th-230	2.7E-10	3.2E-12	3.3E-11	2.8E-09	3.1E-10	3.4E-09
Th-232	3.2E-10	3.9E-12	4.0E-11	2.0E-09	3.7E-10	2.7E-09
Th-234	5.2E-12	2.1E-16	5.1E-13	4.0E-13	9.5E-12	1.6E-11
U-234	8.6E-11	1.1E-11	1.2E-11	2.1E-11	8.2E-10	9.5E-10
U-235	8.2E-11	1.0E-11	1.1E-11	2.1E-10	7.9E-10	1.1E-09
U-238	7.9E-11	9.7E-12	1.1E-11	3.4E-11	7.5E-10	8.9E-10
Np-237	1.3E-10	4.1E-11	2.2E-11	3.1E-10	1.2E-09	1.7E-09
Pu-238	2.7E-10	1.3E-12	2.8E-11	1.7E-13	2.5E-10	5.5E-10
Pu-239	3.0E-10	1.8E-12	3.1E-11	2.1E-10	2.8E-10	8.3E-10
Pu-240	3.0E-10	1.8E-12	3.1E-11	1.2E-13	2.8E-10	6.1E-10
Pu-241	5.6E-12	1.3E-14	5.7E-13	1.4E-11	5.3E-12	2.6E-11

Radio-nuclide*	DPURs for child irrigated food consumer family (µSv/y per Bq/y)					
	Green veg	Root veg	Fruit	External, soil	Ingestion, water	Total
Pu-242	2.9E-10	1.7E-12	3.0E-11	3.5E-11	2.7E-10	6.3E-10
Am-241	2.4E-10	2.3E-12	2.6E-11	3.2E-10	4.2E-10	1.0E-09
Am-242	3.2E-14	2.7E-19	3.2E-15	9.3E-13	1.2E-12	2.2E-12
Am-243	2.4E-10	2.4E-12	2.6E-11	2.6E-10	4.2E-10	9.5E-10
Cm-242	2.4E-11	4.6E-15	2.4E-12	5.3E-14	2.2E-10	2.5E-10
Cm-243	1.8E-10	1.4E-12	1.8E-11	3.7E-10	1.5E-09	2.0E-09
Cm-244	1.5E-10	9.3E-13	1.6E-11	2.5E-13	1.3E-09	1.5E-09

*radionuclides with a half-life of less than 3 hours were not considered.

Table 25. Dose per unit release factors for adult irrigated food consumer family – river release scenario

Radio-nuclide*	DPURs for adult irrigated food consumer family (µSv/y per Bq/y)					
	Green veg	Root veg	Fruit	External, soil	Ingestion, water	Total
H-3	2.2E-14	3.6E-14	2.1E-14	0.0E+00	3.4E-13	4.2E-13
H-3 organic	1.1E-14	1.8E-14	1.0E-14	0.0E+00	7.4E-13	7.8E-13
C-14	3.2E-11	4.1E-11	3.0E-11	0.0E+00	1.0E-11	1.1E-10
Na-22	1.0E-11	1.5E-11	2.5E-11	6.3E-10	6.1E-11	7.5E-10
Na-24	4.7E-14	3.0E-16	3.7E-15	9.6E-13	8.2E-12	9.2E-12
P-32	3.4E-12	2.0E-12	3.7E-12	0.0E+00	4.6E-11	5.5E-11
P-33	4.5E-13	3.9E-13	6.8E-13	0.0E+00	4.6E-12	6.1E-12
S-35	3.9E-13	5.0E-13	7.6E-13	0.0E+00	2.5E-12	4.1E-12
Cl-36	1.3E-10	1.8E-10	2.0E-10	2.4E-13	1.8E-11	5.3E-10
Ca-45	3.1E-12	8.0E-14	3.4E-13	2.7E-20	1.3E-11	1.6E-11
Ca-47	1.1E-12	4.0E-15	7.3E-14	2.3E-12	2.9E-11	3.3E-11
V-48	2.8E-12	1.8E-15	2.8E-13	1.9E-11	3.8E-11	6.0E-11
Cr-51	6.4E-14	2.1E-18	4.1E-15	3.6E-13	4.0E-13	8.3E-13
Mn-52	1.3E-12	6.8E-15	1.1E-13	8.0E-12	8.2E-12	1.8E-11
Mn-54	1.9E-12	1.8E-13	8.2E-13	9.6E-11	3.2E-12	1.0E-10
Fe-55	9.5E-13	2.8E-15	1.6E-13	8.2E-16	5.2E-12	6.3E-12
Fe-59	3.6E-12	3.8E-15	4.9E-13	2.1E-11	2.9E-11	5.4E-11
Co-56	5.6E-12	5.0E-14	8.6E-13	1.1E-10	1.7E-11	1.3E-10
Co-57	5.4E-13	1.3E-14	9.4E-14	1.1E-11	1.4E-12	1.3E-11
Co-58	1.6E-12	1.4E-14	2.5E-13	2.8E-11	5.1E-12	3.5E-11
Co-60	9.7E-12	1.5E-12	1.7E-12	1.2E-09	2.3E-11	1.2E-09
Ni-63	7.5E-13	1.5E-13	1.6E-13	0.0E+00	2.0E-12	3.1E-12
Cu-61	3.0E-15	1.8E-17	2.0E-16	5.0E-14	2.2E-12	2.3E-12
Cu-64	1.1E-14	6.8E-17	7.2E-16	4.3E-14	2.2E-12	2.3E-12
Zn-62	6.4E-14	1.4E-16	4.7E-15	2.4E-13	1.8E-11	1.8E-11
Zn-65	1.1E-11	5.7E-13	7.2E-12	5.3E-11	7.3E-11	1.4E-10
Ga-67	9.1E-14	1.6E-18	6.3E-15	2.0E-13	3.6E-12	3.9E-12
Se-75	9.1E-12	1.2E-11	1.8E-11	1.8E-11	4.3E-11	1.0E-10
Br-76	5.4E-14	4.3E-16	4.3E-15	7.1E-13	8.0E-12	8.8E-12
Br-77	3.6E-14	2.3E-15	6.8E-15	3.1E-13	1.7E-12	2.0E-12
Br-82	1.3E-13	4.0E-15	1.7E-14	1.6E-12	9.4E-12	1.1E-11
Rb-81	1.8E-15	1.3E-17	1.2E-16	5.0E-14	4.8E-13	5.3E-13
Rb-83	5.1E-12	6.6E-12	1.1E-11	1.8E-11	1.7E-11	5.7E-11
Sr-83	1.1E-13	4.0E-16	7.2E-15	1.8E-11	8.9E-12	2.7E-11
Sr-85	1.2E-12	3.3E-14	1.8E-13	1.3E-11	1.0E-11	2.5E-11
Sr-89	5.4E-12	1.2E-13	7.5E-13	1.7E-15	4.7E-11	5.3E-11
Sr-90	1.7E-10	1.7E-10	1.8E-11	1.3E-17	5.1E-10	8.7E-10
Y-90	1.1E-12	3.1E-17	7.4E-14	6.6E-20	4.9E-11	5.1E-11
Zr-89	3.8E-13	2.0E-17	2.6E-14	1.6E-12	1.4E-11	1.6E-11
Zr-95	2.0E-12	3.2E-15	3.0E-13	5.1E-11	1.7E-11	7.1E-11
Nb-95	1.1E-12	1.6E-15	1.4E-13	1.1E-11	1.1E-11	2.3E-11
Mo-99	2.5E-13	7.8E-16	1.7E-14	3.2E-13	7.7E-12	8.3E-12
Tc-99	2.2E-10	2.3E-10	1.4E-10	0.0E+00	1.2E-11	6.0E-10
Tc-99m	1.4E-15	3.2E-16	1.1E-16	1.2E-14	4.2E-13	4.3E-13

Radio-nuclide*	DPURs for adult irrigated food consumer family (µSv/y per Bq/y)					
	Green veg	Root veg	Fruit	External, soil	Ingestion, water	Total
Ru-103	1.4E-12	5.8E-16	8.8E-14	7.7E-12	6.1E-12	1.5E-11
Ru-106	1.7E-11	5.0E-14	1.1E-12	2.7E-11	5.8E-11	1.0E-10
Ag-110m	7.1E-12	1.7E-14	2.0E-12	2.6E-10	4.5E-12	2.7E-10
In-111	1.2E-13	1.7E-18	8.4E-15	4.5E-13	1.8E-12	2.4E-12
Sb-125	2.9E-12	8.5E-15	6.1E-13	1.3E-10	1.7E-11	1.5E-10
I-123	2.0E-14	1.2E-16	1.5E-15	2.2E-12	3.4E-12	5.6E-12
I-124	7.9E-12	1.2E-12	2.8E-12	1.9E-12	2.1E-10	2.2E-10
I-125	3.7E-11	4.3E-11	7.2E-11	2.4E-13	2.4E-10	4.0E-10
I-129	5.0E-10	7.8E-10	9.0E-10	4.2E-12	1.8E-09	4.0E-09
I-131	2.2E-11	7.4E-12	1.5E-11	1.3E-12	3.6E-10	4.0E-10
I-133	6.4E-13	7.8E-15	5.7E-14	2.3E-13	7.0E-11	7.0E-11
I-135	4.5E-14	9.3E-17	3.1E-15	2.0E-13	1.5E-11	1.5E-11
Cs-134	6.0E-11	8.9E-11	1.5E-10	3.8E-10	1.7E-10	8.4E-10
Cs-136	4.1E-12	2.2E-12	4.0E-12	1.2E-11	2.6E-11	4.8E-11
Cs-137	4.5E-11	7.2E-11	1.1E-10	6.9E-10	1.1E-10	1.0E-09
Ba-140	3.2E-12	8.8E-16	2.9E-13	1.4E-11	4.6E-11	6.4E-11
La-140	5.4E-13	9.5E-18	3.6E-14	1.6E-12	1.1E-11	1.3E-11
Ce-141	1.3E-12	2.8E-16	8.1E-14	9.2E-13	1.4E-12	3.6E-12
Ce-144	1.3E-11	1.7E-14	8.1E-13	4.9E-12	1.0E-11	2.8E-11
Pm-147	6.7E-13	2.1E-14	8.6E-14	9.9E-16	4.1E-12	4.9E-12
Sm-153	2.3E-13	1.2E-17	1.5E-14	3.7E-14	3.0E-12	3.3E-12
Eu-152	3.6E-12	1.8E-13	3.4E-13	9.5E-10	2.6E-11	9.8E-10
Eu-154	5.1E-12	1.9E-13	4.4E-13	8.2E-10	3.7E-11	8.6E-10
Eu-155	8.1E-13	1.7E-14	6.3E-14	2.0E-11	6.0E-12	2.7E-11
Er-169	3.7E-13	3.6E-17	2.4E-14	8.4E-20	7.2E-13	1.1E-12
Lu-177	4.3E-13	3.5E-17	2.8E-14	9.3E-14	1.0E-12	1.6E-12
Re-188	2.5E-13	5.9E-14	2.3E-14	1.6E-14	2.6E-11	2.7E-11
Au-198	4.1E-13	7.1E-17	2.6E-14	4.7E-13	1.6E-12	2.5E-12
Tl-201	4.4E-14	4.2E-15	1.1E-14	9.4E-14	1.0E-12	1.2E-12
Pb-210	2.0E-09	1.3E-10	5.9E-10	6.7E-13	9.4E-09	1.2E-08
Pb-212	4.7E-13	5.3E-17	3.0E-14	6.3E-14	8.1E-11	8.2E-11
Po-210	3.4E-09	4.6E-09	7.7E-09	4.6E-16	8.8E-09	2.4E-08
At-211	5.9E-13	1.3E-15	4.0E-14	1.9E-09	1.8E-10	2.0E-09
Ra-223	1.2E-10	1.6E-13	1.0E-11	1.3E-12	1.5E-09	1.6E-09
Ra-226	9.2E-10	4.5E-10	3.3E-10	2.8E-09	4.1E-09	8.6E-09
Ac-225	2.5E-11	2.1E-15	1.6E-12	7.5E-13	9.8E-11	1.3E-10
Th-227	1.3E-11	2.5E-16	8.2E-13	4.3E-12	1.9E-11	3.7E-11
Th-230	5.3E-10	3.8E-12	4.3E-11	2.8E-09	4.6E-10	3.9E-09
Th-232	5.8E-10	4.2E-12	4.8E-11	2.0E-09	5.1E-10	3.1E-09
Th-234	5.4E-12	1.3E-16	3.5E-13	4.0E-13	7.5E-12	1.4E-11
U-234	1.3E-10	9.5E-12	1.2E-11	2.1E-11	9.3E-10	1.1E-09
U-235	1.2E-10	9.1E-12	1.1E-11	2.1E-10	8.9E-10	1.3E-09
U-238	1.2E-10	8.8E-12	1.1E-11	3.4E-11	8.5E-10	1.0E-09
Np-237	3.0E-10	5.6E-11	3.4E-11	3.1E-10	2.1E-09	2.8E-09
Pu-238	5.8E-10	1.7E-12	4.0E-11	1.7E-13	4.1E-10	1.0E-09
Pu-239	6.3E-10	2.2E-12	4.4E-11	2.1E-10	4.5E-10	1.3E-09
Pu-240	6.3E-10	2.2E-12	4.4E-11	1.2E-13	4.5E-10	1.1E-09

Radio-nuclide*	DPURs for adult irrigated food consumer family (µSv/y per Bq/y)					
	Green veg	Root veg	Fruit	External, soil	Ingestion, water	Total
Pu-241	1.2E-11	1.7E-14	8.0E-13	1.4E-11	8.6E-12	3.6E-11
Pu-242	6.1E-10	2.1E-12	4.2E-11	3.5E-11	4.3E-10	1.1E-09
Am-241	5.1E-10	2.9E-12	3.5E-11	3.2E-10	6.6E-10	1.5E-09
Am-242	3.4E-14	1.8E-19	2.2E-15	9.3E-13	9.8E-13	2.0E-12
Am-243	5.1E-10	3.0E-12	3.5E-11	2.6E-10	6.6E-10	1.5E-09
Cm-242	2.8E-11	3.1E-15	1.8E-12	5.3E-14	1.9E-10	2.2E-10
Cm-243	3.8E-10	1.8E-12	2.6E-11	3.7E-10	2.4E-09	3.2E-09
Cm-244	3.0E-10	1.1E-12	2.0E-11	2.5E-13	1.9E-09	2.2E-09

*radionuclides with a half-life of less than 3 hours were not considered.

Table 26. Dose rate per unit release factors for worst affected freshwater reference organism – river release scenario

These DPURs are multiplied by the factor Q_{eff} (see Table G.10) when assessing exposure of river wildlife via the sewer release scenario.

Radionuclide*	Worst total DPUR (µGy/h per Bq/y)	Worst affected reference organism
H-3	2.6E-16	Vascular plant
H-3 organic	4.4E-11	Mollusc – bivalve
C-14	1.6E-10	Benthic fish
Na-22	3.4E-11	Reptile
Na-24	6.8E-11	Reptile
P-32	8.4E-09	Reptile
P-33	9.6E-10	Benthic fish
S-35	2.2E-13	Mollusc – gastropod
Cl-36	6.3E-12	Mollusc – bivalve
Ca-45	2.0E-12	Benthic fish
Ca-47	4.1E-11	Benthic fish
V-48	5.7E-11	Mammal
Cr-51	6.6E-12	Insect larvae
Mn-52	1.2E-09	Insect larvae
Mn-54	2.9E-10	Insect larvae
Fe-55	2.4E-12	Mollusc – bivalve
Fe-59	1.1E-10	Insect larvae
Co-56	1.1E-09	Insect larvae
Co-57	3.6E-11	Insect larvae
Co-58	2.8E-10	Insect larvae
Co-60	7.1E-10	Insect larvae
Ni-63	5.2E-13	Insect larvae
Cu-61	1.8E-10	Reptile
Cu-64	6.4E-11	Reptile
Zn-62	6.2E-10	Reptile
Zn-65	4.0E-11	Reptile
Ga-67	7.0E-12	Mammal
Se-75	2.6E-11	Insect larvae
Br-76	1.2E-10	Insect larvae
Br-77	1.2E-11	Insect larvae
Br-82	1.0E-10	Insect larvae
Rb-81	1.7E-10	Insect larvae
Rb-83	1.2E-10	Insect larvae
Sr-83	6.8E-11	Mammal
Sr-85	2.7E-11	Mammal
Sr-89	1.2E-10	Mammal
Sr-90	2.3E-10	Mammal
Y-90	2.0E-11	Reptile
Zr-89	2.2E-11	Insect larvae
Zr-95	1.5E-11	Insect larvae
Nb-95	1.6E-11	Mammal

Radionuclide*	Worst total DPUR (µGy/h per Bq/y)	Worst affected reference organism
Mo-99	7.1E-11	Insect larvae
Tc-99	1.8E-13	Reptile
Tc-99m	9.7E-14	Mammal
Ru-103	1.2E-10	Insect larvae
Ru-106	3.6E-10	Insect larvae
Ag-110m	1.2E-09	Insect larvae
In-111	1.2E-10	Insect larvae
Sb-125	3.4E-11	Insect larvae
I-123	1.2E-11	Insect larvae
I-124	8.4E-11	Insect larvae
I-125	2.9E-12	Insect larvae
I-129	1.9E-12	Insect larvae
I-131	2.9E-11	Insect larvae
I-133	5.6E-11	Insect larvae
I-135	1.3E-10	Insect larvae
Cs-134	3.9E-10	Insect larvae
Cs-136	5.6E-10	Insect larvae
Cs-137	1.6E-10	Insect larvae
Ba-140	1.2E-10	Insect larvae
La-140	8.5E-10	Insect larvae
Ce-141	4.2E-11	Insect larvae
Ce-144	4.3E-10	Insect larvae
Pm-147	7.7E-12	Phytoplankton
Sm-153	4.6E-11	Insect larvae
Eu-152	3.7E-11	Mammal
Eu-154	5.6E-11	Mammal
Eu-155	9.4E-12	Mammal
Er-169	4.3E-12	Insect larvae
Lu-177	2.3E-11	Insect larvae
Re-188	5.1E-12	Insect larvae
Au-198	2.2E-10	Insect larvae
Tl-201	2.0E-11	Insect larvae
Pb-210	5.2E-11	Insect larvae
Pb-212	9.5E-09	Insect larvae
Po-210	4.7E-08	Insect larvae
At-211	3.4E-10	Reptile
Ra-223	2.5E-08	Insect larvae
Ra-226	8.2E-08	Insect larvae
Ac-225	1.1E-07	Vascular plant
Th-227	1.2E-08	Vascular plant
Th-230	9.7E-09	Vascular plant
Th-232	8.3E-09	Vascular plant
Th-234	2.6E-10	Insect larvae
U-234	4.9E-10	Mollusc – gastropod
U-235	4.5E-10	Mollusc – bivalve
U-238	4.2E-10	Mollusc – gastropod
Np-237	4.8E-10	Mollusc – gastropod

Radionuclide*	Worst total DPUR (µGy/h per Bq/y)	Worst affected reference organism
Pu-238	5.6E-10	Reptile
Pu-239	5.2E-10	Reptile
Pu-240	5.2E-10	Reptile
Pu-241	1.4E-13	Reptile
Pu-242	5.0E-10	Reptile
Am-241	1.8E-09	Crustacean
Am-242	2.1E-11	Insect larvae
Am-243	1.8E-09	Crustacean
Cm-242	5.5E-09	Phytoplankton
Cm-243	5.2E-09	Phytoplankton
Cm-244	5.2E-09	Phytoplankton

*radionuclides with a half-life of less than 3 hours were not considered.

Table 27. Dose rate per unit release factors for freshwater reference organisms (µGy/h per Bq/y) – river release scenario

Radio-nuclide*	Amphibian	Benthic fish	Bird	Crust-acean	Insect larvae	Mammal	Mollusc - bivalve	Mollusc, gastro-pod	Pelagic fish	Phyto-plankton	Reptile	Vascular plant	Zoo-plankton
H-3	2.6E-16	2.6E-16	2.6E-16	2.6E-16	2.6E-16	2.6E-16	2.6E-16	2.6E-16	2.6E-16	2.6E-16	2.6E-16	2.6E-16	2.6E-16
H-3 organic	4.4E-11	4.4E-11	4.4E-11	4.4E-11	4.4E-11	4.4E-11	4.4E-11	4.4E-11	4.4E-11	9.7E-13	4.3E-11	2.1E-12	4.4E-11
C-14	1.5E-10	1.6E-10	1.6E-10	1.5E-10	1.5E-10	1.6E-10	1.5E-10	1.5E-10	1.6E-10	3.2E-12	1.5E-10	7.1E-12	1.5E-10
Na-22	2.0E-11	2.9E-11	2.0E-11	5.1E-12	5.7E-12	2.6E-11	7.4E-13	5.6E-13	2.8E-11	3.3E-13	3.4E-11	9.9E-13	2.5E-13
Na-24	4.6E-11	5.8E-11	4.0E-11	7.2E-12	8.2E-12	5.0E-11	1.7E-12	1.3E-12	5.7E-11	3.5E-13	6.8E-11	2.0E-12	3.1E-13
P-32	7.9E-09	8.4E-09	8.4E-09	2.3E-10	2.5E-10	8.4E-09	7.2E-10	6.5E-10	8.4E-09	2.4E-12	8.4E-09	8.1E-12	1.4E-10
P-33	9.6E-10	9.6E-10	9.6E-10	7.9E-11	7.9E-11	9.6E-10	8.5E-11	8.5E-11	9.6E-10	1.6E-12	9.6E-10	1.7E-12	7.7E-11
S-35	2.2E-13	2.2E-13	2.2E-13	2.1E-13	2.2E-13	2.2E-13	2.2E-13	2.2E-13	2.2E-13	1.7E-13	2.2E-13	1.8E-13	2.1E-13
Cl-36	6.3E-12	6.3E-12	6.3E-12	4.4E-12	4.5E-12	6.3E-12	6.3E-12	5.9E-12	6.3E-12	5.3E-13	6.2E-12	9.8E-13	3.2E-12
Ca-45	1.7E-12	2.0E-12	7.5E-13	9.0E-13	1.5E-13	5.4E-13	1.0E-12	1.0E-12	2.0E-12	2.9E-13	6.9E-13	3.8E-13	5.3E-14
Ca-47	2.2E-11	4.1E-11	1.1E-11	2.5E-11	3.4E-11	8.7E-12	2.7E-11	2.7E-11	2.8E-11	2.2E-12	2.3E-11	2.0E-11	4.6E-13
V-48	2.0E-11	2.6E-12	4.2E-11	4.6E-12	7.3E-12	5.7E-11	7.8E-12	6.1E-12	3.3E-13	4.8E-12	4.2E-11	1.0E-11	1.5E-12
Cr-51	9.6E-15	2.8E-12	3.5E-15	3.4E-12	6.6E-12	2.6E-13	3.2E-12	3.3E-12	3.4E-14	4.6E-14	3.0E-12	3.3E-12	1.6E-13
Mn-52	7.0E-13	5.3E-10	1.7E-12	6.0E-10	1.2E-09	1.1E-12	5.8E-10	6.0E-10	6.1E-12	5.5E-14	5.3E-10	6.0E-10	2.6E-12
Mn-54	1.6E-13	1.3E-10	4.2E-13	1.4E-10	2.9E-10	2.7E-13	1.4E-10	1.4E-10	1.5E-12	1.5E-14	1.3E-10	1.4E-10	6.5E-13
Fe-55	1.6E-13	6.3E-13	1.6E-13	8.0E-13	2.3E-12	7.4E-14	2.4E-12	2.4E-12	6.3E-13	3.9E-14	1.6E-13	1.1E-12	2.3E-12
Fe-59	1.8E-12	5.1E-11	3.1E-12	5.2E-11	1.1E-10	1.8E-12	7.3E-11	6.8E-11	1.1E-11	2.7E-13	4.3E-11	5.4E-11	1.6E-11
Co-56	4.0E-13	4.6E-10	2.6E-12	5.3E-10	1.1E-09	1.2E-12	5.0E-10	5.2E-10	7.9E-13	1.6E-13	4.6E-10	5.3E-10	5.1E-13
Co-57	8.4E-14	1.5E-11	3.1E-13	1.9E-11	3.6E-11	1.2E-13	1.7E-11	1.8E-11	1.0E-13	2.0E-13	1.5E-11	1.8E-11	5.9E-13
Co-58	1.3E-13	1.2E-10	8.3E-13	1.4E-10	2.8E-10	3.9E-13	1.3E-10	1.4E-10	2.5E-13	1.4E-13	1.2E-10	1.4E-10	4.1E-13
Co-60	3.1E-13	3.3E-10	1.9E-12	3.5E-10	7.1E-10	8.9E-13	3.6E-10	3.5E-10	5.7E-13	3.6E-13	3.2E-10	3.5E-10	1.0E-12
Ni-63	5.6E-14	5.6E-14	5.6E-14	5.2E-13	5.2E-13	5.6E-14	6.1E-14	6.2E-14	5.6E-14	1.4E-13	2.6E-13	1.5E-13	5.1E-13
Cu-61	4.4E-12	6.3E-11	1.2E-11	5.6E-11	6.2E-11	1.4E-11	8.2E-12	7.8E-12	5.9E-11	5.9E-12	1.8E-10	6.2E-12	3.4E-11
Cu-64	1.8E-12	2.2E-11	4.2E-12	3.6E-11	3.7E-11	4.9E-12	2.6E-12	2.5E-12	2.1E-11	5.5E-12	6.4E-11	2.0E-12	2.8E-11
Zn-62	1.6E-11	2.2E-10	4.0E-11	9.3E-11	1.1E-10	4.7E-11	2.4E-11	2.1E-11	2.1E-10	9.4E-12	6.2E-10	1.5E-11	5.4E-11
Zn-65	5.4E-13	1.5E-11	2.5E-12	8.9E-12	1.2E-11	3.8E-12	3.1E-12	2.9E-12	1.2E-11	1.3E-12	4.0E-11	2.8E-12	6.1E-12
Ga-67	4.6E-12	4.0E-13	6.0E-12	1.3E-12	1.7E-12	7.0E-12	1.5E-12	1.4E-12	4.6E-14	3.2E-12	6.2E-12	3.8E-12	8.5E-13
Se-75	1.9E-12	1.4E-11	1.5E-14	1.3E-11	2.6E-11	5.0E-12	1.4E-11	1.4E-11	3.4E-12	1.3E-14	1.4E-11	1.3E-11	2.1E-12
Br-76	3.7E-12	5.1E-11	6.8E-13	6.2E-11	1.2E-10	6.2E-12	5.1E-11	5.5E-11	5.1E-12	1.1E-13	5.1E-11	6.0E-11	1.6E-13
Br-77	2.0E-13	5.6E-12	5.0E-14	6.2E-12	1.2E-11	5.0E-13	5.8E-12	6.0E-12	3.5E-13	2.1E-14	5.6E-12	6.2E-12	3.1E-14

Radio-nuclide*	Amphibian	Benthic fish	Bird	Crust-acean	Insect larvae	Mammal	Mollusc - bivalve	Mollusc, gastro-pod	Pelagic fish	Phyto-plankt on	Reptile	Vascular plant	Zoo-plankton
Br-82	1.3E-12	4.7E-11	3.6E-13	5.1E-11	1.0E-10	3.7E-12	4.9E-11	5.0E-11	2.5E-12	1.3E-13	4.7E-11	5.1E-11	1.9E-13
Rb-81	7.6E-12	7.4E-11	5.7E-12	8.7E-11	1.7E-10	6.6E-12	7.2E-11	7.6E-11	8.2E-12	1.1E-13	7.5E-11	8.5E-11	8.3E-14
Rb-83	3.7E-12	5.7E-11	3.1E-12	6.3E-11	1.2E-10	3.8E-12	5.8E-11	6.0E-11	4.4E-12	1.0E-13	5.8E-11	6.2E-11	6.7E-14
Sr-83	3.9E-11	1.1E-11	3.5E-11	1.0E-11	2.4E-11	6.8E-11	9.5E-12	9.6E-12	3.9E-12	1.4E-13	6.3E-11	9.3E-12	4.4E-12
Sr-85	8.4E-12	5.9E-12	1.2E-11	5.6E-12	1.2E-11	2.7E-11	5.4E-12	5.4E-12	1.3E-12	3.3E-14	2.3E-11	5.4E-12	7.8E-13
Sr-89	1.1E-10	8.7E-12	7.3E-11	7.1E-12	2.1E-11	1.2E-10	4.8E-12	4.9E-12	8.6E-12	2.2E-13	1.2E-10	4.0E-12	8.4E-12
Sr-90	2.1E-10	1.7E-11	1.4E-10	1.3E-11	3.9E-11	2.3E-10	9.2E-12	9.6E-12	1.6E-11	4.5E-13	2.3E-10	8.3E-12	1.6E-11
Y-90	1.8E-11	1.5E-11	4.8E-13	9.8E-12	1.6E-11	2.0E-11	1.5E-11	1.4E-11	1.5E-11	2.8E-12	2.0E-11	5.7E-12	2.1E-12
Zr-89	3.3E-12	1.3E-11	1.6E-13	1.2E-11	2.2E-11	7.6E-12	1.3E-11	1.2E-11	4.1E-12	1.1E-12	1.4E-11	1.1E-11	7.8E-13
Zr-95	3.2E-12	9.0E-12	1.3E-13	8.3E-12	1.5E-11	6.0E-12	8.8E-12	8.6E-12	3.4E-12	2.7E-12	1.0E-11	6.9E-12	1.6E-12
Nb-95	6.1E-12	6.9E-13	1.2E-11	1.5E-12	2.2E-12	1.6E-11	2.2E-12	1.8E-12	9.5E-14	3.0E-12	1.2E-11	3.9E-12	7.7E-13
Mo-99	2.2E-11	1.8E-11	2.4E-11	3.7E-11	7.1E-11	2.5E-11	2.5E-11	2.7E-11	1.8E-13	5.9E-12	4.1E-11	4.4E-11	1.8E-12
Tc-99	1.8E-13	1.8E-13	1.8E-13	1.7E-13	1.7E-13	1.8E-13	1.8E-13	1.8E-13	1.8E-13	6.1E-14	1.8E-13	6.5E-14	1.6E-13
Tc-99m	5.1E-14	8.0E-14	7.7E-14	4.4E-14	4.9E-14	9.7E-14	5.8E-14	5.0E-14	7.3E-14	1.7E-14	7.9E-14	2.2E-14	3.9E-14
Ru-103	1.2E-13	5.1E-11	1.7E-13	6.2E-11	1.2E-10	1.9E-13	5.8E-11	6.0E-11	1.5E-13	1.1E-12	5.2E-11	6.4E-11	9.1E-14
Ru-106	9.8E-13	3.4E-11	1.1E-12	1.8E-10	3.6E-10	1.2E-12	5.0E-11	8.8E-11	1.1E-12	1.1E-12	3.5E-11	1.6E-10	1.2E-13
Ag-110m	4.6E-13	5.1E-10	1.1E-12	5.8E-10	1.2E-09	1.5E-12	5.5E-10	5.8E-10	2.7E-13	5.9E-14	5.0E-10	5.8E-10	1.9E-12
In-111	7.0E-14	5.1E-11	3.1E-12	6.2E-11	1.2E-10	1.6E-13	5.8E-11	6.0E-11	1.1E-13	1.9E-12	5.2E-11	6.2E-11	2.4E-13
Sb-125	4.6E-12	1.4E-11	6.3E-12	1.7E-11	3.4E-11	7.7E-12	1.5E-11	1.6E-11	9.5E-14	1.1E-13	2.0E-11	1.7E-11	1.2E-13
I-123	2.4E-13	5.0E-12	4.7E-14	6.0E-12	1.2E-11	4.4E-13	5.4E-12	5.7E-12	3.5E-13	3.2E-14	5.0E-12	5.9E-12	4.8E-14
I-124	1.1E-12	3.4E-11	2.3E-13	4.2E-11	8.4E-11	2.1E-12	3.6E-11	3.8E-11	1.6E-12	4.8E-14	3.4E-11	4.1E-11	7.3E-14
I-125	2.5E-13	9.7E-13	3.9E-14	1.5E-12	2.9E-12	3.5E-13	1.1E-12	1.3E-12	3.1E-13	3.5E-14	9.6E-13	1.5E-12	5.5E-14
I-129	4.2E-13	8.9E-13	5.7E-14	9.9E-13	1.9E-12	4.8E-13	7.6E-13	8.8E-13	4.5E-13	6.6E-14	9.0E-13	9.6E-13	1.0E-13
I-131	1.0E-12	1.2E-11	1.5E-13	1.5E-11	2.9E-11	1.4E-12	1.3E-11	1.3E-11	1.2E-12	1.0E-13	1.2E-11	1.5E-11	1.7E-13
I-133	2.1E-12	2.1E-11	3.0E-13	2.8E-11	5.6E-11	2.7E-12	2.1E-11	2.2E-11	2.4E-12	1.0E-13	2.1E-11	2.7E-11	1.9E-13
I-135	2.1E-12	5.3E-11	3.8E-13	6.3E-11	1.3E-10	3.4E-12	5.5E-11	5.7E-11	2.8E-12	1.2E-13	5.3E-11	6.2E-11	2.0E-13
Cs-134	7.6E-12	1.8E-10	7.3E-12	2.0E-10	3.9E-10	9.3E-12	1.8E-10	1.9E-10	1.0E-11	1.2E-13	1.8E-10	2.0E-10	9.0E-14
Cs-136	7.7E-12	2.5E-10	8.3E-12	2.8E-10	5.6E-10	1.1E-11	2.6E-10	2.6E-10	1.1E-11	1.5E-13	2.5E-10	2.8E-10	1.1E-13
Cs-137	8.7E-12	6.9E-11	6.3E-12	8.1E-11	1.6E-10	7.0E-12	6.6E-11	7.0E-11	8.9E-12	1.5E-13	7.1E-11	7.9E-11	1.1E-13
Ba-140	3.0E-12	4.6E-11	7.6E-11	6.6E-11	1.2E-10	4.4E-12	6.8E-11	6.7E-11	3.7E-12	3.0E-13	4.6E-11	5.9E-11	6.9E-12
La-140	7.7E-13	3.3E-10	1.1E-12	4.3E-10	8.5E-10	1.2E-12	3.7E-10	3.9E-10	5.6E-13	5.1E-13	3.3E-10	4.2E-10	2.0E-12
Ce-141	5.7E-14	1.3E-11	1.6E-12	2.2E-11	4.2E-11	6.2E-14	1.5E-11	1.6E-11	6.2E-14	2.0E-12	1.3E-11	2.3E-11	2.5E-13

Radio-nuclide*	Amphibian	Benthic fish	Bird	Crust-acean	Insect larvae	Mammal	Mollusc - bivalve	Mollusc, gastro-pod	Pelagic fish	Phyto-plankton	Reptile	Vascular plant	Zoo-plankton
Ce-144	3.6E-13	2.2E-11	1.0E-11	2.2E-10	4.3E-10	4.0E-13	4.1E-11	8.4E-11	4.0E-13	2.8E-12	2.3E-11	1.8E-10	3.8E-13
Pm-147	1.6E-13	1.7E-13	4.3E-12	1.1E-12	1.2E-12	1.6E-13	1.0E-12	1.0E-12	1.6E-13	7.7E-12	6.1E-13	9.5E-13	9.2E-13
Sm-153	1.9E-13	9.0E-12	5.1E-12	2.4E-11	4.6E-11	2.0E-13	1.2E-11	1.4E-11	2.0E-13	5.6E-12	9.7E-12	2.5E-11	7.3E-13
Eu-152	1.8E-11	4.8E-12	3.0E-11	7.9E-12	1.3E-11	3.7E-11	9.7E-12	8.9E-12	3.4E-13	3.5E-13	3.3E-11	5.7E-12	2.3E-12
Eu-154	3.5E-11	5.4E-12	4.7E-11	1.1E-11	1.7E-11	5.6E-11	1.5E-11	1.3E-11	5.4E-13	6.3E-13	5.1E-11	6.9E-12	4.4E-12
Eu-155	7.8E-12	3.2E-13	8.7E-12	2.2E-12	2.4E-12	9.4E-12	2.3E-12	2.2E-12	9.9E-14	2.9E-13	8.9E-12	5.8E-13	1.9E-12
Er-169	3.6E-14	8.0E-14	9.2E-13	2.4E-12	4.3E-12	3.6E-14	3.3E-13	5.0E-13	3.6E-14	1.5E-12	1.8E-13	3.1E-12	1.9E-13
Lu-177	4.8E-14	6.2E-12	1.3E-12	1.2E-11	2.3E-11	5.1E-14	7.3E-12	7.9E-12	5.0E-14	1.8E-12	6.4E-12	1.3E-11	2.2E-13
Re-188	1.3E-12	1.6E-12	1.4E-12	2.8E-12	5.1E-12	1.4E-12	1.7E-12	1.9E-12	1.4E-12	9.2E-14	1.6E-12	2.2E-12	2.6E-13
Au-198	5.2E-14	7.3E-11	6.0E-14	1.1E-10	2.2E-10	6.5E-14	8.2E-11	8.7E-11	5.9E-14	8.2E-15	7.4E-11	1.1E-10	2.3E-14
Tl-201	3.0E-12	1.0E-11	2.0E-12	1.1E-11	2.0E-11	2.2E-12	8.6E-12	9.1E-12	2.9E-12	9.4E-14	1.1E-11	9.7E-12	6.0E-14
Pb-210	3.0E-14	2.5E-12	1.4E-12	3.2E-11	5.2E-11	2.6E-12	3.4E-11	3.4E-11	2.1E-12	3.3E-12	3.0E-12	1.2E-11	2.0E-11
Pb-212	6.1E-12	5.1E-10	2.7E-10	9.4E-09	9.5E-09	5.0E-10	6.7E-09	6.7E-09	4.1E-10	1.8E-09	6.0E-10	4.8E-10	9.2E-09
Po-210	7.7E-10	7.7E-10	7.7E-10	3.1E-09	4.7E-08	7.7E-10	4.7E-08	4.7E-08	7.7E-10	6.0E-10	1.4E-09	6.0E-10	4.7E-08
At-211	3.4E-10	3.4E-10	4.1E-11	8.9E-11	9.1E-11	3.4E-10	8.9E-11	8.9E-11	3.4E-10	5.7E-11	3.4E-10	5.9E-11	8.8E-11
Ra-223	6.5E-09	2.0E-10	6.5E-09	3.2E-10	2.5E-08	2.2E-13	2.5E-08	2.5E-08	1.9E-10	5.7E-10	8.1E-10	1.2E-09	2.5E-08
Ra-226	2.1E-08	7.1E-10	2.2E-08	1.0E-09	8.2E-08	7.7E-13	8.0E-08	8.0E-08	6.3E-10	1.9E-09	2.7E-09	3.8E-09	8.2E-08
Ac-225	3.5E-09	8.1E-10	3.5E-09	7.4E-10	2.9E-09	3.5E-09	1.1E-08	1.1E-08	7.7E-10	1.3E-08	1.2E-09	1.1E-07	5.8E-10
Th-227	4.0E-10	1.1E-10	4.0E-10	9.7E-11	3.6E-10	4.0E-10	1.3E-09	1.3E-09	8.8E-11	1.5E-09	1.5E-10	1.2E-08	6.7E-11
Th-230	3.2E-10	7.1E-11	3.2E-10	6.0E-11	2.5E-10	3.2E-10	1.0E-09	1.0E-09	7.1E-11	1.2E-09	1.0E-10	9.7E-09	5.3E-11
Th-232	2.7E-10	6.0E-11	2.7E-10	5.1E-11	2.1E-10	2.7E-10	8.8E-10	8.8E-10	6.0E-11	9.9E-10	8.7E-11	8.3E-09	4.6E-11
Th-234	5.5E-12	1.1E-11	5.9E-12	1.3E-10	2.6E-10	5.9E-12	3.6E-11	5.5E-11	1.3E-12	3.9E-12	1.2E-11	1.9E-10	2.3E-13
U-234	1.0E-10	6.4E-11	4.7E-11	1.8E-10	1.8E-10	1.0E-10	4.9E-10	4.9E-10	6.4E-11	6.1E-11	1.0E-10	3.3E-10	1.8E-10
U-235	9.5E-11	5.9E-11	4.3E-11	1.6E-10	1.6E-10	9.4E-11	4.5E-10	4.5E-10	5.9E-11	5.7E-11	9.4E-11	3.1E-10	1.6E-10
U-238	8.8E-11	5.5E-11	4.0E-11	1.5E-10	1.5E-10	8.8E-11	4.2E-10	4.2E-10	5.5E-11	5.4E-11	8.9E-11	2.8E-10	1.5E-10
Np-237	1.0E-10	6.3E-11	4.6E-11	1.8E-10	1.8E-10	1.0E-10	4.8E-10	4.8E-10	6.3E-11	6.2E-11	1.0E-10	2.0E-10	1.8E-10
Pu-238	4.4E-10	8.0E-11	2.8E-10	5.7E-11	2.4E-10	4.4E-10	5.2E-10	5.2E-10	8.0E-11	5.6E-10	5.6E-10	1.0E-10	5.1E-11
Pu-239	4.1E-10	7.5E-11	2.6E-10	5.4E-11	2.2E-10	4.1E-10	4.9E-10	4.9E-10	7.5E-11	5.2E-10	5.2E-10	9.5E-11	4.8E-11
Pu-240	4.1E-10	7.5E-11	2.6E-10	5.4E-11	2.2E-10	4.1E-10	4.9E-10	4.9E-10	7.5E-11	5.2E-10	5.2E-10	9.6E-11	4.8E-11
Pu-241	1.1E-13	2.0E-14	7.0E-14	1.5E-14	6.1E-14	1.1E-13	1.3E-13	1.3E-13	2.0E-14	1.4E-13	1.4E-13	2.7E-14	1.3E-14
Pu-242	3.9E-10	7.0E-11	2.5E-10	5.1E-11	2.1E-10	3.9E-10	4.6E-10	4.6E-10	7.0E-11	5.0E-10	5.0E-10	9.0E-11	4.5E-11

Radio-nuclide*	Amphibian	Benthic fish	Bird	Crust-acean	Insect larvae	Mammal	Mollusc - bivalve	Mollusc, gastro-pod	Pelagic fish	Phyto-plankt on	Reptile	Vascular plant	Zoo-plankton
Am-241	5.6E-10	1.4E-10	5.6E-10	1.8E-09	3.2E-10	5.6E-10	1.8E-09	1.8E-09	1.3E-10	2.3E-10	5.6E-10	2.4E-10	3.0E-10
Am-242	1.9E-12	2.9E-12	2.0E-12	1.6E-11	2.1E-11	2.0E-12	9.3E-12	1.0E-11	4.6E-13	5.0E-13	4.4E-12	1.2E-11	7.1E-13
Am-243	5.4E-10	1.6E-10	5.4E-10	1.8E-09	3.9E-10	5.4E-10	1.8E-09	1.8E-09	1.3E-10	2.2E-10	5.7E-10	2.7E-10	2.9E-10
Cm-242	7.1E-11	7.7E-10	7.1E-11	2.3E-10	2.3E-10	7.1E-11	1.6E-11	1.6E-11	7.7E-10	5.5E-09	7.2E-11	2.2E-12	2.3E-10
Cm-243	6.8E-11	7.3E-10	6.7E-11	2.3E-10	2.3E-10	6.7E-11	1.9E-11	2.0E-11	7.3E-10	5.2E-09	7.2E-11	7.6E-12	2.2E-10
Cm-244	6.7E-11	7.3E-10	6.7E-11	2.2E-10	2.2E-10	6.7E-11	1.5E-11	1.5E-11	7.3E-10	5.2E-09	6.8E-11	2.1E-12	2.2E-10

*radionuclides with a half-life of less than 3 hours were not considered.

Table 28. Dose per unit release factors for adult sewage treatment workers – sewage release scenario

Radionuclide	DPURs for adult sewage treatment workers (µSv/y per Bq/y)		
	External	Inadvertent intake	Total
H-3	0.0E+00	3.8E-14	3.8E-14
H-3 organic	0.0E+00	8.8E-14	8.8E-14
C-11	4.6E-10	3.2E-16	4.6E-10
C-14	1.4E-13	1.3E-12	1.4E-12
F-18	2.3E-09	3.4E-15	2.3E-09
Na-22	1.2E-07	4.8E-12	1.2E-07
Na-24	5.2E-08	1.3E-13	5.2E-08
P-32	8.2E-10	1.6E-11	8.4E-10
P-33	2.4E-12	2.1E-12	4.5E-12
S-35	1.1E-13	2.3E-13	3.4E-13
Cl-36	2.3E-11	1.6E-12	2.4E-11
Ca-45	1.6E-12	3.7E-12	5.2E-12
Ca-47	8.4E-08	3.2E-12	8.4E-08
V-48	8.2E-07	1.6E-11	8.2E-07
Cr-51	8.7E-09	3.4E-13	8.7E-09
Mn-52	6.2E-07	8.9E-12	6.2E-07
Mn-54	3.3E-07	8.2E-12	3.3E-07
Mn-56	1.2E-08	4.6E-14	1.2E-08
Fe-55	0.0E+00	3.6E-12	3.6E-12
Fe-59	4.2E-07	1.8E-11	4.2E-07
Co-56	1.4E-06	2.6E-11	1.4E-06
Co-57	2.9E-08	2.3E-12	2.9E-08
Co-58	3.4E-07	7.6E-12	3.4E-07
Co-60	1.0E-06	3.9E-11	1.0E-06
Ni-63	0.0E+00	1.7E-12	1.7E-12
Cu-61	6.6E-09	2.9E-14	6.6E-09
Cu-64	4.6E-09	8.9E-14	4.6E-09
Zn-62	1.2E-08	2.3E-13	1.2E-08
Zn-65	3.2E-08	5.7E-12	3.2E-08
Ga-67	1.3E-08	6.0E-13	1.3E-08
Ga-68	2.5E-09	7.8E-15	2.5E-09
Se-75	6.5E-08	1.5E-11	6.5E-08
Br-76	3.2E-08	1.5E-13	3.2E-08
Br-77	5.6E-09	5.3E-14	5.6E-09
Br-82	4.2E-08	2.4E-13	4.2E-08
Rb-81	3.1E-09	8.4E-15	3.1E-09
Rb-82	2.9E-11	3.7E-20	2.9E-11
Rb-83	2.4E-08	2.7E-12	2.4E-08
Sr-83	2.3E-08	4.1E-13	2.3E-08
Sr-85	7.7E-08	2.6E-12	7.7E-08
Sr-89	4.1E-10	1.2E-11	4.2E-10

Radionuclide	DPURs for adult sewage treatment workers (µSv/y per Bq/y)		
	External	Inadvertent intake	Total
Sr-90	1.2E-09	1.4E-10	1.4E-09
Y-90	6.8E-10	7.5E-12	6.9E-10
Zr-89	7.7E-08	1.5E-12	7.7E-08
Zr-95	1.5E-07	5.9E-12	1.5E-07
Nb-95	1.4E-07	3.2E-12	1.4E-07
Mo-99	4.6E-09	3.6E-13	4.6E-09
Tc-94m	2.1E-09	3.2E-15	2.1E-09
Tc-99	9.9E-13	1.1E-12	2.1E-12
Tc-99m	5.8E-10	4.2E-15	5.8E-10
Ru-103	2.1E-08	1.0E-12	2.1E-08
Ru-106	1.1E-08	1.1E-11	1.1E-08
Ag-110m	1.0E-06	3.1E-11	1.0E-06
In-111	3.0E-08	8.1E-13	3.0E-08
In-113m	9.4E-10	3.3E-15	9.4E-10
Sb-125	2.1E-08	1.8E-12	2.1E-08
I-123	1.4E-09	7.3E-14	1.4E-09
I-124	4.3E-08	1.4E-11	4.3E-08
I-125	1.8E-10	3.6E-11	2.1E-10
I-129	1.5E-10	2.9E-10	4.5E-10
I-131	1.9E-08	3.4E-11	1.9E-08
I-132	7.6E-09	2.7E-14	7.6E-09
I-133	9.2E-09	1.9E-12	9.2E-09
I-134	3.4E-09	4.0E-15	3.4E-09
I-135	1.4E-08	2.1E-13	1.4E-08
Cs-134	8.1E-08	2.8E-11	8.1E-08
Cs-136	8.4E-08	3.3E-12	8.4E-08
Cs-137	2.9E-08	1.9E-11	2.9E-08
Ba-140	3.1E-07	9.0E-12	3.1E-07
La-140	1.3E-07	2.9E-12	1.3E-07
Ce-141	9.1E-09	4.0E-12	9.2E-09
Ce-144	1.2E-08	3.6E-11	1.2E-08
Pm-147	1.6E-12	2.3E-12	3.9E-12
Sm-153	1.1E-09	9.3E-13	1.1E-09
Eu-152	2.5E-07	1.5E-11	2.5E-07
Eu-154	2.7E-07	2.0E-11	2.7E-07
Eu-155	6.0E-09	2.9E-12	6.0E-09
Er-169	2.7E-12	1.4E-12	4.1E-12
Lu-177	2.7E-09	1.7E-12	2.7E-09
Re-188	6.2E-10	4.6E-13	6.2E-10
Au-198	2.1E-08	1.6E-12	2.1E-08
Tl-201	2.7E-09	1.7E-13	2.7E-09
Pb-210	4.9E-10	7.6E-09	8.1E-09
Pb-212	3.6E-08	6.1E-12	3.6E-08
Bi-213	2.4E-10	3.7E-14	2.4E-10
Po-210	3.1E-12	1.3E-08	1.3E-08

Radionuclide	DPURs for adult sewage treatment workers (µSv/y per Bq/y)		
	External	Inadvertent intake	Total
At-211	1.9E-10	3.3E-12	1.9E-10
Ra-223	3.3E-08	1.1E-09	3.5E-08
Ra-226	4.0E-07	2.2E-09	4.0E-07
Ac-225	4.6E-08	1.5E-09	4.7E-08
Th-227	9.2E-08	2.0E-09	9.4E-08
Th-230	7.0E-11	5.8E-09	5.9E-09
Th-232	3.0E-11	8.8E-09	8.8E-09
Th-234	7.5E-09	3.2E-11	7.6E-09
U-234	3.1E-12	2.0E-10	2.0E-10
U-235	6.3E-09	1.8E-10	6.5E-09
U-238	1.2E-09	1.7E-10	1.4E-09
Np-237	6.4E-10	9.8E-10	1.6E-09
Pu-238	1.1E-12	2.0E-09	2.0E-09
Pu-239	2.4E-12	2.2E-09	2.2E-09
Pu-240	1.0E-12	2.2E-09	2.2E-09
Pu-241	4.8E-14	3.9E-11	3.9E-11
Pu-242	9.1E-13	2.1E-09	2.1E-09
Am-241	1.4E-09	7.3E-09	8.7E-09
Am-242	1.6E-10	4.1E-13	1.6E-10
Am-243	3.0E-08	7.2E-09	3.7E-08
Cm-242	8.1E-12	1.4E-09	1.4E-09
Cm-243	3.5E-08	9.5E-09	4.4E-08
Cm-244	5.8E-12	8.1E-09	8.1E-09

Table 29. Dose per unit release factors for children playing in a brook – sewage release scenario

These DPURs are multiplied by the factor Q_{eff} (see Table G.10) to take account of partitioning and decay during transit thourhg the sewage treatment works. See Appendix G for more details.

Radionuclide*	DPURs for children playing in brook (µSv/y per Bq/y)		
	External	Inadvertent intake	Total
H-3	0.0E+00	3.6E-14	3.6E-14
H-3 organic	0.0E+00	2.6E-13	2.6E-13
C-14	2.0E-14	3.6E-12	3.6E-12
Na-22	1.3E-12	8.7E-12	1.0E-11
Na-24	4.2E-13	1.2E-12	1.6E-12
P-32	6.0E-13	8.8E-12	9.4E-12
P-33	2.5E-15	8.8E-13	8.8E-13
S-35	2.4E-15	5.1E-13	5.2E-13
Cl-36	2.4E-13	3.3E-12	3.5E-12
Ca-45	5.5E-14	5.9E-12	5.9E-12
Ca-47	1.3E-09	9.8E-12	1.3E-09
V-48	3.1E-10	6.8E-12	3.2E-10
Cr-51	1.8E-09	1.5E-12	1.8E-09
Mn-52	7.1E-08	1.1E-10	7.1E-08
Mn-54	9.0E-08	4.1E-11	9.0E-08
Fe-55	0.0E+00	9.0E-12	9.0E-12
Fe-59	3.0E-08	3.8E-11	3.0E-08
Co-56	3.5E-07	1.6E-10	3.5E-07
Co-57	7.1E-09	1.6E-11	7.1E-09
Co-58	8.7E-08	4.6E-11	8.7E-08
Co-60	2.4E-07	3.0E-10	2.4E-07
Ni-63	0.0E+00	3.6E-12	3.6E-12
Cu-61	4.5E-10	5.4E-13	4.5E-10
Cu-64	1.0E-10	5.9E-13	1.0E-10
Zn-62	8.0E-10	4.7E-12	8.0E-10
Zn-65	1.7E-09	1.5E-11	1.7E-09
Ga-67	4.8E-11	8.2E-13	4.9E-11
Se-75	6.2E-09	4.2E-11	6.2E-09
Br-76	5.9E-09	4.3E-12	5.9E-09
Br-77	7.3E-10	8.4E-13	7.3E-10
Br-82	6.1E-09	4.7E-12	6.1E-09
Rb-81	9.1E-09	2.3E-12	9.1E-09
Rb-83	3.6E-08	7.3E-11	3.6E-08
Sr-83	9.9E-10	3.1E-12	1.0E-09
Sr-85	3.1E-09	5.1E-12	3.1E-09
Sr-89	1.7E-11	2.0E-11	3.7E-11
Sr-90	4.6E-11	2.0E-10	2.5E-10
Y-90	2.2E-11	1.8E-11	4.0E-11
Zr-89	1.2E-09	5.0E-12	1.2E-09
Zr-95	8.1E-09	5.9E-12	8.1E-09

Radionuclide*	DPURs for children playing in brook (µSv/y per Bq/y)		
	External	Inadvertent intake	Total
Nb-95	4.3E-10	1.9E-12	4.3E-10
Mo-99	2.3E-09	1.6E-11	2.3E-09
Tc-99	5.3E-16	2.1E-12	2.1E-12
Tc-99m	6.6E-13	6.8E-14	7.3E-13
Ru-103	3.5E-08	3.6E-11	3.5E-08
Ru-106	1.7E-08	3.6E-10	1.7E-08
Ag-110m	3.6E-07	2.0E-10	3.6E-07
In-111	7.0E-09	1.7E-11	7.0E-09
Sb-125	9.3E-09	1.7E-11	9.3E-09
I-123	6.1E-10	3.7E-12	6.1E-10
I-124	4.4E-09	2.3E-10	4.7E-09
I-125	4.3E-11	2.3E-10	2.8E-10
I-129	3.5E-11	1.4E-09	1.5E-09
I-131	1.6E-09	3.9E-10	2.0E-09
I-133	2.5E-09	7.5E-11	2.6E-09
I-135	6.3E-09	1.7E-11	6.3E-09
Cs-134	1.2E-07	3.2E-10	1.2E-07
Cs-136	3.2E-08	1.0E-10	3.2E-08
Cs-137	4.2E-08	2.3E-10	4.2E-08
Ba-140	5.0E-09	2.6E-11	5.0E-09
La-140	4.4E-08	1.2E-10	4.4E-08
Ce-141	6.4E-09	5.6E-11	6.4E-09
Ce-144	7.3E-09	4.1E-10	7.7E-09
Pm-147	1.7E-13	4.7E-12	4.8E-12
Sm-153	9.9E-10	5.2E-11	1.0E-09
Eu-152	3.2E-09	6.1E-12	3.2E-09
Eu-154	3.5E-09	9.7E-12	3.5E-09
Eu-155	7.7E-11	1.6E-12	7.9E-11
Er-169	1.1E-12	3.0E-11	3.2E-11
Lu-177	8.2E-10	4.5E-11	8.6E-10
Re-188	3.3E-11	6.5E-12	3.9E-11
Au-198	1.0E-08	8.3E-11	1.0E-08
Tl-201	9.3E-10	3.5E-12	9.3E-10
Pb-210	5.2E-11	2.5E-08	2.5E-08
Pb-212	1.2E-08	2.6E-10	1.2E-08
Po-210	7.4E-13	6.7E-08	6.7E-08
At-211	1.5E-10	1.7E-10	3.2E-10
Ra-223	1.8E-09	4.8E-09	6.6E-09
Ra-226	5.9E-08	8.5E-09	6.8E-08
Ac-225	4.8E-09	1.8E-09	6.6E-09
Th-227	9.5E-09	8.4E-10	1.0E-08
Th-230	2.3E-11	8.8E-09	8.8E-09
Th-232	3.3E-07	1.1E-08	3.4E-07
Th-234	2.9E-09	2.7E-10	3.2E-09
U-234	1.7E-14	1.2E-10	1.2E-10
U-235	3.4E-11	1.2E-10	1.5E-10

Radionuclide*	DPURs for children playing in brook (µSv/y per Bq/y)		
	External	Inadvertent intake	Total
U-238	6.7E-12	1.1E-10	1.2E-10
Np-237	9.9E-12	1.8E-10	1.9E-10
Pu-238	2.6E-12	9.0E-09	9.0E-09
Pu-239	5.8E-12	1.0E-08	1.0E-08
Pu-240	2.5E-12	1.0E-08	1.0E-08
Pu-241	1.2E-13	1.9E-10	1.9E-10
Pu-242	2.2E-12	9.7E-09	9.7E-09
Am-241	7.5E-10	7.6E-09	8.3E-09
Am-242	2.8E-10	2.2E-11	3.1E-10
Am-243	1.6E-08	7.6E-09	2.4E-08
Cm-242	5.2E-13	2.0E-10	2.0E-10
Cm-243	2.2E-09	1.3E-09	3.5E-09
Cm-244	3.6E-13	1.1E-09	1.1E-09

*radionuclides with a half-life of less than 3 hours were not considered.

Table 30. Dose per unit release factors for worst age group farming family (use of sludge as soil conditioner) – sewage release scenario

Radionuclide*	Worst total DPUR (µSv/y per Bq/y)	Worst age group
H-3	5.1E-11	Infant
H-3 organic	6.9E-12	Infant
C-14	8.4E-08	Offspring
Na-22	2.7E-07	Offspring
P-32	3.8E-08	Offspring
P-33	3.2E-08	Offspring
S-35	9.2E-09	Infant
Cl-36	1.3E-06	Infant
Ca-45	4.0E-07	Offspring
Ca-47	3.0E-10	Offspring
V-48	3.2E-08	Adult
Cr-51	8.3E-10	Adult
Mn-52	3.5E-09	Adult
Mn-54	4.2E-07	Adult
Fe-55	2.4E-08	Infant
Fe-59	5.7E-08	Adult
Co-56	3.2E-07	Adult
Co-57	3.8E-08	Adult
Co-58	8.3E-08	Adult
Co-60	4.2E-06	Adult
Ni-63	2.1E-08	Infant
Zn-65	9.7E-08	Infant
Se-75	2.3E-06	Infant
Rb-83	1.6E-08	Infant
Sr-85	1.7E-08	Adult
Sr-89	6.8E-09	Infant
Sr-90	3.8E-06	Infant
Zr-95	8.2E-08	Adult
Nb-95	1.5E-08	Adult
Tc-99	8.7E-06	Infant
Ru-103	2.2E-09	Adult
Ru-106	1.1E-08	Adult
Ag-110m	3.9E-06	Infant
Sb-125	5.3E-08	Adult
I-124	8.8E-11	Adult
I-125	1.8E-08	Infant
I-129	8.5E-07	Child
I-131	1.3E-09	Infant
Cs-134	2.4E-07	Adult
Cs-136	1.9E-09	Adult
Cs-137	3.8E-07	Adult
Ba-140	8.7E-09	Adult
Ce-141	1.3E-09	Adult
Ce-144	2.7E-08	Infant

Radionuclide*	Worst total DPUR (µSv/y per Bq/y)	Worst age group
Pm-147	4.0E-10	Infant
Eu-152	1.8E-06	Adult
Eu-154	1.6E-06	Adult
Eu-155	3.8E-08	Adult
Er-169	1.1E-12	Infant
Lu-177	3.0E-11	Adult
Pb-210	3.0E-05	Infant
Po-210	1.6E-05	Infant
Ra-223	7.9E-09	Infant
Ra-226	9.3E-06	Child
Ac-225	8.0E-10	Adult
Th-227	7.9E-09	Adult
Th-230	1.0E-05	Adult
Th-232	7.2E-06	Adult
Th-234	9.7E-10	Adult
U-234	2.2E-07	Infant
U-235	2.5E-07	Infant
U-238	2.1E-07	Infant
Np-237	2.4E-07	Adult
Pu-238	6.4E-08	Adult
Pu-239	1.6E-07	Adult
Pu-240	7.4E-08	Adult
Pu-241	6.5E-09	Adult
Pu-242	8.4E-08	Adult
Am-241	1.2E-06	Adult
Am-243	1.1E-06	Adult
Cm-242	3.4E-09	Infant
Cm-243	1.6E-06	Adult
Cm-244	2.6E-07	Adult

*radionuclides with a half-life of less than 4 days were not considered.

Table 31. Dose per unit release factors for offspring in a farming family – use of sludge as soil conditioner – sewage release scenario

Radionuclide*	DPURs for offspring in a farming family sludge to land (µSv/y per Bq/y)										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
H-3	0.0E+00	0.0E+00	3.2E-12	1.3E-12	3.8E-12	8.4E-13	2.3E-11	0.0E+00	1.8E-17	3.2E-18	3.3E-11
H-3 organic	0.0E+00	0.0E+00	4.9E-13	2.0E-13	5.9E-13	1.3E-13	2.5E-12	0.0E+00	4.3E-15	7.3E-16	3.9E-12
C-14	2.5E-08	3.3E-08	4.6E-09	1.8E-09	5.2E-09	1.1E-09	1.3E-08	0.0E+00	4.5E-15	9.3E-15	8.4E-08
Na-22	1.3E-10	1.9E-10	6.8E-09	2.7E-09	7.5E-09	1.7E-09	8.1E-09	2.4E-07	1.6E-14	8.2E-15	2.7E-07
P-32	nc	nc	1.6E-09	2.6E-10	2.7E-08	3.2E-10	9.0E-09	0.0E+00	4.5E-15	2.9E-15	3.8E-08
P-33	nc	nc	1.5E-09	2.3E-10	2.4E-08	2.9E-10	6.5E-09	0.0E+00	2.2E-15	1.5E-15	3.2E-08
S-35	2.5E-12	3.7E-12	9.2E-10	4.3E-10	2.6E-09	5.8E-10	8.6E-10	0.0E+00	1.9E-17	4.3E-17	5.4E-09
Cl-36	<p	<p	<p	<p	<p	<p	<p	9.3E-11	<p	<p	9.3E-11
Ca-45	6.9E-09	3.8E-10	5.5E-08	2.2E-08	5.4E-08	1.8E-09	2.6E-07	3.8E-17	1.7E-14	1.5E-14	4.0E-07
Ca-47	nc	nc	1.3E-12	5.1E-13	1.2E-12	4.0E-14	3.2E-11	2.6E-10	1.8E-17	2.4E-17	3.0E-10
V-48	nc	nc	<p	<p	<p	<p	<p	3.2E-08	<p	<p	3.2E-08
Cr-51	nc	nc	<p	<p	<p	<p	<p	8.2E-10	<p	<p	8.2E-10
Mn-52	nc	nc	<p	<p	<p	<p	<p	3.5E-09	<p	<p	3.5E-09
Mn-54	<p	<p	<p	<p	<p	<p	<p	3.4E-07	<p	<p	3.4E-07
Fe-55	<p	<p	<p	<p	<p	<p	<p	2.8E-12	<p	<p	2.8E-12
Fe-59	<p	<p	<p	<p	<p	<p	<p	5.6E-08	<p	<p	5.6E-08
Co-56	<p	<p	<p	<p	<p	<p	<p	3.2E-07	<p	<p	3.2E-07
Co-57	<p	<p	<p	<p	<p	<p	<p	3.7E-08	<p	<p	3.7E-08
Co-58	<p	<p	<p	<p	<p	<p	<p	8.2E-08	<p	<p	8.2E-08
Co-60	<p	<p	<p	<p	<p	<p	<p	4.1E-06	<p	<p	4.1E-06
Ni-63	<p	<p	<p	<p	<p	<p	<p	0.0E+00	<p	<p	0.0E+00
Zn-65	<p	<p	<p	<p	<p	<p	<p	1.9E-08	<p	<p	1.9E-08
Se-75	6.6E-10	1.0E-09	8.4E-08	6.8E-07	1.1E-07	5.9E-07	6.9E-08	3.2E-08	1.0E-14	4.2E-15	1.6E-06
Rb-83	<p	<p	<p	<p	<p	<p	<p	5.9E-09	<p	<p	5.9E-09
Sr-85	<p	<p	<p	<p	<p	<p	<p	1.7E-08	<p	<p	1.7E-08

Radionuclide*	DPURs for offspring in a farming family sludge to land (µSv/y per Bq/y)										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
Sr-89	2.2E-11	1.1E-11	7.9E-11	3.2E-11	1.3E-10	2.8E-11	3.3E-09	2.1E-12	5.3E-15	5.2E-15	3.7E-09
Sr-90	2.4E-07	3.9E-07	1.9E-08	7.5E-09	6.1E-08	1.3E-08	1.5E-06	2.0E-14	3.0E-12	2.5E-12	2.2E-06
Zr-95	<p	<p	<p	<p	<p	<p	<p	8.2E-08	<p	<p	8.2E-08
Nb-95	<p	<p	<p	<p	<p	<p	<p	1.5E-08	<p	<p	1.5E-08
Tc-99	<p	<p	<p	<p	<p	<p	<p	0.0E+00	<p	<p	0.0E+00
Ru-103	<p	<p	<p	<p	<p	<p	<p	2.2E-09	<p	<p	2.2E-09
Ru-106	<p	<p	<p	<p	<p	<p	<p	1.0E-08	<p	<p	1.0E-08
Ag-110m	<p	<p	<p	<p	<p	<p	<p	8.6E-07	<p	<p	8.6E-07
Sb-125	<p	<p	<p	<p	<p	<p	<p	5.0E-08	<p	<p	5.0E-08
I-124	nc	nc	<p	<p	<p	<p	<p	8.6E-11	<p	<p	8.6E-11
I-125	<p	<p	<p	<p	<p	<p	<p	1.5E-10	<p	<p	1.5E-10
I-129	<p	<p	<p	<p	<p	<p	<p	3.2E-09	<p	<p	3.2E-09
I-131	nc	nc	7.7E-12	3.1E-12	9.4E-12	2.1E-12	1.2E-10	2.3E-10	4.0E-16	1.9E-16	3.7E-10
Cs-134	<p	<p	<p	<p	<p	<p	<p	1.4E-07	<p	<p	1.4E-07
Cs-136	nc	nc	<p	<p	<p	<p	<p	1.8E-09	<p	<p	1.8E-09
Cs-137	<p	<p	<p	<p	<p	<p	<p	2.6E-07	<p	<p	2.6E-07
Ba-140	nc	nc	<p	<p	<p	<p	<p	8.7E-09	<p	<p	8.7E-09
Ce-141	<p	<p	<p	<p	<p	<p	<p	1.2E-09	<p	<p	1.2E-09
Ce-144	<p	<p	<p	<p	<p	<p	<p	9.1E-09	<p	<p	9.1E-09
Pm-147	<p	<p	<p	<p	<p	<p	<p	1.9E-12	<p	<p	1.9E-12
Eu-152	<p	<p	<p	<p	<p	<p	<p	1.8E-06	<p	<p	1.8E-06
Eu-154	<p	<p	<p	<p	<p	<p	<p	1.6E-06	<p	<p	1.6E-06
Eu-155	<p	<p	<p	<p	<p	<p	<p	3.8E-08	<p	<p	3.8E-08
Er-169	nc	nc	<p	<p	<p	<p	<p	4.6E-17	<p	<p	4.6E-17
Lu-177	nc	nc	<p	<p	<p	<p	<p	3.0E-11	<p	<p	3.0E-11
Pb-210	<p	<p	<p	<p	<p	<p	<p	2.3E-09	<p	<p	2.3E-09
Po-210	<p	<p	<p	<p	<p	<p	<p	1.5E-12	<p	<p	1.5E-12
Ra-223	nc	nc	<p	<p	<p	<p	<p	9.2E-10	<p	<p	9.2E-10
Ra-226	4.5E-07	9.7E-07	1.8E-07	7.3E-08	8.3E-07	5.4E-08	1.0E-06	5.4E-06	6.7E-11	3.7E-11	9.0E-06
Ac-225	nc	nc	<p	<p	<p	<p	<p	8.0E-10	<p	<p	8.0E-10

Radionuclide*	DPURs for offspring in a farming family sludge to land (µSv/y per Bq/y)										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
Th-227	nc	nc	<p	<p	<p	<p	<p	7.9E-09	<p	<p	7.9E-09
Th-230	<p	<p	<p	<p	<p	<p	<p	9.8E-06	<p	<p	9.8E-06
Th-232	<p	<p	<p	<p	<p	<p	<p	6.9E-06	<p	<p	6.9E-06
Th-234	<p	<p	<p	<p	<p	<p	<p	9.6E-10	<p	<p	9.6E-10
U-234	<p	<p	<p	<p	<p	<p	<p	8.1E-09	<p	<p	8.1E-09
U-235	<p	<p	<p	<p	<p	<p	<p	8.2E-08	<p	<p	8.2E-08
U-238	<p	<p	<p	<p	<p	<p	<p	1.3E-08	<p	<p	1.3E-08
Np-237	<p	<p	<p	<p	<p	<p	<p	1.2E-07	<p	<p	1.2E-07
Pu-238	<p	<p	<p	<p	<p	<p	<p	6.6E-11	<p	<p	6.6E-11
Pu-239	<p	<p	<p	<p	<p	<p	<p	8.2E-08	<p	<p	8.2E-08
Pu-240	<p	<p	<p	<p	<p	<p	<p	4.7E-11	<p	<p	4.7E-11
Pu-241	<p	<p	<p	<p	<p	<p	<p	5.5E-09	<p	<p	5.5E-09
Pu-242	<p	<p	<p	<p	<p	<p	<p	1.3E-08	<p	<p	1.3E-08
Am-241	<p	<p	<p	<p	<p	<p	<p	6.1E-07	<p	<p	6.1E-07
Am-243	<p	<p	<p	<p	<p	<p	<p	4.9E-07	<p	<p	4.9E-07
Cm-242	<p	<p	<p	<p	<p	<p	<p	1.7E-10	<p	<p	1.7E-10
Cm-243	<p	<p	<p	<p	<p	<p	<p	1.3E-06	<p	<p	1.3E-06
Cm-244	<p	<p	<p	<p	<p	<p	<p	8.7E-10	<p	<p	8.7E-10

*radionuclides with a half-life of less than 4 days were not considered.
<p: not calculated as dose rate to parent greater than dose rate to offspring
nc: not considered as half-life less than 30 days.

Table 32. Dose per unit release factors for infant in a farming family – use of sludge as soil conditioner – sewage release scenario

Radionuclide*	DPURs for infant in a farming family sludge to land (µSv/y per Bq/y)										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
H-3	0.0E+00	0.0E+00	6.0E-13	5.5E-13	1.3E-12	3.6E-13	4.8E-11	0.0E+00	1.4E-18	5.2E-18	5.1E-11
H-3 organic	0.0E+00	0.0E+00	1.1E-13	1.0E-13	2.5E-13	6.8E-14	6.4E-12	0.0E+00	3.6E-16	1.5E-15	6.9E-12
C-14	9.4E-09	2.3E-08	1.1E-09	1.0E-09	2.3E-09	6.3E-10	3.6E-08	0.0E+00	2.1E-14	2.0E-14	7.3E-08
Na-22	1.0E-10	2.8E-10	3.4E-09	3.1E-09	6.9E-09	1.9E-09	4.5E-08	8.3E-08	4.7E-15	3.6E-14	1.4E-07
P-32	nc	nc	1.5E-10	5.4E-11	4.5E-09	6.8E-11	9.1E-09	0.0E+00	4.9E-16	2.4E-15	1.4E-08
P-33	nc	nc	6.6E-11	2.4E-11	2.0E-09	3.0E-11	3.3E-09	0.0E+00	4.0E-16	5.9E-16	5.4E-09
S-35	2.0E-12	5.5E-12	4.8E-10	5.2E-10	2.5E-09	7.0E-10	5.0E-09	0.0E+00	2.7E-16	2.0E-16	9.2E-09
Cl-36	6.4E-08	1.6E-07	4.4E-08	5.4E-08	1.2E-07	3.4E-08	7.9E-07	3.2E-11	1.2E-13	1.1E-13	1.3E-06
Ca-45	7.3E-10	7.4E-11	3.7E-09	3.4E-09	6.7E-09	2.9E-10	1.9E-07	1.3E-17	4.2E-15	9.0E-15	2.1E-07
Ca-47	nc	nc	1.8E-13	1.7E-13	3.1E-13	1.3E-14	5.1E-11	9.0E-11	6.6E-18	3.0E-17	1.4E-10
V-48	nc	nc	1.4E-14	1.3E-14	6.5E-16	6.9E-15	2.6E-13	1.1E-08	5.1E-16	1.9E-15	1.1E-08
Cr-51	nc	nc	1.3E-12	1.2E-12	2.1E-12	5.7E-13	1.3E-11	2.8E-10	2.3E-17	9.7E-17	3.0E-10
Mn-52	nc	nc	6.4E-14	1.1E-11	1.0E-13	8.4E-12	1.1E-12	1.2E-09	2.8E-17	1.4E-16	1.2E-09
Mn-54	1.7E-10	5.0E-10	2.8E-10	5.6E-08	4.9E-10	4.5E-08	1.2E-09	1.2E-07	1.4E-14	2.6E-14	2.2E-07
Fe-55	3.9E-10	5.0E-12	1.1E-11	3.0E-10	2.9E-10	2.3E-08	9.5E-11	9.7E-13	8.3E-15	5.4E-14	2.4E-08
Fe-59	4.4E-12	1.6E-14	1.3E-12	3.5E-11	2.8E-11	2.2E-09	9.6E-11	1.9E-08	2.8E-15	1.1E-14	2.2E-08
Co-56	4.5E-11	1.8E-11	4.8E-11	3.6E-09	3.1E-11	2.0E-09	8.7E-10	1.1E-07	9.8E-15	2.7E-14	1.2E-07
Co-57	5.1E-11	5.0E-11	2.4E-11	1.9E-09	1.8E-11	1.1E-09	2.6E-10	1.3E-08	4.0E-15	1.1E-14	1.6E-08
Co-58	1.0E-11	3.7E-12	1.2E-11	9.1E-10	7.8E-12	5.0E-10	2.3E-10	2.8E-08	2.7E-15	6.8E-15	3.0E-08
Co-60	4.5E-09	1.2E-08	1.8E-09	1.3E-07	1.5E-09	9.8E-08	1.5E-08	1.4E-06	3.7E-13	1.1E-12	1.7E-06
Ni-63	1.3E-09	9.7E-10	1.5E-13	1.4E-12	2.0E-12	5.5E-12	1.9E-08	0.0E+00	9.5E-14	1.6E-13	2.1E-08
Zn-65	2.0E-10	1.2E-10	3.0E-10	1.2E-10	3.9E-08	1.3E-10	5.0E-08	6.7E-09	1.2E-15	1.1E-14	9.7E-08
Se-75	6.0E-10	1.7E-09	4.9E-08	8.9E-07	1.1E-07	7.8E-07	4.5E-07	1.1E-08	2.6E-15	2.1E-14	2.3E-06
Rb-83	5.6E-12	2.0E-11	1.2E-10	1.1E-10	2.8E-10	7.7E-11	1.3E-08	2.0E-09	2.2E-16	1.9E-15	1.6E-08
Sr-85	3.1E-12	3.2E-12	3.5E-12	3.2E-12	1.1E-11	2.9E-12	1.7E-09	5.9E-09	5.1E-16	1.9E-15	7.5E-09
Sr-89	6.1E-12	5.6E-12	1.4E-11	1.3E-11	4.2E-11	1.2E-11	6.7E-09	7.2E-13	2.9E-15	8.2E-15	6.8E-09

Radionuclide*	DPURs for infant in a farming family sludge to land (µSv/y per Bq/y)										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
Sr-90	7.5E-08	2.3E-07	3.8E-09	3.5E-09	2.3E-08	6.3E-09	3.4E-06	7.0E-15	1.8E-12	4.5E-12	3.8E-06
Zr-95	4.5E-12	7.0E-14	2.0E-13	1.8E-13	3.1E-14	7.1E-14	3.3E-12	2.8E-08	3.3E-15	4.3E-15	2.8E-08
Nb-95	1.2E-13	5.1E-15	1.5E-14	1.4E-14	6.3E-16	6.7E-15	1.3E-13	5.3E-09	4.6E-16	1.1E-15	5.3E-09
Tc-99	1.2E-07	2.3E-07	1.2E-06	3.2E-06	1.2E-07	1.3E-07	3.8E-06	0.0E+00	2.9E-14	4.1E-14	8.7E-06
Ru-103	7.3E-14	1.8E-15	5.8E-14	2.5E-13	1.5E-12	1.3E-13	1.1E-12	7.6E-10	1.8E-16	3.8E-16	7.6E-10
Ru-106	2.0E-10	2.6E-11	1.3E-11	5.8E-11	3.6E-10	3.0E-11	6.1E-11	3.5E-09	2.9E-14	4.8E-14	4.3E-09
Ag-110m	3.1E-10	5.3E-12	4.9E-11	2.8E-07	2.7E-09	3.0E-07	3.0E-06	3.0E-07	4.7E-14	8.9E-14	3.9E-06
Sb-125	3.3E-11	9.2E-13	3.6E-11	3.3E-09	5.3E-11	1.2E-09	5.6E-11	1.7E-08	1.1E-14	1.5E-14	2.2E-08
I-124	nc	nc	8.3E-14	7.6E-14	2.4E-13	6.7E-14	2.1E-11	3.0E-11	1.4E-17	1.3E-16	5.1E-11
I-125	1.7E-11	3.0E-11	2.9E-10	2.7E-10	3.1E-10	8.6E-11	1.6E-08	5.3E-11	1.7E-15	1.6E-14	1.8E-08
I-129	4.8E-08	1.4E-07	2.1E-08	1.9E-08	1.2E-08	3.3E-09	5.7E-07	1.1E-09	1.2E-12	1.1E-11	8.2E-07
I-131	nc	nc	7.2E-12	6.6E-12	1.6E-11	4.5E-12	1.2E-09	8.1E-11	1.7E-16	1.6E-15	1.3E-09
Cs-134	1.1E-10	3.2E-10	2.6E-09	2.4E-09	4.8E-09	1.3E-09	3.1E-08	4.9E-08	3.7E-15	3.1E-14	9.2E-08
Cs-136	nc	nc	8.6E-12	7.9E-12	1.4E-11	3.9E-12	2.1E-10	6.3E-10	1.8E-17	1.2E-16	8.7E-10
Cs-137	3.2E-10	1.4E-09	3.6E-09	3.3E-09	5.6E-09	1.5E-09	3.5E-08	9.1E-08	2.2E-14	1.8E-13	1.4E-07
Ba-140	nc	nc	6.3E-13	5.8E-13	3.3E-13	3.2E-13	4.3E-11	3.0E-09	2.6E-16	9.0E-16	3.1E-09
Ce-141	1.1E-13	1.6E-15	3.5E-15	2.5E-11	3.3E-13	1.8E-11	2.4E-11	4.3E-10	8.5E-16	1.5E-15	4.9E-10
Ce-144	5.3E-10	4.0E-11	1.3E-12	9.6E-09	2.0E-10	1.1E-08	2.1E-09	3.1E-09	1.7E-13	1.6E-13	2.7E-08
Pm-147	1.0E-10	8.2E-11	1.3E-11	7.2E-11	3.1E-11	6.9E-11	2.9E-11	6.5E-13	5.7E-14	2.3E-14	4.0E-10
Eu-152	4.2E-10	6.1E-10	1.0E-10	5.7E-10	3.7E-10	8.1E-10	2.0E-10	6.3E-07	1.3E-12	3.8E-13	6.3E-07
Eu-154	5.7E-10	6.9E-10	1.5E-10	8.3E-10	4.9E-10	1.1E-09	2.9E-10	5.4E-07	1.4E-12	4.3E-13	5.5E-07
Eu-155	8.2E-11	7.1E-11	2.2E-11	1.2E-10	6.3E-11	1.4E-10	4.3E-11	1.3E-08	1.3E-13	4.7E-14	1.4E-08
Er-169	nc	nc	3.1E-17	2.3E-13	2.8E-15	1.6E-13	7.2E-13	1.6E-17	3.0E-17	9.1E-17	1.1E-12
Lu-177	nc	nc	7.5E-18	5.5E-14	6.9E-16	3.8E-14	2.4E-13	1.0E-11	1.5E-17	5.3E-17	1.1E-11
Pb-210	8.9E-07	7.6E-07	4.9E-07	1.3E-06	2.2E-06	1.7E-06	2.2E-05	7.9E-10	1.2E-10	4.4E-10	3.0E-05
Po-210	1.1E-07	2.0E-07	6.4E-07	7.0E-06	7.1E-07	5.2E-06	2.0E-06	5.1E-13	1.0E-11	3.1E-11	1.6E-05
Ra-223	nc	nc	4.5E-11	4.1E-11	3.1E-10	2.5E-11	7.2E-09	3.2E-10	2.8E-13	5.5E-14	7.9E-09
Ra-226	2.5E-07	1.0E-06	6.6E-08	6.1E-08	5.5E-07	4.5E-08	4.0E-06	1.9E-06	3.6E-10	1.2E-10	7.9E-06
Ac-225	nc	nc	1.3E-14	2.3E-12	2.4E-14	1.3E-12	8.6E-12	2.8E-10	4.1E-13	1.2E-14	2.9E-10

Radionuclide*	DPURs for infant in a farming family sludge to land (µSv/y per Bq/y)										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
Th-227	nc	nc	2.6E-13	2.4E-12	1.2E-12	1.4E-12	3.3E-11	2.7E-09	1.8E-12	1.6E-14	2.8E-09
Th-230	2.5E-08	9.0E-09	2.4E-09	2.2E-08	3.1E-08	3.7E-08	3.2E-08	3.4E-06	2.1E-09	9.4E-11	3.5E-06
Th-232	2.8E-08	9.9E-09	2.7E-09	2.4E-08	3.4E-08	4.0E-08	3.5E-08	2.4E-06	3.0E-09	1.0E-10	2.6E-06
Th-234	1.0E-12	1.6E-15	2.5E-13	2.3E-12	1.1E-12	1.3E-12	2.5E-11	3.3E-10	3.2E-15	9.8E-15	3.6E-10
U-234	2.1E-09	3.4E-09	4.3E-10	3.9E-10	1.4E-09	2.0E-10	2.1E-07	2.8E-09	7.4E-11	3.3E-12	2.2E-07
U-235	2.1E-09	3.4E-09	4.3E-10	3.9E-10	1.4E-09	2.0E-10	2.1E-07	2.8E-08	6.7E-11	3.3E-12	2.5E-07
U-238	2.0E-09	3.1E-09	4.0E-10	3.6E-10	1.3E-09	1.9E-10	2.0E-07	4.5E-09	6.3E-11	3.1E-12	2.1E-07
Np-237	4.2E-09	1.4E-08	1.8E-10	1.2E-08	1.0E-09	3.4E-08	5.8E-10	4.0E-08	2.7E-10	5.3E-12	1.1E-07
Pu-238	2.5E-09	3.9E-10	1.7E-10	1.1E-08	3.6E-10	1.2E-08	2.1E-10	2.3E-11	4.1E-10	8.5E-12	2.7E-08
Pu-239	2.6E-09	5.0E-10	1.8E-10	1.2E-08	4.0E-10	1.3E-08	2.3E-10	2.8E-08	5.1E-10	1.1E-11	5.8E-08
Pu-240	2.6E-09	5.0E-10	1.8E-10	1.2E-08	4.0E-10	1.3E-08	2.3E-10	1.6E-11	5.1E-10	1.1E-11	3.0E-08
Pu-241	3.3E-11	2.6E-12	2.0E-12	1.3E-10	3.9E-12	1.3E-10	2.2E-12	1.9E-09	2.6E-12	5.8E-14	2.2E-09
Pu-242	2.5E-09	4.7E-10	1.7E-10	1.1E-08	3.8E-10	1.3E-08	2.2E-10	4.6E-09	4.9E-10	1.0E-11	3.3E-08
Am-241	1.2E-08	3.5E-09	1.2E-09	7.9E-08	5.5E-09	1.8E-07	3.2E-09	2.1E-07	2.2E-09	4.5E-11	5.0E-07
Am-243	1.2E-08	3.6E-09	1.2E-09	8.1E-08	5.6E-09	1.9E-07	3.2E-09	1.7E-07	2.3E-09	4.7E-11	4.7E-07
Cm-242	9.7E-10	6.3E-12	2.2E-11	1.4E-09	2.4E-11	8.0E-10	1.4E-11	5.9E-11	1.9E-11	3.1E-13	3.4E-09
Cm-243	1.9E-08	4.5E-09	1.2E-09	7.7E-08	2.4E-09	8.2E-08	1.4E-09	4.5E-07	2.2E-09	4.5E-11	6.4E-07
Cm-244	1.6E-08	3.1E-09	9.7E-10	6.3E-08	1.9E-09	6.5E-08	1.1E-09	3.0E-10	1.6E-09	3.1E-11	1.5E-07

*radionuclides with a half-life of less than 4 days were not considered.
nc: not considered as half-life less than 30 days.

Table 33. Dose per unit release factors for child in a farming family – use of sludge as soil conditioner – sewage release scenario

Radionuclide*	DPURs for child in a farming family sludge to land (µSv/y per Bq/y)										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
H-3	0.0E+00	0.0E+00	9.5E-13	4.8E-13	1.9E-12	3.1E-13	1.7E-11	0.0E+00	3.8E-18	2.0E-18	2.1E-11
H-3 organic	0.0E+00	0.0E+00	1.8E-13	8.8E-14	3.5E-13	5.9E-14	2.3E-12	0.0E+00	1.0E-15	5.7E-16	2.9E-12
C-14	1.1E-08	2.4E-08	1.8E-09	9.1E-10	3.4E-09	5.7E-10	1.3E-08	0.0E+00	5.3E-14	8.1E-15	5.5E-08
Na-22	9.0E-11	2.1E-10	4.1E-09	2.1E-09	7.6E-09	1.3E-09	1.2E-08	1.2E-07	8.9E-15	1.1E-14	1.5E-07
P-32	nc	nc	1.4E-10	2.8E-11	3.8E-09	3.4E-11	1.9E-09	0.0E+00	1.0E-15	5.4E-16	5.9E-09
P-33	nc	nc	6.5E-11	1.3E-11	1.7E-09	1.6E-11	7.2E-10	0.0E+00	1.1E-15	1.4E-16	2.6E-09
S-35	1.5E-12	3.6E-12	4.9E-10	2.9E-10	2.4E-09	3.9E-10	1.2E-09	0.0E+00	7.0E-16	5.1E-17	4.7E-09
Cl-36	4.5E-08	1.0E-07	4.4E-08	3.0E-08	1.1E-07	1.9E-08	1.8E-07	4.7E-11	2.7E-13	2.8E-14	5.3E-07
Ca-45	6.2E-10	5.7E-11	4.6E-09	2.3E-09	7.4E-09	1.9E-10	5.4E-08	1.9E-17	1.1E-14	2.7E-15	6.9E-08
Ca-47	nc	nc	2.0E-13	9.8E-14	3.0E-13	7.8E-15	1.2E-11	1.3E-10	1.5E-17	8.0E-18	1.5E-10
V-48	nc	nc	1.7E-14	8.3E-15	6.9E-16	4.5E-15	6.8E-14	1.6E-08	1.2E-15	5.7E-16	1.6E-08
Cr-51	nc	nc	1.5E-12	7.5E-13	2.1E-12	3.5E-13	3.2E-12	4.2E-10	4.3E-17	2.7E-17	4.3E-10
Mn-52	nc	nc	8.2E-14	8.0E-12	1.2E-13	5.9E-12	3.2E-13	1.8E-09	5.8E-17	4.4E-17	1.8E-09
Mn-54	1.7E-10	4.4E-10	3.9E-10	4.3E-08	6.2E-10	3.4E-08	3.7E-10	1.7E-07	3.1E-14	9.1E-15	2.5E-07
Fe-55	4.2E-10	4.9E-12	1.7E-11	2.5E-10	4.0E-10	1.9E-08	3.3E-11	1.4E-12	2.1E-14	2.0E-14	2.0E-08
Fe-59	3.7E-12	1.2E-14	1.5E-12	2.3E-11	3.0E-11	1.4E-09	2.6E-11	2.9E-08	6.9E-15	3.2E-15	3.0E-08
Co-56	4.1E-11	1.5E-11	6.1E-11	2.6E-09	3.6E-11	1.4E-09	2.5E-10	1.6E-07	2.0E-14	8.4E-15	1.7E-07
Co-57	4.3E-11	3.8E-11	2.9E-11	1.2E-09	1.9E-11	7.4E-10	7.0E-11	1.9E-08	8.9E-15	3.3E-15	2.1E-08
Co-58	9.0E-12	3.0E-12	1.5E-11	6.4E-10	9.0E-12	3.5E-10	6.8E-11	4.2E-08	5.7E-15	2.2E-15	4.3E-08
Co-60	4.3E-09	1.1E-08	2.4E-09	1.0E-07	1.9E-09	7.2E-08	4.6E-09	2.1E-06	9.4E-13	3.7E-13	2.3E-06
Ni-63	1.0E-09	6.8E-10	1.6E-13	8.2E-13	2.0E-12	3.3E-12	4.7E-09	0.0E+00	2.0E-13	4.4E-14	6.4E-09
Zn-65	1.9E-10	1.0E-10	4.1E-10	9.0E-11	4.7E-08	9.8E-11	1.5E-08	9.8E-09	2.5E-15	3.6E-15	7.3E-08
Se-75	6.4E-10	1.7E-09	7.5E-08	7.5E-07	1.6E-07	6.5E-07	1.5E-07	1.6E-08	6.3E-15	8.1E-15	1.8E-06
Rb-83	4.9E-12	1.6E-11	1.6E-10	7.8E-11	3.2E-10	5.4E-11	3.7E-09	3.0E-09	4.4E-16	5.8E-16	7.3E-09
Sr-85	3.5E-12	3.3E-12	5.7E-12	2.8E-12	1.5E-11	2.6E-12	6.0E-10	8.6E-09	1.1E-15	7.6E-16	9.3E-09

Radionuclide*	DPURs for child in a farming family sludge to land (µSv/y per Bq/y)										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
Sr-89	4.6E-12	3.8E-12	1.5E-11	7.7E-12	4.1E-11	6.8E-12	1.6E-09	1.1E-12	6.4E-15	2.2E-15	1.7E-09
Sr-90	1.4E-07	4.0E-07	1.1E-08	5.3E-09	5.6E-08	9.4E-09	2.1E-06	1.0E-14	4.8E-12	3.0E-12	2.7E-06
Zr-95	3.5E-12	5.0E-14	2.2E-13	1.1E-13	3.1E-14	4.4E-14	8.5E-13	4.2E-08	8.1E-15	1.2E-15	4.2E-08
Nb-95	9.9E-14	3.7E-15	1.7E-14	8.6E-15	6.5E-16	4.2E-15	3.4E-14	7.8E-09	1.1E-15	3.0E-16	7.8E-09
Tc-99	7.6E-08	1.3E-07	1.0E-06	1.6E-06	9.6E-08	6.4E-08	7.7E-07	0.0E+00	7.4E-14	9.0E-15	3.7E-06
Ru-103	5.6E-14	1.3E-15	6.3E-14	1.5E-13	1.5E-12	7.5E-14	2.6E-13	1.1E-09	4.4E-16	1.0E-16	1.1E-09
Ru-106	1.4E-10	1.7E-11	1.4E-11	3.2E-11	3.3E-10	1.7E-11	1.4E-11	5.2E-09	6.2E-14	1.2E-14	5.8E-09
Ag-110m	2.7E-10	4.2E-12	6.0E-11	1.9E-07	3.0E-09	2.0E-07	8.4E-07	4.4E-07	1.2E-13	2.7E-14	1.7E-06
Sb-125	2.6E-11	6.7E-13	4.1E-11	2.0E-09	5.5E-11	7.7E-10	1.4E-11	2.5E-08	2.6E-14	4.3E-15	2.8E-08
I-124	nc	nc	7.8E-14	3.9E-14	2.1E-13	3.4E-14	4.5E-12	4.4E-11	2.0E-17	3.1E-17	4.8E-11
I-125	2.2E-11	3.4E-11	5.3E-10	2.7E-10	5.1E-10	8.5E-11	6.7E-09	7.8E-11	4.7E-15	7.1E-15	8.2E-09
I-129	9.7E-08	2.6E-07	6.1E-08	3.0E-08	3.1E-08	5.2E-09	3.7E-07	1.7E-09	5.2E-12	7.9E-12	8.5E-07
I-131	nc	nc	7.0E-12	3.5E-12	1.4E-11	2.4E-12	2.7E-10	1.2E-10	2.6E-16	3.8E-16	4.1E-10
Cs-134	2.3E-10	5.9E-10	7.6E-09	3.8E-09	1.3E-08	2.1E-09	2.0E-08	7.3E-08	1.6E-14	2.2E-14	1.2E-07
Cs-136	nc	nc	1.3E-11	6.6E-12	2.0E-11	3.3E-12	7.2E-11	9.3E-10	4.0E-17	4.7E-17	1.0E-09
Cs-137	6.2E-10	2.5E-09	9.9E-09	5.0E-09	1.4E-08	2.3E-09	2.2E-08	1.3E-07	8.6E-14	1.2E-13	1.9E-07
Ba-140	nc	nc	6.8E-13	3.4E-13	3.2E-13	1.9E-13	1.0E-11	4.4E-09	5.8E-16	2.4E-16	4.5E-09
Ce-141	7.9E-14	9.8E-16	3.4E-15	1.4E-11	2.9E-13	9.6E-12	5.3E-12	6.3E-10	2.1E-15	3.6E-16	6.6E-10
Ce-144	3.5E-10	2.4E-11	1.2E-12	4.9E-09	1.7E-10	5.8E-09	4.5E-10	4.6E-09	3.4E-13	3.6E-14	1.6E-08
Pm-147	7.0E-11	5.2E-11	1.3E-11	3.9E-11	2.8E-11	3.8E-11	6.5E-12	9.6E-13	1.3E-13	5.7E-15	2.5E-10
Eu-152	3.5E-10	4.6E-10	1.2E-10	3.6E-10	3.9E-10	5.2E-10	5.2E-11	9.2E-07	3.8E-12	1.1E-13	9.3E-07
Eu-154	4.5E-10	5.0E-10	1.7E-10	5.1E-10	5.0E-10	6.7E-10	7.3E-11	8.0E-07	3.5E-12	1.2E-13	8.0E-07
Eu-155	5.9E-11	4.6E-11	2.3E-11	6.8E-11	5.8E-11	7.7E-11	1.0E-11	1.9E-08	3.0E-13	1.2E-14	1.9E-08
Er-169	nc	nc	3.0E-17	1.2E-13	2.5E-15	8.3E-14	1.6E-13	2.3E-17	7.5E-17	2.2E-17	3.7E-13
Lu-177	nc	nc	7.7E-18	3.1E-14	6.4E-16	2.1E-14	5.6E-14	1.5E-11	3.6E-17	1.3E-17	1.5E-11
Pb-210	1.1E-06	8.5E-07	8.6E-07	1.2E-06	3.4E-06	1.6E-06	8.9E-06	1.2E-09	2.8E-10	1.9E-10	1.8E-05
Po-210	7.5E-08	1.3E-07	6.3E-07	3.8E-06	6.3E-07	2.8E-06	4.5E-07	7.5E-13	2.5E-11	7.5E-12	8.5E-06
Ra-223	nc	nc	6.1E-11	3.1E-11	3.8E-10	1.9E-11	2.2E-09	4.7E-10	7.6E-13	1.8E-14	3.2E-09
Ra-226	4.9E-07	1.8E-06	1.8E-07	9.2E-08	1.4E-06	6.8E-08	2.5E-06	2.8E-06	9.2E-10	8.0E-11	9.3E-06
Ac-225	nc	nc	1.3E-14	1.3E-12	2.2E-14	7.3E-13	1.9E-12	4.1E-10	1.1E-12	3.0E-15	4.1E-10

Radionuclide*	DPURs for child in a farming family sludge to land (µSv/y per Bq/y)										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
Th-227	nc	nc	2.9E-13	1.4E-12	1.1E-12	8.3E-13	8.1E-12	4.0E-09	4.9E-12	4.3E-15	4.0E-09
Th-230	3.5E-08	1.1E-08	4.7E-09	2.4E-08	5.4E-08	3.9E-08	1.4E-08	5.0E-06	5.6E-09	4.5E-11	5.2E-06
Th-232	4.2E-08	1.3E-08	5.7E-09	2.9E-08	6.5E-08	4.7E-08	1.7E-08	3.5E-06	9.1E-09	5.4E-11	3.7E-06
Th-234	7.2E-13	1.0E-15	2.5E-13	1.3E-12	9.9E-13	7.2E-13	5.5E-12	4.9E-10	6.6E-15	2.4E-15	5.0E-10
U-234	2.8E-09	4.0E-09	8.1E-10	4.1E-10	2.4E-09	2.1E-10	9.0E-08	4.1E-09	1.9E-10	1.5E-12	1.1E-07
U-235	2.7E-09	3.9E-09	7.8E-10	3.9E-10	2.3E-09	2.0E-10	8.7E-08	4.2E-08	1.7E-10	1.5E-12	1.4E-07
U-238	2.6E-09	3.7E-09	7.5E-10	3.7E-10	2.2E-09	1.9E-10	8.3E-08	6.6E-09	1.6E-10	1.4E-12	1.0E-07
Np-237	5.1E-09	1.6E-08	3.1E-10	1.1E-08	1.6E-09	3.2E-08	2.3E-10	6.0E-08	8.6E-10	2.3E-12	1.3E-07
Pu-238	3.5E-09	5.0E-10	3.4E-10	1.2E-08	6.5E-10	1.3E-08	9.3E-11	3.3E-11	1.4E-09	4.2E-12	3.2E-08
Pu-239	4.0E-09	6.8E-10	3.9E-10	1.4E-08	7.7E-10	1.6E-08	1.1E-10	4.2E-08	1.9E-09	5.6E-12	7.9E-08
Pu-240	4.0E-09	6.8E-10	3.9E-10	1.4E-08	7.7E-10	1.6E-08	1.1E-10	2.4E-11	1.9E-09	5.6E-12	3.8E-08
Pu-241	7.0E-11	4.9E-12	6.0E-12	2.1E-10	1.0E-11	2.1E-10	1.5E-12	2.8E-09	1.3E-11	4.2E-14	3.3E-09
Pu-242	3.8E-09	6.5E-10	3.8E-10	1.4E-08	7.4E-10	1.5E-08	1.1E-10	6.8E-09	1.8E-09	5.4E-12	4.3E-08
Am-241	1.6E-08	4.4E-09	2.4E-09	8.6E-08	9.7E-09	2.0E-07	1.4E-09	3.1E-07	7.5E-09	2.2E-11	6.4E-07
Am-243	1.7E-08	4.6E-09	2.4E-09	8.7E-08	1.0E-08	2.0E-07	1.4E-09	2.5E-07	7.8E-09	2.3E-11	5.8E-07
Cm-242	7.2E-10	4.2E-12	2.4E-11	8.3E-10	2.3E-11	4.6E-10	3.3E-12	8.7E-11	4.6E-11	8.1E-14	2.2E-09
Cm-243	2.2E-08	4.6E-09	1.9E-09	6.7E-08	3.5E-09	7.2E-08	5.1E-10	6.6E-07	6.5E-09	1.8E-11	8.4E-07
Cm-244	1.8E-08	3.1E-09	1.6E-09	5.6E-08	2.8E-09	5.7E-08	4.0E-10	4.4E-10	4.4E-09	1.2E-11	1.4E-07

*radionuclides with a half-life of less than 4 days were not considered.
nc: not considered as half-life less than 30 days.

Table 34. Dose per unit release factors for adult in a farming family – use of sludge as soil conditioner – sewage release scenario

Radionuclide*	DPURs for adult in a farming family sludge to land (µSv/y per Bq/y)										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
H-3	0.0E+00	0.0E+00	1.9E-12	7.5E-13	2.2E-12	4.9E-13	1.4E-11	0.0E+00	1.1E-17	1.8E-18	1.9E-11
H-3 organic	0.0E+00	0.0E+00	3.3E-13	1.3E-13	3.9E-13	8.7E-14	1.7E-12	0.0E+00	2.8E-15	4.9E-16	2.6E-12
C-14	1.8E-08	2.4E-08	3.3E-09	1.3E-09	3.7E-09	8.3E-10	9.7E-09	0.0E+00	1.4E-13	6.7E-15	6.1E-08
Na-22	1.2E-10	1.7E-10	6.0E-09	2.4E-09	6.6E-09	1.5E-09	7.2E-09	2.4E-07	1.7E-14	7.3E-15	2.6E-07
P-32	nc	nc	1.6E-10	2.5E-11	2.6E-09	3.1E-11	8.7E-10	0.0E+00	2.3E-15	2.8E-16	3.6E-09
P-33	nc	nc	7.3E-11	1.2E-11	1.2E-09	1.4E-11	3.3E-10	0.0E+00	2.7E-15	7.4E-17	1.6E-09
S-35	1.6E-12	2.4E-12	5.9E-10	2.8E-10	1.7E-09	3.8E-10	5.6E-10	0.0E+00	1.8E-15	2.8E-17	3.5E-09
Cl-36	5.1E-08	6.9E-08	5.4E-08	2.9E-08	8.2E-08	1.8E-08	8.8E-08	9.3E-11	7.1E-13	1.6E-14	3.9E-07
Ca-45	5.6E-10	3.1E-11	4.5E-09	1.8E-09	4.4E-09	1.5E-10	2.1E-08	3.8E-17	2.7E-14	1.2E-15	3.3E-08
Ca-47	nc	nc	2.6E-13	1.0E-13	2.4E-13	8.3E-15	6.6E-12	2.6E-10	3.4E-17	4.9E-18	2.7E-10
V-48	nc	nc	2.1E-14	8.5E-15	5.3E-16	4.6E-15	3.5E-14	3.2E-08	2.3E-15	3.3E-16	3.2E-08
Cr-51	nc	nc	1.8E-12	7.3E-13	1.5E-12	3.4E-13	1.6E-12	8.2E-10	8.6E-17	1.5E-17	8.3E-10
Mn-52	nc	nc	1.1E-13	8.5E-12	9.5E-14	6.2E-12	1.7E-13	3.5E-09	1.2E-16	2.7E-17	3.5E-09
Mn-54	2.1E-10	3.3E-10	5.3E-10	4.6E-08	5.1E-10	3.7E-08	2.0E-10	3.4E-07	7.0E-14	5.7E-15	4.2E-07
Fe-55	2.9E-10	2.0E-12	1.3E-11	1.5E-10	1.8E-10	1.2E-08	9.8E-12	2.8E-12	4.7E-14	7.0E-15	1.2E-08
Fe-59	3.2E-12	6.2E-15	1.5E-12	1.8E-11	1.7E-11	1.1E-09	9.9E-12	5.6E-08	1.7E-14	1.4E-15	5.7E-08
Co-56	4.0E-11	8.6E-12	6.6E-11	2.2E-09	2.3E-11	1.2E-09	1.1E-10	3.2E-07	4.7E-14	4.2E-15	3.2E-07
Co-57	3.6E-11	1.9E-11	2.7E-11	8.9E-10	1.0E-11	5.3E-10	2.5E-11	3.7E-08	2.1E-14	1.4E-15	3.8E-08
Co-58	8.9E-12	1.8E-12	1.7E-11	5.6E-10	5.9E-12	3.0E-10	3.0E-11	8.2E-08	1.4E-14	1.1E-15	8.3E-08
Co-60	3.1E-09	4.5E-09	1.9E-09	6.2E-08	8.7E-10	4.5E-08	1.4E-09	4.1E-06	2.3E-12	1.3E-13	4.2E-06
Ni-63	1.3E-09	5.0E-10	2.2E-13	8.8E-13	1.6E-12	3.5E-12	2.5E-09	0.0E+00	5.0E-13	2.7E-14	4.3E-09
Zn-65	2.6E-10	8.6E-11	6.2E-10	1.1E-10	4.3E-08	1.2E-10	9.2E-09	1.9E-08	6.0E-15	2.5E-15	7.3E-08
Se-75	6.4E-10	9.9E-10	8.1E-08	6.5E-07	1.0E-07	5.6E-07	6.7E-08	3.2E-08	9.1E-15	4.1E-15	1.5E-06
Rb-83	6.7E-12	1.3E-11	2.3E-10	9.2E-11	2.9E-10	6.4E-11	2.2E-09	5.9E-09	8.4E-16	4.0E-16	8.8E-09
Sr-85	3.0E-12	1.7E-12	5.3E-12	2.1E-12	8.6E-12	1.9E-12	2.2E-10	1.7E-08	2.2E-15	3.3E-16	1.7E-08
Sr-89	4.7E-12	2.3E-12	1.7E-11	6.9E-12	2.8E-11	6.1E-12	7.3E-10	2.1E-12	1.5E-14	1.1E-15	7.9E-10

Radionuclide*	DPURs for adult in a farming family sludge to land (µSv/y per Bq/y)										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
Sr-90	1.5E-07	2.5E-07	1.2E-08	4.9E-09	3.9E-08	8.8E-09	9.8E-07	2.0E-14	1.2E-11	1.6E-12	1.5E-06
Zr-95	4.1E-12	3.4E-14	2.8E-13	1.1E-13	2.4E-14	4.4E-14	4.2E-13	8.2E-08	2.0E-14	7.0E-16	8.2E-08
Nb-95	1.2E-13	2.7E-15	2.3E-14	9.1E-15	5.1E-16	4.4E-15	1.8E-14	1.5E-08	2.7E-15	1.8E-16	1.5E-08
Tc-99	8.5E-08	8.7E-08	1.3E-06	1.5E-06	7.1E-08	6.3E-08	3.8E-07	0.0E+00	1.9E-13	5.1E-15	3.5E-06
Ru-103	6.2E-14	8.5E-16	7.6E-14	1.5E-13	1.1E-12	7.3E-14	1.3E-13	2.2E-09	1.1E-15	5.6E-17	2.2E-09
Ru-106	1.5E-10	1.1E-11	1.6E-11	3.0E-11	2.3E-10	1.6E-11	6.6E-12	1.0E-08	1.5E-13	6.5E-15	1.1E-08
Ag-110m	3.3E-10	3.1E-12	8.1E-11	2.0E-07	2.4E-09	2.2E-07	4.5E-07	8.6E-07	2.6E-13	1.7E-14	1.7E-06
Sb-125	3.1E-11	4.8E-13	5.4E-11	2.1E-09	4.3E-11	8.0E-10	7.6E-12	5.0E-08	6.6E-14	2.6E-15	5.3E-08
I-124	nc	nc	8.2E-14	3.3E-14	1.3E-13	2.9E-14	1.9E-12	8.6E-11	2.9E-17	1.5E-17	8.8E-11
I-125	2.4E-11	2.3E-11	6.5E-10	2.6E-10	3.7E-10	8.2E-11	3.2E-09	1.5E-10	7.8E-15	3.9E-15	4.8E-09
I-129	1.3E-07	2.0E-07	8.8E-08	3.5E-08	2.7E-08	6.1E-09	2.1E-07	3.2E-09	1.0E-11	5.3E-12	7.1E-07
I-131	nc	nc	7.4E-12	2.9E-12	9.0E-12	2.0E-12	1.1E-10	2.3E-10	3.7E-16	1.9E-16	3.7E-10
Cs-134	7.2E-10	1.1E-09	2.6E-08	1.0E-08	2.6E-08	5.7E-09	2.7E-08	1.4E-07	7.0E-14	3.4E-14	2.4E-07
Cs-136	nc	nc	2.3E-11	9.1E-12	2.0E-11	4.5E-12	4.9E-11	1.8E-09	8.6E-17	3.7E-17	1.9E-09
Cs-137	1.8E-09	4.4E-09	3.2E-08	1.3E-08	2.7E-08	6.1E-09	2.8E-08	2.6E-07	3.9E-13	1.9E-13	3.8E-07
Ba-140	nc	nc	7.6E-13	3.0E-13	2.1E-13	1.7E-13	4.7E-12	8.7E-09	1.4E-15	1.2E-16	8.7E-09
Ce-141	8.5E-14	6.4E-16	4.0E-15	1.3E-11	2.0E-13	9.1E-12	2.5E-12	1.2E-09	5.2E-15	2.0E-16	1.3E-09
Ce-144	3.8E-10	1.5E-11	1.4E-12	4.6E-09	1.2E-10	5.5E-09	2.1E-10	9.1E-09	7.9E-13	2.0E-14	2.0E-08
Pm-147	7.3E-11	3.2E-11	1.5E-11	3.6E-11	1.9E-11	3.4E-11	3.0E-12	1.9E-12	3.3E-13	3.0E-15	2.2E-10
Eu-152	4.2E-10	3.4E-10	1.6E-10	3.9E-10	3.1E-10	5.6E-10	2.8E-11	1.8E-06	1.2E-11	6.7E-14	1.8E-06
Eu-154	5.1E-10	3.3E-10	2.1E-10	5.0E-10	3.7E-10	6.5E-10	3.6E-11	1.6E-06	1.0E-11	6.7E-14	1.6E-06
Eu-155	6.4E-11	3.0E-11	2.7E-11	6.4E-11	4.1E-11	7.3E-11	4.7E-12	3.8E-08	8.1E-13	6.5E-15	3.8E-08
Er-169	nc	nc	3.4E-17	1.1E-13	1.7E-15	7.5E-14	7.1E-14	4.6E-17	1.8E-16	1.1E-17	2.6E-13
Lu-177	nc	nc	8.5E-18	2.7E-14	4.2E-16	1.9E-14	2.5E-14	3.0E-11	9.0E-17	6.8E-18	3.0E-11
Pb-210	9.1E-07	4.2E-07	7.8E-07	8.8E-07	1.9E-06	1.2E-06	3.2E-06	2.3E-09	7.4E-10	7.9E-11	9.3E-06
Po-210	7.9E-08	8.0E-08	7.2E-07	3.5E-06	4.3E-07	2.6E-06	2.1E-07	1.5E-12	6.4E-11	4.0E-12	7.6E-06
Ra-223	nc	nc	3.4E-11	1.4E-11	1.3E-10	8.3E-12	4.9E-10	9.2E-10	2.0E-12	4.7E-15	1.6E-09
Ra-226	3.9E-07	8.5E-07	1.6E-07	6.4E-08	7.3E-07	4.7E-08	8.8E-07	5.4E-06	2.4E-09	3.2E-11	8.5E-06
Ac-225	nc	nc	1.4E-14	1.1E-12	1.5E-14	6.5E-13	8.6E-13	8.0E-10	3.2E-12	1.5E-15	8.0E-10

Radionuclide*	DPURs for adult in a farming family sludge to land (µSv/y per Bq/y)										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
Th-227	nc	nc	2.7E-13	1.1E-12	6.6E-13	6.4E-13	3.1E-12	7.9E-09	1.3E-11	1.9E-15	7.9E-09
Th-230	6.9E-08	1.3E-08	1.0E-08	4.2E-08	7.1E-08	6.9E-08	1.2E-08	9.8E-06	1.8E-08	4.5E-11	1.0E-05
Th-232	7.6E-08	1.5E-08	1.1E-08	4.5E-08	7.8E-08	7.5E-08	1.4E-08	6.9E-06	3.1E-08	5.0E-11	7.2E-06
Th-234	7.6E-13	6.3E-16	2.9E-13	1.2E-12	6.8E-13	6.6E-13	2.5E-12	9.6E-10	1.7E-14	1.3E-15	9.7E-10
U-234	4.3E-09	3.7E-09	1.3E-09	5.4E-10	2.4E-09	2.7E-10	6.0E-08	8.1E-09	4.9E-10	1.2E-12	8.1E-08
U-235	4.1E-09	3.5E-09	1.3E-09	5.2E-10	2.3E-09	2.6E-10	5.7E-08	8.2E-08	4.3E-10	1.1E-12	1.5E-07
U-238	3.9E-09	3.4E-09	1.2E-09	4.9E-10	2.2E-09	2.5E-10	5.5E-08	1.3E-08	4.1E-10	1.1E-12	8.0E-08
Np-237	1.2E-08	2.1E-08	7.8E-10	2.2E-08	2.4E-09	6.5E-08	2.3E-10	1.2E-07	3.2E-09	2.6E-12	2.4E-07
Pu-238	7.6E-09	6.6E-10	8.1E-10	2.3E-08	9.3E-10	2.5E-08	8.9E-11	6.6E-11	5.4E-09	4.6E-12	6.4E-08
Pu-239	8.4E-09	8.6E-10	9.1E-10	2.6E-08	1.1E-09	2.9E-08	1.0E-10	8.2E-08	7.0E-09	6.0E-12	1.6E-07
Pu-240	8.4E-09	8.6E-10	9.1E-10	2.6E-08	1.1E-09	2.9E-08	1.0E-10	4.7E-11	7.0E-09	6.0E-12	7.4E-08
Pu-241	1.5E-10	6.4E-12	1.4E-11	4.0E-10	1.5E-11	4.0E-10	1.4E-12	5.5E-09	5.0E-11	4.6E-14	6.5E-09
Pu-242	8.1E-09	8.2E-10	8.7E-10	2.5E-08	1.0E-09	2.8E-08	9.9E-11	1.3E-08	6.7E-09	5.8E-12	8.4E-08
Am-241	3.4E-08	5.5E-09	5.5E-09	1.6E-07	1.3E-08	3.6E-07	1.3E-09	6.1E-07	2.8E-08	2.3E-11	1.2E-06
Am-243	3.4E-08	5.7E-09	5.5E-09	1.6E-07	1.4E-08	3.7E-07	1.3E-09	4.9E-07	2.9E-08	2.4E-11	1.1E-06
Cm-242	8.2E-10	2.9E-12	2.9E-11	8.3E-10	1.7E-11	4.6E-10	1.7E-12	1.7E-10	1.2E-10	4.7E-14	2.4E-09
Cm-243	4.6E-08	5.9E-09	4.4E-09	1.3E-07	5.0E-09	1.3E-07	4.8E-10	1.3E-06	2.3E-08	1.9E-11	1.6E-06
Cm-244	3.6E-08	3.7E-09	3.3E-09	9.5E-08	3.6E-09	9.8E-08	3.5E-10	8.7E-10	1.6E-08	1.2E-11	2.6E-07

*radionuclides with a half-life of less than 4 days were not considered.
nc: not considered as half-life less than 30 days.

Table 35. Dose rate per unit release factors for worst affected terrestrial reference organism - use of sludge as soil conditioner – sewage release scenario

Radionuclide*	Worst total DPUR (µGy/h per Bq/y)	Worst affected reference organism
H-3	1.8E-12	Amphibian, Annelid, Arthropod – detritivorous, Bird, Grasses & Herbs, Mammal – large, Mammal - small-burrowing, Mollusc – gastropod, Reptile, Shrub, Tree
H-3 organic	1.9E-09	Amphibian, Bird, Mammal – large, Mammal - small-burrowing, Reptile
C-14	6.7E-09	Bird, Mammal – large, Mammal - small-burrowing, Reptile
Na-22	1.0E-10	Mammal - large
P-32	9.1E-10	Mammal - large
P-33	2.7E-10	Amphibian, Bird, Mammal – large, Mammal - small-burrowing, Reptile
S-35	1.4E-11	Grasses & Herbs, Shrub, Tree
Cl-36	7.6E-10	Grasses & Herbs
Ca-45	9.6E-12	Mammal - large
Ca-47	4.1E-13	Mammal - large
V-48	3.7E-12	Annelid
Cr-51	9.0E-14	Annelid
Mn-52	3.9E-13	Arthropod – detritivorous
Mn-54	5.2E-11	Arthropod - detritivorous
Fe-55	1.1E-11	Shrub
Fe-59	7.0E-12	Arthropod - detritivorous
Co-56	4.5E-11	Arthropod - detritivorous
Co-57	4.3E-12	Amphibian
Co-58	1.1E-11	Annelid
Co-60	7.4E-10	Amphibian
Ni-63	9.6E-12	Reptile
Zn-65	6.2E-12	Mammal – large
Se-75	5.3E-12	Annelid
Rb-83	2.5E-12	Mammal - large
Sr-85	3.2E-12	Mammal – large

Radionuclide*	Worst total DPUR (µGy/h per Bq/y)	Worst affected reference organism
Sr-89	5.7E-12	Lichen & Bryophytes
Sr-90	1.2E-09	Lichen & Bryophytes
Zr-95	4.2E-12	Amphibian
Nb-95	1.9E-12	Annelid
Tc-99	9.3E-11	Grasses & Herbs
Ru-103	5.9E-13	Lichen & Bryophytes
Ru-106	2.1E-11	Lichen & Bryophytes
Ag-110m	1.3E-10	Annelid
Sb-125	7.7E-12	Annelid
I-124	1.0E-14	Amphibian
I-125	7.1E-14	Mammal – large
I-129	1.7E-11	Mammal – large
I-131	2.9E-14	Amphibian
Cs-134	6.1E-11	Mammal – large
Cs-136	5.3E-13	Mammal – large
Cs-137	2.5E-10	Mammal – large
Ba-140	6.5E-12	Bird
Ce-141	1.1E-13	Amphibian
Ce-144	3.2E-12	Bird
Pm-147	4.2E-13	Bird
Eu-152	4.0E-10	Annelid
Eu-154	3.1E-10	Arthropod – detritivorous
Eu-155	1.0E-11	Bird
Er-169	2.0E-15	Bird
Lu-177	2.7E-15	Annelid
Pb-210	8.2E-10	Lichen & Bryophytes
Po-210	3.8E-09	Lichen & Bryophytes
Ra-223	7.4E-11	Lichen & Bryophytes
Ra-226	1.7E-07	Lichen & Bryophytes
Ac-225	5.6E-11	Lichen & Bryophytes

Radionuclide*	Worst total DPUR (µGy/h per Bq/y)	Worst affected reference organism
Th-227	4.0E-11	Lichen & Bryophytes
Th-230	3.2E-08	Lichen & Bryophytes
Th-232	2.7E-08	Lichen & Bryophytes
Th-234	5.4E-13	Lichen & Bryophytes
U-234	8.7E-09	Lichen & Bryophytes
U-235	8.1E-09	Lichen & Bryophytes
U-238	7.6E-09	Lichen & Bryophytes
Np-237	9.4E-09	Lichen & Bryophytes
Pu-238	1.2E-09	Lichen & Bryophytes
Pu-239	1.3E-09	Lichen & Bryophytes
Pu-240	1.3E-09	Lichen & Bryophytes
Pu-241	1.5E-13	Lichen & Bryophytes
Pu-242	1.3E-09	Lichen & Bryophytes
Am-241	5.2E-08	Lichen & Bryophytes
Am-243	5.2E-08	Lichen & Bryophytes
Cm-242	2.0E-09	Lichen & Bryophytes
Cm-243	6.2E-08	Lichen & Bryophytes
Cm-244	4.8E-08	Lichen & Bryophytes

*radionuclides with a half-life of less than 4 days were not considered.

Table 36. Dose rate per unit release factors for terrestrial reference organisms (µGy/h per Bq/y) – use of sludge as soil conditioner – sewage release scenario

Radio-nuclide*	Amphibian	Annelid	Arthropod, detriti-vorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryo-phytes	Mammal - large	Mammal - small-burrowing	Mollusc, gastro-pod	Reptile	Shrub	Tree
H-3	1.8E-12	1.8E-12	1.8E-12	1.8E-12	1.7E-12	1.8E-12	1.8E-12	1.8E-12	1.8E-12	1.8E-12	1.8E-12	1.8E-12	1.8E-12
H-3 organic	1.9E-09	5.9E-10	6.0E-10	1.9E-09	5.6E-10	1.2E-09	1.2E-09	1.9E-09	1.9E-09	6.0E-10	1.9E-09	1.2E-09	1.8E-09
C-14	6.4E-09	2.1E-09	2.1E-09	6.7E-09	2.1E-09	4.3E-09	4.3E-09	6.7E-09	6.7E-09	2.1E-09	6.7E-09	4.3E-09	6.5E-09
Na-22	4.0E-11	3.8E-11	3.8E-11	1.9E-11	1.5E-11	1.9E-11	2.7E-11	1.0E-10	6.0E-11	1.5E-11	3.8E-11	2.2E-11	1.5E-11
P-32	8.4E-10	2.4E-10	1.8E-10	8.9E-10	2.1E-10	5.0E-10	3.3E-10	9.1E-10	8.9E-10	2.3E-10	8.7E-10	5.0E-10	8.9E-10
P-33	2.7E-10	8.6E-11	8.4E-11	2.7E-10	8.4E-11	1.8E-10	1.7E-10	2.7E-10	2.7E-10	8.6E-11	2.7E-10	1.8E-10	2.6E-10
S-35	4.6E-12	4.6E-12	4.6E-12	4.6E-12	4.5E-12	1.4E-11	1.3E-11	4.6E-12	4.6E-12	4.6E-12	4.6E-12	1.4E-11	1.4E-11
Cl-36	2.7E-10	6.5E-12	1.0E-11	2.7E-10	1.0E-11	7.6E-10	3.0E-11	2.7E-10	2.7E-10	6.1E-12	2.7E-10	3.8E-11	5.5E-11
Ca-45	9.6E-12	2.1E-13	1.1E-13	6.4E-14	1.1E-13	3.3E-13	2.2E-12	9.6E-12	9.6E-12	5.3E-14	9.6E-12	2.1E-13	8.3E-13
Ca-47	2.5E-13	3.6E-14	3.4E-14	1.3E-14	1.5E-14	2.0E-14	5.4E-14	4.1E-13	2.7E-13	1.4E-14	2.6E-13	1.6E-14	4.3E-14
V-48	3.6E-12	3.7E-12	3.7E-12	1.4E-12	1.4E-12	1.4E-12	1.4E-12	8.3E-13	3.5E-12	1.5E-12	3.4E-12	1.3E-12	1.1E-12
Cr-51	8.8E-14	9.0E-14	9.0E-14	3.9E-14	3.7E-14	3.8E-14	3.9E-14	1.8E-14	8.4E-14	3.8E-14	8.0E-14	3.5E-14	3.0E-14
Mn-52	3.8E-13	3.9E-13	3.9E-13	1.4E-13	1.5E-13	1.4E-13	1.5E-13	7.6E-14	3.6E-13	1.5E-13	3.5E-13	2.0E-13	1.3E-13
Mn-54	5.1E-11	5.1E-11	5.2E-11	2.0E-11	2.0E-11	1.9E-11	2.1E-11	9.9E-12	4.9E-11	2.0E-11	4.7E-11	2.7E-11	1.7E-11
Fe-55	4.4E-14	6.2E-14	2.6E-13	2.6E-14	2.4E-13	2.5E-13	1.5E-12	6.3E-15	2.2E-14	1.2E-13	3.9E-14	1.1E-11	1.6E-13
Fe-59	6.8E-12	6.9E-12	7.0E-12	2.5E-12	2.7E-12	2.6E-12	3.1E-12	1.4E-12	6.5E-12	2.7E-12	6.3E-12	6.1E-12	2.4E-12
Co-56	4.5E-11	4.5E-11	4.5E-11	1.6E-11	1.7E-11	1.6E-11	1.7E-11	1.4E-11	4.3E-11	1.7E-11	4.2E-11	1.5E-11	1.3E-11
Co-57	4.3E-12	3.8E-12	3.9E-12	1.8E-12	1.9E-12	2.0E-12	2.1E-12	2.1E-12	4.2E-12	1.9E-12	4.1E-12	1.8E-12	1.5E-12
Co-58	1.1E-11	1.1E-11	1.1E-11	4.3E-12	4.2E-12	4.0E-12	4.3E-12	3.6E-12	1.1E-11	4.2E-12	1.0E-11	3.8E-12	3.4E-12
Co-60	7.4E-10	7.3E-10	7.3E-10	2.8E-10	2.8E-10	2.7E-10	2.8E-10	2.4E-10	6.9E-10	2.8E-10	6.9E-10	2.5E-10	2.2E-10
Ni-63	3.4E-12	2.3E-12	5.5E-13	3.4E-12	5.3E-13	4.2E-12	7.7E-12	3.4E-12	3.4E-12	5.7E-13	9.6E-12	3.2E-12	6.8E-13
Zn-65	3.5E-12	3.4E-12	3.0E-12	2.6E-12	1.2E-12	1.1E-12	1.2E-12	6.2E-12	3.8E-12	1.6E-12	2.6E-12	1.1E-12	1.0E-12
Se-75	3.9E-12	5.3E-12	3.9E-12	2.1E-12	1.7E-12	2.1E-12	1.7E-12	1.5E-12	3.8E-12	1.7E-12	3.5E-12	2.2E-12	1.7E-12
Rb-83	8.8E-13	8.1E-13	8.2E-13	4.5E-13	3.3E-13	4.9E-13	8.8E-13	2.5E-12	1.6E-12	3.2E-13	8.5E-13	6.1E-13	3.3E-13
Sr-85	2.5E-12	2.3E-12	2.3E-12	1.4E-12	9.2E-13	9.7E-13	1.3E-12	3.2E-12	2.7E-12	9.0E-13	2.2E-12	8.4E-13	1.4E-12
Sr-89	2.5E-12	1.2E-13	4.5E-13	2.5E-12	5.3E-13	1.4E-12	5.7E-12	3.4E-12	3.4E-12	1.6E-13	8.1E-13	3.1E-13	1.0E-12
Sr-90	6.5E-10	2.9E-11	1.0E-10	6.4E-10	1.2E-10	3.3E-10	1.2E-09	9.0E-10	8.6E-10	3.8E-11	2.0E-10	7.6E-11	2.6E-10

Radio-nuclide*	Amphibian	Annelid	Arthropod, detriti-vorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryo-phytes	Mammal - large	Mammal - small-burrowing	Mollusc, gastro-pod	Reptile	Shrub	Tree
Zr-95	4.2E-12	4.2E-12	4.2E-12	1.8E-12	1.6E-12	1.6E-12	1.7E-12	7.8E-13	3.9E-12	1.6E-12	3.9E-12	1.5E-12	1.3E-12
Nb-95	1.9E-12	1.9E-12	1.9E-12	7.5E-13	7.3E-13	6.8E-13	7.2E-13	4.1E-13	1.8E-12	7.5E-13	1.7E-12	6.4E-13	5.6E-13
Tc-99	2.6E-12	2.6E-12	2.5E-12	1.1E-12	2.6E-12	9.3E-11	8.9E-11	2.6E-12	2.6E-12	2.6E-12	2.6E-12	7.8E-14	7.8E-14
Ru-103	2.8E-13	2.8E-13	2.8E-13	1.2E-13	1.1E-13	1.1E-13	5.9E-13	8.4E-14	2.7E-13	1.1E-13	2.6E-13	1.3E-13	1.9E-13
Ru-106	2.6E-12	1.5E-12	1.5E-12	1.8E-12	6.0E-13	6.9E-13	2.1E-11	1.7E-12	2.6E-12	6.1E-13	2.5E-12	3.3E-12	5.3E-12
Ag-110m	1.3E-10	1.3E-10	1.3E-10	6.0E-11	4.8E-11	6.1E-11	4.8E-11	7.0E-11	1.3E-10	5.2E-11	1.2E-10	4.4E-11	6.9E-11
Sb-125	7.6E-12	7.7E-12	7.6E-12	2.9E-12	3.0E-12	3.0E-12	3.6E-12	1.4E-12	7.2E-12	3.1E-12	6.9E-12	2.8E-12	2.6E-12
I-124	1.0E-14	9.7E-15	9.9E-15	4.7E-15	4.0E-15	3.8E-15	3.7E-15	5.0E-15	1.0E-14	3.9E-15	9.6E-15	3.3E-15	3.9E-15
I-125	6.4E-14	3.6E-14	4.8E-14	6.3E-14	3.6E-14	2.6E-14	2.0E-14	7.1E-14	6.8E-14	2.4E-14	6.5E-14	9.6E-15	2.9E-14
I-129	1.6E-11	7.6E-12	1.2E-11	1.6E-11	1.1E-11	6.0E-12	5.3E-12	1.7E-11	1.7E-11	6.7E-12	1.6E-11	1.1E-12	6.4E-12
I-131	2.9E-14	2.5E-14	2.7E-14	1.6E-14	1.3E-14	1.1E-14	1.1E-14	1.7E-14	2.8E-14	1.2E-14	2.7E-14	8.8E-15	1.2E-14
Cs-134	2.3E-11	2.2E-11	2.2E-11	1.1E-11	8.7E-12	1.1E-11	1.7E-11	6.1E-11	3.6E-11	8.5E-12	2.2E-11	1.3E-11	8.6E-12
Cs-136	2.1E-13	2.0E-13	2.0E-13	1.0E-13	8.0E-14	9.5E-14	1.3E-13	5.3E-13	3.2E-13	7.9E-14	2.0E-13	1.1E-13	7.8E-14
Cs-137	7.7E-11	6.5E-11	6.7E-11	4.5E-11	2.8E-11	5.5E-11	1.2E-10	2.5E-10	1.8E-10	2.6E-11	7.6E-11	8.0E-11	2.8E-11
Ba-140	9.9E-13	1.0E-12	1.0E-12	6.5E-12	3.8E-13	3.8E-13	4.0E-13	2.3E-13	9.5E-13	3.9E-13	9.2E-13	5.3E-13	3.9E-13
Ce-141	1.1E-13	1.1E-13	1.1E-13	8.0E-14	4.9E-14	5.8E-14	5.6E-14	2.4E-14	1.1E-13	7.6E-14	1.0E-13	5.2E-14	4.1E-14
Ce-144	1.4E-12	1.4E-12	1.3E-12	3.2E-12	5.4E-13	8.8E-13	7.4E-13	4.5E-13	1.4E-12	2.3E-12	1.3E-12	7.3E-13	4.7E-13
Pm-147	3.0E-14	2.9E-14	1.3E-14	4.2E-13	1.3E-14	8.2E-14	9.6E-14	3.0E-14	3.0E-14	4.2E-13	3.0E-14	5.5E-14	1.0E-14
Eu-152	4.0E-10	4.0E-10	4.0E-10	2.2E-10	1.6E-10	1.5E-10	1.6E-10	8.7E-11	3.8E-10	1.6E-10	3.7E-10	1.5E-10	1.3E-10
Eu-154	3.1E-10	3.1E-10	3.1E-10	1.9E-10	1.2E-10	1.2E-10	1.2E-10	6.8E-11	2.9E-10	1.2E-10	2.8E-10	1.1E-10	9.3E-11
Eu-155	5.0E-12	4.7E-12	4.7E-12	1.0E-11	2.3E-12	2.6E-12	2.4E-12	1.6E-12	4.8E-12	2.3E-12	4.7E-12	2.3E-12	2.0E-12
Er-169	1.4E-16	1.4E-16	6.0E-17	2.0E-15	6.1E-17	3.9E-16	4.5E-16	1.4E-16	1.4E-16	2.0E-15	1.4E-16	2.6E-16	5.0E-17
Lu-177	2.6E-15	2.7E-15	2.6E-15	2.2E-15	1.2E-15	1.4E-15	1.4E-15	5.9E-16	2.5E-15	2.2E-15	2.4E-15	1.2E-15	9.6E-16
Pb-210	5.1E-11	1.9E-10	1.3E-10	2.7E-11	1.5E-10	4.6E-11	8.2E-10	1.6E-11	1.6E-11	3.2E-12	1.7E-11	1.2E-10	3.0E-11
Po-210	1.5E-10	1.5E-11	1.5E-11	1.5E-11	1.5E-11	4.1E-10	3.8E-09	1.3E-10	1.3E-10	1.5E-11	1.9E-10	4.9E-10	1.1E-10
Ra-223	4.7E-12	4.6E-12	4.6E-12	3.8E-12	4.5E-12	1.9E-11	7.4E-11	4.6E-12	4.7E-12	5.0E-12	4.7E-12	3.4E-11	1.2E-12
Ra-226	1.2E-08	1.1E-08	1.1E-08	9.3E-09	1.0E-08	4.2E-08	1.7E-07	1.1E-08	1.1E-08	1.1E-08	1.1E-08	7.6E-08	3.2E-09
Ac-225	1.6E-13	1.5E-12	8.5E-13	9.5E-14	7.9E-13	2.4E-11	5.6E-11	4.0E-14	1.2E-13	1.4E-12	4.1E-13	9.1E-12	2.2E-13
Th-227	1.8E-13	1.1E-12	6.8E-13	1.0E-13	5.9E-13	1.7E-11	4.0E-11	4.2E-14	1.5E-13	1.0E-12	3.6E-13	6.4E-12	1.8E-13
Th-230	3.3E-11	7.7E-10	4.3E-10	3.3E-11	4.3E-10	1.3E-08	3.2E-08	1.2E-11	1.2E-11	7.7E-10	1.8E-10	5.1E-09	1.1E-10
Th-232	2.8E-11	6.6E-10	3.6E-10	2.8E-11	3.6E-10	1.1E-08	2.7E-08	9.8E-12	1.0E-11	6.6E-10	1.6E-10	4.4E-09	9.1E-11

Radio-nuclide*	Amphibian	Annelid	Arthropod, detriti-vorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryo-phytes	Mammal - large	Mammal - small-burrowing	Mollusc, gastro-pod	Reptile	Shrub	Tree
Th-234	6.0E-14	7.9E-14	6.6E-14	2.6E-14	3.3E-14	3.7E-13	5.4E-13	1.2E-14	5.9E-14	4.3E-14	5.9E-14	1.5E-13	2.3E-14
U-234	5.3E-11	3.3E-10	1.0E-10	1.2E-11	1.0E-10	1.2E-09	8.7E-09	5.3E-11	5.3E-11	3.3E-10	5.0E-11	5.9E-10	6.4E-11
U-235	7.2E-11	3.2E-10	1.2E-10	2.1E-11	1.0E-10	1.2E-09	8.1E-09	5.3E-11	7.1E-11	3.1E-10	6.7E-11	5.5E-10	6.6E-11
U-238	4.6E-11	2.8E-10	8.7E-11	1.0E-11	8.6E-11	1.1E-09	7.6E-09	4.6E-11	4.6E-11	2.8E-10	4.3E-11	5.1E-10	5.5E-11
Np-237	1.3E-09	1.7E-09	9.7E-10	3.0E-10	9.5E-10	1.6E-09	9.4E-09	5.2E-09	5.2E-09	5.2E-09	5.2E-09	2.1E-09	6.4E-11
Pu-238	1.3E-10	2.8E-10	2.4E-10	2.1E-11	2.4E-10	1.5E-10	1.2E-09	1.3E-10	1.3E-10	1.1E-09	1.1E-10	6.5E-10	6.5E-10
Pu-239	1.5E-10	3.2E-10	2.7E-10	2.4E-11	2.7E-10	1.7E-10	1.3E-09	1.5E-10	1.5E-10	1.2E-09	1.2E-10	7.3E-10	7.3E-10
Pu-240	1.5E-10	3.2E-10	2.7E-10	2.4E-11	2.7E-10	1.7E-10	1.3E-09	1.5E-10	1.5E-10	1.2E-09	1.2E-10	7.3E-10	7.3E-10
Pu-241	1.6E-14	3.4E-14	2.9E-14	2.6E-15	2.7E-14	1.8E-14	1.5E-13	1.6E-14	1.6E-14	1.3E-13	1.3E-14	7.8E-14	7.8E-14
Pu-242	1.4E-10	3.0E-10	2.5E-10	2.2E-11	2.5E-10	1.6E-10	1.3E-09	1.4E-10	1.4E-10	1.2E-09	1.1E-10	6.9E-10	6.9E-10
Am-241	7.2E-09	9.4E-09	5.3E-09	1.7E-09	5.3E-09	5.4E-09	5.2E-08	1.3E-09	1.3E-09	7.7E-09	3.4E-09	1.4E-09	1.4E-09
Am-243	7.3E-09	9.5E-09	5.4E-09	1.7E-09	5.4E-09	5.5E-09	5.2E-08	1.3E-09	1.4E-09	7.7E-09	3.5E-09	1.5E-09	1.5E-09
Cm-242	2.6E-10	3.5E-10	2.7E-10	6.1E-11	2.7E-10	9.9E-13	2.0E-09	1.1E-09	1.1E-09	1.1E-09	1.1E-09	4.4E-10	1.8E-11
Cm-243	8.5E-09	1.1E-08	8.7E-09	2.0E-09	8.6E-09	7.4E-11	6.2E-08	3.4E-08	3.4E-08	3.4E-08	3.4E-08	1.4E-08	6.2E-10
Cm-244	6.5E-09	8.5E-09	6.6E-09	1.5E-09	6.6E-09	2.4E-11	4.8E-08	2.6E-08	2.6E-08	2.6E-08	2.6E-08	1.1E-08	4.5E-10

*radionuclides with a half-life of less than 4 days were not considered.

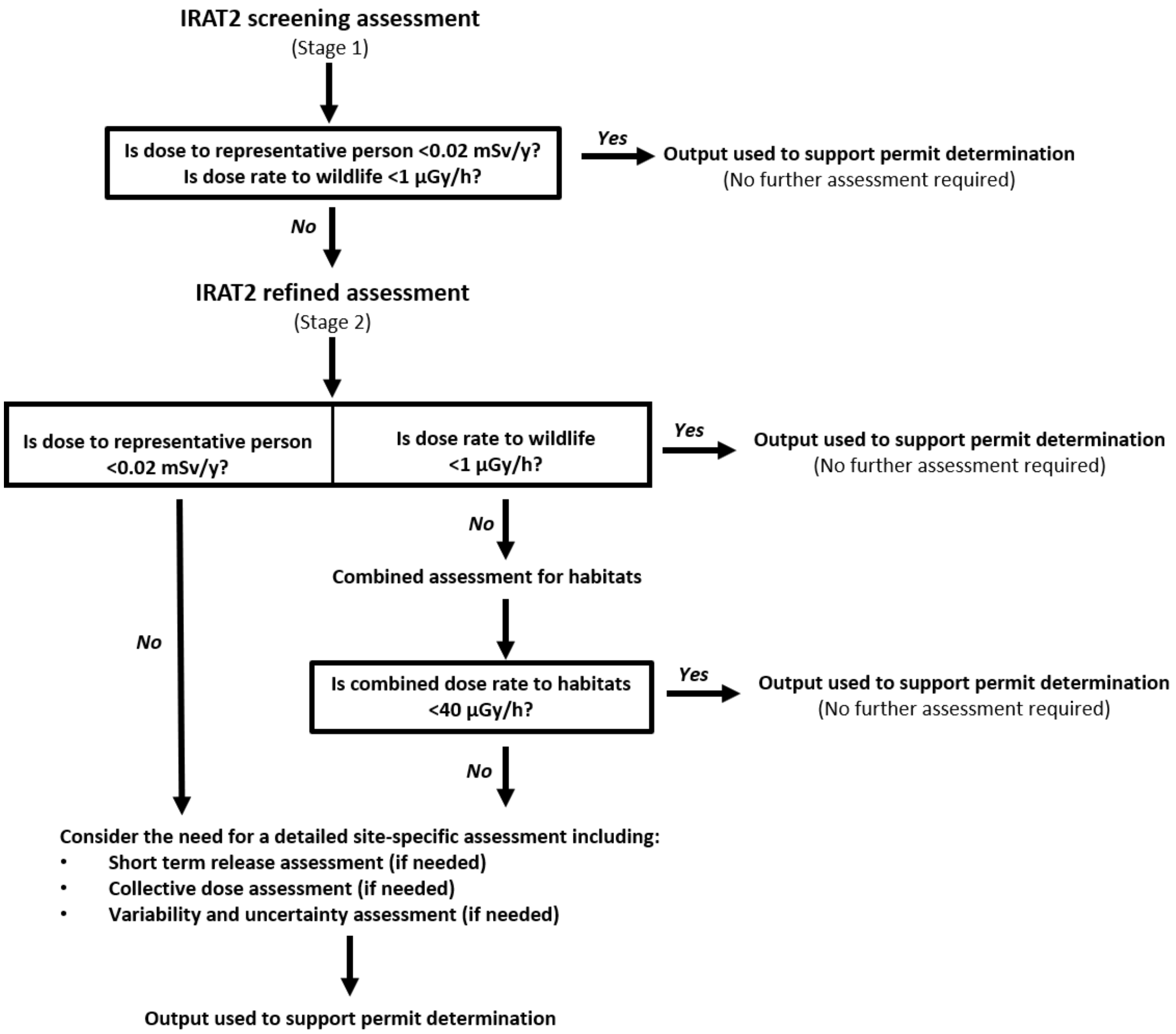

Figure 1. Stages of dose assessment process for discharge permits

Appendix A: Dose factors for exposure of wildlife

A.1 Overview

It is necessary to evaluate doses to wildlife to ensure that the environment is adequately protected from ionising radiation. In its 2007 recommendations [A.1] ICRP 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. Furthermore, ICRP concluded that the approach to protecting the environment can draw upon the radiological protection framework developed for humans [A.2].

Doses of ionising radiation to wildlife are measured in grays (Gy) which is a unit of absorbed dose. One gray is defined as the absorption of 1 joule of radiation energy per kilogram of matter. Dose rates to wildlife are measured in micro-grays per hour (μGy/hr). Dose rates are weighted to account for the relative biological effectiveness (RBE) of different types of radiation.

Assessments of dose rates to wildlife use a ‘reference organism’ approach, where reference organisms are used to represent species present in a protected habitat. The information required for biokinetic modelling (the approach used to calculate dose factors for humans) is less readily available for non-human species than humans. Therefore a simpler approach, using absorbed dose calculations for simplified geometries, has been used to determine dose factors for wildlife. This approach is widely used by industry and regulators to assess the impact of radiological discharges on wildlife.

Dose rate per unit concentration (DPUC) factors were derived for each reference organism and radionuclide combination, for terrestrial, marine and freshwater environments. These DPUC factors were then used to derive dose rate per unit release (DPUR) factors for use in each discharge scenario (discharge to air, discharge to coast, discharge to river and discharge to sewer). This appendix describes the derivation of the DPUC factors for wildlife. Subsequent appendices describe the derivation of DPUR factors.

A.2 Methodology

ICRP [A.2] has defined a set of Reference Animals and Plants (RAPs) for dose assessment purposes. It has explored the use of RAPs for the protection of the environment, but has yet to supplement this preliminary work with further advice on the application of this approach.

A more developed dose assessment approach is available in the ERICA tool [A.3, A.4, A.5]. This was developed as part of a European Commission project to support decisions about radiological protection of the environment. ERICA is widely used and is the established standard for calculating reference dose factors for wildlife in Europe. The Environment Agency recommends the use of the ERICA integrated approach for wildlife radiological assessments.

The ERICA tool is a freely available software tool which implements the ERICA Integrated Assessment Approach, designed to assess the impacts of ionising radiation on wildlife in European ecosystems [A.3, A.4]. ERICA tool v1.2 [A.5] was used to derive dose factors for IRAT2.

In the ERICA tool, the user can undertake assessments in three tiers of increasing complexity: tier 1 is a simple and conservative screening assessment; tier 2 allows the user to alter the default parameters, add additional radionuclides to the assessment and create new reference organisms; tier 3 is a detailed probabilistic risk assessment. Tier two was used to derive DPUC factors as this enabled additional radionuclides to be added to the tool.

Inputs to the ERICA tool are activity concentrations of radionuclides in water, soil or air. Biota receive doses of ionising radiation via internal exposure resulting from the intake of radionuclides, and via external exposure from radionuclides in the surrounding environment. The ERICA tool calculates dose rates from both internal and external sources and provides total dose rates to reference organisms.
The outputs of the ERICA tool are dose rates to a range of reference organisms in terrestrial, marine and freshwater environments.

The ERICA tool cannot be used to assess dose rates from noble gases. Therefore, the Ar-Kr-Xe calculator tool [A.6] was used to derive dose factors for noble gases.

A.3 Input data and parameters

The radionuclides included in the wildlife assessments were the same as those for the public assessments and are listed in Table 1.

The default ERICA reference organisms were used as the exposure groups for wildlife and are shown in Table A.1. The terrestrial reference organisms were used to represent the exposed wildlife in the aerial release scenario. The marine reference organisms were used to represent exposed wildlife in the coastal and sewer release scenarios. The freshwater reference organisms were used to represent exposed wildlife in the river and sewer release scenarios.

DPUC factors were derived from unit activity concentrations i.e. 1 Bq per litre of water for the freshwater and marine assessments, 1 Bq per kg of soil for the terrestrial assessment and 1 Bq per m^3 of air for gaseous radionuclides (aerial assessment).

For the ERICA calculations it was necessary to assign appropriate values for sorption coefficients (K_d) for use in the marine and freshwater assessments. The K_d is the ratio of the concentration of radionuclides in the (dry) sediment and concentration of radionuclides in the water. K_d values differ for different elements and for the type of aquatic environment, freshwater or marine. The ERICA tool uses the K_d values to determine the concentration of radionuclides in sediment from that of water, and vice versa, and is used in the calculation of dose rates from internal and external radionuclides. All of the default K_d values in the ERICA tool were updated for the generation of freshwater and marine DPUC factors. This was because the default K_d values in the ERICA tool were not readily traceable to original published data sources. Therefore, K_d values from published sources were manually added to the ERICA tool. K_d values used to generate DPUC factors are shown in Table A.2.

A concentration ratio (CR) is the ratio of the concentration of radionuclides in wildlife and the concentration of radionuclides in the environmental media (soil, water or air). The ERICA tool uses CR values to determine the concentration of radionuclides within wildlife based on the concentration of radionuclides in the surrounding environment. This is used to calculate dose rates from internal exposure to radionuclides. CRs differ for different wildlife types (in this case represented by reference organisms) and for different elements. Where possible, default CR data, which were already available in the ERICA tool (v.1.2.1), were used. However, default CR data were not available for all elements. Therefore, CR data were assigned to these elements based on CR data for other similar radionuclides. In addition, the CR for carbon was used for the assessments of organically bound tritium (OBT). See Table A.3 for details of analogues used for CRs. CRs for radium-223 (Ra-223) used in the river and coastal release scenarios were derived using a factor (*K*) to take into account the relatively short half-life of Ra-223 (see Section A.3.1). In the coastal release scenario, lead-211 (Pb-211) is explicitaly considered as progeny of Ra-223; for consistency, the CRs for Pb-211 were also amended using factor *K*.

CRs used for terrestrial reference organisms are shown in Table A.4. CRs used for marine reference oganisms are shown in Table A.5. CRs used for freshwater reference organisms are shown in Table A.6. ERICA (v.1.2.1) default values were used for all other parameters.

With the exception of the derivation of CRs for Ra-223 for the river and coastal release scenarios (see Section A.3.1), the approach used to derive wildlife dose factors for IRAT2 is consistent with the approach used to derive dose factors for the RSR habitats assessments [A.7]. This report also contains more details about the reference organisms and input parameters.

A.3.1 Derivation of CRs for radium-223 (Ra-223) and lead-211 (Pb-211) for freshwater and marine reference organisms

Radium-223 (Ra-223) is discharged from hospitals where it is used to treat prostate cancer which has spread to bones. The RSR habitats assessments [A.7] found high dose rates to reference organisms in freshwater environments driven by releases of Ra-223 to rivers and recommended refinement of the assessment of Ra-223. For IRAT2, amended CRs were calculated for Ra-223 and its progeny, lead-211 (Pb-211), and used to calculate DPUCs for freshwater and marine reference organisms.

Amended CRs were calculated due to the half-life of Ra-223 being relatively short (11.43 days). CRs for stable elements are conservative when used to represent radionuclides with relatively short half-lifes and relatively long biological half-lives, as radioactive decay of these radionuclides can reduce their concentration in biota [A.8]. To account for the relatively short half-life of Ra-223, the CRs for Ra-223 can be multiplied by a factor (*K*), which is defined as:

$$K = \frac{\lambda_b}{\lambda_b + \lambda_r}$$

Where:

λ_b	Biological decay constant (0.693 t_b^{-1} (/d))
λ_r	Radiological decay constant (0.693 t_r^{-1} (/d))
t_b	Biological half-life (d)
t_r	Radiological half-life (d)

For screening purposes, a $t_b$of 30 days can be assumed [A.8].

For Ra-223, *K* is calculated as 2.76E-01. The default CRs from the ERICA tool (v.1.2.1) were multiplied by *K*, to given amended CRs for Ra-223 for freshwater and marine reference organisms. These amended CRs were used in the ERICA tool (v.1.2.1) to derive DPUCs, as for all other radionuclides (see Section A.4).

Pb-211 is a significant progeny of Ra-223 and included in the derivation of marine DPURs for Ra-223. Pb-211 has a short half-life (36.1 minutes) and therefore a similar approach was applied to generate amended CRs for Pb-211. *K* for Pb-211 was calculated as 8.35E-04.

The amended CRs for Ra-223 in the freshwater environment, and resulting DPUCs are shown in Tables A.6 and A.9 respectively. The ameded CRs for Ra-223 and Pb-211 in the marine environment, and resulting DPUCs are shown in Tables A.5 and A.8 respectively.

For IRAT2, the factor (*K*) was used to amend CRs for Ra-223 (and Pb-211) in the freshwater and marine environments only. This method was not used to amend CRs for Ra-223 in the terrestrial environment, or for any other radionuclide with short half-lives. This approach could be applied to other radionuclides if required.

A.4 DPUC factors

DPUC factors, expressed in terms of absorbed dose per unit concentration, were derived for each release scenario in IRAT2.

DPUC factors for absorbed dose per unit concentration in soil (or air for gasesous radionuclides) for each terrestrial reference organism are shown in Table A.7. DPUC factors for absorbed dose per unit concentration in seawater for each marine reference organism are shown in Table A.8. DPUC factors for absorbed dose per unit concentration in river water each freshwater reference organism are shown in Table A.9.

A.5 Use of DPUC factors

DPUC factors were used to generate DPUR factors for wildlife in each of the release scenarios. Section D.7 of Appendix D describes generation of the DPUR for wildlife in the release to air scenario. Section E.7 of Appendix E describes gereration of the DPUR for wildlife in the release to coast scenario. Section F.8 of Appendix F describes generation of the DPUR for wildlife in the release to river scenario. Section G.7 of Appendix G describes generation of the DPUR for wildlife in the release to sewer scenario.

A.6 References

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Table A.1. ERICA default reference organisms used to represent exposed wildlife (ERICA v1.2.1)

Terrestrial reference organisms – used in the aerial release scenario.	Marine reference orgnisms – used in the coastal and sewer release scenarios	Freshwater reference organisms – used in the river and sewer release scenarios
Amphibian	Benthic fish	Amphibian
Annelid	Bird	Benthic fish
Arthropod - detritivorous	Crustacean	Bird
Bird	Macroalgae	Crustacean
Flying insect	Mammal	Insect larvae
Grasses and herbs	Mollusc - bivalve	Mammal
Lichen and bryophytes	Pelagic fish	Mollusc - bivalve
Mammal - large	Phytoplankton	Mollusc - gastropod
Mammal - small burrowing	Polychaete worm	Pelagic fish
Mollusc - gastropod	Reptile	Phytoplankton
Reptile	Sea anemone and true corals	Reptile
Shrub	Vascular plant	Vascular plant
Tree	Zooplankton	Zooplankton

Table A.2. Sorption coefficients for marine and freshwater environments, used to calculate wildlife DPUC factors

Element		Marine K_d (l/kg)	Reference	Freshwater K_d (l/kg)	Reference
Ac	Actinium	2000000	[A.9]	91000	Samarium used as analogue*
Ag	Silver	10000	[A.9]	270000	Average of values in [A.8]
Am	Americium	2000000	[A.9]	120000	[A.8]
At	Astatine	70	Iodine used as analogue*	4400	Iodine used as analogue*
Au	Gold	10000	Silver used as analogue*	270000	Silver used as analogue*
Ba	Barium	2000	[A.9]	2000	[A.8]
Bi^	Bismuth^	100000	Lead used as analogue*	n/a	n/a
Br	Bromine	0.03	Chlorine as an analogue*	2300	[A.11]
C	Carbon	1000	[A.9]	2000	[A.12]
Ca	Calcium	500	[A.9]	1100	[A.11]
Ce	Cerium	3000000	[A.9]	220000	[A.8]
Cl	Chlorine	0.03	[A.9]	98	[A.13]
Cm	Curium	2000000	[A.9]	5000	[A.8]
Co	Cobalt	300000	[A.9]	44000	[A.8]
Cr	Chromium	50000	[A.9]	20000	[A.12]
Cs	Caesium	4000	[A.9]	29000	[A.8]
Cu	Copper	70000	Zinc used as analogue*	500	Zinc used as analogue*
Er	Erbium	3000000	Cerium used as analogue*	220000	Cerium used as analogue*
Eu	Europium	2000000	[A.9]	500	[A.8]
Fe	Iron	3E+08	[A.9]	5000	[A.8]
Ga	Gallium	300	Soil value used [A.8]*	300	Use value for soil in [A.8]*
Gd^	Gadolinium^	2000000	[A.9]	n/a	n/a
H	Tritium	1	[A.9]	0.03	[A.12]
H-3 org.	Organically bound tritium	1000	Carbon used as analogue*	2000	Carbon used as analogue*
I	Iodine	70	[A.9]	4400	[A.8]
In	Indium	50000	[A.9]	50000	Ocean margin value used [A.9]*
La	Lanthanum	1200000	[A.10]	60000	[A.12]

Lu	Lutetium	3000000	Cerium used as analogue*	220000	Cerium used as analogue*
Mn	Manganese	2000000	[A.9]	79000	[A.8]
Mo	Molybdenum	2300	[A.11]	12000	[A.11]
Na	Sodium	0.1	[A.9]	0.1	Ocean margin value used [A.9]*
Nb	Niobium	800000	[A.9]	100	[A.12]
Ni	Nickel	20000	[A.9]	10000	[A.12]
Np	Neptunium	1000	[A.9]	10	[A.8]
P	Phosphorus	100	[A.12]	50	[A.12]
Pa^	Protactinium^	5000000	[A.9]	n/a	n/a
Pb	Lead	100000	[A.9]	10000	[A.12]
Pm	Promethium	2000000	[A.9]	5000	[A.8]
Po	Polonium	20000000	[A.9]	40000	[A.12]
Pu	Plutonium	100000	[A.9]	240000	[A.8]
Ra	Radium	2000	[A.9]	7400	[A.8]
Rb	Rubidium	4000	Caesium used as analogue*	29000	Caesium used as analogue*
Re	Rhenium	110	[A.11]	430	[A.11]
Ru	Ruthenium	40000	[A.9]	32000	[A.8]
S	Sulphur	0.5	[A.9]	200	[A.12]
Sb	Antimony	2000	[A.9]	5000	[A.8]
Sc^	Scandium^	5000000	[A.9]	n/a	n/a
Se	Selenium	3000	[A.9]	4000	[A.12]
Sm	Samarium	3000000	[A.9]	91000	[A.11]
Sr	Strontium	8	[A.9]	1200	[A.8]
Tc	Technetium	100	[A.9]	5	[A.8]
Te^	Tellurium^	1000	[A.9]	n/a	n/a
Th	Thorium	3000000	[A.9]	190000	[A.8]
Tl	Thallium	20000	[A.9]	20000	Ocean margin value used [A.9]*
U	Uranium	1000	[A.9]	50	[A.8]
V	Vanadium	800000	Niobium used as analogue*	100	Niobium used as analogue*
Y	Yttrium	900000	[A.9]	1000	Zirconium used as an analogue*
Zn	Zinc	70000	[A.9]	500	[A.8]
Zr	Zirconium	2000000	[A.9]	1000	[A.8]

* see Tables C4 and C5
^element used only in calculations for progeny in marine assessments and not applicable to the freshwater assessments.

Table A.3. Analogues used to fill gaps in concentration ratio (CR) data for wildlife assessments

See Table C.6 for narrative on the reasons for analogue selection.

Element		Analogue used for terrestrial assessment	Analogue used for marine assessment	Analogue used for freshwater assessment
Ac	Actinium	Thorium	Thorium	Thorium
Ag	Silver	-	-	-
Am	Americium	-	-	-
Ar	Argon	-	n/a	n/a
At	Astatine	Iodine	Iodine	Iodine
Au	Gold	Technetium	Technetium	Technetium
Ba	Barium	-	-	-
Bi	Bismuth	Lead	Lead	n/a
Br	Bromine	Iodine	Iodine	Iodine
C	Carbon	-	-	-
Ca	Calcium	-	-	-
Ce	Cerium	-	-	-
Cl	Chlorine	-	-	-
Cm	Curium	-	-	-
Co	Cobalt	-	-	-
Cr	Chromium	-	-	-
Cs	Caesium	-	-	-
Cu	Copper	Zinc	Zinc	Zinc
Er	Erbium	Cerium	Cerium	Cerium
Eu	Europium	-	-	-
F	Fluorine	Chlorine	n/a	n/a
Fe	Iron	Manganese	Manganese	Manganese
Ga	Gallium	Niobium	Niobium	Niobium
Gd	Gadolinium	n/a	Cerium	n/a
H	Tritium	-	-	-
H org.	Organically bound tritium	Carbon	Carbon	Carbon
I	Iodine	-	-	-
In	Indium	Cerium	Cerium	Cerium
Kr	Krypton	-	n/a	n/a
La	Lanthanum	-	-	-
Lu	Lutetium	Cerium	Cerium	Cerium
Mn	Manganese	-	-	-
Mo	Molybdenum	Niobium	Niobium	Niobium
N	Nitrogen	Phosphorus	n/a	n/a

Na	Sodium	Caesium	Caesium	Caesium
Nb	Niobium	-	-	-
Ni	Nickel	-	-	-
Np	Neptunium	-	-	-
O	Oxygen	Sulphur	n/a	n/a
P	Phosphorus	-	-	-
Pa	Protactinium	n/a	-	n/a
Pb	Lead	-	-	-
Pm	Promethium	Cerium	Cerium	Cerium
Po	Polonium	-	-	-
Pu	Plutonium	-	-	-
Ra	Radium	-	-	-
Rb	Rubidium	Caesium	Caesium	Caesium
Re	Rhenium	Technetium	Technetium	Technetium
Rn	Radon	Assumed to be 0	n/a	n/a
Ru	Ruthenium	-	-	-
S	Sulphur	-	-	-
Sb	Antimony	-	-	-
Sc	Scandium	n/a	Zirconium	n/a
Se	Selenium	-	-	-
Sm	Samarium	Cerium	Cerium	Cerium
Sr	Strontium	-	-	-
Tc	Technetium	-	-	-
Te	Tellurium	n/a	-	n/a
Th	Thorium	-	-	-
Tl	Thallium	Caesium	Caesium	Caesium
U	Uranium	-	-	-
V	Vanadium	Niobium	Niobium	Niobium
Xe	Xenon	-	n/a	n/a
Y	Yttrium	Zirconium	Zirconium	Zirconium
Zn	Zinc	-	-	-
Zr	Zirconium	-	-	-

- default CR used in ERICA tool or Ar-Kr-Xe calculator.
n/a: radionuclides of this element not assessed

Table A.4. CRs for terrestrial reference organisms (Bq/kg per Bq/l (or Bq/kg per Bq/m^3 for H, C, S, P, Rn, Ar, Kr and Xe)).

Element	Amphibian	Annelid	Arthropod - detritivorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryophytes	Mammal - large	Mammal - small-burrowing	Mollusc - gastropod	Reptile	Shrub	Tree
Ac	3.9E-04	9.2E-03	5.1E-03	3.9E-04	5.1E-03	1.6E-01	3.8E-01	1.4E-04	1.4E-04	9.2E-03	2.2E-03	6.1E-02	1.3E-03
Ag	5.4E-01	5.4E-01	2.2E-02	5.4E-01	2.2E-02	2.3E+00	1.1E-02	5.4E-01	5.4E-01	5.4E-01	5.4E-01	5.2E-03	4.2E-01
Am	1.3E-01	1.8E-01	1.0E-01	3.1E-02	1.0E-01	1.0E-01	9.9E-01	2.4E-02	2.4E-02	1.4E-01	6.4E-02	2.7E-02	2.7E-02
Ar	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
At	4.0E-01	1.6E-01	3.0E-01	4.0E-01	3.0E-01	1.4E-01	1.4E-01	4.0E-01	4.0E-01	1.8E-01	4.0E-01	7.0E-04	1.4E-01
Au	3.9E-01	3.9E-01	3.9E-01	1.7E-01	3.9E-01	1.4E+01	1.4E+01	3.9E-01	3.9E-01	3.9E-01	3.9E-01	1.2E-02	1.2E-02
Ba	2.8E-02	1.4E-02	1.6E-02	1.2E+01	1.6E-02	3.0E-02	9.3E-02	2.8E-02	2.8E-02	4.8E-02	2.8E-02	5.2E-01	1.0E-01
Bi	1.2E-01	4.8E-01	4.0E-01	6.1E-02	4.0E-01	1.2E-01	2.6E+00	3.7E-02	3.7E-02	7.3E-03	3.9E-02	3.2E-01	7.0E-02
Br	4.0E-01	1.6E-01	3.0E-01	4.0E-01	3.0E-01	1.4E-01	1.4E-01	4.0E-01	4.0E-01	1.8E-01	4.0E-01	7.0E-04	1.4E-01
C	1.3E+03	4.3E+02	4.3E+02	1.3E+03	4.3E+02	8.9E+02	8.9E+02	1.3E+03	1.3E+03	4.3E+02	1.3E+03	8.9E+02	1.3E+03
Ca	8.5E+00	1.9E-01	1.0E-01	5.7E-02	1.0E-01	3.0E-01	2.0E+00	8.5E+00	8.5E+00	4.8E-02	8.5E+00	1.9E-01	7.4E-01
Ce	4.9E-03	4.8E-03	2.2E-03	6.9E-02	2.2E-03	1.4E-02	1.6E-02	4.9E-03	4.9E-03	6.9E-02	4.9E-03	9.1E-03	1.7E-03
Cl	7.0E+00	1.8E-01	3.0E-01	7.0E+00	3.0E-01	2.1E+01	9.6E-01	7.0E+00	7.0E+00	1.7E-01	7.0E+00	1.0E+00	1.4E+00
Cm	1.3E-01	1.8E-01	1.4E-01	3.1E-02	1.4E-01	5.0E-04	9.9E-01	5.4E-01	5.4E-01	5.4E-01	5.4E-01	2.2E-01	9.4E-03
Co	1.9E-01	1.9E-02	7.1E-03	1.3E-02	7.1E-03	1.9E-02	8.4E-02	1.9E-01	1.9E-01	1.9E-02	1.9E-01	1.3E-02	5.4E-03
Cr	5.9E-03	2.8E-02	3.1E-03	9.2E-02	3.1E-03	2.1E-02	5.6E-02	5.9E-03	5.9E-03	2.8E-02	5.9E-03	1.0E-02	5.7E-03
Cs	4.6E-01	8.1E-02	1.1E-01	5.6E-01	1.1E-01	1.1E+00	3.8E+00	3.4E+00	3.4E+00	4.0E-02	5.7E-01	2.0E+00	1.4E-01
Cu	3.0E+00	3.9E+00	1.1E+00	3.0E+00	1.1E+00	1.0E-01	6.6E-01	3.0E+00	3.0E+00	3.9E+00	2.0E-01	9.2E-01	1.1E-01
Er	4.9E-03	4.8E-03	2.2E-03	6.9E-02	2.2E-03	1.4E-02	1.6E-02	4.9E-03	4.9E-03	6.9E-02	4.9E-03	9.1E-03	1.7E-03
Eu	3.4E-02	5.9E-03	2.1E-03	5.7E-01	2.1E-03	1.4E-02	1.3E-02	3.4E-02	3.4E-02	5.9E-03	3.4E-02	2.8E-03	2.4E-03
F	7.0E+00	1.8E-01	3.0E-01	7.0E+00	3.0E-01	2.1E+01	9.6E-01	7.0E+00	7.0E+00	1.7E-01	7.0E+00	1.0E+00	1.4E+00
Fe	1.0E-02	1.7E-02	9.8E-02	1.0E-02	9.8E-02	9.2E-02	6.2E-01	2.5E-03	2.5E-03	4.6E-02	1.0E-02	4.4E+00	6.3E-02
Ga	4.2E-02	1.5E-01	9.5E-04	1.7E-01	9.5E-04	1.3E-03	2.8E-02	4.2E-02	4.2E-02	1.5E-01	4.2E-02	1.2E-03	1.2E-02
H	1.5E+02	1.5E+02	1.5E+02	1.5E+02	1.5E+02	1.5E+02	1.5E+02	1.5E+02	1.5E+02	1.5E+02	1.5E+02	1.5E+02	1.5E+02
H org.	1.3E+03	4.3E+02	4.3E+02	1.3E+03	4.3E+02	8.9E+02	8.9E+02	1.3E+03	1.3E+03	4.3E+02	1.3E+03	8.9E+02	1.3E+03
I	4.0E-01	1.6E-01	3.0E-01	4.0E-01	3.0E-01	1.4E-01	1.4E-01	4.0E-01	4.0E-01	1.8E-01	4.0E-01	7.0E-04	1.4E-01
In	4.9E-03	4.8E-03	2.2E-03	6.9E-02	2.2E-03	1.4E-02	1.6E-02	4.9E-03	4.9E-03	6.9E-02	4.9E-03	9.1E-03	1.7E-03
Kr	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
La	5.7E-01	5.9E-03	1.7E-03	5.7E-01	1.7E-03	1.4E-02	2.2E-02	3.4E-02	3.4E-02	5.9E-03	5.7E-01	3.5E-03	3.9E-03

Element	Amphibian	Annelid	Arthropod - detritivorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryophytes	Mammal - large	Mammal - small-burrowing	Mollusc - gastropod	Reptile	Shrub	Tree
Lu	4.9E-03	4.8E-03	2.2E-03	6.9E-02	2.2E-03	1.4E-02	1.6E-02	4.9E-03	4.9E-03	6.9E-02	4.9E-03	9.1E-03	1.7E-03
Mn	1.0E-02	1.7E-02	9.8E-02	1.0E-02	9.8E-02	9.2E-02	6.2E-01	2.5E-03	2.5E-03	4.6E-02	1.0E-02	4.4E+00	6.3E-02
Mo	4.2E-02	1.5E-01	9.5E-04	1.7E-01	9.5E-04	1.3E-03	2.8E-02	4.2E-02	4.2E-02	1.5E-01	4.2E-02	1.2E-03	1.2E-02
N	1.3E+03	4.3E+02	4.3E+02	1.3E+03	4.3E+02	8.9E+02	8.9E+02	1.3E+03	1.3E+03	4.3E+02	1.3E+03	8.9E+02	1.3E+03
Na	4.6E-01	8.1E-02	1.1E-01	5.6E-01	1.1E-01	1.1E+00	3.8E+00	3.4E+00	3.4E+00	4.0E-02	5.7E-01	2.0E+00	1.4E-01
Nb	4.2E-02	1.5E-01	9.5E-04	1.7E-01	9.5E-04	1.3E-03	2.8E-02	4.2E-02	4.2E-02	1.5E-01	4.2E-02	1.2E-03	1.2E-02
Ni	1.1E-01	7.2E-02	1.7E-02	1.1E-01	1.7E-02	1.3E-01	2.4E-01	1.1E-01	1.1E-01	1.8E-02	3.0E-01	9.9E-02	2.1E-02
Np	1.3E-01	1.8E-01	1.0E-01	3.1E-02	1.0E-01	1.7E-01	9.9E-01	5.4E-01	5.4E-01	5.4E-01	5.4E-01	2.2E-01	6.6E-03
O	5.0E+01	5.0E+01	5.0E+01	5.0E+01	5.0E+01	1.5E+02	1.5E+02	5.0E+01	5.0E+01	5.0E+01	5.0E+01	1.5E+02	1.5E+02
P	1.3E+03	4.3E+02	4.3E+02	1.3E+03	4.3E+02	8.9E+02	8.9E+02	1.3E+03	1.3E+03	4.3E+02	1.3E+03	8.9E+02	1.3E+03
Pb	1.2E-01	4.8E-01	4.0E-01	6.1E-02	4.0E-01	1.2E-01	2.6E+00	3.7E-02	3.7E-02	7.3E-03	3.9E-02	3.2E-01	7.0E-02
Pm	4.9E-03	4.8E-03	2.2E-03	6.9E-02	2.2E-03	1.4E-02	1.6E-02	4.9E-03	4.9E-03	6.9E-02	4.9E-03	9.1E-03	1.7E-03
Po	1.0E-01	1.0E-02	1.0E-02	1.0E-02	1.0E-02	2.8E-01	2.6E+00	8.9E-02	8.9E-02	1.0E-02	1.3E-01	3.3E-01	7.3E-02
Pu	1.4E-02	3.1E-02	2.6E-02	2.3E-03	2.6E-02	1.6E-02	1.3E-01	1.4E-02	1.4E-02	1.2E-01	1.1E-02	7.0E-02	7.0E-02
Ra	4.4E-02	4.3E-02	4.3E-02	3.6E-02	4.3E-02	1.8E-01	7.1E-01	4.4E-02	4.4E-02	4.8E-02	4.4E-02	3.3E-01	1.2E-02
Rb	4.6E-01	8.1E-02	1.1E-01	5.6E-01	1.1E-01	1.1E+00	3.8E+00	3.4E+00	3.4E+00	4.0E-02	5.7E-01	2.0E+00	1.4E-01
Re	3.9E-01	3.9E-01	3.9E-01	1.7E-01	3.9E-01	1.4E+01	1.4E+01	3.9E-01	3.9E-01	3.9E-01	3.9E-01	1.2E-02	1.2E-02
Rn	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ru	1.2E-01	6.4E-03	6.4E-03	1.2E-01	6.4E-03	2.0E-02	6.5E+00	1.2E-01	1.2E-01	6.4E-03	1.2E-01	4.1E-01	4.1E-01
S	5.0E+01	5.0E+01	5.0E+01	5.0E+01	5.0E+01	1.5E+02	1.5E+02	5.0E+01	5.0E+01	5.0E+01	5.0E+01	1.5E+02	1.5E+02
Sb	3.5E-03	4.6E-02	1.1E-02	3.5E-03	1.1E-02	3.7E-02	3.0E-01	3.5E-03	3.5E-03	4.6E-02	3.5E-03	3.7E-02	3.7E-02
Se	1.9E-01	3.1E+00	1.4E-01	3.5E-01	1.4E-01	9.8E-01	1.4E-01	1.9E-01	1.9E-01	3.5E-02	1.9E-01	1.4E+00	1.1E-01
Sm	4.9E-03	4.8E-03	2.2E-03	6.9E-02	2.2E-03	1.4E-02	1.6E-02	4.9E-03	4.9E-03	6.9E-02	4.9E-03	9.1E-03	1.7E-03
Sr	1.3E+00	6.6E-02	3.4E-01	1.2E+00	3.4E-01	7.8E-01	4.6E+00	1.7E+00	1.7E+00	9.2E-02	4.1E-01	1.8E-01	4.8E-01
Tc	3.9E-01	3.9E-01	3.9E-01	1.7E-01	3.9E-01	1.4E+01	1.4E+01	3.9E-01	3.9E-01	3.9E-01	3.9E-01	1.2E-02	1.2E-02
Th	3.9E-04	9.2E-03	5.1E-03	3.9E-04	5.1E-03	1.6E-01	3.8E-01	1.4E-04	1.4E-04	9.2E-03	2.2E-03	6.1E-02	1.3E-03
Tl	4.6E-01	8.1E-02	1.1E-01	5.6E-01	1.1E-01	1.1E+00	3.8E+00	3.4E+00	3.4E+00	4.0E-02	5.7E-01	2.0E+00	1.4E-01
U	5.5E-03	3.4E-02	1.0E-02	1.3E-03	1.0E-02	1.3E-01	9.1E-01	5.5E-03	5.5E-03	3.4E-02	5.2E-03	6.1E-02	6.6E-03
V	4.2E-02	1.5E-01	9.5E-04	1.7E-01	9.5E-04	1.3E-03	2.8E-02	4.2E-02	4.2E-02	1.5E-01	4.2E-02	1.2E-03	1.2E-02
Xe	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Y	1.3E-01	9.6E-03	7.7E-03	1.3E-01	7.7E-03	3.9E-02	1.8E-01	2.5E-04	2.5E-04	9.6E-03	1.3E-01	5.3E-03	1.1E-02
Zn	3.0E+00	3.9E+00	1.1E+00	3.0E+00	1.1E+00	1.0E-01	6.6E-01	3.0E+00	3.0E+00	3.9E+00	2.0E-01	9.2E-01	1.1E-01

Element	Amphibian	Annelid	Arthropod - detritivorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryophytes	Mammal - large	Mammal - small-burrowing	Mollusc - gastropod	Reptile	Shrub	Tree
Zr	1.3E-01	9.6E-03	7.7E-03	1.3E-01	7.7E-03	3.9E-02	1.8E-01	2.5E-04	2.5E-04	9.6E-03	1.3E-01	5.3E-03	1.1E-02

Table A.5. CRs for marine reference organisms (Bq/kg per Bq/l)

Element	Benthic fish	Bird	Crustacean	Macro-algae	Mammal	Mollusc - bivalve	Pelagic fish	Phyto-plankton	Polychaete worm	Reptile	Sea anemones & true coral	Vascular plant	Zoo-plankton
Ac	1.3E+03	1.7E+03	3.8E+04	4.6E+03	1.7E+03	1.7E+03	1.3E+03	7.3E+05	1.7E+03	1.7E+03	1.7E+03	4.6E+03	7.2E+03
Ag	1.1E+04	2.2E+04	3.6E+04	3.9E+03	2.2E+04	3.6E+04	1.1E+04	6.9E+04	2.7E+04	2.2E+04	1.3E+02	3.9E+03	6.0E+03
Am	4.2E+02	4.1E+02	5.0E+02	4.3E+02	1.3E+03	9.9E+04	4.2E+02	2.1E+05	9.9E+04	1.3E+03	4.5E+01	4.3E+02	4.0E+03
At	9.0E+00	6.8E-01	3.9E+01	4.2E+03	6.8E-01	8.8E+03	9.0E+00	9.5E+02	8.8E+03	6.8E-01	8.8E+03	2.4E+01	3.1E+03
Au	8.0E+01	1.7E+04	1.7E+04	5.3E+04	1.7E+04	8.2E+03	8.0E+01	4.9E+00	1.7E+04	1.7E+04	1.7E+04	5.3E+04	1.0E+02
Ba	2.5E+01	1.6E+02	4.9E+01	2.9E+01	1.6E+02	1.5E+02	2.5E+01	1.9E+02	4.6E-01	1.6E+02	9.5E+01	3.0E+00	6.8E+01
Bi*	3.3E+04	1.9E+04	2.1E+04	1.0E+03	1.9E+04	6.3E+03	3.3E+04	4.8E+05	4.0E+04	1.9E+04	3.3E+04	1.0E+03	1.7E+04
Br	9.0E+00	6.8E-01	3.9E+01	4.2E+03	6.8E-01	8.8E+03	9.0E+00	9.5E+02	8.8E+03	6.8E-01	8.8E+03	2.4E+01	3.1E+03
C	1.7E+03	1.7E+03	1.4E+03	1.3E+03	1.7E+03	6.5E+02	1.7E+03	2.5E+02	1.0E+04	1.7E+03	1.7E+03	1.3E+03	1.0E+04
Ca	8.2E+00	1.6E+02	1.0E+01	3.7E+00	1.6E+02	2.2E+00	8.2E+00	1.9E+02	4.6E-01	1.6E+02	9.5E+01	3.0E+00	6.8E+01
Ce	3.9E+02	2.2E+03	1.0E+02	2.1E+03	2.2E+03	2.2E+03	3.9E+02	1.1E+04	2.2E+03	2.2E+03	1.3E+02	1.6E+02	6.0E+03
Cl	5.6E-02	5.6E-02	5.6E-02	8.2E-01	5.6E-02	4.7E-02	5.6E-02	8.2E-01	5.6E-02	5.6E-02	5.6E-02	8.2E-01	5.6E-02
Cm	1.4E+03	4.1E+02	5.0E+02	1.2E+04	1.3E+03	3.2E+04	1.4E+03	2.7E+05	3.2E+04	1.3E+03	4.5E+01	1.2E+04	6.3E+03
Co	5.3E+03	5.0E+02	3.5E+03	1.7E+03	5.0E+02	5.3E+03	5.3E+03	3.1E+03	8.0E+03	5.0E+02	6.1E+02	3.3E+02	4.8E+03
Cr	2.0E+02	2.0E+03	1.0E+02	6.0E+03	2.0E+03	2.0E+03	2.0E+02	5.0E+03	2.0E+03	2.0E+03	2.0E+03	6.0E+03	1.0E+03
Cs	8.4E+01	4.8E+02	5.3E+01	9.6E+01	2.2E+02	5.0E+01	8.4E+01	8.5E+00	1.8E+02	4.8E+02	2.3E+02	1.0E+01	1.3E+02
Cu	2.5E+04	2.5E+04	3.0E+05	2.0E+03	2.5E+04	8.0E+04	2.5E+04	1.0E+04	2.5E+04	2.5E+04	2.5E+04	2.0E+03	1.0E+05
Er	3.9E+02	2.2E+03	1.0E+02	2.1E+03	2.2E+03	2.2E+03	3.9E+02	1.1E+04	2.2E+03	2.2E+03	1.3E+02	1.6E+02	6.0E+03
Eu	7.3E+02	2.3E+04	2.3E+04	1.7E+03	2.3E+04	6.9E+03	7.3E+02	1.1E+04	2.3E+04	2.3E+04	2.3E+04	1.7E+03	4.0E+03
Fe	2.6E+03	4.5E+03	4.5E+04	8.6E+03	4.5E+03	1.2E+04	2.6E+03	3.5E+03	3.2E+03	4.5E+03	1.0E+01	3.0E+04	2.5E+03
Ga	3.0E+01	8.8E+02	1.0E+02	4.9E+02	8.8E+02	8.8E+02	3.0E+01	1.0E+03	8.8E+02	8.8E+02	8.8E+02	4.9E+02	2.0E+04
Gd*	3.9E+02	2.2E+03	1.0E+02	2.1E+03	2.2E+03	2.2E+03	3.9E+02	1.1E+04	2.2E+03	2.2E+03	1.3E+02	1.6E+02	6.0E+03
H	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00
H org.	1.7E+03	1.7E+03	1.4E+03	1.3E+03	1.7E+03	6.5E+02	1.7E+03	2.5E+02	1.0E+04	1.7E+03	1.7E+03	1.3E+03	1.0E+04
I	9.0E+00	6.8E-01	3.9E+01	4.2E+03	6.8E-01	8.8E+03	9.0E+00	9.5E+02	8.8E+03	6.8E-01	8.8E+03	2.4E+01	3.1E+03
In	3.9E+02	2.2E+03	1.0E+02	2.1E+03	2.2E+03	2.2E+03	3.9E+02	1.1E+04	2.2E+03	2.2E+03	1.3E+02	1.6E+02	6.0E+03
La	1.1E+04	1.1E+04	5.7E+03	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04	1.1E+04
Lu	3.9E+02	2.2E+03	1.0E+02	2.1E+03	2.2E+03	2.2E+03	3.9E+02	1.1E+04	2.2E+03	2.2E+03	1.3E+02	1.6E+02	6.0E+03
Mn	2.6E+03	4.5E+03	4.5E+04	8.6E+03	4.5E+03	1.2E+04	2.6E+03	3.5E+03	3.2E+03	4.5E+03	1.0E+01	3.0E+04	2.5E+03
Mo	3.0E+01	8.8E+02	1.0E+02	4.9E+02	8.8E+02	8.8E+02	3.0E+01	1.0E+03	8.8E+02	8.8E+02	8.8E+02	4.9E+02	2.0E+04

Element	Benthic fish	Bird	Crustacean	Macro-algae	Mammal	Mollusc - bivalve	Pelagic fish	Phyto-plankton	Polychaete worm	Reptile	Sea anemones & true coral	Vascular plant	Zoo-plankton
Na	8.4E+01	4.8E+02	5.3E+01	9.6E+01	2.2E+02	5.0E+01	8.4E+01	8.5E+00	1.8E+02	4.8E+02	2.3E+02	1.0E+01	1.3E+02
Nb	3.0E+01	8.8E+02	1.0E+02	4.9E+02	8.8E+02	8.8E+02	3.0E+01	1.0E+03	8.8E+02	8.8E+02	8.8E+02	4.9E+02	2.0E+04
Ni	2.5E+02	5.0E+02	1.3E+03	9.5E+02	5.0E+02	6.4E+03	2.5E+02	5.7E+02	4.2E+03	5.0E+02	6.4E+03	9.5E+02	5.0E+02
Np	8.8E+00	8.8E+00	3.6E+00	5.2E+01	8.8E+00	3.8E+02	8.8E+00	1.4E+02	3.8E+02	8.8E+00	3.6E+00	5.2E+01	1.7E+01
P	9.9E+04	3.8E+04	9.9E+04	9.8E+03	3.8E+04	2.0E+04	9.9E+04	3.3E+04	2.6E+04	3.8E+04	9.9E+04	9.8E+03	2.3E+04
Pa*	5.0E+01	5.0E+02	1.0E+01	1.0E+02	5.0E+02	5.0E+02	5.0E+01	1.0E+03	5.0E+02	5.0E+02	5.0E+02	1.0E+02	1.0E+03
Pb-211*^	2.8E+01	1.6E+01	1.8E+01	8.3E-01	1.6E+01	5.3E+00	2.8E+01	4.0E+02	3.3E+01	1.6E+01	2.8E+01	8.3E-01	1.4E+01
Pb other	3.3E+04	1.9E+04	2.1E+04	1.0E+03	1.9E+04	6.3E+03	3.3E+04	4.8E+05	4.0E+04	1.9E+04	3.3E+04	1.0E+03	1.7E+04
Pm	3.9E+02	2.2E+03	1.0E+02	2.1E+03	2.2E+03	2.2E+03	3.9E+02	1.1E+04	2.2E+03	2.2E+03	1.3E+02	1.6E+02	6.0E+03
Po	8.0E+04	7.7E+04	2.1E+05	2.8E+03	7.7E+04	6.4E+04	8.0E+04	5.3E+04	4.6E+05	7.7E+04	2.1E+05	2.8E+03	1.0E+05
Pu	1.4E+03	4.1E+02	1.2E+02	4.1E+03	1.3E+03	1.1E+03	1.4E+03	1.3E+05	1.5E+03	1.3E+03	4.9E+02	4.1E+03	6.3E+03
Ra-223^	3.9E+01	4.5E+01	2.4E+01	2.5E+01	4.5E+01	1.8E+01	3.9E+01	3.2E+02	3.9E+01	4.5E+01	3.9E+01	2.5E+01	2.2E+01
Ra other^	1.4E+02	1.6E+02	8.6E+01	9.0E+01	1.6E+02	6.5E+01	1.4E+02	1.1E+03	1.4E+02	1.6E+02	1.4E+02	9.0E+01	8.1E+01
Rb	8.4E+01	4.8E+02	5.3E+01	9.6E+01	2.2E+02	5.0E+01	8.4E+01	8.5E+00	1.8E+02	4.8E+02	2.3E+02	1.0E+01	1.3E+02
Re	8.0E+01	1.7E+04	1.7E+04	5.3E+04	1.7E+04	8.2E+03	8.0E+01	4.9E+00	1.7E+04	1.7E+04	1.7E+04	5.3E+04	1.0E+02
Ru	2.9E+01	1.6E+03	1.0E+02	1.2E+03	1.6E+03	1.6E+03	2.9E+01	6.7E+03	1.6E+03	1.6E+03	2.9E+01	1.2E+03	3.0E+04
S	1.0E+00	1.5E+00	2.0E+00	3.0E+00	1.5E+00	3.2E+00	1.0E+00	9.0E-01	1.8E+00	1.5E+00	3.2E+00	3.0E+00	1.0E+00
Sb	6.0E+02	8.3E+03	3.0E+02	2.2E+02	8.3E+03	4.7E+02	6.0E+02	1.0E+03	4.5E+03	8.3E+03	9.0E+01	2.2E+02	1.3E+03
Sc*	8.5E+01	8.5E+01	4.9E+01	1.7E+03	8.5E+01	3.3E+03	8.5E+01	3.3E+04	3.3E+03	8.5E+01	1.3E+02	1.1E+03	2.2E+04
Se	6.9E+02	8.3E+03	1.0E+04	4.3E+02	8.3E+03	1.5E+03	6.9E+02	3.6E+03	4.5E+03	8.3E+03	1.0E+01	7.1E+01	9.8E+02
Sm	3.9E+02	2.2E+03	1.0E+02	2.1E+03	2.2E+03	2.2E+03	3.9E+02	1.1E+04	2.2E+03	2.2E+03	1.3E+02	1.6E+02	6.0E+03
Sr	2.5E+01	1.6E+02	4.9E+01	2.9E+01	1.6E+02	1.5E+02	2.5E+01	1.9E+02	4.6E-01	1.6E+02	9.5E+01	3.0E+00	6.8E+01
Tc	8.0E+01	1.7E+04	1.7E+04	5.3E+04	1.7E+04	8.2E+03	8.0E+01	4.9E+00	1.7E+04	1.7E+04	1.7E+04	5.3E+04	1.0E+02
Te*	6.9E+02	8.3E+03	1.0E+03	4.3E+02	8.3E+03	1.5E+03	6.9E+02	1.3E+04	4.5E+03	8.3E+03	1.0E+01	4.3E+02	1.0E+03
Th	1.3E+03	1.7E+03	3.8E+04	4.6E+03	1.7E+03	1.7E+03	1.3E+03	7.3E+05	1.7E+03	1.7E+03	1.7E+03	4.6E+03	7.2E+03
Tl	8.4E+01	4.8E+02	5.3E+01	9.6E+01	2.2E+02	5.0E+01	8.4E+01	8.5E+00	1.8E+02	4.8E+02	2.3E+02	1.0E+01	1.3E+02
U	8.8E+00	8.8E+00	3.6E+00	8.3E+01	8.8E+00	3.2E+01	8.8E+00	2.2E+02	9.9E+02	8.8E+00	9.9E+02	2.4E+02	3.7E+00
V	3.0E+01	8.8E+02	1.0E+02	4.9E+02	8.8E+02	8.8E+02	3.0E+01	1.0E+03	8.8E+02	8.8E+02	8.8E+02	4.9E+02	2.0E+04
Y	8.5E+01	8.5E+01	4.9E+01	1.7E+03	8.5E+01	3.3E+03	8.5E+01	3.3E+04	3.3E+03	8.5E+01	1.3E+02	1.1E+03	2.2E+04
Zn	2.5E+04	2.5E+04	3.0E+05	2.0E+03	2.5E+04	8.0E+04	2.5E+04	1.0E+04	2.5E+04	2.5E+04	2.5E+04	2.0E+03	1.0E+05
Zr	8.5E+01	8.5E+01	4.9E+01	1.7E+03	8.5E+01	3.3E+03	8.5E+01	3.3E+04	3.3E+03	8.5E+01	1.3E+02	1.1E+03	2.2E+04

* Progeny only
^Amended CRs were used to derive DPUCs for Ra-223 and Pb-211 (see section A.3.1). ERICA default CRs were used to derive DPUCs for other radium and lead radionuclides (in this case, Ra-226, Pb-210 and Pb-212).

Table A.6. CRs for freshwater reference organisms (Bq/kg per Bq/l)

Element	Amphibian	Benthic fish	Bird	Crustacean	Insect larvae	Mammal	Mollusc - bivalve	Mollusc - gastropod	Pelagic fish	Phyto-plankton	Reptile	Vascular plant	Zoo-plankton
Ac	3.2E+03	7.1E+02	3.2E+03	6.0E+02	2.5E+03	3.2E+03	1.0E+04	1.0E+04	7.1E+02	1.2E+04	1.0E+03	9.8E+04	5.4E+02
Ag	1.5E+03	4.1E+02	1.5E+03	2.1E+04	2.1E+04	1.5E+03	2.1E+04	2.1E+04	4.1E+02	6.7E+02	1.5E+03	6.7E+02	2.1E+04
Am	3.2E+03	7.6E+02	3.2E+03	1.0E+04	1.8E+03	3.2E+03	1.0E+04	1.0E+04	7.6E+02	1.3E+03	3.2E+03	1.3E+03	1.8E+03
At	3.2E+02	3.2E+02	3.9E+01	8.3E+01	8.3E+01	3.2E+02	8.3E+01	8.3E+01	3.2E+02	5.4E+01	3.2E+02	5.4E+01	8.3E+01
Au	9.9E+01	9.9E+01	9.9E+01	9.9E+01	9.9E+01	9.9E+01	9.9E+01	9.9E+01	9.9E+01	4.0E+01	9.9E+01	4.0E+01	9.9E+01
Ba	1.7E+02	1.7E+02	3.4E+03	1.2E+03	1.2E+03	1.7E+02	1.2E+03	1.2E+03	1.7E+02	5.0E+01	1.4E+02	4.5E+02	1.2E+03
Br	3.2E+02	3.2E+02	3.9E+01	8.3E+01	8.3E+01	3.2E+02	8.3E+01	8.3E+01	3.2E+02	5.4E+01	3.2E+02	5.4E+01	8.3E+01
C	1.8E+05	1.8E+05	1.8E+05	1.8E+05	1.8E+05	1.8E+05	1.8E+05	1.8E+05	1.8E+05	4.0E+03	1.8E+05	8.8E+03	1.8E+05
Ca	1.2E+03	1.4E+03	5.5E+02	6.6E+02	4.3E+01	3.9E+02	7.4E+02	7.4E+02	1.4E+03	2.4E+02	5.0E+02	2.5E+02	4.3E+01
Ce	1.7E+02	1.7E+02	4.4E+03	1.0E+03	1.0E+03	1.7E+02	1.0E+03	1.0E+03	1.7E+02	8.8E+03	6.3E+02	8.8E+02	1.0E+03
Cl	1.2E+03	1.2E+03	1.2E+03	1.2E+03	1.2E+03	1.2E+03	1.2E+03	1.2E+03	1.2E+03	2.6E+02	1.2E+03	2.6E+02	1.2E+03
Cm	7.7E+01	8.3E+02	7.7E+01	2.5E+02	2.5E+02	7.7E+01	1.7E+01	1.7E+01	8.3E+02	5.9E+03	7.7E+01	2.3E+00	2.5E+02
Co	2.3E+02	2.3E+02	7.0E+02	1.9E+03	1.9E+03	2.3E+02	1.1E+03	1.1E+03	2.3E+02	6.5E+02	1.2E+01	9.3E+02	1.9E+03
Cr	6.5E+01	2.0E+02	1.9E+01	1.3E+03	1.3E+03	1.3E+03	1.3E+03	1.3E+03	2.0E+02	3.7E+02	1.3E+03	3.7E+02	1.3E+03
Cs	4.0E+03	3.4E+03	2.3E+03	1.8E+03	2.0E+03	2.3E+03	1.3E+02	1.3E+02	3.4E+03	1.4E+02	4.0E+03	3.6E+02	9.0E+01
Cu	7.3E+02	7.8E+03	1.5E+03	2.0E+04	2.0E+04	1.6E+03	7.4E+02	7.4E+02	7.8E+03	4.4E+03	2.3E+04	5.8E+02	2.0E+04
Er	1.7E+02	1.7E+02	4.4E+03	1.0E+03	1.0E+03	1.7E+02	1.0E+03	1.0E+03	1.7E+02	8.8E+03	6.3E+02	8.8E+02	1.0E+03
Eu	5.7E+03	6.6E+01	5.7E+03	1.5E+03	1.5E+03	5.7E+03	1.5E+03	1.5E+03	6.6E+01	2.3E+02	5.7E+03	2.3E+02	1.5E+03
Fe	7.4E+02	2.9E+03	7.4E+02	3.8E+03	1.1E+04	3.4E+02	1.1E+04	1.1E+04	2.9E+03	1.9E+02	7.4E+02	5.1E+03	1.1E+04
Ga	4.3E+03	3.2E+01	4.3E+03	9.6E+02	9.6E+02	4.3E+03	9.6E+02	9.6E+02	3.2E+01	3.8E+03	4.3E+03	3.8E+03	9.6E+02
H	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00
H org.	1.8E+05	1.8E+05	1.8E+05	1.8E+05	1.8E+05	1.8E+05	1.8E+05	1.8E+05	1.8E+05	4.0E+03	1.8E+05	8.8E+03	1.8E+05
I	3.2E+02	3.2E+02	3.9E+01	8.3E+01	8.3E+01	3.2E+02	8.3E+01	8.3E+01	3.2E+02	5.4E+01	3.2E+02	5.4E+01	8.3E+01
In	1.7E+02	1.7E+02	4.4E+03	1.0E+03	1.0E+03	1.7E+02	1.0E+03	1.0E+03	1.7E+02	8.8E+03	6.3E+02	8.8E+02	1.0E+03
La	2.4E+02	1.3E+02	2.4E+02	2.7E+03	2.7E+03	2.4E+02	2.7E+03	2.7E+03	1.3E+02	8.6E+02	2.4E+02	8.6E+02	2.7E+03
Lu	1.7E+02	1.7E+02	4.4E+03	1.0E+03	1.0E+03	1.7E+02	1.0E+03	1.0E+03	1.7E+02	8.8E+03	6.3E+02	8.8E+02	1.0E+03
Mn	7.4E+02	2.9E+03	7.4E+02	3.8E+03	1.1E+04	3.4E+02	1.1E+04	1.1E+04	2.9E+03	1.9E+02	7.4E+02	5.1E+03	1.1E+04
Mo	4.3E+03	3.2E+01	4.3E+03	9.6E+02	9.6E+02	4.3E+03	9.6E+02	9.6E+02	3.2E+01	3.8E+03	4.3E+03	3.8E+03	9.6E+02
Na	4.0E+03	3.4E+03	2.3E+03	1.8E+03	2.0E+03	2.3E+03	1.3E+02	1.3E+02	3.4E+03	1.4E+02	4.0E+03	3.6E+02	9.0E+01
Nb	4.3E+03	3.2E+01	4.3E+03	9.6E+02	9.6E+02	4.3E+03	9.6E+02	9.6E+02	3.2E+01	3.8E+03	4.3E+03	3.8E+03	9.6E+02

Element	Amphibian	Benthic fish	Bird	Crustacean	Insect larvae	Mammal	Mollusc - bivalve	Mollusc - gastropod	Pelagic fish	Phyto-plankton	Reptile	Vascular plant	Zoo-plankton
Ni	2.0E+02	2.0E+02	2.0E+02	1.9E+03	1.9E+03	2.0E+02	2.2E+02	2.2E+02	2.0E+02	5.2E+02	9.5E+02	5.2E+02	1.9E+03
Np	1.2E+02	7.2E+01	5.3E+01	2.0E+02	2.0E+02	1.2E+02	5.6E+02	5.6E+02	7.2E+01	7.1E+01	1.2E+02	2.2E+02	2.0E+02
P	6.8E+05	6.8E+05	6.8E+05	6.0E+04	6.0E+04	6.8E+05	6.0E+04	6.0E+04	6.8E+05	1.3E+03	6.8E+05	1.3E+03	6.0E+04
Pb	5.3E+00	3.6E+02	2.4E+02	8.2E+03	8.2E+03	4.4E+02	5.8E+03	5.8E+03	3.6E+02	1.6E+03	4.4E+02	3.0E+02	8.2E+03
Pm	1.7E+02	1.7E+02	4.4E+03	1.0E+03	1.0E+03	1.7E+02	1.0E+03	1.0E+03	1.7E+02	8.8E+03	6.3E+02	8.8E+02	1.0E+03
Po	2.0E+03	2.0E+03	2.0E+03	8.3E+03	1.2E+05	2.0E+03	1.2E+05	1.2E+05	2.0E+03	1.6E+03	3.6E+03	1.6E+03	1.2E+05
Pu	4.6E+03	8.3E+02	2.9E+03	6.0E+02	2.5E+03	4.6E+03	5.5E+03	5.5E+03	8.3E+02	5.9E+03	5.9E+03	1.1E+03	5.4E+02
Ra-223^	1.7E+03	5.0E+01	1.7E+03	7.4E+01	6.6E+03	5.8E-02	6.6E+03	6.6E+03	5.0E+01	1.5E+02	2.1E+02	3.0E+02	6.6E+03
Ra other^	6.3E+03	1.8E+02	6.3E+03	2.7E+02	2.4E+04	2.1E-01	2.4E+04	2.4E+04	1.8E+02	5.5E+02	7.7E+02	1.1E+03	2.4E+04
Rb	4.0E+03	3.4E+03	2.3E+03	1.8E+03	2.0E+03	2.3E+03	1.3E+02	1.3E+02	3.4E+03	1.4E+02	4.0E+03	3.6E+02	9.0E+01
Re	9.9E+01	9.9E+01	9.9E+01	9.9E+01	9.9E+01	9.9E+01	9.9E+01	9.9E+01	9.9E+01	4.0E+01	9.9E+01	4.0E+01	9.9E+01
Ru	1.0E+02	1.0E+02	1.0E+02	1.0E+02	1.0E+02	1.0E+02	1.0E+02	1.0E+02	1.0E+02	1.3E+03	1.0E+02	2.1E+03	1.0E+02
S	2.4E+02	2.4E+02	2.4E+02	2.4E+02	2.4E+02	2.4E+02	2.4E+02	2.4E+02	2.4E+02	2.0E+02	2.4E+02	2.0E+02	2.4E+02
Sb	2.3E+03	3.4E+01	2.3E+03	1.7E+02	8.2E+01	2.3E+03	4.9E+01	4.9E+01	3.4E+01	8.3E+01	2.3E+03	3.6E+01	8.2E+01
Se	2.7E+03	2.7E+03	6.9E+00	4.4E+02	3.2E+03	2.7E+03	3.3E+03	3.3E+03	2.7E+03	1.8E+01	2.7E+03	2.2E+02	5.4E+03
Sm	1.7E+02	1.7E+02	4.4E+03	1.0E+03	1.0E+03	1.7E+02	1.0E+03	1.0E+03	1.7E+02	8.8E+03	6.3E+02	8.8E+02	1.0E+03
Sr	1.2E+04	8.6E+02	7.3E+03	8.4E+02	3.7E+03	1.2E+04	4.6E+02	4.6E+02	8.6E+02	1.2E+02	1.2E+04	1.8E+02	3.7E+03
Tc	9.9E+01	9.9E+01	9.9E+01	9.9E+01	9.9E+01	9.9E+01	9.9E+01	9.9E+01	9.9E+01	4.0E+01	9.9E+01	4.0E+01	9.9E+01
Th	3.2E+03	7.1E+02	3.2E+03	6.0E+02	2.5E+03	3.2E+03	1.0E+04	1.0E+04	7.1E+02	1.2E+04	1.0E+03	9.8E+04	5.4E+02
Tl	4.0E+03	3.4E+03	2.3E+03	1.8E+03	2.0E+03	2.3E+03	1.3E+02	1.3E+02	3.4E+03	1.4E+02	4.0E+03	3.6E+02	9.0E+01
U	1.2E+02	7.2E+01	5.3E+01	2.0E+02	2.0E+02	1.2E+02	5.6E+02	5.6E+02	7.2E+01	7.1E+01	1.2E+02	3.7E+02	2.0E+02
V	4.3E+03	3.2E+01	4.3E+03	9.6E+02	9.6E+02	4.3E+03	9.6E+02	9.6E+02	3.2E+01	3.8E+03	4.3E+03	3.8E+03	9.6E+02
Y	1.2E+03	9.3E+02	3.0E+01	9.6E+02	9.6E+02	1.2E+03	9.6E+02	9.6E+02	9.3E+02	1.7E+03	1.2E+03	9.9E+01	9.6E+02
Zn	7.3E+02	7.8E+03	1.5E+03	2.0E+04	2.0E+04	1.6E+03	7.4E+02	7.4E+02	7.8E+03	4.4E+03	2.3E+04	5.8E+02	2.0E+04
Zr	1.2E+03	9.3E+02	3.0E+01	9.6E+02	9.6E+02	1.2E+03	9.6E+02	9.6E+02	9.3E+02	1.7E+03	1.2E+03	9.9E+01	9.6E+02

^ Amended CRs were used to derive DPUCs for Ra-223 (see section A.3.1). ERICA default CRs were used to derive DPUCs for other radium radionuclides (in this case, Ra-226).

Table A.7. Dose rate factors (DPUC) for exposure of terrestrial reference organisms to radionuclides in soil, µGy/h per Bq/kg (or in air for iosotopes of H, C, S, P, Rn, Ar, Kr, Xe µGy/h per Bq/m^3)

Radio-nuclide	Amphi-bian	Annelid	Arthropod – detriti-vorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryo-phytes	Mammal - large	Mammal - small-burrowing	Mollusc - gastropod	Reptile	Shrub	Tree
H-3	1.2E-03	1.2E-03	1.2E-03	1.2E-03	1.2E-03	1.2E-03	1.2E-03	1.2E-03	1.2E-03	1.2E-03	1.2E-03	1.2E-03	1.2E-03
H-3 org.	1.1E-02	3.5E-03	3.5E-03	1.1E-02	3.3E-03	7.3E-03	7.3E-03	1.1E-02	1.1E-02	3.5E-03	1.1E-02	7.3E-03	1.1E-02
C-11	3.2E-01	9.2E-02	7.8E-02	4.1E-01	8.6E-02	1.9E-01	1.5E-01	7.9E-01	3.7E-01	9.0E-02	3.6E-01	1.9E-01	7.3E-01
C-14	3.8E-02	1.2E-02	1.2E-02	4.0E-02	1.2E-02	2.5E-02	2.6E-02	4.0E-02	4.0E-02	1.2E-02	4.0E-02	2.5E-02	3.8E-02
N-13	4.0E-01	1.1E-01	9.0E-02	4.9E-01	1.0E-01	2.3E-01	1.7E-01	8.7E-01	4.4E-01	1.1E-01	4.3E-01	2.3E-01	8.2E-01
O-15	2.1E-02	1.9E-02	1.3E-02	2.5E-02	1.6E-02	5.3E-02	3.4E-02	4.0E-02	2.4E-02	1.7E-02	2.3E-02	5.3E-02	1.2E-01
F-18	1.7E-03	5.7E-04	5.8E-04	1.8E-03	2.5E-04	3.3E-03	3.3E-04	3.7E-03	1.9E-03	2.3E-04	1.8E-03	3.5E-04	8.6E-04
Na-22	1.2E-03	1.2E-03	1.2E-03	5.7E-04	4.5E-04	5.7E-04	8.3E-04	3.1E-03	1.8E-03	4.5E-04	1.2E-03	6.5E-04	4.5E-04
Na-24	2.2E-03	2.1E-03	2.1E-03	1.0E-03	7.8E-04	1.1E-03	1.5E-03	5.5E-03	3.6E-03	7.7E-04	2.2E-03	1.3E-03	7.7E-04
P-32	5.0E-01	1.4E-01	1.0E-01	5.2E-01	1.2E-01	2.9E-01	1.9E-01	5.4E-01	5.2E-01	1.4E-01	5.1E-01	2.9E-01	5.2E-01
P-33	6.0E-02	1.9E-02	1.9E-02	6.0E-02	1.9E-02	4.0E-02	3.8E-02	6.0E-02	6.0E-02	1.9E-02	6.0E-02	4.0E-02	5.8E-02
S-35	1.5E-03	1.5E-03	1.5E-03	1.5E-03	1.4E-03	4.4E-03	4.3E-03	1.5E-03	1.5E-03	1.5E-03	1.5E-03	4.4E-03	4.4E-03
Cl-36	1.1E-03	2.7E-05	4.3E-05	1.1E-03	4.3E-05	3.1E-03	1.2E-04	1.1E-03	1.1E-03	2.5E-05	1.1E-03	1.6E-04	2.3E-04
Ar-41*	3.0E-04	7.7E-08	3.4E-04	2.8E-04	3.3E-04	6.4E-04	3.6E-04	1.6E-04	6.9E-08	3.2E-04	3.0E-04	3.7E-04	4.1E-04
Ca-45	3.8E-04	8.4E-06	4.4E-06	2.6E-06	4.5E-06	1.3E-05	8.8E-05	3.9E-04	3.8E-04	2.1E-06	3.8E-04	8.3E-06	3.3E-05
Ca-47	5.6E-03	8.1E-04	7.7E-04	3.0E-04	3.4E-04	4.4E-04	1.2E-03	9.2E-03	6.0E-03	3.1E-04	5.9E-03	3.6E-04	9.7E-04
V-48	1.5E-03	1.5E-03	1.5E-03	5.9E-04	5.8E-04	5.6E-04	5.9E-04	3.4E-04	1.4E-03	6.0E-04	1.4E-03	5.3E-04	4.7E-04
Cr-51	1.5E-05	1.6E-05	1.5E-05	6.7E-06	6.4E-06	6.5E-06	6.8E-06	3.1E-06	1.4E-05	6.6E-06	1.4E-05	6.0E-06	5.2E-06
Mn-52	1.8E-03	1.8E-03	1.8E-03	6.4E-04	7.0E-04	6.8E-04	7.2E-04	3.6E-04	1.7E-03	6.9E-04	1.6E-03	9.6E-04	6.1E-04
Mn-54	4.4E-04	4.4E-04	4.5E-04	1.7E-04	1.7E-04	1.6E-04	1.8E-04	8.5E-05	4.2E-04	1.7E-04	4.0E-04	2.3E-04	1.5E-04
Mn-56	8.7E-04	8.9E-04	9.1E-04	3.1E-04	3.6E-04	3.5E-04	4.5E-04	1.8E-04	8.3E-04	3.5E-04	8.1E-04	1.9E-03	3.2E-04
Fe-55	1.4E-07	2.0E-07	8.4E-07	8.6E-08	7.9E-07	8.2E-07	4.9E-06	2.1E-08	7.0E-08	3.8E-07	1.3E-07	3.6E-05	5.2E-07
Fe-59	6.1E-04	6.2E-04	6.3E-04	2.2E-04	2.4E-04	2.3E-04	2.8E-04	1.2E-04	5.8E-04	2.4E-04	5.6E-04	5.5E-04	2.1E-04
Co-56	1.9E-03	1.9E-03	1.9E-03	6.5E-04	6.9E-04	6.7E-04	7.0E-04	5.9E-04	1.8E-03	6.9E-04	1.7E-03	6.3E-04	5.5E-04
Co-57	4.6E-05	4.1E-05	4.1E-05	2.0E-05	2.0E-05	2.2E-05	2.2E-05	2.3E-05	4.5E-05	2.1E-05	4.4E-05	1.9E-05	1.6E-05
Co-58	5.2E-04	5.2E-04	5.2E-04	2.0E-04	2.0E-04	1.9E-04	2.0E-04	1.7E-04	5.0E-04	2.0E-04	4.8E-04	1.8E-04	1.6E-04
Co-60	1.3E-03	1.3E-03	1.3E-03	4.9E-04	5.0E-04	4.8E-04	5.0E-04	4.2E-04	1.2E-03	5.0E-04	1.2E-03	4.5E-04	3.9E-04

Radionuclide	Amphibian	Annelid	Arthropod – detritivorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryophytes	Mammal - large	Mammal - small-burrowing	Mollusc - gastropod	Reptile	Shrub	Tree
Ni-63	1.3E-06	8.8E-07	2.1E-07	1.3E-06	2.0E-07	1.6E-06	2.9E-06	1.3E-06	1.3E-06	2.2E-07	3.7E-06	1.2E-06	2.6E-07
Cu-61	1.0E-03	1.1E-03	5.8E-04	9.2E-04	3.4E-04	1.8E-04	2.5E-04	1.5E-03	1.1E-03	8.2E-04	4.3E-04	3.1E-04	1.9E-04
Cu-64	3.3E-04	3.9E-04	1.7E-04	3.1E-04	1.1E-04	4.6E-05	8.1E-05	4.4E-04	3.4E-04	3.2E-04	1.1E-04	1.0E-04	4.6E-05
Zn-62	2.9E-03	3.0E-03	1.1E-03	2.9E-03	7.5E-04	3.5E-04	4.7E-04	4.0E-03	3.1E-03	2.3E-03	8.4E-04	7.7E-04	3.8E-04
Zn-65	3.7E-04	3.7E-04	3.2E-04	2.7E-04	1.3E-04	1.1E-04	1.2E-04	6.6E-04	4.0E-04	1.8E-04	2.8E-04	1.2E-04	1.1E-04
Ga-67	6.5E-05	6.9E-05	6.5E-05	3.3E-05	2.8E-05	2.9E-05	2.9E-05	1.6E-05	6.2E-05	3.3E-05	6.0E-05	2.7E-05	2.4E-05
Ga-68	5.1E-04	5.6E-04	5.1E-04	2.7E-04	2.0E-04	1.9E-04	2.0E-04	1.3E-04	4.9E-04	2.5E-04	4.7E-04	1.8E-04	1.6E-04
Se-75	1.7E-04	2.3E-04	1.7E-04	9.1E-05	7.7E-05	9.4E-05	7.6E-05	6.5E-05	1.7E-04	7.5E-05	1.6E-04	9.7E-05	7.7E-05
Br-76	1.5E-03	1.4E-03	1.4E-03	7.0E-04	5.7E-04	5.3E-04	5.3E-04	7.6E-04	1.5E-03	5.6E-04	1.4E-03	4.7E-04	5.6E-04
Br-77	1.7E-04	1.6E-04	1.7E-04	7.5E-05	6.8E-05	6.5E-05	6.6E-05	8.2E-05	1.6E-04	6.7E-05	1.6E-04	5.9E-05	6.7E-05
Br-82	1.4E-03	1.4E-03	1.4E-03	6.1E-04	5.6E-04	5.3E-04	5.5E-04	6.6E-04	1.4E-03	5.5E-04	1.3E-03	4.9E-04	5.4E-04
Kr-79	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc
Kr-81m	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc
Kr-85*	1.7E-06	9.9E-10	9.8E-06	8.6E-07	5.8E-06	8.4E-06	1.8E-05	2.9E-07	2.4E-10	3.5E-06	1.4E-06	1.9E-05	8.8E-07
Kr-85m	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc
Rb-81	3.7E-04	3.2E-04	3.3E-04	2.1E-04	1.4E-04	2.5E-04	4.8E-04	1.2E-03	8.1E-04	1.3E-04	3.7E-04	3.4E-04	1.4E-04
Rb-82	8.9E-04	6.2E-04	6.1E-04	6.9E-04	2.7E-04	7.9E-04	1.1E-03	4.2E-03	3.3E-03	2.4E-04	9.5E-04	1.2E-03	3.3E-04
Rb-83	2.9E-04	2.7E-04	2.7E-04	1.5E-04	1.1E-04	1.6E-04	2.9E-04	8.4E-04	5.2E-04	1.0E-04	2.8E-04	2.0E-04	1.1E-04
Sr-83	5.5E-04	4.2E-04	4.4E-04	3.4E-04	1.9E-04	2.3E-04	4.8E-04	6.9E-04	6.1E-04	1.7E-04	4.3E-04	1.6E-04	2.9E-04
Sr-85	2.9E-04	2.7E-04	2.7E-04	1.6E-04	1.1E-04	1.1E-04	1.5E-04	3.7E-04	3.1E-04	1.1E-04	2.5E-04	9.9E-05	1.7E-04
Sr-89	4.1E-04	1.9E-05	7.2E-05	4.1E-04	8.6E-05	2.2E-04	9.1E-04	5.5E-04	5.5E-04	2.6E-05	1.3E-04	5.0E-05	1.6E-04
Sr-90	7.8E-04	3.4E-05	1.2E-04	7.7E-04	1.4E-04	4.0E-04	1.5E-03	1.1E-03	1.0E-03	4.5E-05	2.4E-04	9.2E-05	3.1E-04
Y-90	6.3E-05	3.9E-06	1.9E-06	6.8E-05	2.5E-06	1.6E-05	4.0E-05	1.4E-07	1.3E-07	3.6E-06	6.4E-05	2.1E-06	6.0E-06
Zr-89	6.2E-04	6.1E-04	6.2E-04	2.4E-04	2.4E-04	2.3E-04	2.5E-04	1.2E-04	5.8E-04	2.4E-04	5.7E-04	2.2E-04	1.9E-04
Zr-95	4.0E-04	4.0E-04	4.0E-04	1.7E-04	1.5E-04	1.5E-04	1.6E-04	7.4E-05	3.7E-04	1.5E-04	3.7E-04	1.4E-04	1.2E-04
Nb-95	4.1E-04	4.2E-04	4.1E-04	1.7E-04	1.6E-04	1.5E-04	1.6E-04	8.9E-05	3.9E-04	1.7E-04	3.7E-04	1.4E-04	1.2E-04
Mo-99	1.3E-04	1.5E-04	1.2E-04	9.1E-05	5.1E-05	5.1E-05	5.5E-05	3.8E-05	1.2E-04	8.3E-05	1.2E-04	4.8E-05	4.4E-05
Tc-94m	1.1E-03	1.1E-03	1.1E-03	4.4E-04	4.8E-04	5.0E-03	2.8E-03	6.0E-04	1.1E-03	5.0E-04	1.1E-03	3.5E-04	3.0E-04
Tc-99	2.3E-05	2.3E-05	2.2E-05	9.7E-06	2.2E-05	8.0E-04	7.7E-04	2.3E-05	2.3E-05	2.2E-05	2.3E-05	6.7E-07	6.7E-07
Tc-99m	5.1E-05	5.1E-05	5.1E-05	2.3E-05	2.6E-05	2.1E-04	1.9E-04	3.4E-05	5.1E-05	2.7E-05	4.9E-05	2.1E-05	1.8E-05
Ru-103	2.5E-04	2.5E-04	2.5E-04	1.1E-04	9.7E-05	9.6E-05	5.3E-04	7.5E-05	2.4E-04	9.7E-05	2.3E-04	1.2E-04	1.7E-04

Radio-nuclide	Amphi-bian	Annelid	Arthropod – detriti-vorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryo-phytes	Mammal - large	Mammal - small-burrowing	Mollusc - gastropod	Reptile	Shrub	Tree
Ru-106	1.9E-04	1.1E-04	1.1E-04	1.4E-04	4.4E-05	5.1E-05	1.6E-03	1.3E-04	1.9E-04	4.5E-05	1.8E-04	2.5E-04	3.9E-04
Ag-110m	1.5E-03	1.5E-03	1.5E-03	6.9E-04	5.6E-04	7.1E-04	5.6E-04	8.0E-04	1.5E-03	6.0E-04	1.4E-03	5.1E-04	7.9E-04
In-111	1.7E-04	1.7E-04	1.7E-04	7.2E-05	7.4E-05	7.5E-05	7.5E-05	3.4E-05	1.6E-04	7.6E-05	1.6E-04	7.1E-05	6.0E-05
In-113m	1.3E-04	1.3E-04	1.3E-04	5.4E-05	5.2E-05	5.3E-05	5.3E-05	2.6E-05	1.2E-04	5.7E-05	1.2E-04	4.9E-05	4.1E-05
Sb-125	2.2E-04	2.2E-04	2.2E-04	8.5E-05	8.7E-05	8.8E-05	1.0E-04	4.2E-05	2.1E-04	8.9E-05	2.0E-04	8.3E-05	7.5E-05
I-123	7.4E-05	6.7E-05	7.1E-05	4.2E-05	3.5E-05	3.2E-05	3.1E-05	4.9E-05	7.3E-05	3.2E-05	7.0E-05	2.7E-05	3.5E-05
I-124	6.2E-04	5.9E-04	6.0E-04	2.8E-04	2.4E-04	2.3E-04	2.3E-04	3.0E-04	6.0E-04	2.3E-04	5.8E-04	2.0E-04	2.3E-04
I-125	1.7E-05	9.6E-06	1.3E-05	1.7E-05	9.6E-06	6.9E-06	5.3E-06	1.9E-05	1.8E-05	6.4E-06	1.7E-05	2.5E-06	7.7E-06
I-129	2.3E-05	1.1E-05	1.8E-05	2.3E-05	1.5E-05	8.6E-06	7.7E-06	2.4E-05	2.4E-05	9.7E-06	2.3E-05	1.6E-06	9.3E-06
I-131	2.4E-04	2.1E-04	2.2E-04	1.3E-04	1.1E-04	9.2E-05	9.1E-05	1.4E-04	2.3E-04	9.8E-05	2.2E-04	7.2E-05	9.6E-05
I-132	1.3E-03	1.2E-03	1.3E-03	6.4E-04	5.3E-04	4.9E-04	4.9E-04	6.7E-04	1.3E-03	5.0E-04	1.2E-03	4.3E-04	5.0E-04
I-133	4.2E-04	3.5E-04	3.7E-04	2.3E-04	1.8E-04	1.5E-04	1.5E-04	2.4E-04	4.0E-04	1.6E-04	3.9E-04	1.2E-04	1.6E-04
I-134	1.5E-03	1.4E-03	1.5E-03	7.1E-04	6.1E-04	5.6E-04	5.6E-04	7.6E-04	1.5E-03	5.8E-04	1.4E-03	4.8E-04	5.7E-04
I-135	9.4E-04	8.8E-04	9.0E-04	4.4E-04	3.8E-04	3.4E-04	3.5E-04	4.7E-04	9.2E-04	3.6E-04	8.9E-04	3.0E-04	3.5E-04
Xe-133*	1.0E-05	2.6E-09	1.2E-05	8.2E-06	1.1E-05	2.2E-05	1.3E-05	2.6E-06	2.2E-09	1.1E-05	9.7E-06	1.4E-05	9.4E-06
Cs-134	8.8E-04	8.4E-04	8.5E-04	4.3E-04	3.3E-04	4.2E-04	6.4E-04	2.3E-03	1.4E-03	3.2E-04	8.4E-04	4.9E-04	3.3E-04
Cs-136	1.2E-03	1.1E-03	1.1E-03	5.7E-04	4.5E-04	5.3E-04	7.4E-04	3.0E-03	1.8E-03	4.4E-04	1.1E-03	6.0E-04	4.4E-04
Cs-137	3.7E-04	3.1E-04	3.2E-04	2.2E-04	1.3E-04	2.7E-04	5.6E-04	1.2E-03	8.6E-04	1.3E-04	3.7E-04	3.8E-04	1.3E-04
Ba-140	1.5E-03	1.5E-03	1.5E-03	9.6E-03	5.6E-04	5.5E-04	5.9E-04	3.3E-04	1.4E-03	5.8E-04	1.4E-03	7.7E-04	5.7E-04
La-140	1.4E-03	1.2E-03	1.2E-03	6.9E-04	4.5E-04	4.4E-04	4.6E-04	2.7E-04	1.1E-03	4.5E-04	1.3E-03	4.2E-04	3.6E-04
Ce-141	2.7E-05	2.7E-05	2.7E-05	2.0E-05	1.2E-05	1.4E-05	1.4E-05	5.9E-06	2.6E-05	1.9E-05	2.5E-05	1.3E-05	1.0E-05
Ce-144	2.6E-05	2.6E-05	2.4E-05	5.9E-05	9.9E-06	1.6E-05	1.4E-05	8.2E-06	2.5E-05	4.3E-05	2.4E-05	1.3E-05	8.6E-06
Pm-147	1.8E-07	1.8E-07	7.9E-08	2.5E-06	7.8E-08	5.0E-07	5.8E-07	1.8E-07	1.8E-07	2.5E-06	1.8E-07	3.3E-07	6.3E-08
Sm-153	1.6E-05	1.6E-05	1.6E-05	1.8E-05	7.3E-06	1.0E-05	9.2E-06	3.7E-06	1.5E-05	1.8E-05	1.4E-05	8.7E-06	6.3E-06
Eu-152	5.7E-04	5.8E-04	5.8E-04	3.1E-04	2.3E-04	2.2E-04	2.3E-04	1.3E-04	5.5E-04	2.3E-04	5.3E-04	2.1E-04	1.8E-04
Eu-154	6.4E-04	6.3E-04	6.4E-04	3.9E-04	2.5E-04	2.4E-04	2.5E-04	1.4E-04	6.1E-04	2.5E-04	5.9E-04	2.2E-04	1.9E-04
Eu-155	1.7E-05	1.6E-05	1.6E-05	3.5E-05	7.7E-06	9.0E-06	8.2E-06	5.4E-06	1.6E-05	7.9E-06	1.6E-05	8.0E-06	6.8E-06
Er-169	3.2E-07	3.1E-07	1.4E-07	4.5E-06	1.4E-07	8.7E-07	1.0E-06	3.2E-07	3.2E-07	4.4E-06	3.2E-07	5.9E-07	1.1E-07
Lu-177	1.4E-05	1.4E-05	1.4E-05	1.2E-05	6.3E-06	7.4E-06	7.4E-06	3.2E-06	1.3E-05	1.2E-05	1.3E-05	6.6E-06	5.1E-06
Re-188	1.9E-04	1.7E-04	1.2E-04	8.4E-05	1.3E-04	5.0E-03	3.1E-03	1.9E-04	2.0E-04	1.5E-04	1.9E-04	1.4E-05	1.4E-05

Radio-nuclide	Amphi-bian	Annelid	Arthropod – detriti-vorous	Bird	Flying insects	Grasses & Herbs	Lichen & Bryo-phytes	Mammal - large	Mammal - small-burrowin g	Mollusc - gastropo d	Reptile	Shrub	Tree
Au-198	2.8E-04	2.8E-04	2.7E-04	1.1E-04	1.5E-04	2.6E-03	2.1E-03	1.7E-04	2.8E-04	1.5E-04	2.7E-04	8.0E-05	6.9E-05
Tl-201	4.5E-05	2.9E-05	3.0E-05	3.9E-05	1.6E-05	5.8E-05	1.6E-04	2.7E-04	1.8E-04	1.3E-05	4.9E-05	9.2E-05	2.1E-05
Pb-210	3.0E-05	1.2E-04	8.0E-05	1.6E-05	8.8E-05	2.8E-05	4.9E-04	9.8E-06	9.8E-06	2.0E-06	1.0E-05	7.3E-05	1.8E-05
Pb-212	6.9E-03	2.5E-02	2.1E-02	3.4E-03	2.0E-02	6.3E-03	1.3E-01	2.1E-03	2.7E-03	6.8E-04	2.8E-03	1.6E-02	3.8E-03
Bi-213	5.9E-03	2.3E-02	1.9E-02	3.0E-03	1.9E-02	5.8E-03	1.3E-01	1.8E-03	1.9E-03	3.9E-04	2.0E-03	1.5E-02	3.4E-03
Po-210	3.2E-03	3.1E-04	3.1E-04	3.2E-04	3.1E-04	8.7E-03	7.9E-02	2.8E-03	2.8E-03	3.1E-04	4.0E-03	1.0E-02	2.3E-03
At-211	1.6E-02	6.1E-03	1.2E-02	1.6E-02	1.2E-02	5.5E-03	5.5E-03	1.6E-02	1.6E-02	7.0E-03	1.6E-02	3.3E-05	5.5E-03
Rn-222	9.0E-04	9.1E-04	9.1E-04	3.2E-04	3.5E-04	3.4E-04	3.5E-04	1.8E-04	8.6E-04	3.5E-04	8.3E-04	3.2E-04	2.7E-04
Ra-223	6.9E-03	6.7E-03	6.7E-03	5.6E-03	6.7E-03	2.8E-02	1.1E-01	6.8E-03	6.9E-03	7.3E-03	6.9E-03	5.0E-02	1.8E-03
Ra-226	6.9E-03	6.8E-03	6.8E-03	5.5E-03	6.2E-03	2.5E-02	9.9E-02	6.3E-03	6.8E-03	6.9E-03	6.8E-03	4.5E-02	1.9E-03
Ac-225	1.7E-04	1.6E-03	9.2E-04	1.0E-04	8.5E-04	2.5E-02	6.0E-02	4.3E-05	1.2E-04	1.5E-03	4.4E-04	9.7E-03	2.4E-04
Th-227	5.9E-05	3.6E-04	2.2E-04	3.2E-05	1.9E-04	5.4E-03	1.3E-02	1.4E-05	4.8E-05	3.3E-04	1.2E-04	2.1E-03	5.9E-05
Th-230	1.1E-05	2.5E-04	1.4E-04	1.1E-05	1.4E-04	4.3E-03	1.0E-02	3.7E-06	3.8E-06	2.5E-04	5.9E-05	1.6E-03	3.4E-05
Th-232	9.1E-06	2.1E-04	1.2E-04	9.0E-06	1.2E-04	3.7E-03	8.8E-03	3.1E-06	3.2E-06	2.1E-04	5.0E-05	1.4E-03	2.9E-05
Th-234	1.1E-05	1.5E-05	1.2E-05	4.8E-06	6.3E-06	6.9E-05	1.0E-04	2.3E-06	1.1E-05	8.1E-06	1.1E-05	2.9E-05	4.4E-06
U-234	1.5E-04	9.4E-04	2.9E-04	3.5E-05	2.9E-04	3.6E-03	2.5E-02	1.5E-04	1.5E-04	9.4E-04	1.5E-04	1.7E-03	1.8E-04
U-235	2.1E-04	9.4E-04	3.3E-04	6.1E-05	3.0E-04	3.3E-03	2.3E-02	1.5E-04	2.0E-04	9.0E-04	1.9E-04	1.6E-03	1.9E-04
U-238	1.3E-04	8.1E-04	2.5E-04	3.0E-05	2.5E-04	3.1E-03	2.2E-02	1.3E-04	1.3E-04	8.1E-04	1.2E-04	1.5E-03	1.6E-04
Np-237	3.7E-03	4.9E-03	2.8E-03	8.6E-04	2.8E-03	4.5E-03	2.7E-02	1.5E-02	1.5E-02	1.5E-02	1.5E-02	6.2E-03	1.8E-04
Pu-238	4.5E-04	9.8E-04	8.2E-04	7.3E-05	8.2E-04	5.2E-04	4.1E-03	4.5E-04	4.5E-04	3.8E-03	3.7E-04	2.2E-03	2.2E-03
Pu-239	4.2E-04	9.2E-04	7.7E-04	6.9E-05	7.7E-04	4.9E-04	3.9E-03	4.2E-04	4.2E-04	3.6E-03	3.5E-04	2.1E-03	2.1E-03
Pu-240	4.2E-04	9.2E-04	7.7E-04	6.9E-05	7.7E-04	4.9E-04	3.9E-03	4.2E-04	4.2E-04	3.6E-03	3.5E-04	2.1E-03	2.1E-03
Pu-241	1.1E-07	2.5E-07	2.1E-07	1.9E-08	2.0E-07	1.3E-07	1.1E-06	1.1E-07	1.1E-07	9.7E-07	9.3E-08	5.6E-07	5.6E-07
Pu-242	4.0E-04	8.6E-04	7.2E-04	6.4E-05	7.2E-04	4.6E-04	3.7E-03	4.0E-04	4.0E-04	3.4E-03	3.2E-04	2.0E-03	2.0E-03
Am-241	4.3E-03	5.6E-03	3.2E-03	9.9E-04	3.2E-03	3.2E-03	3.1E-02	7.6E-04	7.7E-04	4.6E-03	2.0E-03	8.6E-04	8.6E-04
Am-242	1.9E-05	2.3E-05	1.4E-05	5.4E-06	1.2E-05	1.3E-05	9.7E-05	3.6E-06	6.7E-06	1.7E-05	1.1E-05	5.0E-06	4.9E-06
Am-243	4.2E-03	5.5E-03	3.1E-03	9.8E-04	3.1E-03	3.2E-03	3.0E-02	7.5E-04	8.1E-04	4.4E-03	2.0E-03	8.6E-04	8.6E-04
Cm-242	4.7E-03	6.2E-03	4.8E-03	1.1E-03	4.8E-03	1.8E-05	3.5E-02	1.9E-02	1.9E-02	1.9E-02	1.9E-02	7.9E-03	3.3E-04
Cm-243	4.5E-03	6.0E-03	4.6E-03	1.0E-03	4.6E-03	4.0E-05	3.3E-02	1.8E-02	1.8E-02	1.8E-02	1.8E-02	7.5E-03	3.3E-04
Cm-244	4.4E-03	5.9E-03	4.5E-03	1.0E-03	4.5E-03	1.7E-05	3.3E-02	1.8E-02	1.8E-02	1.8E-02	1.8E-02	7.4E-03	3.1E-04

*Dose factor calculated using Ar-Kr-Xe Dose Calculator tool [A.6]
nc: not calculated. Unable to calculate dose factors due to lack of data in the relevant dose tools.

Table A.8. Dose rate factors (DPUC) for exposure of marine reference organisms to radionuclides in seawater, µGy/h per Bq/l

Radio-nuclide	Benthic fish	Bird	Crusta-cean	Macro-algae	Mammal	Mollusc - bivalve	Pelagic fish	Phyto-plankto n	Polychaete worm	Reptile	Sea anemones & true coral	Vascular plant	Zoo-plankton
H-3	8.3E-06	8.3E-06	8.3E-06	8.2E-06	8.3E-06	8.3E-06	8.3E-06	8.2E-06	8.3E-06	8.3E-06	8.3E-06	8.3E-06	8.3E-06
H-3 org.	1.4E-02	1.4E-02	1.2E-02	1.1E-02	1.4E-02	5.4E-03	1.4E-02	2.1E-03	8.3E-02	1.4E-02	1.4E-02	1.1E-02	8.3E-02
C-14	5.0E-02	5.0E-02	4.1E-02	3.8E-02	5.0E-02	1.9E-02	5.0E-02	6.9E-03	2.9E-01	5.0E-02	4.9E-02	3.7E-02	2.9E-01
Na-22	1.9E-02	1.4E-01	1.4E-02	1.4E-02	1.7E-01	8.2E-03	2.1E-02	1.9E-03	2.5E-02	3.7E-01	3.0E-02	2.2E-03	1.5E-02
Na-24	4.0E-02	2.7E-01	2.9E-02	3.0E-02	3.0E-01	1.9E-02	4.3E-02	3.1E-03	5.8E-02	6.5E-01	6.8E-02	4.9E-03	2.7E-02
P-32	3.8E+01	1.5E+01	3.9E+01	2.9E+00	1.5E+01	7.2E+00	3.9E+01	1.9E+00	8.8E+00	1.5E+01	3.2E+01	3.6E+00	4.6E+00
P-33	4.4E+00	1.7E+00	4.4E+00	4.3E-01	1.7E+00	9.0E-01	4.4E+00	1.3E+00	1.2E+00	1.7E+00	4.4E+00	4.4E-01	1.0E+00
S-35	2.9E-05	4.4E-05	5.7E-05	8.7E-05	4.4E-05	9.3E-05	2.9E-05	2.6E-05	5.2E-05	4.4E-05	9.3E-05	8.8E-05	3.0E-05
Cl-36	9.9E-06	1.0E-05	9.8E-06	1.3E-04	9.3E-06	1.0E-05	1.1E-05	1.5E-04	8.7E-06	9.3E-06	1.4E-05	1.3E-04	3.8E-05
Ca-45	3.9E-04	7.4E-03	4.8E-04	3.4E-04	7.4E-03	1.6E-04	3.7E-04	7.4E-03	1.5E-04	7.4E-03	4.4E-03	1.9E-04	3.0E-03
Ca-47	2.0E-01	1.1E-01	2.0E-01	2.2E-01	1.7E-01	2.1E-01	6.0E-03	5.6E-02	4.3E-01	1.7E-01	2.7E-01	2.1E-01	3.2E-02
V-48	6.2E+02	2.7E-01	6.0E+02	6.6E+02	8.5E-01	6.5E+02	8.9E-03	4.2E-02	1.3E+03	8.3E-01	6.6E+02	6.5E+02	1.6E+00
Cr-51	4.1E-01	2.0E-02	4.0E-01	4.9E-01	3.7E-02	4.5E-01	1.9E-03	3.5E-02	9.0E-01	3.6E-02	4.6E-01	4.8E-01	7.2E-03
Mn-52	1.8E+03	1.4E+00	1.8E+03	1.9E+03	4.9E+00	1.9E+03	6.2E-01	9.8E-02	3.9E+03	4.8E+00	2.0E+03	1.9E+03	1.2E-01
Mn-54	4.4E+02	3.3E-01	4.3E+02	4.7E+02	1.2E+00	4.7E+02	1.5E-01	2.7E-02	9.4E+02	1.2E+00	4.7E+02	4.6E+02	2.4E-02
Fe-55	2.3E+00	3.7E-02	3.0E+00	7.3E+00	3.7E-02	9.4E+00	2.1E-02	2.7E-02	2.2E+01	3.7E-02	1.9E+01	8.2E+00	2.0E-02
Fe-59	9.5E+04	7.0E-01	9.2E+04	1.0E+05	1.9E+00	1.0E+05	3.4E-01	1.8E-01	2.0E+05	1.8E+00	1.0E+05	1.0E+05	1.6E-01
Co-56	2.9E+02	1.6E-01	2.8E+02	3.1E+02	5.4E-01	3.0E+02	1.3E+00	6.0E-02	6.1E+02	5.3E-01	3.1E+02	3.0E+02	2.4E-01
Co-57	9.6E+00	1.9E-02	9.3E+00	1.0E+01	3.7E-02	1.0E+01	1.9E-01	8.3E-02	2.1E+01	3.7E-02	1.0E+01	1.0E+01	1.4E-01
Co-58	7.7E+01	5.2E-02	7.5E+01	8.2E+01	1.7E-01	8.1E+01	4.4E-01	5.6E-02	1.7E+02	1.6E-01	8.3E+01	8.1E+01	1.2E-01
Co-60	2.0E+02	1.2E-01	2.0E+02	2.1E+02	3.9E-01	2.1E+02	1.0E+00	1.4E-01	4.2E+02	3.9E-01	2.1E+02	2.1E+02	2.7E-01
Ni-63	3.1E-03	6.1E-03	1.6E-02	1.2E-02	6.1E-03	7.9E-02	3.1E-03	6.9E-03	5.2E-02	6.1E-03	7.9E-02	1.2E-02	6.1E-03
Cu-61	2.1E+01	6.2E+00	8.6E+01	1.8E+01	1.1E+01	3.2E+01	5.7E+00	4.3E-01	3.8E+01	1.1E+01	2.1E+01	1.7E+01	1.2E+01
Cu-64	5.6E+00	2.2E+00	3.0E+01	4.0E+00	3.4E+00	9.8E+00	2.1E+00	4.1E-01	9.5E+00	3.4E+00	5.7E+00	3.9E+00	6.5E+00
Zn-62	4.9E+01	2.2E+01	2.8E+02	4.0E+01	3.2E+01	8.7E+01	2.1E+01	6.9E-01	8.6E+01	3.1E+01	5.1E+01	3.4E+01	2.3E+01
Zn-65	1.2E+01	1.4E+00	2.5E+01	1.1E+01	4.6E+00	1.3E+01	1.1E+00	9.7E-02	2.3E+01	4.5E+00	1.2E+01	1.1E+01	1.1E+00
Ga-67	1.3E-02	3.9E-02	1.6E-02	2.9E-02	7.6E-02	4.2E-02	1.3E-03	2.8E-02	5.5E-02	7.5E-02	4.1E-02	2.9E-02	5.9E-01

Radio-nuclide	Benthic fish	Bird	Crusta-cean	Macro-algae	Mammal	Mollusc - bivalve	Pelagic fish	Phyto-plankton	Polychaete worm	Reptile	Sea anemones & true coral	Vascular plant	Zoo-plankton
Se-75	3.3E-01	4.3E-01	7.6E-01	3.4E-01	1.3E+00	3.7E-01	2.9E-02	5.0E-02	7.6E-01	1.3E+00	3.3E-01	3.3E-01	1.6E-02
Br-76	5.0E-03	1.7E-03	2.2E-02	1.2E+00	1.6E-03	3.2E+00	6.0E-03	3.5E-02	2.9E+00	1.6E-03	2.4E+00	9.9E-03	3.6E-01
Br-77	3.6E-04	1.8E-04	1.5E-03	7.5E-02	1.6E-04	1.7E-01	4.6E-04	9.8E-03	1.5E-01	1.6E-04	1.4E-01	5.7E-04	3.8E-02
Br-82	2.6E-03	1.5E-03	1.1E-02	4.9E-01	1.3E-03	1.1E+00	3.5E-03	5.5E-02	1.0E+00	1.3E-03	8.9E-01	4.0E-03	2.5E-01
Rb-81	6.6E-01	8.3E-02	6.3E-01	7.3E-01	7.3E-02	7.0E-01	1.3E-02	8.6E-04	1.4E+00	1.6E-01	7.5E-01	6.9E-01	1.2E-02
Rb-83	5.3E-01	4.5E-02	5.1E-01	5.7E-01	4.8E-02	5.6E-01	7.2E-03	6.9E-04	1.1E+00	1.0E-01	5.8E-01	5.5E-01	6.7E-03
Sr-83	5.2E-03	2.6E-02	9.2E-03	4.8E-03	5.7E-02	1.8E-02	3.9E-03	6.9E-03	3.7E-03	5.6E-02	1.1E-02	2.3E-03	5.0E-03
Sr-85	2.1E-03	9.2E-03	3.5E-03	1.8E-03	3.0E-02	4.4E-03	1.3E-03	1.5E-03	2.3E-03	2.9E-02	2.7E-03	1.3E-03	9.4E-04
Sr-89	8.1E-03	5.4E-02	1.6E-02	8.0E-03	5.4E-02	4.7E-02	8.3E-03	1.1E-02	4.9E-04	5.4E-02	2.7E-02	1.0E-03	1.2E-02
Sr-90	1.5E-02	1.0E-01	3.1E-02	1.5E-02	1.1E-01	8.7E-02	1.6E-02	2.2E-02	1.1E-03	1.1E-01	4.8E-02	2.1E-03	2.0E-02
Y-90	2.2E+01	4.4E-02	1.0E+01	8.1E+01	4.6E-02	3.5E+01	4.4E-02	1.7E+00	9.7E+01	4.6E-02	6.6E+01	3.1E+01	4.2E+00
Zr-89	6.1E+02	1.4E-02	5.9E+02	6.6E+02	3.7E-02	6.5E+02	1.2E-02	6.9E-01	1.3E+03	3.6E-02	6.6E+02	6.5E+02	1.0E+00
Zr-95	3.9E+02	1.1E-02	3.8E+02	4.2E+02	2.6E-02	4.1E+02	9.8E-03	1.7E+00	8.4E+02	2.6E-02	4.2E+02	4.1E+02	1.4E+00
Nb-95	1.6E+02	7.8E-02	1.6E+02	1.7E+02	2.4E-01	1.7E+02	2.6E-03	2.5E-02	3.4E+02	2.3E-01	1.7E+02	1.7E+02	5.6E-01
Mo-99	1.8E-01	2.3E-01	1.9E-01	3.2E-01	2.9E-01	3.9E-01	7.7E-03	7.4E-02	6.0E-01	2.9E-01	4.0E-01	3.0E-01	3.3E+00
Tc-99	4.6E-03	1.0E+00	1.0E+00	3.1E+00	1.0E+00	4.8E-01	4.6E-03	2.5E-04	1.0E+00	1.0E+00	9.8E-01	3.1E+00	5.6E-03
Tc-99m	4.9E-03	4.1E-01	3.8E-01	7.8E-01	1.0E+00	1.3E-01	1.7E-03	1.3E-04	2.5E-01	1.0E+00	2.4E-01	8.1E-01	1.3E-03
Ru-103	5.0E+00	1.9E-01	4.8E+00	5.4E+00	3.6E-01	5.3E+00	3.1E-03	4.0E-01	1.1E+01	3.6E-01	5.4E+00	5.3E+00	2.0E+00
Ru-106	4.4E+00	1.3E+00	3.3E+00	9.5E+00	1.4E+00	6.7E+00	2.3E-02	4.0E-01	1.5E+01	1.4E+00	9.0E+00	6.2E+00	6.1E+00
Ag-110m	9.5E+00	5.7E+00	1.5E+01	8.1E+00	2.0E+01	1.1E+01	2.3E+00	2.1E+00	1.8E+01	1.9E+01	8.0E+00	7.9E+00	2.9E-01
In-111	5.2E+00	1.5E-01	5.0E+00	5.7E+00	3.9E-01	5.6E+00	2.2E-02	2.3E-01	1.1E+01	3.8E-01	5.7E+00	5.6E+00	1.5E-01
Sb-125	2.7E-01	8.6E-01	2.4E-01	2.6E-01	1.7E+00	2.7E-01	5.6E-02	4.9E-02	8.0E-01	1.7E+00	2.5E-01	2.6E-01	8.0E-02
I-123	3.3E-03	1.1E-04	4.4E-03	1.1E-01	9.2E-05	2.4E-01	4.2E-04	1.9E-02	2.3E-01	9.3E-05	2.2E-01	4.0E-03	6.8E-02
I-124	2.2E-02	6.8E-04	2.7E-02	4.5E-01	6.0E-04	1.1E+00	2.2E-03	1.9E-02	1.0E+00	6.1E-04	9.1E-01	2.5E-02	1.7E-01
I-125	8.0E-04	3.5E-05	1.9E-03	1.2E-01	3.3E-05	2.5E-01	3.2E-04	2.2E-02	2.4E-01	3.3E-05	2.3E-01	1.3E-03	7.4E-02
I-129	8.0E-04	4.4E-05	2.3E-03	2.0E-01	4.2E-05	4.3E-01	4.8E-04	4.3E-02	4.2E-01	4.2E-05	4.2E-01	1.6E-03	1.4E-01
I-131	8.3E-03	2.9E-04	1.2E-02	4.8E-01	2.5E-04	1.1E+00	1.4E-03	6.1E-02	9.8E-01	2.6E-04	9.8E-01	1.0E-02	3.0E-01
I-133	1.4E-02	4.9E-04	2.2E-02	8.9E-01	4.4E-04	2.1E+00	2.8E-03	5.9E-02	2.0E+00	4.5E-04	1.9E+00	1.8E-02	5.0E-01
I-135	3.4E-02	1.1E-03	4.3E-02	9.1E-01	9.5E-04	2.1E+00	3.6E-03	6.1E-02	2.0E+00	9.5E-04	1.9E+00	3.9E-02	4.7E-01
Cs-134	1.7E+00	1.1E-01	1.6E+00	1.8E+00	1.3E-01	1.7E+00	1.7E-02	1.4E-03	3.5E+00	2.8E-01	1.8E+00	1.7E+00	1.2E-02

Radio-nuclide	Benthic fish	Bird	Crusta-cean	Macro-algae	Mammal	Mollusc - bivalve	Pelagic fish	Phyto-plankton	Polychaete worm	Reptile	Sea anemones & true coral	Vascular plant	Zoo-plankton
Cs-136	2.2E+00	1.2E-01	2.2E+00	2.5E+00	1.7E-01	2.4E+00	1.8E-02	1.8E-03	4.8E+00	3.6E-01	2.4E+00	2.4E+00	1.2E-02
Cs-137	6.1E-01	9.1E-02	5.9E-01	6.7E-01	7.3E-02	6.5E-01	1.5E-02	9.7E-04	1.3E+00	1.5E-01	6.9E-01	6.4E-01	1.6E-02
Ba-140	1.6E+00	1.2E-01	1.5E+00	1.7E+00	2.3E-01	1.7E+00	1.9E-02	3.3E-02	3.3E+00	2.2E-01	1.7E+00	1.6E+00	2.7E-02
La-140	7.5E+02	5.3E+00	7.2E+02	8.2E+02	1.1E+01	8.0E+02	4.8E+00	6.8E-01	1.6E+03	1.1E+01	8.2E+02	7.9E+02	2.1E+00
Ce-141	5.9E+01	2.5E-01	5.7E+01	6.9E+01	2.9E-01	6.6E+01	4.0E-02	7.8E-01	1.4E+02	2.9E-01	6.9E+01	6.5E+01	5.6E-01
Ce-144	1.7E+02	1.6E+00	9.8E+01	4.4E+02	1.7E+00	2.3E+02	2.8E-01	1.1E+00	6.0E+02	1.7E+00	4.1E+02	2.1E+02	1.5E+00
Pm-147	5.5E-02	8.0E-02	5.1E-02	5.1E-01	8.0E-02	2.3E-01	1.4E-02	3.6E-01	3.9E-01	8.0E-02	3.1E-01	1.4E-01	2.1E-01
Sm-153	4.7E+01	3.7E-01	4.4E+01	6.6E+01	4.2E-01	5.6E+01	6.5E-02	1.0E+00	1.2E+02	4.1E-01	6.3E+01	5.5E+01	8.5E-01
Eu-152	6.1E+02	3.8E+00	5.9E+02	6.5E+02	9.7E+00	6.5E+02	1.0E-01	5.0E-01	1.3E+03	9.7E+00	6.6E+02	6.4E+02	2.6E-01
Eu-154	6.6E+02	6.0E+00	6.5E+02	7.2E+02	1.2E+01	7.0E+02	1.8E-01	9.3E-01	1.4E+03	1.2E+01	7.2E+02	7.0E+02	5.3E-01
Eu-155	3.0E+01	1.1E+00	3.0E+01	3.4E+01	1.5E+00	3.4E+01	3.4E-02	4.4E-01	6.9E+01	1.5E+00	3.5E+01	3.3E+01	1.7E-01
Er-169	2.3E-01	1.4E-01	2.4E-01	2.2E+00	1.4E-01	8.9E-01	2.5E-02	5.9E-01	1.8E+00	1.4E-01	1.5E+00	6.6E-01	3.7E-01
Lu-177	2.8E+01	2.0E-01	2.7E+01	3.4E+01	2.2E-01	3.1E+01	3.5E-02	6.8E-01	6.4E+01	2.2E-01	3.3E+01	3.0E+01	4.8E-01
Re-188	3.7E-02	7.7E+00	7.6E+00	1.7E+01	8.1E+00	3.3E+00	3.5E-02	7.3E-04	6.6E+00	8.1E+00	6.1E+00	2.2E+01	2.0E-02
Au-198	1.1E+00	3.8E+00	4.8E+00	1.1E+01	5.7E+00	2.7E+00	1.7E-02	6.9E-04	5.6E+00	5.6E+00	4.3E+00	1.1E+01	1.5E-02
Tl-201	4.6E-01	2.4E-02	4.4E-01	5.0E-01	1.7E-02	5.0E-01	4.0E-03	3.7E-04	1.0E+00	3.6E-02	5.2E-01	5.0E-01	5.1E-03
Pb-210	8.5E+00	4.9E+00	5.5E+00	1.9E+00	4.9E+00	2.2E+00	8.2E+00	4.4E+01	1.2E+01	4.9E+00	8.9E+00	8.5E-01	3.2E+00
Pb-212	1.7E+03	9.6E+02	1.1E+03	1.0E+02	9.6E+02	3.7E+02	1.7E+03	2.4E+04	2.1E+03	9.6E+02	1.7E+03	1.0E+02	8.5E+02
Po-210	2.5E+03	2.4E+03	6.6E+03	8.6E+01	2.4E+03	2.0E+03	2.5E+03	1.6E+03	1.4E+04	2.4E+03	6.6E+03	8.7E+01	3.1E+03
At-211	3.5E-01	2.7E-02	1.5E+00	1.6E+02	2.7E-02	3.4E+02	3.5E-01	3.7E+01	3.4E+02	2.7E-02	3.4E+02	9.4E-01	1.2E+02
Ra-223	6.1E+00	6.9E+00	3.8E+00	4.1E+00	6.9E+00	2.9E+00	5.9E+00	4.8E+01	6.3E+00	6.9E+00	6.1E+00	4.0E+00	3.4E+00
Ra-226	2.0E+01	2.4E+01	1.3E+01	1.4E+01	2.3E+01	9.8E+00	1.9E+01	1.6E+02	2.1E+01	2.3E+01	2.0E+01	1.3E+01	1.1E+01
Ac-225	3.3E+02	2.7E+02	6.2E+03	9.0E+02	2.7E+02	4.1E+02	2.1E+02	1.2E+05	5.9E+02	2.7E+02	4.4E+02	8.7E+02	1.1E+03
Th-227	1.3E+02	5.7E+01	1.4E+03	2.4E+02	5.8E+01	1.5E+02	4.4E+01	2.5E+04	2.4E+02	5.8E+01	1.5E+02	2.4E+02	2.4E+02
Th-230	3.6E+01	4.6E+01	1.0E+03	1.2E+02	4.6E+01	4.7E+01	3.5E+01	2.0E+04	4.7E+01	4.6E+01	4.7E+01	1.2E+02	1.9E+02
Th-232	3.0E+01	3.9E+01	8.8E+02	1.1E+02	3.9E+01	4.0E+01	3.0E+01	1.7E+04	4.0E+01	3.9E+01	4.0E+01	1.1E+02	1.7E+02
Th-234	7.7E+01	8.5E-01	6.5E+01	2.4E+02	8.8E-01	1.1E+02	6.4E-01	6.7E+01	3.0E+02	8.8E-01	2.0E+02	1.0E+02	1.7E+00
U-234	2.5E-01	2.5E-01	1.0E-01	2.3E+00	2.5E-01	9.0E-01	2.5E-01	6.0E+00	2.8E+01	2.5E-01	2.8E+01	6.6E+00	1.0E-01
U-235	2.7E-01	2.3E-01	1.4E-01	2.2E+00	2.2E-01	8.7E-01	2.3E-01	5.6E+00	2.6E+01	2.2E-01	2.6E+01	6.1E+00	9.6E-02
U-238	2.1E-01	2.1E-01	8.7E-02	2.0E+00	2.1E-01	7.7E-01	2.1E-01	5.3E+00	2.4E+01	2.1E-01	2.4E+01	5.6E+00	8.9E-02
Np-237	2.5E-01	2.4E-01	1.1E-01	1.4E+00	2.4E-01	1.0E+01	2.4E-01	3.9E+00	1.0E+01	2.4E-01	1.1E-01	1.4E+00	4.7E-01

Radio-nuclide	Benthic fish	Bird	Crusta-cean	Macro-algae	Mammal	Mollusc - bivalve	Pelagic fish	Phyto-plankton	Polychaete worm	Reptile	Sea anemones & true coral	Vascular plant	Zoo-plankton
Pu-238	4.5E+01	1.3E+01	3.7E+00	1.3E+02	4.3E+01	3.5E+01	4.5E+01	4.0E+03	4.9E+01	4.3E+01	1.6E+01	1.3E+02	2.0E+02
Pu-239	4.2E+01	1.2E+01	3.5E+00	1.2E+02	4.0E+01	3.3E+01	4.2E+01	3.8E+03	4.6E+01	4.0E+01	1.5E+01	1.2E+02	1.9E+02
Pu-240	4.2E+01	1.2E+01	3.5E+00	1.2E+02	4.0E+01	3.3E+01	4.2E+01	3.8E+03	4.6E+01	4.0E+01	1.5E+01	1.2E+02	1.9E+02
Pu-241	1.1E-02	3.3E-03	9.8E-04	3.3E-02	1.1E-02	8.9E-03	1.1E-02	1.0E+00	1.2E-02	1.1E-02	4.0E-03	3.3E-02	5.1E-02
Pu-242	4.0E+01	1.2E+01	3.3E+00	1.1E+02	3.8E+01	3.1E+01	4.0E+01	3.6E+03	4.3E+01	3.8E+01	1.4E+01	1.1E+02	1.8E+02
Am-241	2.5E+01	1.3E+01	2.7E+01	2.9E+01	4.3E+01	3.2E+03	1.3E+01	6.6E+03	3.2E+03	4.3E+01	1.7E+01	2.9E+01	1.3E+02
Am-242	8.1E+00	4.6E-02	7.7E+00	1.4E+01	1.6E-01	2.1E+01	4.7E-02	1.4E+01	3.5E+01	1.6E-01	1.3E+01	1.0E+01	3.9E-01
Am-243	1.3E+02	1.3E+01	1.2E+02	1.4E+02	4.1E+01	3.2E+03	1.3E+01	6.4E+03	3.3E+03	4.1E+01	1.3E+02	1.4E+02	1.2E+02
Cm-242	4.9E+01	1.4E+01	1.8E+01	4.2E+02	4.7E+01	1.1E+03	4.9E+01	9.5E+03	1.1E+03	4.7E+01	2.2E+00	4.2E+02	2.2E+02
Cm-243	1.1E+02	1.4E+01	8.1E+01	4.8E+02	4.5E+01	1.1E+03	4.6E+01	9.1E+03	1.2E+03	4.5E+01	7.7E+01	4.7E+02	2.1E+02
Cm-244	4.6E+01	1.4E+01	1.7E+01	4.0E+02	4.4E+01	1.1E+03	4.6E+01	9.0E+03	1.1E+03	4.4E+01	2.1E+00	4.0E+02	2.1E+02
Sc-47*	1.4E+02	8.9E-03	1.4E+02	1.6E+02	1.1E-02	1.6E+02	8.6E-03	2.0E+00	3.2E+02	1.1E-02	1.6E+02	1.5E+02	1.8E+00
Cu-62*	3.9E+01	2.0E+01	2.5E+02	3.1E+01	2.7E+01	7.5E+01	1.9E+01	4.9E-01	6.7E+01	2.6E+01	4.1E+01	2.5E+01	2.0E+01
Te-123*	1.2E-02	1.2E-01	1.7E-02	9.0E-03	1.5E-01	2.0E-02	9.5E-03	1.1E-01	5.4E-02	1.5E-01	5.2E-03	8.9E-03	8.5E-03
Te-125m*	6.3E-02	7.2E-01	9.0E-02	4.2E-02	7.7E-01	1.3E-01	5.8E-02	9.2E-01	3.7E-01	7.7E-01	1.0E-02	4.2E-02	7.4E-02
Sm-147*	5.1E+00	2.9E+01	1.3E+00	2.7E+01	2.9E+01	2.9E+01	5.1E+00	1.4E+02	2.9E+01	2.9E+01	1.7E+00	2.1E+00	7.8E+01
Gd-152*	4.8E+00	2.7E+01	1.2E+00	2.6E+01	2.7E+01	2.7E+01	4.8E+00	1.4E+02	2.7E+01	2.7E+01	1.6E+00	2.0E+00	7.4E+01
Pb-211*	4.8E+00	6.5E-01	3.9E+00	8.6E+00	6.5E-01	5.1E+00	1.1E+00	1.6E+01	1.4E+01	6.5E-01	8.2E+00	4.7E+00	5.8E-01
Bi-212*	1.5E+03	8.6E+02	9.9E+02	9.2E+01	8.7E+02	3.3E+02	1.5E+03	2.2E+04	1.9E+03	8.7E+02	1.5E+03	8.8E+01	7.7E+02
Ra-228*	5.7E-01	6.3E-02	5.3E-01	6.1E-01	9.9E-02	5.8E-01	5.1E-02	1.5E-01	1.2E+00	9.9E-02	6.2E-01	5.8E-01	1.8E-02
Pa-231*	5.2E+01	1.4E+01	4.8E+01	6.1E+01	1.4E+01	7.2E+01	1.4E+00	2.9E+01	1.3E+02	1.4E+01	7.6E+01	6.0E+01	2.9E+01
U-233*	2.4E-01	2.4E-01	1.0E-01	2.3E+00	2.4E-01	8.9E-01	2.4E-01	6.1E+00	2.8E+01	2.4E-01	2.8E+01	6.5E+00	1.0E-01
U-236*	2.3E-01	2.3E-01	9.4E-02	2.2E+00	2.3E-01	8.3E-01	2.3E-01	5.7E+00	2.6E+01	2.3E-01	2.6E+01	6.1E+00	9.7E-02

*These radionuclides are only considered as radioactive progeny of parent radionuclides. Their dose contribution is added to that of the parent.

Table A.9. Dose rate factors (DPUC) for exposure of freshwater reference organisms to radionuclides in river water, µGy/h per Bq/l

Radio-nuclide	Amphi-bian	Benthic fish	Bird	Crusta-cean	Insect larvae	Mammal	Mollusc - bivalve	Mollusc - gastropod	Pelagic fish	Phyto-plankton	Reptile	Vascular plant	Zoo-plankton
H-3	8.3E-06	8.3E-06	8.3E-06	8.3E-06	8.3E-06	8.3E-06	8.3E-06	8.3E-06	8.3E-06	8.2E-06	8.2E-06	8.3E-06	8.3E-06
H-3 org.	1.5E+00	1.5E+00	1.5E+00	1.5E+00	1.5E+00	1.5E+00	1.5E+00	1.5E+00	1.5E+00	3.3E-02	1.5E+00	7.3E-02	1.5E+00
C-14	5.1E+00	5.3E+00	5.3E+00	5.1E+00	5.1E+00	5.3E+00	5.1E+00	5.1E+00	5.3E+00	1.1E-01	5.3E+00	2.4E-01	5.0E+00
Na-22	6.3E-01	9.2E-01	6.4E-01	1.6E-01	1.8E-01	8.3E-01	2.3E-02	1.8E-02	8.8E-01	1.0E-02	1.1E+00	3.1E-02	7.8E-03
Na-24	1.4E+00	1.8E+00	1.3E+00	2.3E-01	2.6E-01	1.6E+00	5.2E-02	4.1E-02	1.8E+00	1.1E-02	2.2E+00	6.2E-02	9.7E-03
P-32	2.5E+02	2.6E+02	2.6E+02	7.2E+00	7.8E+00	2.6E+02	2.3E+01	2.0E+01	2.6E+02	7.5E-02	2.6E+02	2.6E-01	4.4E+00
P-33	3.0E+01	3.0E+01	3.0E+01	2.5E+00	2.5E+00	3.0E+01	2.7E+00	2.7E+00	3.0E+01	5.2E-02	3.0E+01	5.4E-02	2.4E+00
S-35	7.0E-03	7.0E-03	7.0E-03	6.8E-03	6.9E-03	7.0E-03	7.0E-03	7.0E-03	7.0E-03	5.5E-03	7.0E-03	5.7E-03	6.7E-03
Cl-36	2.0E-01	2.0E-01	2.0E-01	1.4E-01	1.4E-01	2.0E-01	2.0E-01	1.9E-01	2.0E-01	1.7E-02	2.0E-01	3.1E-02	1.0E-01
Ca-45	5.5E-02	6.5E-02	2.5E-02	3.0E-02	5.0E-03	1.8E-02	3.3E-02	3.3E-02	6.4E-02	9.5E-03	2.3E-02	1.3E-02	1.7E-03
Ca-47	7.1E-01	1.4E+00	3.7E-01	8.2E-01	1.1E+00	2.9E-01	8.9E-01	8.8E-01	9.4E-01	7.2E-02	7.4E-01	6.6E-01	1.5E-02
V-48	6.5E-01	8.4E-02	1.3E+00	1.5E-01	2.3E-01	1.8E+00	2.5E-01	1.9E-01	1.1E-02	1.5E-01	1.3E+00	3.3E-01	4.8E-02
Cr-51	5.4E-04	1.6E-01	2.0E-04	1.9E-01	3.8E-01	1.5E-02	1.8E-01	1.9E-01	1.9E-03	2.6E-03	1.7E-01	1.9E-01	9.3E-03
Mn-52	9.2E-02	7.0E+01	2.3E-01	7.9E+01	1.6E+02	1.5E-01	7.6E+01	7.8E+01	8.0E-01	7.2E-03	6.9E+01	7.9E+01	3.5E-01
Mn-54	2.1E-02	1.7E+01	5.5E-02	1.9E+01	3.8E+01	3.6E-02	1.9E+01	1.9E+01	1.9E-01	1.9E-03	1.7E+01	1.9E+01	8.6E-02
Fe-55	6.1E-03	2.4E-02	6.1E-03	3.0E-02	8.8E-02	2.8E-03	9.2E-02	9.2E-02	2.4E-02	1.5E-03	6.1E-03	4.1E-02	8.6E-02
Fe-59	6.9E-02	1.9E+00	1.2E-01	2.0E+00	4.1E+00	6.8E-02	2.8E+00	2.6E+00	4.2E-01	1.0E-02	1.6E+00	2.0E+00	5.9E-01
Co-56	3.5E-02	4.0E+01	2.3E-01	4.6E+01	9.3E+01	1.1E-01	4.4E+01	4.5E+01	6.9E-02	1.4E-02	4.0E+01	4.6E+01	4.4E-02
Co-57	7.3E-03	1.3E+00	2.7E-02	1.6E+00	3.2E+00	1.1E-02	1.5E+00	1.5E+00	8.9E-03	1.7E-02	1.3E+00	1.6E+00	5.1E-02
Co-58	1.2E-02	1.1E+01	7.3E-02	1.2E+01	2.5E+01	3.4E-02	1.2E+01	1.2E+01	2.2E-02	1.2E-02	1.1E+01	1.2E+01	3.6E-02
Co-60	2.7E-02	2.9E+01	1.7E-01	3.1E+01	6.2E+01	7.8E-02	3.1E+01	3.1E+01	5.0E-02	3.1E-02	2.8E+01	3.1E+01	9.0E-02
Ni-63	2.5E-03	2.5E-03	2.5E-03	2.3E-02	2.3E-02	2.5E-03	2.7E-03	2.7E-03	2.5E-03	6.4E-03	1.2E-02	6.7E-03	2.2E-02
Cu-61	1.4E-01	2.0E+00	3.7E-01	1.8E+00	2.0E+00	4.6E-01	2.6E-01	2.5E-01	1.9E+00	1.9E-01	5.8E+00	2.0E-01	1.1E+00
Cu-64	5.6E-02	7.2E-01	1.3E-01	1.1E+00	1.2E+00	1.6E-01	8.4E-02	8.2E-02	6.9E-01	1.8E-01	2.1E+00	6.4E-02	9.2E-01
Zn-62	5.1E-01	6.9E+00	1.3E+00	3.0E+00	3.5E+00	1.5E+00	7.7E-01	6.9E-01	6.6E+00	3.0E-01	2.0E+01	4.9E-01	1.7E+00
Zn-65	1.8E-02	4.8E-01	8.2E-02	2.9E-01	3.7E-01	1.2E-01	1.0E-01	9.5E-02	3.9E-01	4.3E-02	1.3E+00	9.0E-02	2.0E-01
Ga-67	1.5E-01	1.3E-02	1.9E-01	4.1E-02	5.5E-02	2.2E-01	4.7E-02	4.4E-02	1.5E-03	1.0E-01	2.0E-01	1.2E-01	2.7E-02
Se-75	7.0E-02	5.1E-01	5.5E-04	4.7E-01	9.7E-01	1.8E-01	5.2E-01	5.1E-01	1.2E-01	4.7E-04	5.1E-01	4.6E-01	7.7E-02
Br-76	1.3E-01	1.7E+00	2.4E-02	2.1E+00	4.3E+00	2.2E-01	1.8E+00	1.9E+00	1.7E-01	3.8E-03	1.7E+00	2.1E+00	5.6E-03

Radio-nuclide	Amphi-bian	Benthic fish	Bird	Crusta-cean	Insect larvae	Mammal	Mollusc - bivalve	Mollusc - gastropod	Pelagic fish	Phyto-plankton	Reptile	Vascular plant	Zoo-plankton
Br-77	6.8E-03	1.9E-01	1.7E-03	2.1E-01	4.2E-01	1.7E-02	2.0E-01	2.1E-01	1.2E-02	7.3E-04	1.9E-01	2.1E-01	1.1E-03
Br-82	4.6E-02	1.6E+00	1.3E-02	1.8E+00	3.5E+00	1.3E-01	1.7E+00	1.7E+00	8.5E-02	4.6E-03	1.6E+00	1.8E+00	6.7E-03
Rb-81	5.2E-01	5.0E+00	3.9E-01	5.9E+00	1.2E+01	4.5E-01	4.9E+00	5.2E+00	5.6E-01	7.6E-03	5.1E+00	5.8E+00	5.7E-03
Rb-83	2.5E-01	3.9E+00	2.1E-01	4.3E+00	8.5E+00	2.6E-01	3.9E+00	4.1E+00	3.0E-01	7.0E-03	3.9E+00	4.2E+00	4.5E-03
Sr-83	1.3E+00	3.7E-01	1.2E+00	3.4E-01	7.9E-01	2.3E+00	3.1E-01	3.2E-01	1.3E-01	4.7E-03	2.1E+00	3.1E-01	1.5E-01
Sr-85	2.8E-01	2.0E-01	4.0E-01	1.8E-01	3.8E-01	9.1E-01	1.8E-01	1.8E-01	4.3E-02	1.1E-03	7.7E-01	1.8E-01	2.6E-02
Sr-89	3.7E+00	2.9E-01	2.4E+00	2.3E-01	7.0E-01	3.9E+00	1.6E-01	1.6E-01	2.8E-01	7.4E-03	3.9E+00	1.3E-01	2.8E-01
Sr-90	7.0E+00	5.5E-01	4.6E+00	4.4E-01	1.3E+00	7.6E+00	3.1E-01	3.2E-01	5.4E-01	1.5E-02	7.5E+00	2.7E-01	5.2E-01
Y-90	5.9E-01	4.9E-01	1.6E-02	3.2E-01	5.3E-01	6.4E-01	5.0E-01	4.6E-01	4.8E-01	9.2E-02	6.5E-01	1.9E-01	6.8E-02
Zr-89	1.1E-01	4.3E-01	5.3E-03	3.8E-01	7.3E-01	2.5E-01	4.1E-01	4.0E-01	1.4E-01	3.7E-02	4.8E-01	3.5E-01	2.5E-02
Zr-95	1.0E-01	3.0E-01	4.3E-03	2.7E-01	4.9E-01	2.0E-01	2.9E-01	2.8E-01	1.1E-01	8.9E-02	3.4E-01	2.3E-01	5.3E-02
Nb-95	1.9E-01	2.2E-02	3.8E-01	4.7E-02	6.9E-02	5.2E-01	7.0E-02	5.6E-02	3.0E-03	9.4E-02	3.8E-01	1.2E-01	2.5E-02
Mo-99	1.0E+00	8.3E-01	1.1E+00	1.7E+00	3.3E+00	1.2E+00	1.2E+00	1.3E+00	8.4E-03	2.8E-01	1.9E+00	2.0E+00	8.6E-02
Tc-99	5.7E-03	5.7E-03	5.7E-03	5.3E-03	5.3E-03	5.7E-03	5.7E-03	5.7E-03	5.7E-03	1.9E-03	5.8E-03	2.1E-03	5.0E-03
Tc-99m	1.6E-03	2.5E-03	2.4E-03	1.4E-03	1.5E-03	3.1E-03	1.8E-03	1.6E-03	2.3E-03	5.3E-04	2.5E-03	6.9E-04	1.2E-03
Ru-103	8.4E-03	3.7E+00	1.2E-02	4.5E+00	9.0E+00	1.4E-02	4.2E+00	4.3E+00	1.1E-02	7.6E-02	3.7E+00	4.6E+00	6.6E-03
Ru-106	7.1E-02	2.5E+00	8.1E-02	1.3E+01	2.6E+01	8.4E-02	3.6E+00	6.3E+00	8.0E-02	7.6E-02	2.5E+00	1.2E+01	8.5E-03
Ag-110m	1.7E-01	1.9E+02	3.9E-01	2.2E+02	4.3E+02	5.6E-01	2.1E+02	2.2E+02	1.0E-01	2.2E-02	1.9E+02	2.2E+02	7.0E-01
In-111	6.6E-03	4.8E+00	2.9E-01	5.9E+00	1.2E+01	1.5E-02	5.5E+00	5.7E+00	1.1E-02	1.8E-01	4.9E+00	5.9E+00	2.3E-02
Sb-125	1.7E-01	5.3E-01	2.4E-01	6.6E-01	1.3E+00	2.9E-01	5.8E-01	6.0E-01	3.6E-03	4.3E-03	7.6E-01	6.5E-01	4.5E-03
I-123	9.1E-03	1.9E-01	1.7E-03	2.2E-01	4.4E-01	1.6E-02	2.0E-01	2.1E-01	1.3E-02	1.2E-03	1.9E-01	2.2E-01	1.8E-03
I-124	4.3E-02	1.3E+00	8.4E-03	1.6E+00	3.1E+00	7.9E-02	1.3E+00	1.4E+00	6.1E-02	1.8E-03	1.3E+00	1.5E+00	2.7E-03
I-125	9.3E-03	3.6E-02	1.5E-03	5.5E-02	1.1E-01	1.3E-02	4.0E-02	4.8E-02	1.1E-02	1.3E-03	3.6E-02	5.4E-02	2.1E-03
I-129	1.6E-02	3.3E-02	2.1E-03	3.7E-02	7.0E-02	1.8E-02	2.8E-02	3.3E-02	1.7E-02	2.5E-03	3.3E-02	3.5E-02	3.8E-03
I-131	3.8E-02	4.6E-01	5.7E-03	5.6E-01	1.1E+00	5.1E-02	4.7E-01	4.9E-01	4.5E-02	3.7E-03	4.6E-01	5.5E-01	6.2E-03
I-133	7.7E-02	7.7E-01	1.1E-02	1.0E+00	2.1E+00	9.9E-02	7.7E-01	8.3E-01	9.0E-02	3.9E-03	7.6E-01	1.0E+00	6.9E-03
I-135	7.9E-02	2.0E+00	1.4E-02	2.3E+00	4.6E+00	1.3E-01	2.0E+00	2.1E+00	1.0E-01	4.5E-03	2.0E+00	2.3E+00	7.6E-03
Cs-134	5.1E-01	1.2E+01	5.0E-01	1.3E+01	2.7E+01	6.3E-01	1.2E+01	1.3E+01	7.1E-01	8.1E-03	1.2E+01	1.3E+01	6.1E-03
Cs-136	5.3E-01	1.7E+01	5.7E-01	1.9E+01	3.8E+01	7.7E-01	1.7E+01	1.7E+01	7.8E-01	1.0E-02	1.7E+01	1.9E+01	7.3E-03
Cs-137	5.9E-01	4.7E+00	4.3E-01	5.5E+00	1.1E+01	4.8E-01	4.5E+00	4.8E+00	6.1E-01	9.9E-03	4.8E+00	5.4E+00	7.2E-03
Ba-140	1.0E-01	1.6E+00	2.6E+00	2.2E+00	4.2E+00	1.5E-01	2.3E+00	2.3E+00	1.3E-01	1.0E-02	1.6E+00	2.0E+00	2.4E-01

Radio-nuclide	Amphi-bian	Benthic fish	Bird	Crusta-cean	Insect larvae	Mammal	Mollusc - bivalve	Mollusc - gastropod	Pelagic fish	Phyto-plankton	Reptile	Vascular plant	Zoo-plankton
La-140	8.2E-02	3.6E+01	1.1E-01	4.6E+01	9.1E+01	1.3E-01	4.0E+01	4.1E+01	6.0E-02	5.5E-02	3.6E+01	4.5E+01	2.2E-01
Ce-141	1.7E-02	4.1E+00	5.0E-01	6.7E+00	1.3E+01	1.9E-02	4.7E+00	5.1E+00	1.9E-02	6.2E-01	4.2E+00	7.1E+00	7.9E-02
Ce-144	1.1E-01	6.9E+00	3.2E+00	6.8E+01	1.3E+02	1.2E-01	1.3E+01	2.6E+01	1.2E-01	8.6E-01	7.1E+00	5.6E+01	1.2E-01
Pm-147	6.2E-03	6.3E-03	1.6E-01	4.0E-02	4.5E-02	6.2E-03	3.8E-02	3.8E-02	6.2E-03	2.9E-01	2.3E-02	3.6E-02	3.5E-02
Sm-153	2.8E-02	1.3E+00	7.5E-01	3.5E+00	6.7E+00	3.0E-02	1.7E+00	2.0E+00	2.9E-02	8.2E-01	1.4E+00	3.6E+00	1.1E-01
Eu-152	5.7E-01	1.6E-01	9.6E-01	2.6E-01	4.2E-01	1.2E+00	3.1E-01	2.9E-01	1.1E-02	1.1E-02	1.1E+00	1.8E-01	7.6E-02
Eu-154	1.1E+00	1.8E-01	1.5E+00	3.7E-01	5.5E-01	1.8E+00	4.7E-01	4.3E-01	1.7E-02	2.0E-02	1.7E+00	2.2E-01	1.4E-01
Eu-155	2.5E-01	1.0E-02	2.8E-01	7.1E-02	7.8E-02	3.0E-01	7.3E-02	7.1E-02	3.2E-03	9.4E-03	2.9E-01	1.9E-02	6.1E-02
Er-169	1.1E-02	2.5E-02	2.9E-01	7.4E-01	1.3E+00	1.1E-02	1.0E-01	1.5E-01	1.1E-02	4.7E-01	5.6E-02	9.6E-01	5.7E-02
Lu-177	1.5E-02	1.9E+00	4.0E-01	3.8E+00	7.2E+00	1.6E-02	2.3E+00	2.5E+00	1.5E-02	5.4E-01	2.0E+00	4.2E+00	6.8E-02
Re-188	4.1E-02	5.3E-02	4.4E-02	9.0E-02	1.6E-01	4.5E-02	5.5E-02	6.1E-02	4.4E-02	3.0E-03	5.3E-02	7.0E-02	8.4E-03
Au-198	1.9E-02	2.7E+01	2.2E-02	4.2E+01	8.3E+01	2.4E-02	3.0E+01	3.3E+01	2.2E-02	3.0E-03	2.7E+01	4.1E+01	8.5E-03
Tl-201	1.7E-01	5.9E-01	1.1E-01	6.1E-01	1.2E+00	1.2E-01	4.9E-01	5.2E-01	1.6E-01	5.3E-03	6.2E-01	5.5E-01	3.4E-03
Pb-210	1.3E-03	1.1E-01	6.2E-02	1.4E+00	2.3E+00	1.1E-01	1.5E+00	1.5E+00	9.3E-02	1.5E-01	1.3E-01	5.3E-01	8.8E-01
Pb-212	2.7E-01	2.3E+01	1.2E+01	4.2E+02	4.2E+02	2.2E+01	3.0E+02	3.0E+02	1.8E+01	7.9E+01	2.7E+01	2.1E+01	4.1E+02
Po-210	6.3E+01	6.3E+01	6.3E+01	2.6E+02	3.8E+03	6.3E+01	3.8E+03	3.8E+03	6.3E+01	4.9E+01	1.1E+02	5.0E+01	3.8E+03
At-211	1.2E+01	1.3E+01	1.5E+00	3.3E+00	3.4E+00	1.2E+01	3.3E+00	3.3E+00	1.2E+01	2.1E+00	1.3E+01	2.2E+00	3.3E+00
Ra-223	2.7E+02	8.1E+00	2.7E+02	1.3E+01	1.0E+03	9.0E-03	1.0E+03	1.0E+03	7.6E+00	2.3E+01	3.3E+01	4.8E+01	1.0E+03
Ra-226	8.5E+02	2.9E+01	9.0E+02	4.2E+01	3.4E+03	3.1E-02	3.3E+03	3.3E+03	2.6E+01	7.6E+01	1.1E+02	1.6E+02	3.3E+03
Ac-225	5.1E+02	1.2E+02	5.1E+02	1.1E+02	4.2E+02	5.1E+02	1.7E+03	1.7E+03	1.1E+02	1.9E+03	1.7E+02	1.6E+04	8.5E+01
Th-227	1.1E+02	2.9E+01	1.1E+02	2.6E+01	9.6E+01	1.1E+02	3.6E+02	3.6E+02	2.4E+01	4.0E+02	4.0E+01	3.3E+03	1.8E+01
Th-230	8.7E+01	1.9E+01	8.7E+01	1.6E+01	6.8E+01	8.7E+01	2.8E+02	2.8E+02	1.9E+01	3.2E+02	2.8E+01	2.6E+03	1.5E+01
Th-232	7.4E+01	1.6E+01	7.4E+01	1.4E+01	5.8E+01	7.4E+01	2.4E+02	2.4E+02	1.6E+01	2.7E+02	2.4E+01	2.2E+03	1.2E+01
Th-234	1.5E+00	3.1E+00	1.6E+00	3.6E+01	7.1E+01	1.6E+00	9.7E+00	1.5E+01	3.6E-01	1.1E+00	3.3E+00	5.1E+01	6.2E-02
U-234	3.3E+00	2.0E+00	1.5E+00	5.6E+00	5.6E+00	3.3E+00	1.6E+01	1.6E+01	2.0E+00	1.9E+00	3.2E+00	1.0E+01	5.6E+00
U-235	3.0E+00	1.9E+00	1.4E+00	5.2E+00	5.2E+00	3.0E+00	1.4E+01	1.4E+01	1.9E+00	1.8E+00	3.0E+00	9.7E+00	5.2E+00
U-238	2.8E+00	1.7E+00	1.3E+00	4.8E+00	4.8E+00	2.8E+00	1.3E+01	1.3E+01	1.7E+00	1.7E+00	2.8E+00	8.9E+00	4.8E+00
Np-237	3.2E+00	2.0E+00	1.4E+00	5.5E+00	5.5E+00	3.2E+00	1.5E+01	1.5E+01	2.0E+00	1.9E+00	3.2E+00	6.2E+00	5.5E+00
Pu-238	1.5E+02	2.7E+01	9.3E+01	1.9E+01	8.0E+01	1.5E+02	1.8E+02	1.8E+02	2.7E+01	1.9E+02	1.9E+02	3.4E+01	1.7E+01
Pu-239	1.4E+02	2.5E+01	8.7E+01	1.8E+01	7.5E+01	1.4E+02	1.6E+02	1.6E+02	2.5E+01	1.8E+02	1.8E+02	3.2E+01	1.6E+01
Pu-240	1.4E+02	2.5E+01	8.7E+01	1.8E+01	7.5E+01	1.4E+02	1.6E+02	1.6E+02	2.5E+01	1.8E+02	1.8E+02	3.2E+01	1.6E+01
Pu-241	3.7E-02	6.8E-03	2.3E-02	5.0E-03	2.1E-02	3.7E-02	4.4E-02	4.4E-02	6.7E-03	4.8E-02	4.8E-02	9.1E-03	4.3E-03

Radio-nuclide	Amphi-bian	Benthic fish	Bird	Crusta-cean	Insect larvae	Mammal	Mollusc - bivalve	Mollusc - gastropod	Pelagic fish	Phyto-plankton	Reptile	Vascular plant	Zoo-plankton
Pu-242	1.3E+02	2.4E+01	8.2E+01	1.7E+01	7.1E+01	1.3E+02	1.5E+02	1.5E+02	2.4E+01	1.7E+02	1.7E+02	3.0E+01	1.5E+01
Am-241	1.0E+02	2.5E+01	1.0E+02	3.3E+02	5.8E+01	1.0E+02	3.3E+02	3.3E+02	2.4E+01	4.3E+01	1.0E+02	4.4E+01	5.5E+01
Am-242	3.5E-01	5.2E-01	3.6E-01	2.9E+00	3.9E+00	3.6E-01	1.7E+00	1.9E+00	8.5E-02	9.1E-02	8.1E-01	2.3E+00	1.3E-01
Am-243	9.8E+01	3.0E+01	9.9E+01	3.3E+02	7.1E+01	9.9E+01	3.3E+02	3.3E+02	2.3E+01	4.1E+01	1.0E+02	5.0E+01	5.3E+01
Cm-242	2.7E+00	2.9E+01	2.7E+00	8.8E+00	8.8E+00	2.7E+00	6.0E-01	6.0E-01	2.9E+01	2.1E+02	2.7E+00	8.3E-02	8.8E+00
Cm-243	2.6E+00	2.8E+01	2.5E+00	8.6E+00	8.8E+00	2.5E+00	7.4E-01	7.5E-01	2.8E+01	2.0E+02	2.7E+00	2.9E-01	8.3E+00
Cm-244	2.5E+00	2.7E+01	2.5E+00	8.3E+00	8.3E+00	2.5E+00	5.6E-01	5.6E-01	2.7E+01	2.0E+02	2.6E+00	7.8E-02	8.3E+00

Appendix B: Dose coefficients for internal exposures of the public

B.1 Introduction

Dose factors are used in the assessment of the dose that a person may receive resulting from exposure by a pathway (external radiation or internal exposure by ingestion or inhalation of radionuclides) to a quantity of radiation. For the purposes of assessing dose to a representative person, the weighted sum of doses to individual organs and tissues, expressed as effective dose, is the assessed parameter. Effective doses can arise from internal and external exposure to radiation and the quantity can be summed to provide an estimate of the combined radiation exposure.

This appendix presents ingestion and inhalation dose coefficients for people of various age groups which are used in the calculation of doses from internal exposure to radionuclides. The routes of intake for each release are described in Appendices D-G. The dose coefficients used for intake by ingestion or inhalation are presented in this Appendix.

Dose factors for external radiation are dependent on the size and geometry of the radiation source and the type and energy of the radiation, which is dependant on the radionuclide and the particular exposure scenario. External dose factors are presented in relation to each release scenario and the environmental exposure in Appendices D – G.

Radionuclides taken into the body, either by ingestion or inhalation, can cause exposure of organs and tissues. For internal exposure, the dose delivered depends on many factors, including the solubility of the radionuclide and its half life, distribution characteristics and retention in the body. The values of the effective dose coefficients for intakes by inhalation and ingestion used in IRAT2 take into account these factors and use the most recent values published for the public by the International Commission on Radiological Protection (ICRP) [B.1]. They represent the lifetime dose (i.e. the committed effective dose) which would be incurred by an individual following the intake of a unit amount of a radionuclide. Since biokinetic behaviour and body mass (and hence dose incurred) change with age, different values are presented depending on the age of the individual at the time of intake. The age groups considered in IRAT2 are those proposed in the dose principles guidance [B.2] - 1 year olds, 10 year old children and adults >18 years and to unborn children (offspring).

In determining the effective dose arising from ingestion of material containing radionuclides, the fractions of those radionuclides that are absorbed across the wall of the gastrointestinal tract is taken into account. Such absorption is referred to as the gut uptake factor and varies with the physical and chemical form of the radionuclide and with the metabolism and physiology of the individual. Gut uptake factors and the resulting ingestion dose coefficients in IRAT2 are taken from ICRP [B.1].

The effective dose following intake of a radionuclide by inhalation depends upon a number of factors in addition to the radioactive properties of the radionuclide involved. These include the particle size of the inhaled material and the rate at which deposited material can be absorbed into body fluids from the respiratory tract. Inhalation provides two possible uptake routes – one via transfer across the lung into the blood, and one via clearance and then transfer into the stomach and gut where it may be digested and absorbed into the blood. ICRP has derived a standard classification for inhaled material, based on the lung absorption type. Several values are generally cited for each radionuclide, reflecting the range of absorption types that may be encountered. However, for most radionuclides ICRP recommends a default absorption type, which may be assumed in the absence of specific information about absorption behaviour. These default ICRP absorption types have been used in IRAT2. Where no default is specified, the absorption type producing the highest value of dose per unit intake has been taken.

B.2 Dose coefficients for *in utero* exposure of offspring (fetus)

Dose coefficients for assessing effective dose to the embryo and fetus following intake of radionuclides by the mother were issued by the ICRP [B.3]. The Health Protection Agency (HPA) (now UK Health Security Agency) published guidance on the application of these dose factors for the control of exposures of members of the public in the UK for fetal doses using the simplified fetal assessment [B.4]. The term offspring has been applied here to collectively represent the embryo, fetus and newborn child. The HPA advised that for many radionuclides, dose coefficients for the embryo, fetus and newborn child (offspring) are lower than for other age groups (infant, child and adult). Therefore assessments made for these other age groups will represent offspring. However, for 14 radionuclides, the offspring dose co-efficients are higher than other age groups and in these cases, offspring doses have been calculated. The 14 radionuclides are tritium (H-3), organically bound tritium (OBT), carbon-14 (C-14), sodium-22 (Na-22), phosphorus-32 (P-32), phosphorus-33 (P-33), sulphur-35 (S-35), calcium-45 (Ca-45), calcium-47 (Ca-47), selenium-75 (Se-75), strontium-89 (Sr-89), strontium-90 (Sr-90), iodine-131 (I-131) and radium-226 (Ra-226).

B.3 Dose coefficient for rubidium-82 (Rb-82)

ICRP [B.1] does not list dose coefficients for rubidium-82 (Rb-82). Due to its very short half-life of 1.3 minutes, ingestion pathways do not need to be considered for this radionuclide and ICRP does not present any ingestion dose coefficients for Rb-82. Dose coefficients for inhalation of Rb-82 have been derived for the purpose of this study assuming that the only organ or tissue irradiated is the lung, since its half-life is too short for significant translocation to occur to other tissues and organs.

Inhalation dose coefficients for Rb-82 were calculated using the following method and data. The absorbed dose to the respiratory system, *D*, is given by:

$$D = \varepsilon/M$$

where ε is the total energy imparted to the respiratory system and M is the mass of the respiratory system.

The total energy imparted to the respiratory system was derived assuming that for every 1 Bq of Rb-82 inhaled approximately 0.6 Bq will be deposited and 0.4 Bq will be exhaled within a few seconds, without significant decay. The exact partitioning between deposition and exhalation depends to a limited degree on aerosol size. It was then assumed that the 0.6 Bq deposited will decay *in situ*. Taking the decay constant of Rb-82 as 0.00886 per second, this results in a total of 67.72 transformations. From ICRP [B.5], each transformation of Rb-82 results in the emission of 1.11 MeV of photon energy (mainly annihilation radiation) and 1.41 MeV of capture electron radiation. The latter will be locally absorbed in the respiratory system, whereas much of the former will be lost from the respiratory system, and even from the body as a whole. Cautiously assuming that 1.5 MeV are deposited in the respiratory system per transformation and using a conversion factor of 1.6E-13 J per MeV, the total energy deposited in the respiratory system per Bq intake is estimated as 1.63E-11 J.

As the radiation has a low Linear Energy Transfer (LET) and, in adult man, the respiratory system has a mass of 1 kg [B.6], the associated equivalent organ dose is 1.63E-11 Sv. As the respiratory system is by far the most highly irradiated organ or tissue, the effective dose is the equivalent dose multiplied by the respiratory system weighting factor of 0.12 [B.7]. Therefore the equivalent organ dose of 1.63E-11 Sv is multiplied by the weighting factor of 0.12 to give an effective dose of 1.96E-12 Sv, rounded here to 2.0E-12 Sv per Bq intake by inhalation. For children and infants, larger values of 4.0E-12 and 1.5E-11 Sv per Bq were calculated. These values were derived by scaling, taking account of the smaller mass of the respiratory system in children and infants (0.5 kg and 0.13 kg, respectively, see ICRP Publication 23, Table 65 [B.6]).

B.4 Dose coefficient for radon-222 (Rn-222)

ICRP does not provide dose coefficients for radon-222 (Rn-222). Rn-222 inhalation dose coefficients have previously been derived using recommended epidemiological data and using simplifying assumptions to allow for age group scaling.

The dose coefficients used in the IRAT for Rn-222 has been updated from those used previously to take account of the most recent advice from ICRP [B.8]. This recommends an increase in the nominal mortality probability coefficient for Rn-222 from 8E-05 per mJ h/m^3 to 1.4E-04 per mJ h/m^3 (equivalent to 8E-10 per Bq h/m^3). In addition, ICRP has revised its recommended health detriment per unit effective dose from 0.073 to 0.057 per Sv, implying a dose factor of 1.40E-08 Sv per Bq h/m^3. Using an adult breathing rate of 1.2 m^3/h under conditions of light exercise [B.6], this corresponds to 1.2E-08 Sv per Bq intake.

The dose from Rn-222 and its progeny is approximately independent of age for a specified concentration in air, with the lower mass of the respiratory system in children and infants compensated by their lower breathing rates. In order to achieve this age independence, the effective dose per unit intake has to scale as the inverse of the mass of the respiratory system. The average mass of male and female lungs is 1030, 523 and 173 g for adults, children and infants respectively [B.6]. Thus, values of 1.2E-08, 2.3E-08 and 7.0E-08 Sv per Bq are adopted for adults, children and infants.

ICRP does not provide ingestion dose coefficients for Rn-222 because it is a gas and so ingestion doses are not relevant.

It should be noted that the approaches to estimate inhalation dose coefficients for Rb-82 and Rn-222 taken here are simplified, but are deemed appropriate for use in this study.

B.5 Dose coefficients for public

Table B.1 lists the dose per unit intake factors for inhalation. Table B.2 lists the dose per unit intake factors for ingestion.

B.6 References

B.1 ICRP (2012). Compendium of Dose Coefficients based on ICRP Publication 60. ICRP Publication 119, Ann. ICRP 41(Suppl.).

B2. Environment Agency, Scottish Environment Protection Agency, Northern Ireland Environment Agency, Health Protection Agency and Food Standards Agency (2012). Principles for the Assessment of Prospective Public Doses arising from Authorised Discharges of Radioactive Waste to the Environment Radioactive Substances Regulation under the Radioactive Substances Act (RSA-93) or under the Environmental Permitting Regulations (EPR-10).

B.3 ICRP (2001). Doses to the Embryo and Fetus from Intakes of Radionuclides by the Mother. ICRP Publication 88. Ann ICRP 31 (1–3).

B.4 HPA (2008) Guidance on the application of dose coefficients for the embryo, fetus, and breastfed infants in dose assessments for members of the public. RCE-5.

B.5 ICRP (2008). Nuclear Decay Data for Dosimetric Calculations. ICRP Publication 107. Annals of the ICRP 38 (3).

B.6 ICRP (1975). Report of the Task Group on Reference Man, ICRP Publication 23.

B.7 ICRP (2007). The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103, Annals of the ICRP 37 (2 – 4).

B.8 ICRP (2010). Lung Cancer Risk from Radon and Progeny and Statement on Radon. ICRP Publication 115, Ann. ICRP 40(1).

Table B.1. Dose coefficients for intake by inhalation by humans

Radionuclide	Absor. type*	Dose per unit intake by inhalation (Sv/Bq)			
		Offspring$	Infant	Child	Adult
H-3~	V	3.1E-11	4.8E-11	2.3E-11	1.8E-11
H-3 organic	V	6.3E-11	1.1E-10	5.5E-11	4.1E-11
C-11	M		1.1E-10	3.2E-11	1.8E-11
C-14	M	6.6E-11	6.6E-09	2.8E-09	2.0E-09
F-18	S		3.1E-10	1.0E-10	5.9E-11
Na-22	F	1.2E-09	7.3E-09	2.4E-09	1.3E-09
Na-24	F		1.8E-09	5.7E-10	2.7E-10
P-32	M	6.5E-09	1.5E-08	5.3E-09	3.4E-09
P-33	M	1.2E-09	4.6E-09	2.1E-09	1.5E-09
S-35	M	1.5E-11	4.5E-09	2.0E-09	1.4E-09
Cl-36	M		2.6E-08	1.0E-08	7.3E-09
Ca-45	M	1.7E-09	8.8E-09	3.9E-09	2.7E-09
Ca-47	M	1.0E-09	7.7E-09	2.9E-09	1.9E-09
V-48	M		1.1E-08	4.3E-09	2.4E-09
Cr-51	S		2.1E-10	6.6E-11	3.7E-11
Mn-52	M		6.8E-09	2.4E-09	1.4E-09
Mn-54	M		6.2E-09	2.4E-09	1.5E-09
Mn-56	M		7.8E-10	2.4E-10	1.2E-10
Fe-55	M		1.4E-09	6.2E-10	3.8E-10
Fe-59	M		1.3E-08	5.5E-09	3.7E-09
Co-56	M		2.1E-08	7.4E-09	4.8E-09
Co-57	M		2.2E-09	8.5E-10	5.5E-10
Co-58	M		6.5E-09	2.4E-09	1.6E-09
Co-60	M		3.4E-08	1.5E-08	1.0E-08
Ni-63	M		1.9E-09	7.0E-10	4.8E-10
Cu-61	S		4.5E-10	1.4E-10	7.8E-11
Cu-64	S		5.7E-10	2.0E-10	1.2E-10
Zn-62	M		3.5E-09	1.0E-09	5.0E-10
Zn-65	M		6.5E-09	2.4E-09	1.6E-09
Ga-67	M		1.0E-09	3.6E-10	2.4E-10
Ga-68	M		3.1E-10	9.2E-11	4.9E-11
Se-75	F	1.1E-09	6.0E-09	2.5E-09	1.0E-09
Br-76	M		2.3E-09	7.5E-10	4.1E-10
Br-77	M		5.1E-10	1.6E-10	8.4E-11
Br-82	M		3.0E-09	1.1E-09	6.3E-10
Rb-81	F		2.5E-10	7.1E-11	3.4E-11
Rb-82^	F		1.5E-11	4.0E-12	2.0E-12
Rb-83	F		3.8E-09	1.3E-09	6.9E-10
Sr-83	M		1.9E-09	6.0E-10	3.1E-10
Sr-85	M		3.1E-09	1.2E-09	6.4E-10
Sr-89	M	2.1E-09	2.4E-08	9.1E-09	6.1E-09
Sr-90	M	8.8E-09	1.1E-07	5.1E-08	3.6E-08
Y-90	S		8.8E-09	2.7E-09	1.5E-09

Radionuclide	Absor. type*	Dose per unit intake by inhalation (Sv/Bq)			
		Offspring$	Infant	Child	Adult
Zr-89	M		2.8E-09	9.6E-10	5.2E-10
Zr-95	M		1.6E-08	6.8E-09	4.8E-09
Nb-95	M		5.2E-09	2.2E-09	1.5E-09
Mo-99	M		4.4E-09	1.5E-09	8.9E-10
Tc-94m	M		3.0E-10	8.8E-11	4.5E-11
Tc-99	M		1.3E-08	5.7E-09	4.0E-09
Tc-99m	M		9.9E-11	3.4E-11	1.9E-11
Ru-103	M		8.4E-09	3.5E-09	2.4E-09
Ru-106	M		1.1E-07	4.1E-08	2.8E-08
Ag-110m	M		2.8E-08	1.2E-08	7.6E-09
In-111	M		1.2E-09	4.1E-10	2.3E-10
In-113m	M		1.1E-10	3.6E-11	2.0E-11
Sb-125	M		1.6E-08	6.8E-09	4.8E-09
I-123	F		7.9E-10	1.8E-10	7.4E-11
I-124	F		4.5E-08	1.1E-08	4.4E-09
I-125	F		2.3E-08	1.1E-08	5.1E-09
I-129	F		8.6E-08	6.7E-08	3.6E-08
I-131	F	8.1E-09	7.2E-08	1.9E-08	7.4E-09
I-132	F		9.6E-10	2.2E-10	9.4E-11
I-133	F		1.8E-08	3.8E-09	1.5E-09
I-134	F		3.7E-10	9.7E-11	4.5E-11
I-135	F		3.7E-09	7.9E-10	3.2E-10
Cs-134	F		7.3E-09	5.3E-09	6.6E-09
Cs-136	F		5.2E-09	2.0E-09	1.2E-09
Cs-137	F		5.4E-09	3.7E-09	4.6E-09
Ba-140	M		2.0E-08	7.6E-09	5.1E-09
La-140	M		6.3E-09	2.0E-09	1.1E-09
Ce-141	M		1.1E-08	4.6E-09	3.2E-09
Ce-144	M		1.6E-07	5.5E-08	3.6E-08
Pm-147	M		1.8E-08	7.0E-09	5.0E-09
Sm-153	M		2.9E-09	1.0E-09	6.3E-10
Eu-152	M		1.0E-07	4.9E-08	4.2E-08
Eu-154	M		1.5E-07	6.5E-08	5.3E-08
Eu-155	M		2.3E-08	9.2E-09	6.9E-09
Er-169	M		3.5E-09	1.5E-09	1.0E-09
Lu-177	S		4.1E-09	1.7E-09	1.2E-09
Re-188	F		4.4E-09	1.0E-09	4.6E-10
Au-198	S		4.4E-09	1.4E-09	8.6E-10
Tl-201	F		3.3E-10	9.4E-11	4.4E-11
Pb-210	M		3.7E-06	1.5E-06	1.1E-06
Pb-212	M		4.6E-07	2.2E-07	1.7E-07
Bi-213	M		1.2E-07	4.4E-08	3.0E-08
Po-210	M		1.1E-05	4.6E-06	3.3E-06
At-211	M		3.7E-07	1.4E-07	1.1E-07
Rn-222^	G		7.0E-08	2.3E-08	1.2E-08
Ra-223	M		2.1E-05	9.9E-06	7.4E-06

Radionuclide	Absor. type*	Dose per unit intake by inhalation (Sv/Bq)			
		Offspring$	Infant	Child	Adult
Ra-226	M	9.9E-08	1.1E-05	4.9E-06	3.5E-06
Ac-225	S		2.3E-05	1.1E-05	8.5E-06
Th-227	S		3.0E-05	1.4E-05	1.0E-05
Th-230	S		3.5E-05	1.6E-05	1.4E-05
Th-232	S		5.0E-05	2.6E-05	2.5E-05
Th-234	S		3.1E-08	1.1E-08	7.7E-09
U-234	M		1.1E-05	4.8E-06	3.5E-06
U-235	M		1.0E-05	4.3E-06	3.1E-06
U-238	M		9.4E-06	4.0E-06	2.9E-06
Np-237	M		4.0E-05	2.2E-05	2.3E-05
Pu-238	M		7.4E-05	4.4E-05	4.6E-05
Pu-239	M		7.7E-05	4.8E-05	5.0E-05
Pu-240	M		7.7E-05	4.8E-05	5.0E-05
Pu-241	M		9.7E-07	8.3E-07	9.0E-07
Pu-242	M		7.3E-05	4.5E-05	4.8E-05
Am-241	M		6.9E-05	4.0E-05	4.2E-05
Am-242	M		5.9E-08	2.4E-08	1.7E-08
Am-243	M		6.8E-05	4.0E-05	4.1E-05
Cm-242	M		1.8E-05	7.3E-06	5.2E-06
Cm-243	M		6.1E-05	3.1E-05	3.1E-05
Cm-244	M		5.7E-05	2.7E-05	2.7E-05

*Absorption types for particulates are: F – fast, M – moderate, S – slow. V stands for vapour and G for gas.
~Assuming tritiated water
$The offspring dose coefficient includes contributions to the radiation dose delivered *in utero* to the embryo and fetus to birth and postnatally to the offspring from birth to age 70 years from activity retained in the tissues of the newborn child. Values taken from [B.4], adopting the simplified fetus assessment.
^Dose coefficients specifically derived.

Table B.2. Dose coefficients for intake by ingestion by humans

Radionuclide	Dose per unit intake by ingestion (Sv/Bq)			
	Offspring$	Infant	Child	Adult
H-3~	3.1E-11	4.8E-11	2.3E-11	1.8E-11
H-3 organic	6.3E-11	1.2E-10	5.7E-11	4.2E-11
C-11		1.5E-10	4.3E-11	2.4E-11
C-14	8.0E-10	1.6E-09	8.0E-10	5.8E-10
F-18		3.0E-10	9.1E-11	4.9E-11
Na-22	3.6E-09	1.5E-08	5.5E-09	3.2E-09
Na-24		2.3E-09	7.7E-10	4.3E-10
P-32	2.5E-08	1.9E-08	5.3E-09	2.4E-09
P-33	4.8E-09	1.8E-09	5.3E-10	2.4E-10
S-35	2.0E-10	8.7E-10	2.7E-10	1.3E-10
Cl-36		6.3E-09	1.9E-09	9.3E-10
Ca-45	8.7E-09	4.9E-09	1.8E-09	7.1E-10
Ca-47	7.7E-09	9.3E-09	3.0E-09	1.6E-09
V-48		1.1E-08	3.9E-09	2.0E-09
Cr-51		2.3E-10	7.8E-11	3.8E-11
Mn-52		8.8E-09	3.4E-09	1.8E-09
Mn-54		3.1E-09	1.3E-09	7.1E-10
Mn-56		1.7E-09	5.1E-10	2.5E-10
Fe-55		2.4E-09	1.1E-09	3.3E-10
Fe-59		1.3E-08	4.7E-09	1.8E-09
Co-56		1.5E-08	5.8E-09	2.5E-09
Co-57		1.6E-09	5.8E-10	2.1E-10
Co-58		4.4E-09	1.7E-09	7.4E-10
Co-60		2.7E-08	1.1E-08	3.4E-09
Ni-63		8.4E-10	2.8E-10	1.5E-10
Cu-61		7.5E-10	2.3E-10	1.2E-10
Cu-64		8.3E-10	2.5E-10	1.2E-10
Zn-62		6.5E-09	2.0E-09	9.4E-10
Zn-65		1.6E-08	6.4E-09	3.9E-09
Ga-67		1.2E-09	4.0E-10	1.9E-10
Ga-68		6.7E-10	2.0E-10	1.0E-10
Se-75	2.7E-09	1.3E-08	6.0E-09	2.6E-09
Br-76		2.7E-09	8.7E-10	4.6E-10
Br-77		4.4E-10	1.7E-10	9.6E-11
Br-82		2.6E-09	9.5E-10	5.4E-10
Rb-81		3.2E-10	1.0E-10	5.4E-11
Rb-82^		-	-	-
Rb-83		8.4E-09	3.2E-09	1.9E-09
Sr-83		2.7E-09	9.1E-10	4.9E-10
Sr-85		3.1E-09	1.5E-09	5.6E-10
Sr-89	1.2E-08	1.8E-08	5.8E-09	2.6E-09
Sr-90	4.3E-08	7.3E-08	6.0E-08	2.8E-08
Y-90		2.0E-08	5.9E-09	2.7E-09
Zr-89		4.5E-09	1.6E-09	7.9E-10

Radionuclide	Dose per unit intake by ingestion (Sv/Bq)			
	Offspring$	**Infant**	**Child**	**Adult**
Zr-95		5.6E-09	1.9E-09	9.5E-10
Nb-95		3.2E-09	1.1E-09	5.8E-10
Mo-99		3.5E-09	1.1E-09	6.0E-10
Tc-94m		6.5E-10	1.9E-10	1.0E-10
Tc-99		4.8E-09	1.3E-09	6.4E-10
Tc-99m		1.3E-10	4.3E-11	2.2E-11
Ru-103		4.6E-09	1.5E-09	7.3E-10
Ru-106		4.9E-08	1.5E-08	7.0E-09
Ag-110m		1.4E-08	5.2E-09	2.8E-09
In-111		1.7E-09	5.9E-10	2.9E-10
In-113m		1.8E-10	6.2E-11	2.8E-11
Sb-125		6.1E-09	2.1E-09	1.1E-09
I-123		1.9E-09	4.9E-10	2.1E-10
I-124		1.1E-07	3.1E-08	1.3E-08
I-125		5.7E-08	3.1E-08	1.5E-08
I-129		2.2E-07	1.9E-07	1.1E-07
I-131	2.3E-08	1.8E-07	5.2E-08	2.2E-08
I-132		2.4E-09	6.2E-10	2.9E-10
I-133		4.4E-08	1.0E-08	4.3E-09
I-134		7.5E-10	2.1E-10	1.1E-10
I-135		8.9E-09	2.2E-09	9.3E-10
Cs-134		1.6E-08	1.4E-08	1.9E-08
Cs-136		9.5E-09	4.4E-09	3.0E-09
Cs-137		1.2E-08	1.0E-08	1.3E-08
Ba-140		1.8E-08	5.8E-09	2.6E-09
La-140		1.3E-08	4.2E-09	2.0E-09
Ce-141		5.1E-09	1.5E-09	7.1E-10
Ce-144		3.9E-08	1.1E-08	5.2E-09
Pm-147		1.9E-09	5.7E-10	2.6E-10
Sm-153		5.4E-09	1.6E-09	7.4E-10
Eu-152		7.4E-09	2.6E-09	1.4E-09
Eu-154		1.2E-08	4.1E-09	2.0E-09
Eu-155		2.2E-09	6.8E-10	3.2E-10
Er-169		2.8E-09	8.2E-10	3.7E-10
Lu-177		3.9E-09	1.2E-09	5.3E-10
Re-188		1.1E-08	2.9E-09	1.4E-09
Au-198		7.2E-09	2.2E-09	1.0E-09
Tl-201		5.5E-10	1.8E-10	9.5E-11
Pb-210		3.6E-06	1.9E-06	6.9E-07
Pb-212		6.3E-08	2.0E-08	6.0E-09
Bi-213		1.4E-09	3.9E-10	2.0E-10
Po-210		8.8E-06	2.6E-06	1.2E-06
At-211		7.8E-08	2.3E-08	1.1E-08
Rn-222^		-	-	-
Ra-223		1.1E-06	4.5E-07	1.0E-07

Radionuclide	Dose per unit intake by ingestion (Sv/Bq)			
	Offspring$	Infant	Child	Adult
Ra-226	3.2E-07	9.6E-07	8.0E-07	2.8E-07
Ac-225		1.8E-07	5.4E-08	2.4E-08
Th-227		7.0E-08	2.3E-08	8.8E-09
Th-230		4.1E-07	2.4E-07	2.1E-07
Th-232		4.5E-07	2.9E-07	2.3E-07
Th-234		2.5E-08	7.4E-09	3.4E-09
U-234		1.3E-07	7.4E-08	4.9E-08
U-235		1.3E-07	7.1E-08	4.7E-08
U-238		1.2E-07	6.8E-08	4.5E-08
Np-237		2.1E-07	1.1E-07	1.1E-07
Pu-238		4.0E-07	2.4E-07	2.3E-07
Pu-239		4.2E-07	2.7E-07	2.5E-07
Pu-240		4.2E-07	2.7E-07	2.5E-07
Pu-241		5.7E-09	5.1E-09	4.8E-09
Pu-242		4.0E-07	2.6E-07	2.4E-07
Am-241		3.7E-07	2.2E-07	2.0E-07
Am-242		2.2E-09	6.4E-10	3.0E-10
Am-243		3.7E-07	2.2E-07	2.0E-07
Cm-242		7.6E-08	2.4E-08	1.2E-08
Cm-243		3.3E-07	1.6E-07	1.5E-07
Cm-244		2.9E-07	1.4E-07	1.2E-07

~Assuming tritiated water
$The offspring dose coefficient includes contributions to the radiation dose delivered *in utero* to the embryo and fetus to birth and postnatally to the offspring from birth to age 70 years from activity retained in the tissues of the newborn child. Values taken from [B.4], adopting the simplified fetus assessment.
^Ingestion not considered as a pathway.

Appendix C: Approach taken to fill gaps in radionuclide-specific data

C.1 Introduction

As explained in the main text, the majority of radionuclide-specific environmental distribution and transport data used in this study were taken from standard compilations of peer reviewed and published data sets. However, those compilations did not cover all the radionuclides of interest required in IRAT2. This appendix describes how additional data, not available in standard compilations, was obtained. The approach was based on a data selection protocol outlined in section C.2.

C.2 Data selection protocol

A hierarchy of preference was used in selecting parameter values for use in IRAT2 so as to ensure consistency in approach and clarity in the choice of data. The hierarchy, from most preferred to least preferred, was as follows:

1. Recent compilations of data of international standing (e.g. IAEA documents) with preference for field data where possible.
2. Existing data used in the PC-CREAM 08 application.
3. Other published compilations of data (e.g. the Swedish Nuclear Fuel and Waste Management Company, SKB).
4. Values for a chemically analogous element, for the same parameter
5. Values for the same element, but a different environment (where appropriate) scaled
6. Allometric relationships, e.g. transfer factors for cattle could be used to estimate transfer factors for sheep by taking differences in body mass into account [C.1, C.2]. Generally, where no specific transfer data were available for cow and sheep liver, the transfer factors to meat were used.
7. Scaling and extrapolation of data and one off analytical calculations.

It is noted that:

- Environmental distribution and transport data were not required for radionuclides with half-lives of less than 3 hours, because there would not be time for them to accumulate in environmental media. For these radionuclides, only the more immediate pathways of exposure were considered.
- For food exposure, the FARMLAND model from PC-CREAM 08 was used. The animal models for caesium and strontium are hard-wired into the PC-CREAM 08 FARMLAND model. Therefore it was not possible to extract the data for caesium and strontium and use the data as analogues for other elements.
- Organically bound tritium used values for carbon-14 for all environmental and food activity concentrations except:
    - In uptake into the terrestrial food chain for humans where values for tritium were used.

- In sewage sludge to land for which specific values for organically bound tritium were available.
- In irrigated terrestrial foods for which specific values for organically bound tritium were available.

Details on how these data gaps were filled are given in Tables C.1 – C.6.

C.3 References

C.1 Thorne, M C (2003). Estimation of animal transfer factors for radioactive isotopes of iodine, technetium, selenium and uranium. J. Environ. Radioactivity, 70, 3–20.

C.2 IAEA (1994). Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments. IAEA Technical Report Series No 364.

C.3 Coughtrey, P J, Jackson, D and Thorne, M C (1983). Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems, Volume 3, A A Balkema, Rotterdam.

C.4 ICRP (1979–81). Limits for Intakes of Radionuclides by Workers, ICRP Publication 30, Parts 1–3, Annals of the ICRP, 2 (3/4), 4 (3/4), 6 (2/3).

C.5 Coughtrey, P J and Thorne, M C (1983). Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems, Volume 1, A A Balkema, Rotterdam.

C.6 ATSDR (1992). Agency for Toxic Substances and Disease Registry, US Public Health Service, Toxicological Profile for Vanadium and Compounds.

Table C.1. Filling data gaps – radionuclide uptake by animals for human consumption

Biological half-lives in meat and liver		
Element	**Basis**	**Comment**
Sodium	Caesium used as analogue	Sodium is retained mainly in soft tissues and a single biological half-life applies to the majority of the material. The biological half-life is shorter than that for caesium [C.3].
Chlorine	Caesium used as analogue	Chloride is uniformly distributed throughout the body and retained with a single biological half-life that is somewhat shorter than that for caesium [C.3].
Calcium	Strontium used as analogue	These elements behave in a similar way in the body.
Vanadium	Niobium used as analogue	Based on a comparison of biokinetic models from ICRP Publication 30 [C.4].
Copper	Zinc used as an analogue	Similar transition metals.
Gallium	Niobium used as analogue	Based on a comparison of biokinetic models from ICRP Publication 30 [C.4].
Indium	Cerium used as analogue	From ICRP Publication 30 [C.4], indium is only poorly taken up from the gastrointestinal tract but is retained in the body and is accumulated in the liver. These properties are analogous to those of cerium.
Samarium	Cerium used as analogue	Lanthanide elements with similar biokinetic characteristics [C.5].
Erbium	Cerium used as analogue	Lanthanide elements with similar biokinetic characteristics [C.5].
Lutetium	Cerium used as analogue	Lanthanide elements with similar biokinetic characteristics [C.5].
Rhenium	Technetium used as analogue	Rhenium has similar geochemistry to technetium.
Gold	Technetium used as analogue	Both gold and technetium are rapidly excreted from the body [C.4].
Thallium	Caesium used as analogue	Similar biochemical properties.
Astatine	Iodine used as analogue	Both are halogens.
Actinium	Cerium used as analogue	Values for actinides in PC-CREAM 08 cannot be used so cerium taken as most similar available element.
Animal product transfer factors		
Element	**Basis**	**Comment**
Vanadium	Niobium used as analogue	Based on a comparison of biokinetic models from ICRP Publication 30 [C.4].

Copper	Zinc used as an analogue	Similar transition metals, more cautious than nickel
Samarium	Cerium used as analogue	Lanthanide elements with similar biokinetic characteristics [C.5].
Erbium	Cerium used as analogue	Lanthanide elements with similar biokinetic characteristics [C.5].
Lutetium	Cerium used as analogue	Lanthanide elements with similar biokinetic characteristics [C.5].
Rhenium	Technetium used as analogue	Rhenium has similar geochemistry to technetium.
Astatine	Iodine used as analogue	Both are halogens.

Table C.2. Filling data gaps– radionuclide uptake by plants in the human foodchain

Translocation in plants			
Element	**Basis**		**Comment**
Sodium	-	Mobile (m)	Sodium is a major nutritional element in plants and is highly mobile. Coughtrey *et al.* [C.3] noted that it is usually prudent to assume that both foliar-absorbed and root-absorbed sodium becomes uniformly distributed throughout all organs of the plant.
Calcium	Strontium used as analogue	Semi-mobile (s)	The environmental behaviour of these two elements is very similar.
Vanadium	Niobium used as analogue	Semi-mobile (s)	As for plant:soil concentration ratio.
Copper	Zinc used as analogue	Semi-mobile (s)	Similar transition metals.
Gallium	Niobium used as analogue	Semi-mobile (s)	Both are elements that are not considered to be essential for plants, but for which general metal transport processes could operate.
Indium	Niobium used as analogue	Semi-mobile (s)	Both are elements that are not considered to be essential for plants, but for which general metal transport processes could operate.
Rhenium	Technetium used as analogue	Mobile (m)	Both have similar geochemistry.
Lutetium	Cerium used as analogue	Immobile (i)	Both are lanthanides.
Astatine	Iodine used as analogue	Mobile (m)	Both are halogens.
Gold	Cerium used as analogue	Immobile (i)	Lack of other data.
Erbium	Cerium used as analogue	Immobile (i)	Both are lanthanides.
Samarium	Cerium used as analogue	Immobile (i)	Both are lanthanides.
Thallium	Cerium used as analogue	Mobile (m)	Lack of other data.
Plant:soil concentration ratios for pasture			
Element	**Basis**		**Comment**
Calcium	Strontium used as analogue		These elements behave in a similar way in biological tissue.
Vanadium	Niobium used as analogue		Both elements readily adsorb to sediment or soil and are not accumulated by most plants.

Samarium	Cerium used as analogue	Plant uptake of lanthanide elements is very similar [C.5].
Erbium	Cerium used as analogue	Plant uptake of lanthanide elements is very similar [C.5].
Rhenium	Technetium used as analogue	Rhenium has similar geochemistry to technetium.
Lutetium	Cerium used as analogue	Plant uptake of lanthanide elements is very similar [C.5].
Astatine	Iodine used as analogue	Both are halogens.
Plant:soil concentration ratios for green vegetables and root vegetables		
Element	**Basis**	**Comment**
Vanadium	Niobium used as analogue	Both elements readily adsorb to sediment or soil and are not accumulated by most plants.
Samarium	Cerium used as analogue	Plant uptake of lanthanide elements is very similar [C.5].
Erbium	Cerium used as analogue	Plant uptake of lanthanide elements is very similar [C.5].
Rhenium	Technitium used as analogue	Rhenium has similar geochemistry to technetium.
Lutetium	Cerium used as analogue	Plant uptake of lanthanide elements is very similar [C.5].
Thallium	Indium used as analogue	Although relatively mobile, thallium-201 has only a short half-life, so uptake by plants will be limited. This is similar to indium.
Astatine	Iodine used as analogue	Both are halogens.
Gallium	Indium used as analogue	Chemically analogous with indium, limited availability to plants.
Plant:soil concentration ratios for fruit		
Element	**Basis**	**Comment**
Vanadium	Niobium used as analogue	Both elements readily adsorb to sediment or soil and are not accumulated by most plants.
Gallium	Indium used as analogue	Chemically analogous with indium, limited availability to plants.
Samarium	Cerium used as analogue	Plant uptake of lanthanide elements is very similar [C.5].
Erbium	Cerium used as analogue	Plant uptake of lanthanide elements is very similar [C.5].
Rhenium	Technitium used as analogue	Rhenium has similar geochemistry to technetium.
Lutetium	Cerium used as analogue	Plant uptake of lanthanide elements is very similar [C.5].
Thallium	Indium used as analogue	Although relatively mobile, thallium-201 has only a short half-life, so uptake by plants will be limited. This is similar to indium.
Astatine	Iodine used as analogue	Both are halogens.

Table C.3. Filling data gaps – partitioning in sewage

Partitioning coefficient between effluent and sewage sludge		
Element	**Basis**	**Comment**
Barium	Strontium used as analogue	Both are alkaline earths with similar chemical characteristics.
Promethium	Cerium used as analogue	Particle interactions of lanthanides are very similar [C.5].
Europium	Cerium used as analogue	Particle interactions of lanthanides are very similar [C.5].
Erbium	Cerium used as analogue	Particle interactions of lanthanides are very similar [C.5].
Lutetium	Cerium used as analogue	Particle interactions of lanthanides are very similar [C.5].
Gold	Cerium used as analogue	Although gold can exhibit valance states of +1 and +3 in the environment, the +3 state is likely to be dominant, hence the analogy with cerium.
Thallium	Samarium used as analogue	Both have short half-lives.
Astatine	Iodine used as analogue	Both are halogens.

Table C.4. Filling data gaps – radionuclide transport in the marine environment

K_d values for saltwater sediments		
Element	**Basis**	**Comment**
Vanadium	Niobium used as analogue	Both elements readily adsorb to sediment.
Copper	Zinc used as analogue	Both elements are similar transition metals.
Bromine	Chlorine used as analogue	Both elements are halogens.
Rubidium	Caesium used as analogue	Both elements are alkali metals.
Erbium	Cerium used as analogue	Both elements are lanthanides. Particle interactions of lanthanides are very similar [C.5].
Lutetium	Cerium used as analogue	Both elements are lanthanides. Particle interactions of lanthanides are very similar [C.5].
Gold	Silver used as analogue	Based on chemical similarity.
Astatine	Iodine used as analogue	Both elements are halogens.
Gallium	Based on Gallium in soils	Limited data available.
Organically bound tritium	Carbon used as analogue	Both elements are major constituents of organic matter.
Bismuth	Lead used as analogue	Elements are adjacent in the periodic table.
Concentration ratios for saltwater fish, molluscs and crustaceans for human consumption		
Element	**Basis**	**Comment**
Organically bound tritium	Carbon used as analogue	A prudent approach is to assume that the metabolism of hydrogen in such compounds is closely related to that of carbon (as both elements are likely to be present) and to use the concentration factor for carbon-14 also for organic tritium. This is likely to be cautious, as metabolism of such compounds is likely to result in some of the organically bound tritium being lost as tritiated water and only a limited fraction being incorporated into well-retained biochemical components of organs and tissues, such as structural components.
Vanadium	Niobium used as analogue	Based on chemical analogy and environmental observations for vanadium [C.6].
Copper	Zinc used as analogue	Both elements are similar transition metals.

Lanthanum	Cerium used as analogue	Both elements are lanthanides. Biochemical and biokinetic behaviour of all the lanthanides is very similar [C.5].
Erbium	Cerium used as analogue	Both elements are lanthanides. Biochemical and biokinetic behaviour of all the lanthanides is very similar [C.5].
Lutetium	Cerium used as analogue	Both elements are lanthanides. Biochemical and biokinetic behaviour of all the lanthanides is very similar [C.5].
Rhenium	Technetium used as analogue	Both elements have similar geochemistry.
Astatine	Iodine used as analogue	Both elements are halogens.

Table C.5. Filling data gaps – radionuclide transport in freshwater

K_d values for freshwater sediments		
Element	**Basis**	**Comment**
Sodium	Saltwater value used	Limited data available.
Vanadium	Niobium used as analogue	Both elements readily adsorb to sediment.
Copper	Zinc used as analogue	Both elements are similar transition metals.
Gallium	Based on gallium in soils	Limited data available.
Rubidium	Caesium used as analogue.	Both elements are alkali metals
Yttrium	Zirconium used as analogue	Both elements are similar transition metals.
Indium	Saltwater value used	No good reason to make a distinction, but only limited data are readily available.
Erbium	Cerium used as analogue	Both elements are lanthanides. Particle interactions of lanthanides are very similar [C.5].
Lutetium	Cerium used as analogue	Both elements are lanthanides. Particle interactions of lanthanides are very similar [C.5].
Gold	Silver used as analogue	Based on chemical similarity.
Thallium	Saltwater value used	Limited data available.
Astatine	Iodine used as analogue	Both elements are halogens.
Actinium	Samarium used as analogue	Based on chemical similarity.
Organically bound trtium	Carbon used as analogue	Both elements are major constituents of organic matter.
Concentration ratios for freshwater fish for human consumption		
Element	**Basis**	**Comment**
Organically bound tritium	Carbon-14 used as analogue	A prudent approach is to assume that the metabolism of hydrogen in such compounds is closely related to that of carbon (as both elements are likely to be present) and to use the concentration factor for carbon-14 for organically bound tritium. This is likely to be cautious, as the metabolism of such compounds is likely to result in some of the tritium being lost as tritiated water and only a limited fraction being incorporated into well-retained biochemical components of organs and tissues, such as structural components.

Samarium	Promethium used as analogue	Both elements are lanthanides.
Lutetium	Promethium used as analogue	Both elements are lanthanides.
Rhenium	Technetium used as analogue	Both elements have similar geochemistry.

Table C.6. Filling data gaps – wildlife concentration ratios

Element	Basis (analogue used)	Comment
Actinium	Thorium	Both elements are actinides.
Astatine	Iodine	Both elements are halogens.
Gold	Technetium	Both gold and technetium are rapidly excreted from the body [C.4].
Bromine	Iodine	Both elements are halogens.
Copper	Zinc	Both elements are similar transition metals.
Erbium	Cerium	Both elements are lanthanides. Biochemical and biokinetic behaviour of all the lanthanides is very similar [C.5].
Iron	Manganese	Similar geochemistry and adjacent in the periodic table.
Gallium	Niobium	Same analogue as used for biological half-lives in meat and liver, and for translocation in plants.
Organically bound tritium	Carbon	Both elements are major constituents of organic matter.
Indium	Cerium	Same analogue as used for biological half-lives in meat and liver
Lutetium	Cerium	Both elements are lanthanides. Biochemical and biokinetic behaviour of all the lanthanides is very similar [C.5].
Molybdenum	Niobium	Element are adjacent in the periodic table.
Sodium	Caesium	Both elements are alkali metals.
Prometheium	Cerium	Both elements are lanthanides. Biochemical and biokinetic behaviour of all the lanthanides is very similar [C.5].
Rubidium	Caesium	Both elements are alkali metals.
Rhenium	Technetium	Similar geochemistry.
Samarium	Cerium	Both elements are lanthanides. Biochemical and biokinetic behaviour of all the lanthanides is very similar [C.5].
Thallium	Caesium	Similar biochemical properties to potassium which is closely analogous to Caesium. Same analogue as used for biological half-lives in meat and liver.
Vanadium	Niobium	Both elements are Group V transition metals.
Yttrium	Zirconium	Elements are adjacent in the periodic table.
Scandium	Zirconium	Both elements are transition metals.
Gadolinium	Cerium	Both elements are lanthanides. Biochemical and biokinetic behaviour of all the lanthanides is very similar [C.5].
Bismuth	Lead	Elements are adjacent in the periodic table.
Fluorine	Chlorine	Both elements are gaseous halogens.
Nitrogen	Phosphorus	Both elements are essential nutrients and non metals.
Oxygen	Sulphur	Both elements are non metals.

Appendix D: Input data and calculation of DPUR factors for aerial discharges scenario

D.1 Source term

Atmospheric releases of radionuclides can be in the form of particulates, reactive gases and unreactive (noble) gases. The radionuclides considered for atmospheric releases are shown in Table 1.

Atmospheric releases from incineration of combustible solids may also occur. For assessment of radionuclide releases from incineration of radioactive waste, (including derivation of the source term) see Appendix H.

For IRAT2, a single release point is assumed. A single release point is more conservative than assuming multiple points of discharge that will result in a more diffuse plume. Plume rise and building effects are ignored in the modelling because the approach is generic and site specific information on buildings does not apply. However, these effects can be incorporated, to a degree, by assigning an "effective" stack height. For the baseline case in IRAT2, a ground-level release is assumed with an effective stack height of 1 m. This is likely to lead to the highest ground-level air concentrations and is a cautious assumption for distances of up to at least a few kilometres from the release point, which are of relevance here. With increasing stack height and increasing distances from the stack, ground-level air concentrations generally decrease.

D.2 Exposed group for assessments to public

The following exposed group is considered. This is taken to be representative of members of the public exposed to atmospheric releases of radionuclides across the UK:

<u>Local resident family</u>
Pathways included are:

- internal radiation from the inhalation of radionuclides in the effluent plume;
- external radiation from radionuclides in the effluent plume;
- external radiation from radionuclides deposited to the ground;
- internal radiation from consumption of terrestrial food containing radionuclides deposited to the ground (not considered for radionuclides with half-lives of less than 3 hours).

Figure D.1 shows the matrix of pathways that need to be evaluated.

Inhalation of resuspended deposited activity is not included, as it is not usually significant where there is ongoing exposure to the effluent plume itself [D.1].

A habitation distance of 100 m and a food production distance of 500 m from the release point were assumed. It is conservative to assess doses as close as may reasonably be expected from a ground-level release, as air concentrations and deposition rates will be highest closer to the release point. The food production distance is greater, to allow sufficient land to produce enough food to reasonably be considered to form a major part of a family's diet. The habit data relevant to the exposure group, including ingestion rates, attenuation of external radiation and occupation at the receptor locations, are shown in Table D.1.

D.3 Activity concentrations in air and deposition rates

The transfer and dispersion of the radionuclides between the release point and the receptor location was determined by sectorised Gaussian plume dispersion modelling, based on the widely used NRPB R-91 model [D.2] and implemented in PC-CREAM 08's atmospheric module, PLUME. The modelling approach is described in the corresponding report [D.3].

It has been assumed that effects such as re-entrainment of the plume in a building wake may either be ignored or modelled using an effective release height. A conservative approach in the first instance has been to assume a ground level release of radionuclides to air. Plume rise due to the buoyancy effects (i.e. hot discharge) or a high efflux velocity has also been ignored in a conservative approach to dose assessment. Plume rise can be regarded in terms of a greater effective release height and therefore leads to lower overall ground level concentrations.

The discharge is assumed to be continuous and the rate of radionuclide release does not vary with time. If releases are of short duration and/or periodic, the generic DPUR values may not be suitable to assess dose and a specific calculation is likely to be required. Guidance on assessing short-term discharges is presented in [D.4].

The annual variation of meteorological conditions has been represented by a weighted average of stability classes, an approach described in NRPB R-91 [D.2]. It is assumed that Category D conditions (neutral stability, typically overcast) persist for 50 % of the time (see Table D.2) This is a conservative approach for most locations in the UK, since the assumed meterological conditions over-represents those conditions that lead to the highest surface air concentrations when the source is at ground level. Since there is usually a prevailing wind direction (typically prevailing winds come from the southwest in the UK, although the location and local topography may modify this), then a weighting factor is necessary to take into account the asymmetrical shape of the windrose. For a generic calculation it is reasonable to use a uniform windrose as there is no site-specific information. If a more conservative assessment is required, an increase of concentrations by a factor of two from the uniform values can be used to represent habitation downwind of the prevailing wind.

Dry deposition (the settling-out due to gravity of radionuclides associated with fine particles) for a continuous release is calculated by the PLUME model using the formula:

$$D_{dry} = v_g C$$

where D_{dry} is dry deposition rate ($Bq/m^2/s$)
v_g is dry deposition velocity (m/s)
C is air concentration at ground level (Bq/m^3)

Default values for v_g have been assumed to be equal to 0.001 m/s for particulate radionuclides and 0.01 m/s for inorganic (i.e. reactive) iodine. These are values that have been commonly adopted [D.3]. Noble gases are non-depositing (i.e. v_g is equal to 0 m/s), while the deposition of ^3H and ^{14}C have been calculated using the method described in Section D.5.3.

In PLUME, wet deposition (the washout of atmospheric radionuclides due to precipitation) for a continuous release is calculated using the formula:

$$D_{wet} = \frac{\Lambda Q}{x \, \alpha \, u_s}$$

where D_{wet} is wet deposition rate ($Bq/m^2/s$)
Λ is washout coefficient (s)
Q is release rate (Bq/s)
x is distance from the release point to the point of interest (m)
α is angular width of the sector into which the release takes place (radians)
u_s is wind speed at the effective stack height (m/s)

There are large uncertainties in the values that have been reported for Λ due to the difficulty in undertaking experimental measurements. A value equal to 0.0001 s has been used for modelling purposes (except for noble gases where Λ has been assumed to be equal to 0) on the basis this is likely to be reasonably conservative.

It has been assumed to rain for 10% of the time. This is a reasonable average for the whole of the United Kingdom. However, the figure is highly dependent on location. Western parts of the country and locations at higher altitudes experience more frequent rain. Assuming it rains for 10% of the time, the combined wet and dry deposition rate is given by:

$$D_{total} = D_{dry} + 0.1\, D_{wet}$$

Wet deposition is episodic, occurs throughout a plume and is dependent on the extent of horizontal dispersion only, whereas dry deposition is non-episodic and is driven by the surface air concentration. Thus, the dominant process depends on the depth of the boundary layer. An added complication is that nearly all rainfall occurs during neutral or near-neutral conditions and when wind is most likely to be from the prevailing wind direction. As the specific location of the exposed group is not assigned in a generic dose assessment, a uniform windrose has been used when calculating wet deposition (α has a value of 2π). If however, if it were downwind of the release in the direction of the prevailing wind then it is reasonable to assume that all of the rainfall occurs in a quadrant, meaning α would take a value of π/2.

It should be noted that calculated ground level air concentrations (and consequently deposition) have not included the impact of source depletion due to upwind deposition. This effect is likely to be minimal for the short distances of the exposed groups from the source, however.

The PLUME model in PC-CREAM 08[6] was used to calculate air concentration and deposition rates for a unit discharge of 1 Bq/y at a distance of 100 m and 500 m for all radionuclides. The model represents ingrowth and decay of short-lived radionuclides. The resulting activity concentrations in air (Bq/m^3) and deposition rates (Bq/m^2/s) per unit release are listed in Table D.3.

D.4 Dose rates for external exposures

D.4.1 External exposure from cloud immersion

To calculate external exposure from immersion in the effluent cloud, effective dose coefficients for air submersion listed in Eckerman and Leggett and Eckerman and Ryman [D.5, D.6], were applied to the air concentrations. They are based on a semi-infinite cloud source surrounding a standard human phantom standing on the ground. Although decay and ingrowth of progeny between source and receptor point was not considered explicitly, for the purpose of calculating external dose, dose coefficients for radionuclide progeny with half-lives of less than a few minutes were included with their parents. The dose rates for air immersion per unit air concentration are listed in Table D.4, together with parent/progeny details.

PLUME contains an integrated finite cloud gamma dose model. In the original version of IRAT published in 2006 [D.7] a comparison of the external dose rates calculated using Eckerman and Leggett dose coefficients had shown that external dose rates from PLUME were significantly lower. As neither data set has been updated since, the approach remains to be conservative and to use Eckerman and Leggett's values to calculate the external dose from a plume.

D.4.2 External exposure from deposited radionuclides

The PC-CREAM 08 module GRANIS was used to calculate gamma dose rates above soil from radionuclides deposited onto the ground by atmospheric deposition. An undisturbed soil profile consisting of 'generic wet soil' was assumed, represented by up to five compartments to a total depth of 1 m. Transfer between the compartments is based on measurements of the migration in soil of plutonium from bomb fallout [D.3]. GRANIS includes full decay chains when calculating transfer between soil compartments and the contribution of progeny are included in the resulting dose rate of the parent. The doses arising from external gamma radiation exposure to deposited radionuclides in undisturbed soil were calculated for an

[6] PC-CREAM 08 version 1.5.1.85, with database version 2.0.0

integration time of 50 years. The effective dose rate per unit deposition rate (µSv/h per $Bq/m^2/s$) for each radionuclide are listed in Table D.5.

D.4.3 External dose rates per unit release

The effective dose rates from external exposure to the plume were calculated as follows:

$$DR_{ext\_cloud} = DR_{ext\_cloud(u)} A_{air}$$

where DR_{ext_cloud} is external dose rate from activity in air 100 m from the release point (µSv/h per Bq/y)

$DR_{ext\_cloud(u)}$ is external dose rate per unit air concentration (µSv/h per Bq/m^3)

A_{air} is activity concentration in air at 100 m per unit release, calculated using the PLUME model in PC-CREAM 08 (Bq/m^3 per Bq/y)

and from external exposure to deposited activity:

$$DR_{ext\_depos} = DR_{ext\_depos(u)} R_{depos}$$

where DR_{ext_depos} is external dose rate from deposited activity 100 m from the release point (µSv/h per Bq/y)

$DR_{ext\_depos(u)}$ is external dose rate per unit deposition rate (µSv/h per $Bq/m^2/s$)

R_{depos} is total deposition rate (dry + wet) at 100 m per unit release, calculated using the PLUME model in PC-CREAM 08 ($Bq/m^2/s$ per Bq/y)

The resulting external dose rates per unit release are shown in Table D.6.

D.5 Activity concentrations in terrestrial foodstuffs

D.5.1 Terrestrial foodchain transfer modelling

To calculate activity concentrations in terrestrial foodstuffs the foodchain model FARMLAND [D.8] was used, as implemented in PC-CREAM 08[7] [D.3]. FARMLAND is a dynamic model with a modular substructure, which simulates radionuclide transfer through different parts of the foodchain, including major crop types and animals. The movement of radionuclides within each module is represented by transfers between interconnected compartments. For some parts of the foodchain,

[7] Activity concentrations for sodium (Na) and chlorine (Cl) radionuclides in cow milk, cow meat, cow liver, sheep meat and sheep liver were taken from IRAT1 and based on PC-CREAM 98. The activity concentration of phosphorus (P) radionuclides in cow milk was based on a ratio between the activity concentration in cow milk and cow liver from the original version of IRAT. This is due to erroneous values arising from the use of PC-CREAM 08 for these isotopes/foodstuffs. See footnotes to Table D.11.

several modules have been developed of differing levels of complexity. In particular, element-specific modules have been developed for animals to take into account the important biological and metabolic processes for those elements whose transfer through terrestrial foodchains is significant. For some parts of the foodchain, however, fewer data exist and quasi-equilibrium is assumed. FARMLAND contains five different animal models, one each for iodine, strontium, caesium and the actinides, as well as a much simpler one for other radionuclides.

The following foodstuffs were included: green vegetables, root vegetables (including potato), fruit, sheep meat, sheep offal (liver), beef meat, beef offal (liver) and cow's milk. Cereal and cereal products were not considered, as grain produced for human consumption is usually mixed with other supplies obtained over a wide area before processing and distribution. Similarly, regarding pig and poultry products, it was assumed that the animals are housed inside and supplied with feed from a variety of sources [D.1].

The FARMLAND database contains default values for soil-plant concentration factors and transfer factors to animals. The values selected are documented in the supporting PC-CREAM 08 methodology report [D.3]. Since this was released, IAEA has published a compilation of recommended values for representing radionuclide transfer in terrestrial and freshwater environments [D.9]. This database covers the majority of elements included in IRAT2. Where a suitable IAEA value was available, the FARMLAND database was updated with these values, for use for IRAT2. To convert concentration factors between wet and dry weight plant material a 10 % dry matter content was assumed for fruit and green vegetables, 20 % for root crops and potatoes, and 30 % for pasture [D.9].

In some cases no data were available, in which case a value was assumed based on that for a chemically similar element. The assumptions are presented in Appendix C.

The FARMLAND input data used for IRAT2 are listed in the following tables, together with relevant data sources: equilibrium fractions transferred to cow meat, cow liver, cow's milk, sheep meat and sheep liver are listed in Table D.7 and Table D.8 and equilibrium concentration ratios between soil and pasture, root vegetables, green vegetables and fruit are listed in Table D.9 and Table D.10.

The outcomes were calculated activity concentrations in terrestrial foodstuffs (integrated over a 50-year time interval) per unit deposition rate (Bq/kg per $Bq/m^2/s$). These are listed in Table D.11.

D.5.3 Equilibrium modelling for tritium (H-3) and carbon-14 (C-14)

Tritium (H-3) and carbon-14 (C-14) are not included in FARMLAND. The transfer of H-3 and C-14 between the atmosphere and the terrestrial environment is more complex than for other radionuclides, since hydrogen and carbon are fundamental to biological systems. A relatively simple 'specific activity' approach is implemented in the PC-CREAM 08 FARMLAND model to calculate the activity concentrations of H-3 and C-14 in foodstuffs [D.3]. It is assumed that all foodstuffs come into instant equilibrium with atmospheric C-14, and that the specific activity of carbon in the food is equal to that in the atmosphere at the point of interest, assuming an atmospheric carbon concentration of 1.5E-4 kg/m^3. A similar assumption is made for H-3: the specific activity of H-3 in the food can be taken as equal to that in the in atmospheric water vapour, assuming an atmospheric concentration of 8E-3 kg/m^3. Hence the concentrations of H-3 and C-14 are calculated using the formula:

$$C_{food} = C_{plume} \times F^*$$

F^* (Bq/kg per Bq/m^3) is a factor relating the airborne concentration of H-3 or C-14 in the plume at the point of interest to the concentration of the relevant radionuclide in a foodstuff produced at that location. Values for F^* are shown in Table D.12.

Soil activity concentrations for H-3 and C-14 were also derived, although not used in the final DPUR calcualtions. The details have been retained here within this report for future reference if needed. The derivation of activity concentrations in soil for H-3 and C-14 used a specific activity modelling approach, similar to that described for food, and calculated using the formula:

$$C_{soil} = C_{plume} \times F^*$$

C_{soil}	is the concentration of H-3 or C-14 in soil at point of interest (100 m from ground level release point)
C_{plume}	is the concentration of H-3 or C-14 in the plume at point of interest (100 m from ground level release point).

F^* (Bq/kg per Bq/m^3) is a factor relating the airborne concentration of H-3 or C-14 in the plume at the point of interest to the concentration of the relevant radionuclide in soil at the point of interest. The recommendations by IAEA [D.13] were used with the soil composition used in the GRANIS module of PC-CREAM 08 [D.3]. Assuming soil is typically 10 % organic matter, F^* for H-3 in soil is 6.3 Bq/kg per Bq/m^3, and for C-14 is 47 Bq/kg per Bq/m^3 as shown in Table D.12.

D.5.4 Activity concentrations in terrestrial foodstuffs per unit release

Activity concentrations in terrestrial foodstuffs per unit release were calculated as follows:

$$A_{food} = A_{food(u)} R_{depos}$$

where	A_{food}	is activity concentration in terrestrial foodstuffs grown 500 m from the release point (Bq/kg per Bq/y)
	$A_{food(u)}$	is activity concentration in foodstuffs per unit deposition rate (Bq/kg per Bq/m^2/s)
	R_{depos}	is deposition rate at 500 m, calculated by the PLUME model in PC-CREAM 08 (Bq/m^2/s per Bq/y)

Note that for H-3 and C-14 concentrations in foodstuffs were calculated from the activity concentration in air at 500 m and not the deposition rate. The resulting activity concentrations in terrestrial foodstuffs are shown in Table D.13.

D.6 Method to calculate DPUR factors for people

The DPUR factors for the plume inhalation pathway for each age group were calculated as follows:

$$DPUR_{inh,a} = A_{air}\ H_{occ,a}\ B_a\ DF_{inh,a}$$

where	$DPUR_{inh,a}$	is dose per unit release factor from inhalation of the plume 100 m from the point of discharge for the age group considered (µSv/y per Bq/y)
	A_{air}	is activity concentration in air at 100 m (Bq/m^3 per Bq/y)
	$H_{occ,a}$	is total occupancy for the age group considered (h/y)
	B_a	is inhalation rate for the age group considered (m^3/h)
	$DF_{inh,a}$	is inhalation dose coefficient for the age group considered (µSv/Bq)

It was assumed that there is no difference in activity concentration in air between the outside and inside of buildings.

The DPUR factors for external exposure pathways for each age group were calculated as follows:

$$DPUR_{ext,a} = DR_{ext}\ H_{occ,a}\ (F_{ind,a}\ T_{ind} + F_{out,a})$$

where	$DPUR_{ext,a}$	is dose per unit release factor from external exposure to activity in the air or deposited activity for the age group considered (µSv/y per Bq/y)
	DR_{ext}	is external dose rate from either activity in air or deposited activity (µSv/h per Bq/y).
	$H_{occ,a}$	is total occupancy for the age group considered (h/y)
	$F_{ind,a}$	is fraction spent indoors for the age group considered
	T_{ind}	is indoor shielding factor for either cloud shine or ground shine
	$F_{out,a}$	is fraction spent outdoors for age group considered = 1– $F_{ind,a}$

The DPUR factors for ingestion of terrestrial foodstuffs were calculated as follows:

$$DPUR_{food,a} = A_{food}\ I_{food,a}\ DF_{ing,a}$$

where	$DPUR_{food,a}$	is dose per unit release factor from the ingestion of a terrestrial foodstuff for the age group considered (µSv/y per Bq/y)
	A_{food}	is activity concentration in the foodstuff considered (Bq/kg per Bq/y)

$I_{food,a}$	is ingestion rate of the foodstuff for the age group considered (kg/y)
$DF_{ing,a}$	is ingestion dose coefficient for age group (µSv/Bq)

The DPUR factors are shown in the main report: Tables 2-6 for the local resident family exposure group.

D.7 Method to calculate DPUR factors for wildlife

The exposed group for aerial releases to wildlife are the reference organisms for the terrestrial environment, as described in the ERICA approach (see Appendix A). The dose factors (DPUC) for wildlife were calculated using the ERICA tool and the Ar-Kr-Xe dose calculator and are presented in Appendix A, Table A.7.

Activity concentrations and deposition rates used to calculate the DPUR for wildlife are the same as that for the public, as described in Section D.3. The wildlife DPUR are based on reference organisms being located 100 m from a ground level release point. Assumed atmospheric conditions are shown in Table D.2. Deposition rates are the same as those used for the public assessments are are shown in Table D.3. To calculate activity concentrations in well mixed soil, the PC-CREAM 08 module FARMLAND was used. Soil activity concentrations are shown in Table D.14.

DPUR factors for wildlife were calculated from the soil concentration at 100 m:

$$DPUR_{wildlife} = R_{Depos} A_{soil}\ DF_{wildlife}$$

$DPUR_{wildlife}$	is the dose rate per unit release factor for wildlife (µGy/h per Bq/y)
R_{depos}	is deposition rate at 100 m (Bq/m^2/s per Bq/y) (Table D.3)
A_{soil}	is activity concentration in soil per unit deposition rate (Bq/kg per Bq/m^2/s) (Table D.14)
$DF_{wildlife}$	is the dose factor for wildlife per unit concentration (DPUC) in soil (µGy/h per Bq/kg) (See Appendix A, Table A.7)

For radionuclides of tritium, carbon, phosphorus, sulphur, radon and noble gases, the DPUR values were calculated using the air concentration at 100 m:

$$DPUR_{wildlife} = A_{air}\ DF_{wildlife,g}$$

A_{air}	is activity concentration of gaseous radionuclide in air per unit concentration (Bq/m^3 per Bq/y) (Table D.3)
$DF_{wildlife,g}$	is the dose factor for wildlife exposure to noble gases per unit concentration (DPUC) in air (µGy/h per Bq/m^3) (See Appendix A, Table A.7)

The DPUR factors for wildlife exposed to terrestrial releases are shown in Tables 7 and 8 in the main report.

D.8 References

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Table D.1. Habit data of local resident family exposure group

	Infant	Child	Adult	Comment
Food consumption rates (kg/y)*				[D.10]
Green vegetables	15	35	80	
Root vegetables	45	95	130	
Fruit	35	50	75	
Sheep meat	3	10	25	
Sheep liver	2.75	5	10	
Cow meat	10	30	45	
Cow liver	2.75	5	10	
Cow Milk	320	240	240	
Breathing rates (m^3/h)	0.22	0.64	0.92	[D.10]
Occupancy at habitation (h/y)	8,760	8,760	8,760	100%
Fraction of time spent indoors	0.9	0.8	0.5	[D.10]
Cloud shielding factor (indoors)	0.2	0.2	0.2	[D.3]
Shielding factor for deposited radionuclides	0.1	0.1	0.1	[D.3]

* All food intake rates are very conservatively taken to be the 97.5 percentile rate of consumers, from [D.10].

Table D.2. Atmospheric conditions

Pasquill stability category	Frequency of occurrence (%)	Wind speed at 10 m height (m/s)
A	1	1
B	9	2
C	21	5
D	50	5
E	8	3
F	10	2
G	2	1

Table D.3. Air concentrations and deposition rates per unit release rate

Radionuclide	Activity concentration in air (Bq/m^3 per Bq/y)*		Total deposition rate ($Bq/m^2/s$ per Bq/y)*	
	100 m	500 m	100 m	500 m
H-3	2.8E-12	1.4E-13	-	-
H-3 organic	2.8E-12	1.4E-13	-	-
C-11	2.8E-12	1.3E-13	-	-
C-14	2.8E-12	1.4E-13	-	-
N-13	2.7E-12	1.1E-13	2.8E-15	1.2E-16
O-15	2.3E-12	5.3E-14	2.4E-15	6.1E-17
F-18	2.8E-12	1.3E-13	2.9E-15	1.5E-16
Na-22	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Na-24	2.8E-12	1.4E-13	2.9E-15	1.5E-16
P-32	2.8E-12	1.4E-13	2.9E-15	1.5E-16
P-33	2.8E-12	1.4E-13	2.9E-15	1.5E-16
S-35	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Cl-36	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Ar-41	2.8E-12	1.4E-13	-	-
Ca-45	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Ca-47	2.8E-12	1.4E-13	2.9E-15	1.5E-16
V-48	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Cr-51	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Mn-52	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Mn-54	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Mn-56	2.8E-12	1.3E-13	2.9E-15	1.5E-16
Fe-55	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Fe-59	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Co-56	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Co-57	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Co-58	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Co-60	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Ni-63	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Cu-61	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Cu-64	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Zn-62	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Zn-65	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Ga-67	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Ga-68	2.8E-12	1.3E-13	2.9E-15	1.5E-16
Se-75	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Br-76	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Br-77	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Br-82	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Kr-79	2.8E-12	1.4E-13	-	-
Kr-81m	5.5E-13	2.7E-16	-	-
Kr-85	2.8E-12	1.4E-13	-	-
Kr-85m	2.8E-12	1.4E-13	-	-
Rb-81	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Rb-82	2.1E-12	3.4E-14	2.1E-15	3.9E-17

Radionuclide	Activity concentration in air (Bq/m^3 per Bq/y)*		Total deposition rate (Bq/m^2/s per Bq/y)*	
	100 m	500 m	100 m	500 m
Rb-83	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Sr-83	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Sr-85	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Sr-89	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Sr-90	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Y-90	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Zr-89	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Zr-95	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Nb-95	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Mo-99	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Tc-94m	2.8E-12	1.3E-13	2.9E-15	1.4E-16
Tc-99	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Tc-99m	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Ru-103	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Ru-106	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Ag-110m	2.8E-12	1.4E-13	2.9E-15	1.5E-16
In-111	2.8E-12	1.4E-13	2.9E-15	1.5E-16
In-113m	2.8E-12	1.3E-13	2.9E-15	1.5E-16
Sb-125	2.8E-12	1.4E-13	2.9E-15	1.5E-16
I-123	2.6E-12	1.1E-13	2.6E-14	1.1E-15
I-124	2.6E-12	1.1E-13	2.6E-14	1.1E-15
I-125	2.6E-12	1.1E-13	2.6E-14	1.1E-15
I-129	2.6E-12	1.1E-13	2.6E-14	1.1E-15
I-131	2.6E-12	1.1E-13	2.6E-14	1.1E-15
I-132	2.5E-12	1.0E-13	2.6E-14	1.1E-15
I-133	2.6E-12	1.1E-13	2.6E-14	1.1E-15
I-134	2.5E-12	1.0E-13	2.5E-14	1.0E-15
I-135	2.6E-12	1.1E-13	2.6E-14	1.1E-15
Xe-133	2.8E-12	1.4E-13	-	-
Cs-134	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Cs-136	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Cs-137	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Ba-140	2.8E-12	1.4E-13	2.9E-15	1.5E-16
La-140	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Ce-141	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Ce-144	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Pm-147	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Sm-153	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Eu-152	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Eu-154	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Eu-155	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Er-169	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Lu-177	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Re-188	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Au-198	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Tl-201	2.8E-12	1.4E-13	2.9E-15	1.5E-16

Radionuclide	Activity concentration in air (Bq/m^3 per Bq/y)*		Total deposition rate (Bq/m^2/s per Bq/y)*	
	100 m	500 m	100 m	500 m
Pb-210	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Pb-212	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Bi-213	2.8E-12	1.3E-13	2.9E-15	1.4E-16
Po-210	2.8E-12	1.4E-13	2.9E-15	1.5E-16
At-211	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Rn-222	2.8E-12	1.4E-13	-	-
Ra-223	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Ra-226	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Ac-225	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Th-227	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Th-230	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Th-232	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Th-234	2.8E-12	1.4E-13	2.9E-15	1.5E-16
U-234	2.8E-12	1.4E-13	2.9E-15	1.5E-16
U-235	2.8E-12	1.4E-13	2.9E-15	1.5E-16
U-238	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Np-237	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Pu-238	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Pu-239	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Pu-240	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Pu-241	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Pu-242	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Am-241	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Am-242	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Am-243	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Cm-242	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Cm-243	2.8E-12	1.4E-13	2.9E-15	1.5E-16
Cm-244	2.8E-12	1.4E-13	2.9E-15	1.5E-16

*for a release at ground level
- gaseous radionuclide not deposited.

Table D.4. External dose rates from air immersion per unit activity concentration in air

Radionuclide	External dose rate (µSv/h per Bq/m^3)		
	Parent	Parent and all progeny	Comments
H-3	0.0E+00	0.0E+00	
H-3 organic	0.0E+00	0.0E+00	
C-11	1.6E-04	1.6E-04	
C-14	9.4E-09	9.4E-09	
N-13	1.6E-04	1.6E-04	
O-15	1.7E-04	1.7E-04	
F-18	1.6E-04	1.6E-04	
Na-22	3.7E-04	3.7E-04	
Na-24	7.5E-04	7.5E-04	
P-32	1.9E-06	1.9E-06	
P-33	5.2E-08	5.2E-08	
S-35	1.1E-08	1.1E-08	
Cl-36	6.0E-07	6.0E-07	
Ar-41	2.2E-04	2.2E-04	
Ca-45	5.5E-08	5.5E-08	
Ca-47	1.8E-04	1.8E-04	
V-48	4.9E-04	4.9E-04	
Cr-51	5.0E-06	5.0E-06	
Mn-52	5.8E-04	5.8E-04	
Mn-54	1.4E-04	1.4E-04	
Mn-56	2.9E-04	2.9E-04	
Fe-55	0.0E+00	0.0E+00	
Fe-59	2.0E-04	2.0E-04	
Co-56	6.2E-04	6.2E-04	
Co-57	1.8E-05	1.8E-05	
Co-58	1.6E-04	1.6E-04	
Co-60	4.3E-04	4.3E-04	
Ni-63	0.0E+00	0.0E+00	
Cu-61	1.3E-04	1.3E-04	
Cu-64	3.1E-05	3.1E-05	
Zn-62	6.9E-05	6.9E-05	
Zn-65	9.8E-05	9.8E-05	
Ga-67	2.3E-05	2.3E-05	
Ga-68	1.5E-04	1.5E-04	
Se-75	6.0E-05	6.0E-05	
Br-76	4.5E-04	4.5E-04	
Br-77	5.0E-05	5.0E-05	
Br-82	4.4E-04	4.4E-04	
Kr-79	4.0E-05	4.0E-05	
Kr-81m	2.0E-05	2.0E-05	
Kr-85	8.6E-07	8.6E-07	
Kr-85m	2.5E-05	2.5E-05	
Rb-81	9.8E-05	1.2E-04	Kr-81m included

Radionuclide	External dose rate (µSv/h per Bq/m^3)		
	Parent	Parent and all progeny	Comments
Rb-82	1.8E-04	1.8E-04	
Rb-83	8.0E-05	8.0E-05	
Sr-83	1.3E-04	1.3E-04	
Sr-85	8.1E-05	8.1E-05	
Sr-89	1.6E-06	1.6E-06	
Sr-90	3.5E-07	3.5E-07	
Y-90	2.9E-06	2.9E-06	
Zr-89	1.9E-04	1.9E-04	
Zr-95	1.2E-04	1.2E-04	
Nb-95	1.3E-04	1.3E-04	
Mo-99	2.5E-05	2.5E-05	
Tc-94m	3.1E-04	3.1E-04	
Tc-99	1.0E-07	1.0E-07	
Tc-99m	1.9E-05	1.9E-05	
Ru-103	7.5E-05	7.5E-05	
Ru-106	0.0E+00	3.8E-05	Rh-106 included
Ag-110m	4.6E-04	4.6E-04	
In-111	6.0E-05	6.0E-05	
In-113m	4.0E-05	4.0E-05	
Sb-125	6.7E-05	6.7E-05	
I-123	2.3E-05	2.3E-05	
I-124	1.8E-04	1.8E-04	
I-125	1.3E-06	1.3E-06	
I-129	1.0E-06	1.0E-06	
I-131	6.1E-05	6.1E-05	
I-132	3.8E-04	3.8E-04	
I-133	9.9E-05	9.9E-05	
I-134	4.4E-04	4.4E-04	
I-135	2.7E-04	2.7E-04	
Xe-133	4.8E-06	4.8E-06	
Cs-134	2.5E-04	2.5E-04	
Cs-136	3.6E-04	3.6E-04	
Cs-137	3.3E-07	9.2E-05	Ba-137m included
Ba-140	2.9E-05	2.9E-05	
La-140	4.0E-04	4.0E-04	
Ce-141	1.1E-05	1.1E-05	
Ce-144	2.7E-06	2.7E-06	
Pm-147	3.1E-08	3.1E-08	
Sm-153	7.3E-06	7.3E-06	
Eu-152	1.9E-04	1.9E-04	
Eu-154	2.1E-04	2.1E-04	
Eu-155	7.7E-06	7.7E-06	
Er-169	1.1E-07	1.1E-07	
Lu-177	5.4E-06	5.4E-06	
Re-188	1.1E-05	1.1E-05	
Au-198	6.5E-05	6.5E-05	

Radionuclide	External dose rate (µSv/h per Bq/m³)		
	Parent	Parent and all progeny	Comments
Tl-201	1.2E-05	1.2E-05	
Pb-210	1.6E-07	1.6E-07	
Pb-212	2.2E-05	2.2E-05	
Bi-213	2.2E-05	2.2E-05	Po-213 included
Po-210	1.4E-09	1.4E-09	
At-211	4.9E-06	6.2E-06	Po-211 included
Rn-222	6.4E-08	6.5E-08	Po-218 included
Ra-223	2.0E-05	2.9E-05	Rn-219 and Po-215 included
Ra-226	1.0E-06	1.0E-06	
Ac-225	2.3E-06	2.3E-06	
Th-227	1.6E-05	1.6E-05	
Th-230	5.3E-08	5.3E-08	
Th-232	2.6E-08	2.6E-08	
Th-234	1.1E-06	5.4E-06	Pa-234m included
U-234	2.2E-08	2.2E-08	
U-235	2.3E-05	2.3E-05	
U-238	9.0E-09	9.0E-09	
Np-237	3.2E-06	3.2E-06	
Pu-238	1.3E-08	1.3E-08	
Pu-239	1.3E-08	1.3E-08	
Pu-240	1.2E-08	1.2E-08	
Pu-241	2.3E-10	2.3E-10	
Pu-242	1.0E-08	1.0E-08	
Am-241	2.4E-06	2.4E-06	
Am-242	2.2E-06	2.2E-06	
Am-243	6.7E-06	6.7E-06	
Cm-242	1.4E-08	1.4E-08	
Cm-243	1.9E-05	1.9E-05	
Cm-244	1.2E-08	1.2E-08	

Table D.5. External dose rates from deposited radionuclides per unit deposition rate

Radionuclide	External dose rate (for a 50 y integration time) (µSv/h per Bq/m^2/s)
H-3	0.0E+00
H-3 organic	0.0E+00
C-11	0.0E+00
C-14	0.0E+00
N-13	2.1E-03
O-15	4.3E-04
F-18	2.3E-02
Na-22	4.4E+02
Na-24	6.6E-01
P-32	0.0E+00
P-33	0.0E+00
S-35	0.0E+00
Cl-36	1.7E-01
Ca-45	1.8E-08
Ca-47	1.6E+00
V-48	1.3E+01
Cr-51	2.5E-01
Mn-52	5.5E+00
Mn-54	6.6E+01
Mn-56	5.0E-02
Fe-55	5.6E-04
Fe-59	1.5E+01
Co-56	7.4E+01
Co-57	7.6E+00
Co-58	1.9E+01
Co-60	8.3E+02
Ni-63	0.0E+00
Cu-61	3.4E-02
Cu-64	3.0E-02
Zn-62	1.7E-01
Zn-65	3.6E+01
Ga-67	1.4E-01
Ga-68	1.3E-02
Se-75	1.3E+01
Br-76	4.9E-01
Br-77	2.1E-01
Br-82	1.1E+00
Rb-81	3.4E-02
Rb-82	2.9E-04
Rb-83	1.2E+01
Sr-83	1.3E+01
Sr-85	9.1E+00
Sr-89	1.2E-03

Radionuclide	External dose rate (for a 50 y integration time) (µSv/h per Bq/m^2/s)
Sr-90	9.0E-06
Y-90	4.6E-08
Zr-89	1.1E+00
Zr-95	3.5E+01
Nb-95	7.7E+00
Mo-99	2.2E-01
Tc-94m	1.9E-02
Tc-99	0.0E+00
Tc-99m	8.6E-03
Ru-103	5.3E+00
Ru-106	1.9E+01
Ag-110m	1.8E+02
In-111	3.1E-01
In-113m	5.1E-03
Sb-125	9.0E+01
I-123	1.5E+00
I-124	1.3E+00
I-125	1.7E-01
I-129	2.9E+00
I-131	9.1E-01
I-132	6.3E-02
I-133	1.6E-01
I-134	2.7E-02
I-135	1.4E-01
Cs-134	2.6E+02
Cs-136	8.1E+00
Cs-137	4.7E+02
Ba-140	9.9E+00
La-140	1.1E+00
Ce-141	6.4E-01
Ce-144	3.4E+00
Pm-147	6.8E-04
Sm-153	2.5E-02
Eu-152	6.5E+02
Eu-154	5.7E+02
Eu-155	1.4E+01
Er-169	5.8E-08
Lu-177	6.4E-02
Re-188	1.1E-02
Au-198	3.2E-01
Tl-201	6.5E-02
Pb-210	4.6E-01
Pb-212	4.3E-02
Bi-213	2.1E-03
Po-210	3.2E-04
At-211	1.3E+03

Radionuclide	External dose rate (for a 50 y integration time) (µSv/h per Bq/m^2/s)
Ra-223	9.2E-01
Ra-226	1.9E+03
Ac-225	5.2E-01
Th-227	3.0E+00
Th-230	2.0E+03
Th-232	1.4E+03
Th-234	2.7E-01
U-234	1.4E+01
U-235	1.5E+02
U-238	2.3E+01
Np-237	2.1E+02
Pu-238	1.2E-01
Pu-239	1.5E+02
Pu-240	8.5E-02
Pu-241	9.9E+00
Pu-242	2.4E+01
Am-241	2.2E+02
Am-242	6.4E-01
Am-243	1.8E+02
Cm-242	3.7E-02
Cm-243	2.6E+02
Cm-244	1.7E-01

Table D.6. External dose per unit release rate

Radionuclide	Soil activity concentration (50 y integration) (Bq/kg per Bq/y)$		External dose (µSv/h per Bq/y)*	
	100 m	500 m	Air immersion	Deposited radionuclides
H-3	1.8E-11	8.8E-13	0.0E+00	0.0E+00
H-3 organic	1.8E-11	8.8E-13	0.0E+00	0.0E+00
C-11	1.3E-10	6.0E-12	4.5E-16	0.0E+00
C-14	1.3E-10	6.6E-12	2.6E-20	0.0E+00
N-13	5.3E-15	2.4E-16	4.4E-16	5.8E-18
O-15	9.3E-16	2.4E-17	3.8E-16	1.0E-18
F-18	6.0E-14	3.1E-15	4.6E-16	6.6E-17
Na-22	8.1E-10	4.2E-11	1.0E-15	1.3E-12
Na-24	5.0E-13	2.6E-14	2.1E-15	1.9E-15
P-32	1.2E-11	6.3E-13	5.4E-18	0.0E+00
P-33	2.2E-11	1.2E-12	1.5E-19	0.0E+00
S-35	8.8E-11	4.6E-12	3.1E-20	0.0E+00
Cl-36	5.9E-09	3.1E-10	1.7E-18	4.8E-16
Ar-41	0.0E+00	0.0E+00	6.2E-16	0.0E+00
Ca-45	1.7E-10	8.7E-12	1.5E-19	5.3E-23
Ca-47	3.7E-12	1.9E-13	5.1E-16	4.5E-15
V-48	1.4E-11	7.2E-13	1.4E-15	3.8E-14
Cr-51	2.4E-11	1.3E-12	1.4E-17	7.2E-16
Mn-52	4.5E-12	2.4E-13	1.6E-15	1.6E-14
Mn-54	3.0E-10	1.6E-11	3.9E-16	1.9E-13
Mn-56	8.5E-14	4.4E-15	8.2E-16	1.4E-16
Fe-55	8.5E-10	4.4E-11	0.0E+00	1.6E-18
Fe-59	4.1E-11	2.2E-12	5.7E-16	4.2E-14
Co-56	7.9E-11	4.1E-12	1.7E-15	2.1E-13
Co-57	2.7E-10	1.4E-11	5.0E-17	2.2E-14
Co-58	7.0E-11	3.6E-12	4.5E-16	5.5E-14
Co-60	1.5E-09	8.1E-11	1.2E-15	2.4E-12
Ni-63	7.3E-09	3.8E-10	0.0E+00	0.0E+00
Cu-61	1.1E-13	5.9E-15	3.7E-16	9.9E-17
Cu-64	4.2E-13	2.2E-14	8.6E-17	8.5E-17
Zn-62	3.1E-13	1.6E-14	1.9E-16	4.8E-16
Zn-65	2.4E-10	1.3E-11	2.7E-16	1.0E-13
Ga-67	2.6E-12	1.4E-13	6.5E-17	4.0E-16
Ga-68	3.7E-14	1.9E-15	4.3E-16	3.8E-17
Se-75	1.2E-10	6.4E-12	1.7E-16	3.6E-14
Br-76	5.4E-13	2.8E-14	1.3E-15	1.4E-15
Br-77	1.9E-12	9.8E-14	1.4E-16	6.2E-16
Br-82	1.2E-12	6.2E-14	1.2E-15	3.2E-15
Kr-79	0.0E+00	0.0E+00	1.1E-16	0.0E+00
Kr-81m	0.0E+00	0.0E+00	1.1E-17	0.0E+00
Kr-85	0.0E+00	0.0E+00	2.4E-18	0.0E+00
Kr-85m	0.0E+00	0.0E+00	7.0E-17	0.0E+00
Rb-81	1.5E-13	7.9E-15	3.3E-16	9.9E-17

Radionuclide	Soil activity concentration (50 y integration) (Bq/kg per Bq/y)$		External dose (µSv/h per Bq/y)*	
	100 m	500 m	Air immersion	Deposited radionuclides
Rb-82	5.3E-16	9.8E-18	3.7E-16	6.2E-19
Rb-83	8.6E-11	4.5E-12	2.2E-16	3.5E-14
Sr-83	1.1E-12	5.6E-14	3.6E-16	3.6E-14
Sr-85	6.3E-11	3.3E-12	2.3E-16	2.6E-14
Sr-89	4.8E-11	2.5E-12	4.4E-18	3.4E-18
Sr-90	5.2E-09	2.7E-10	9.9E-19	2.6E-20
Y-90	2.1E-12	1.1E-13	8.0E-18	1.3E-22
Zr-89	2.6E-12	1.4E-13	5.4E-16	3.1E-15
Zr-95	6.2E-11	3.3E-12	3.4E-16	1.0E-13
Nb-95	3.2E-11	1.7E-12	3.5E-16	2.2E-14
Mo-99	2.2E-12	1.2E-13	7.0E-17	6.3E-16
Tc-94m	2.9E-14	1.4E-15	8.6E-16	5.4E-17
Tc-99	2.9E-09	1.5E-10	2.9E-19	0.0E+00
Tc-99m	2.0E-13	1.0E-14	5.3E-17	2.5E-17
Ru-103	3.6E-11	1.9E-12	2.1E-16	1.5E-14
Ru-106	3.5E-10	1.8E-11	1.1E-16	5.4E-14
Ag-110m	2.5E-10	1.3E-11	1.3E-15	5.1E-13
In-111	2.3E-12	1.2E-13	1.7E-16	9.0E-16
In-113m	5.5E-14	2.8E-15	1.1E-16	1.5E-17
Sb-125	8.7E-10	4.5E-11	1.9E-16	2.6E-13
I-123	3.9E-12	1.6E-13	6.0E-17	3.8E-14
I-124	3.0E-11	1.3E-12	4.6E-16	3.3E-14
I-125	5.2E-10	2.2E-11	3.4E-18	4.3E-15
I-129	7.5E-08	3.1E-09	2.6E-18	7.4E-14
I-131	5.9E-11	2.5E-12	1.6E-16	2.3E-14
I-132	6.8E-13	2.8E-14	9.6E-16	1.6E-15
I-133	6.2E-12	2.6E-13	2.5E-16	4.1E-15
I-134	2.6E-13	1.0E-14	1.1E-15	7.0E-16
I-135	1.9E-12	8.2E-14	6.9E-16	3.6E-15
Xe-133	0.0E+00	0.0E+00	1.4E-17	0.0E+00
Cs-134	6.6E-10	3.5E-11	7.1E-16	7.5E-13
Cs-136	1.1E-11	5.7E-13	1.0E-15	2.3E-14
Cs-137	5.2E-09	2.7E-10	2.6E-16	1.4E-12
Ba-140	1.1E-11	5.6E-13	8.1E-17	2.8E-14
La-140	1.3E-12	7.0E-14	1.1E-15	3.1E-15
Ce-141	2.9E-11	1.5E-12	3.1E-17	1.8E-15
Ce-144	2.8E-10	1.5E-11	7.7E-18	9.8E-15
Pm-147	8.3E-10	4.3E-11	8.7E-20	2.0E-18
Sm-153	1.6E-12	8.1E-14	2.1E-17	7.2E-17
Eu-152	3.3E-09	1.7E-10	5.3E-16	1.9E-12
Eu-154	2.4E-09	1.3E-10	5.8E-16	1.6E-12
Eu-155	1.5E-09	7.6E-11	2.2E-17	3.9E-14
Er-169	7.7E-12	4.0E-13	3.0E-19	1.7E-22
Lu-177	5.5E-12	2.9E-13	1.5E-17	1.8E-16
Re-188	5.7E-13	3.0E-14	3.2E-17	3.3E-17

Radionuclide	Soil activity concentration (50 y integration) (Bq/kg per Bq/y)$		External dose (µSv/h per Bq/y)*	
	100 m	500 m	Air immersion	Deposited radionuclides
Au-198	2.2E-12	1.1E-13	1.8E-16	9.2E-16
Tl-201	2.5E-12	1.3E-13	3.3E-17	1.9E-16
Pb-210	4.6E-09	2.4E-10	4.5E-19	1.3E-15
Pb-212	3.5E-13	1.8E-14	6.3E-17	1.2E-16
Bi-213	2.5E-14	1.3E-15	6.1E-17	6.0E-18
Po-210	1.4E-10	7.4E-12	3.9E-21	9.2E-19
At-211	2.4E-13	1.2E-14	1.7E-17	3.7E-12
Rn-222	0.0E+00	0.0E+00	1.8E-19	0.0E+00
Ra-223	9.5E-12	5.0E-13	8.0E-17	2.6E-15
Ra-226	8.4E-09	4.4E-10	2.9E-18	5.6E-12
Ac-225	8.3E-12	4.3E-13	6.4E-18	1.5E-15
Th-227	1.6E-11	8.4E-13	4.5E-17	8.5E-15
Th-230	8.5E-09	4.5E-10	1.5E-19	5.6E-12
Th-232	8.5E-09	4.5E-10	7.3E-20	3.9E-12
Th-234	2.1E-11	1.1E-12	1.5E-17	7.9E-16
U-234	8.5E-09	4.5E-10	6.2E-20	4.1E-14
U-235	8.5E-09	4.5E-10	6.5E-17	4.2E-13
U-238	8.5E-09	4.5E-10	2.5E-20	6.7E-14
Np-237	8.5E-09	4.5E-10	8.9E-18	6.0E-13
Pu-238	7.1E-09	3.7E-10	3.5E-20	3.4E-16
Pu-239	8.5E-09	4.5E-10	3.5E-20	4.2E-13
Pu-240	8.5E-09	4.4E-10	3.4E-20	2.4E-16
Pu-241	3.5E-09	1.8E-10	6.4E-22	2.8E-14
Pu-242	8.5E-09	4.5E-10	2.9E-20	6.9E-14
Am-241	8.2E-09	4.3E-10	6.8E-18	6.3E-13
Am-242	5.3E-13	2.8E-14	6.1E-18	1.8E-15
Am-243	8.5E-09	4.4E-10	1.9E-17	5.0E-13
Cm-242	1.7E-10	8.7E-12	4.1E-20	1.1E-16
Cm-243	5.2E-09	2.7E-10	5.3E-17	7.4E-13
Cm-244	4.1E-09	2.1E-10	3.4E-20	5.0E-16

*for a release at ground level
$ derived using PC-CREAM 08. Intermediate values per unit deposition rate are not available.

Table D.7. Environmental transfer factors for animal products – cow meat, liver and milk

Radionuclide	Transfer factors (TF) pasture to animal product (Bq/kg wet muscle or liver or Bq/l milk per Bq/d intake)					
	TF pasture to cow meat	Comment#	TF pasture to cow liver	Comment#	TF pasture to cow milk	Comment#
Ac	1.0E-04		2.0E-02		3.0E-06	
Ag	1.0E-03		4.0E-01		3.0E-02	
Am	5.0E-04	[D.9]	2.0E-02		4.2E-07	[D.9]
At	6.7E-03	As I*	2.0E-03	As I*	5.4E-03	As I*
Au	5.0E-03		5.0E-03		5.5E-06	
Ba	1.4E-04	[D.9]	5.0E-04		1.6E-04	[D.9]
Bi	4.0E-04		4.0E-04		5.0E-04	
Br	2.5E-02		2.5E-01		2.0E-02	
Ca	1.3E-02	[D.9]	2.0E-03		1.0E-02	[D.9]
Ce	1.0E-03		1.0E-01		2.0E-05	[D.9]
Cl	2.0E-02	[D.7]	2.0E-02	[D.7]	1.7E-02	[D.7]
Cm	1.0E-04		2.0E-02		1.0E-06	
Co	4.3E-04	[D.9]	1.0E-01		1.1E-04	[D.9]
Cr	5.0E-03		5.0E-03		4.3E-04	[D.9]
Cs	2.2E-02	[D.9]	3.0E-02		4.6E-03	[D.9]
Cu	1.6E-01	As Zn*	2.0E-03	As Zn*	2.7E-03	As Zn*
Er	1.0E-03	As Ce*	1.0E-01	As Ce*	2.0E-05	As Ce*
Eu	5.0E-03		4.0E-02		2.0E-05	
Fe	1.4E-02	[D.9]	4.0E+00		3.5E-05	[D.9]
Ga	1.0E-03		2.0E-01		2.0E-05	
I	6.7E-03	[D.9]	2.0E-03		5.4E-03	[D.9]
In	8.0E-03		8.0E-03		2.0E-04	
La	1.3E-04	[D.9]	2.0E-01		2.0E-05	
Lu	1.0E-03	As Ce*	1.0E-01	As Ce*	2.0E-05	As Ce*
Mn	6.0E-04	[D.9]	2.0E-01		4.1E-05	[D.9]
Mo	1.0E-03	[D.9]	1.0E-01		1.1E-03	[D.9]
Na	8.0E-02	[D.7]	8.0E-02	[D.7]	1.6E-02	[D.7]
Nb	2.6E-07	[D.9]	1.0E-05		4.1E-07	[D.9]
Ni	1.0E-03		1.0E-02		9.5E-04	[D.9]
Np	1.0E-04		2.0E-02		1.0E-06	
P	5.5E-02	[D.9]	3.0E-03		n/a	
Pb	7.0E-04	[D.9]	2.0E-03		1.9E-04	[D.9]
Pm	5.0E-03		4.0E-02		2.0E-05	
Po	3.0E-03		8.0E-02		2.1E-04	[D.9]
Pu	1.1E-06	[D.9]	2.0E-02		1.0E-05	[D.9]
Ra	1.7E-03	[D.9]	5.0E-04		3.8E-04	[D.9]
Rb	1.0E-02		1.0E-02		1.0E-02	
Re	1.0E-02	As Tc*	4.0E-02	As Tc*	1.0E-02	As Tc*
Ru	3.3E-03	[D.9]	1.0E-03		9.4E-06	[D.9]

Radionuclide	Transfer factors (TF) pasture to animal product (Bq/kg wet muscle or liver or Bq/l milk per Bq/d intake)					
	TF pasture to cow meat	Comment#	TF pasture to cow liver	Comment#	TF pasture to cow milk	Comment#
S	3.0E-01		3.0E-01		7.9E-03	[D.9]
Sb	1.2E-03	[D.9]	1.0E-01		3.8E-05	[D.9]
Se	4.0E-02		1.0E+00		4.0E-03	[D.9]
Sm	1.0E-03	As Ce*	1.0E-01	As Ce*	2.0E-05	As Ce*
Sr	1.3E-03	[D.9]	3.0E-04		1.3E-03	[D.9]
Tc	1.0E-02		4.0E-02		1.0E-02	
Th	2.3E-04	[D.9]	1.0E-03		5.0E-06	
Tl	4.0E-02		4.0E-02		2.0E-03	
U	3.9E-04	[D.9]	2.0E-04		1.8E-03	[D.9]
V	2.6E-07	As Nb*	1.0E-05	As Nb*	4.1E-07	As Nb*
Y	1.0E-03		1.0E-02		2.0E-05	
Zn	1.6E-01	[D.9]	2.0E-03		2.7E-03	[D.9]
Zr	1.2E-06	[D.9]	1.0E-05		3.6E-06	[D.9]

where no comment made, value taken from FARMLAND database in PC-CREAM 08 [D.3]

* see Table C.1 for details

n/a: no transfer factor used. Instead, a ratio between activity concentrations of phosphorus isotopes in cow liver:cow milk was taken from data in the original version of IRAT, and this ratio was applied to cow liver in IRAT2 to generate activity concentrations of phosphorus isotopes in cow milk.

Table D.8. Environmental transfer factors for animal products – sheep meat and liver and biological half-lives

Element	Transfer factors (TF) pasture to animal product (Bq/kg wet muscle or liver per Bq/d intake)				Biological half-lives in meat and liver (y)		
	TF pasture to sheep meat	Comment#	TF pasture to sheep liver	Comment#	Meat biological half-life	Liver biological half-life	Comment#
Ac	1.0E-03		2.0E-01		1.0E+01	1.0E+01	As Ce*
Ag	4.8E-04	[D.9]	3.0E+00		1.0E-01	1.0E-01	
Am	1.1E-04	[D.9]	3.0E-02		n/a	n/a	Transuranics $
At	3.0E-02	As I*	5.0E-02	As I*	n/a	n/a	As I*
Au	5.0E-03		5.0E-03		8.0E-03	8.0E-03	As Tc*
Ba	5.0E-03		5.0E-03		9.0E-02	9.0E-02	
Bi	5.0E-03		3.0E-03		6.5E-03	6.5E-03	
Br	2.5E-01		2.5E+00		1.0E+01	1.0E+01	
Ca	2.0E-01		2.0E-01		n/a	n/a	As Sr*$
Ce	2.5E-04	[D.9]	2.0E+00		1.0E+01	1.0E+01	
Cl	2.0E-01	[D.7]	2.0E-01	[D.7]	n/a	n/a	As Cs*$
Cm	4.0E-04		3.0E-02		n/a	n/a	Transuranics $
Co	1.2E-02	[D.9]	1.0E+00		5.0E-01	5.0E-01	
Cr	5.0E-02		5.0E-02		9.0E-02	9.0E-02	
Cs	1.9E-01	[D.9]	5.0E-01		n/a	n/a	Cs $
Cu	4.5E-02	As Zn*	2.0E-02	As Zn*	8.0E-01	8.0E-01	As Zn*
Er	2.5E-04	As Ce*	2.0E+00	As Ce*	1.0E+01	1.0E+01	As Ce*
Eu	5.0E-02		3.0E-01		1.0E+01	1.0E+01	
Fe	1.0E-02		3.0E-01		5.0E+00	5.0E+00	
Ga	1.0E-02		2.0E+00		3.0E-01	3.0E-01	As Nb*
I	3.0E-02	[D.9]	5.0E-02		n/a	n/a	I $
In	8.0E-02		8.0E-02		1.0E+01	1.0E+01	As Ce*
La	5.0E-02		2.0E+00		1.0E+01	1.0E+01	
Lu	2.5E-04	As Ce*	2.0E+00	As Ce*	1.0E+01	1.0E+01	As Ce*
Mn	9.0E-03	[D.9]	2.0E+00		6.0E-02	7.0E-02	
Mo	5.0E-02		1.0E+00		1.0E-01	1.0E-01	
Na	8.0E-01	[D.7]	8.0E-01	[D.7]	n/a	n/a	As Cs*$
Nb	1.0E-04		1.0E-04		3.0E-01	3.0E-01	
Ni	1.0E-02		1.0E-01		1.2E+03	1.2E+03	
Np	4.0E-04		3.0E-02		n/a	n/a	transuranics $
P	5.0E-02		2.0E-02		3.0E-03	3.0E-03	
Pb	7.1E-03	[D.9]	2.0E-02		7.0E-01	7.0E-01	
Pm	5.0E-02		3.0E-01		1.0E+01	1.0E+01	
Po	5.0E-02		6.0E+00		1.0E-01	1.0E-01	

Elem-ent	Transfer factors (TF) pasture to animal product (Bq/kg wet muscle or liver per Bq/d intake)				Biological half-lives in meat and liver (y)		
	TF pasture to sheep meat	Comment#	TF pasture to sheep liver	Comment#	Meat biological half-life	Liver biological half-life	Comment#
Pu	5.3E-05	[D.9]	3.0E-02		n/a	n/a	transuranics $
Ra	5.0E-03		5.0E-03		7.0E-02	7.0E-02	
Rb	1.0E-01		1.0E-01		1.0E-01	1.0E-01	
Re	1.0E-01	As Tc*	3.0E-01	As Tc*	8.0E-03	8.0E-03	As Tc*
Ru	2.1E-03	[D.9]	1.0E-02		7.0E-01	7.0E-01	
S	1.7E+00	[D.9]	2.0E+00		3.0E-01	3.0E-01	
Sb	1.0E-02		1.0E+00		5.0E-02	5.0E-02	
Se	5.0E-01		1.0E+01		7.0E-02	7.0E-02	
Sm	2.5E-04	As Ce*	2.0E+00	As Ce*	1.0E+01	1.0E+01	As Ce*
Sr	1.5E-03	[D.9]	3.0E-03		n/a	n/a	Sr $
Tc	1.0E-01		3.0E-01		8.0E-03	8.0E-03	
Th	1.0E-03		1.0E-02		2.0E+00	2.0E+00	
Tl	4.0E-01		4.0E-01		n/a	n/a	As Cs*$
U	2.0E-03		2.0E-03		3.0E-02	3.0E-02	
V	1.0E-04		1.0E-04		3.0E-01	3.0E-01	As Nb*
Y	1.0E-02		1.0E-01		4.0E+01	4.0E+01	
Zn	4.5E-02	[D.9]	2.0E-02		8.0E-01	8.0E-01	
Zr	1.0E-04		1.0E-04		2.0E-02	2.0E-02	

where no comment made, value taken from FARMLAND database in PC-CREAM 08 [D.3]
* see Table C.1 for details
$ biological half-lives in meat and liver are not required inputs for the element-specific modules of FARMLAND

Table D.9. Environmental transfer factors for plant products – translocation and concentration ratios for pasture

Radionuclide	Translocation$	Comment#	Plant:soil concentration ratio (Bq/kg plant wet weight per Bq/kg soil dry weight)	
			CR pasture:soil	Comment#
Ac	i		1.0E-03	
Ag	s		2.0E-01	
Am	i		9.9E-03	[D.9]
At	m	As I*	1.1E-03	As I*
Au	i	As Ce*	8.0E-02	[D.11]
Ba	s		1.0E-02	
Bi	i		7.0E-03	
Br	m		2.0E-02	
Ca	s	As Sr*	3.9E-01	As Sr*
Ce	i		1.1E-01	[D.9]
Cl	m		5.0E+00	[D.7]
Cm	i		3.0E-04	[D.9]
Co	s		2.3E-02	[D.9]
Cr	i		6.0E-04	[D.9]
Cs	m		7.5E-02	[D.9]
Cu	s	As Zn*	2.4E-01	[D.9]
Er	i	As Ce*	1.1E-01	As Ce*
Eu	i		3.0E-03	
Fe	s		6.0E-04	[D.9]
Ga	s	As Nb*	2.0E-02	[D.11]
I	m		1.1E-03	
In	s	As Nb*	2.0E-02	[D.11]
La	s		6.0E-03	[D.9]
Lu	i	As Ce*	1.1E-01	As Ce*
Mn	s		1.9E-01	[D.9]
Mo	s		1.0E-01	
Na	m	*	1.2E-01	[D.7]
Nb	s		6.0E-03	[D.9]
Ni	s		5.1E-02	[D.9]
Np	i		1.8E-02	[D.9]
P	m		6.0E-01	[D.9]
Pb	s		9.3E-02	[D.9]
Pm	i		3.0E-02	
Po	m		3.6E-02	[D.9]
Pu	i		1.7E-04	[D.9]
Ra	s		3.9E-02	[D.9]
Rb	m		1.0E-01	
Re	m	As Tc*	2.3E+01	As Tc*
Ru	i		1.0E-02	
S	m		6.0E-01	
Sb	s		1.0E-02	
Se	m		1.0E+00	

Radionuclide	Translocation$	Comment#	Plant:soil concentration ratio (Bq/kg plant wet weight per Bq/kg soil dry weight)	
			CR pasture:soil	Comment#
Sm	i	As Ce*	1.1E-01	As Ce*
Sr	s		3.9E-01	[D.9]
Tc	m		2.3E+01	[D.9]
Th	i		3.0E-02	[D.9]
Tl	m	As Ce*	2.0E-02	[D.11]
U	i		1.4E-02	[D.9]
V	s	As Nb*	6.0E-03	As Nb*
Y	s		1.5E-03	[D.9]
Zn	s		3.0E-01	[D.9]
Zr	s		3.0E-03	[D.9]

$ m-mobile, s-semi-mobile, i-immobile
# where no comment made, value taken from FARMLAND database in PC-CREAM 08 [D.3]
* see Table C.2 for details

Table D.10. Environmental transfer factors for plant products – concentration ratios for green and root vegetables and fruit

Radionuclide	Plant:soil concentration ratio (Bq/kg plant wet weight per Bq/kg soil dry weight)					
	CR green vegetables: soil	Comment#	CR root vegetables: soil	Comment#	CR fruit:soil	Comment#
Ac	1.0E-03		1.0E-03		1.0E-03	
Ag	6.4E-05	[D.9]	2.6E-04	[D.9]	2.0E-01	
Am	3.8E-05	[D.9]	1.3E-04	[D.9]	9.7E-06	[D.9]
At	2.0E-02	As I*	2.0E-02	As I*	1.1E-03	As I*
Au	2.0E-03	[D.12]	3.6E-03	[D.12]	2.8E-03	[D.12]
Ba	5.0E-04	[D.9]	1.0E-03	[D.9]	1.0E-02	
Bi	7.0E-03		1.0E-03		1.0E-02	
Br	2.0E-02		2.0E-02		2.0E-02	
Ca	2.0E+00	[D.9]	7.0E-02	[D.12]	7.0E-02	[D.12]
Ce	1.3E-03	[D.9]	1.2E-03	[D.9]	4.2E-05	[D.9]
Cl	2.6E+00	[D.9]	2.4E+00	[D.9]	5.0E+00	
Cm	1.4E-04	[D.9]	1.7E-04	[D.9]	4.2E-05	[D.9]
Co	1.7E-02	[D.9]	2.2E-02	[D.9]	4.8E-04	[D.9]
Cr	1.0E-04	[D.9]	2.0E-04	[D.9]	3.0E-04	
Cs	6.2E-03	[D.9]	1.1E-02	[D.9]	3.6E-04	[D.9]
Cu	8.0E-02	[D.9]	1.6E-01	[D.9]	6.6E-06	[D.9]
Er	1.3E-03	As Ce*	1.2E-03	As Ce*	4.2E-05	As Ce*
Eu	3.0E-03		3.0E-03		3.0E-03	
Fe	3.7E-02	[D.9]	2.0E-04	[D.9]	2.0E-04	
Ga	8.0E-04	As In*	8.0E-05	As In*	8.0E-05	As In*
I	2.0E-02		2.0E-02		1.1E-03	[D.9]
In	8.0E-04	[D.7]	8.0E-05	[D.7]	8.0E-05	[D.7]
La	6.0E-04	[D.9]	3.2E-04	[D.9]	3.0E-03	
Lu	1.3E-03	As Ce*	1.2E-03	As Ce*	4.2E-05	As Ce*
Mn	4.1E-02	[D.9]	8.4E-02	[D.9]	3.9E-01	[D.9]
Mo	5.1E-02	[D.9]	6.4E-02	[D.9]	1.0E-01	
Na	3.0E-03	[D.9]	6.0E-03	[D.9]	2.4E-03	[D.9]
Nb	1.7E-03	[D.9]	3.4E-03	[D.9]	1.0E-02	
Ni	4.0E-02	[D.9]	1.0E-02		1.0E-02	
Np	2.7E-03	[D.9]	4.4E-03	[D.9]	2.0E-03	
P	1.0E-01	[D.9]	2.0E-01	[D.9]	1.0E+00	
Pb	8.0E-03	[D.9]	3.0E-03	[D.9]	1.0E-02	
Pm	1.7E-02	[D.9]	8.4E-03	[D.9]	3.0E-02	
Po	7.4E-04	[D.9]	1.2E-03	[D.9]	2.0E-04	
Pu	8.3E-06	[D.9]	7.8E-05	[D.9]	1.4E-05	[D.9]
Ra	9.1E-03	[D.9]	1.4E-02	[D.9]	1.0E-02	
Rb	6.2E-02	[D.9]	1.8E-01	[D.9]	1.0E-01	
Re	1.8E+01	As Tc*	9.2E+00	As Tc*	5.0E+00	As Tc*
Ru	9.0E-03	[D.9]	2.0E-03	[D.9]	1.0E-04	[D.9]
S	6.0E-01		6.0E-01		6.0E-01	
Sb	7.0E-04	[D.9]	1.2E-04	[D.9]	1.0E-02	

Radionuclide	Plant:soil concentration ratio (Bq/kg plant wet weight per Bq/kg soil dry weight)					
	CR green vegetables: soil	Comment#	CR root vegetables: soil	Comment#	CR fruit:soil	Comment#
Se	1.0E+00		1.0E+00		1.0E+00	
Sm	1.3E-03	As Ce*	1.2E-03	As Ce*	4.2E-05	As Ce*
Sr	1.4E-01	[D.9]	1.4E-01	[D.9]	3.1E-03	[D.9]
Tc	1.8E+01	[D.9]	9.2E+00	[D.9]	5.0E+00	
Th	1.2E-04	[D.9]	1.6E-04	[D.9]	5.0E-04	
Tl	8.0E-04	As In*	8.0E-05	As In*	8.0E-05	As In*
U	2.0E-03	[D.9]	1.7E-03	[D.9]	1.0E-03	
V	1.7E-03	As Nb*	3.4E-03	As Nb*	1.0E-02	As Nb*
Y	2.0E-04	[D.9]	4.0E-04	[D.9]	1.0E-02	
Zn	2.4E-01	[D.9]	6.0E-02	[D.9]	1.0E+00	
Zr	4.0E-04	[D.9]	8.0E-04	[D.9]	1.0E-04	

where no comment made, value taken from FARMLAND database in PC-CREAM 08 [D.3]
* see Table C.2 for details

Table D.11. Activity concentrations in terrestrial foods per unit deposition rate for atmospheric deposition

Radio-nuclide	50th year activity concentrations in foods per unit deposition rate (Bq/kg or Bq/l per Bq/m²/s)							
	Green vegetables	Root vegetables	Fruit	Cow milk	Cow meat	Cow liver	Sheep Meat	Sheep liver
H-3*	1.0E+02	1.0E+02	1.0E+02	1.1E+02	8.8E+01	8.8E+01	8.8E+01	8.8E+01
H-3 org*	1.0E+02	1.0E+02	1.0E+02	1.1E+02	8.8E+01	8.8E+01	8.8E+01	8.8E+01
C-11*	5.3E+02	5.3E+02	5.3E+02	2.7E+02	8.0E+02	8.0E+02	8.0E+02	8.0E+02
C-14*	5.3E+02	5.3E+02	5.3E+02	2.7E+02	8.0E+02	8.0E+02	8.0E+02	8.0E+02
Na-22	1.3E+05	1.2E+05	3.5E+05	2.1E+05^	1.1E+06^	1.1E+06^	1.9E+06^	1.9E+06^
Na-24	4.5E+03	1.8E+01	3.8E+02	1.1E+03^	4.1E+02^	4.1E+02^	2.3E+03^	2.3E+03^
P-32	5.9E+04	2.2E+04	6.8E+04	4.52E+04^^	7.0E+05	3.8E+04	9.4E+04	3.8E+04
P-33	7.9E+04	4.1E+04	1.3E+05	4.14E+04^^	1.1E+06	6.0E+04	1.6E+05	6.3E+04
S-35	1.2E+05	9.8E+04	2.6E+05	3.9E+05	6.4E+06	6.4E+06	5.1E+06	6.0E+06
Cl-36	5.9E+06	5.0E+06	9.4E+06	3.5E+06^	1.8E+07^	1.8E+07^	2.1E+07^	2.1E+07^
Ca-45	1.8E+05	2.9E+03	2.1E+04	5.6E+05	6.2E+05	9.6E+04	1.4E+06	1.4E+06
Ca-47	2.8E+04	6.3E+01	2.0E+03	1.1E+05	2.1E+04	3.2E+03	4.3E+04	4.3E+04
V-48	5.7E+04	2.3E+01	6.1E+03	7.7E+00	6.3E-01	2.4E+01	3.9E+01	3.9E+01
Cr-51	7.0E+04	1.4E+00	4.8E+03	9.4E+03	4.9E+04	4.9E+04	8.5E+04	8.5E+04
Mn-52	3.0E+04	9.6E+01	2.7E+03	4.8E+02	1.4E+03	4.2E+05	3.0E+03	5.9E+05
Mn-54	1.1E+05	6.6E+03	5.1E+04	2.2E+03	3.0E+04	9.9E+06	7.0E+04	1.5E+07
Mn-56	8.0E+02	1.5E+00	5.8E+01	2.7E+00	1.9E-01	5.6E+01	3.4E-01	6.5E+01
Fe-55	1.2E+05	2.2E+02	2.2E+04	1.0E+03	1.0E+05	3.0E+07	6.8E+03	2.1E+05
Fe-59	8.3E+04	5.4E+01	1.2E+04	8.3E+02	7.7E+03	2.2E+06	9.1E+02	2.7E+04
Co-56	9.3E+04	5.1E+02	1.5E+04	2.9E+03	3.3E+03	7.7E+05	1.5E+04	1.3E+06
Co-57	1.1E+05	1.6E+03	2.0E+04	3.4E+03	7.4E+03	1.7E+06	3.1E+04	2.6E+06
Co-58	9.2E+04	4.7E+02	1.5E+04	2.9E+03	3.0E+03	7.1E+05	1.4E+04	1.2E+06
Co-60	1.2E+05	1.1E+04	2.2E+04	4.6E+03	1.5E+04	3.5E+06	5.7E+04	4.8E+06
Ni-63	2.1E+05	2.5E+04	4.8E+04	9.2E+04	3.2E+02	3.2E+03	8.8E+01	8.8E+02
Cu-61	1.1E+03	3.8E+00	7.3E+01	3.2E+02	9.2E+00	1.2E-01	2.7E-01	1.2E-01
Cu-64	3.8E+03	1.4E+01	2.6E+02	2.7E+03	2.9E+02	3.6E+00	9.1E+00	4.0E+00
Zn-62	2.8E+03	3.9E+00	2.2E+02	1.7E+03	1.3E+02	1.7E+00	4.1E+00	1.8E+00
Zn-65	1.2E+05	3.7E+03	8.1E+04	1.6E+05	4.0E+06	5.1E+04	1.3E+05	5.8E+04
Ga-67	2.0E+04	2.1E-01	1.5E+03	1.5E+02	2.2E+02	4.4E+04	1.5E+02	1.5E+02
Ga-68	3.5E+02	6.3E-04	2.4E+01	2.7E-01	5.8E-03	1.2E+00	3.4E-03	3.4E-03
Se-75	1.5E+05	1.2E+05	3.0E+05	3.3E+05	2.6E+06	6.6E+07	4.5E+06	9.0E+07
Br-76	4.9E+03	2.4E+01	4.2E+02	2.9E+04	6.6E+00	6.6E+01	7.2E+00	7.2E+01
Br-77	1.5E+04	6.1E+02	3.2E+03	1.2E+05	9.3E+01	9.3E+02	1.2E+02	1.2E+03
Br-82	1.0E+04	1.9E+02	1.4E+03	7.4E+04	3.7E+01	3.7E+02	4.3E+01	4.3E+02
Rb-81	1.4E+03	6.3E+00	1.0E+02	2.0E+03	1.0E+01	1.0E+01	1.1E+01	1.1E+01
Rb-82	6.8E+00	2.7E-02	4.7E-01	6.2E-02	1.5E-06	1.5E-06	1.6E-06	1.6E-06
Rb-83	1.1E+05	8.8E+04	2.5E+05	3.0E+05	2.1E+05	2.1E+05	3.6E+05	3.6E+05
Sr-83	9.3E+03	2.1E+01	6.5E+02	9.1E+02	6.8E+01	6.8E+01	9.7E+01	9.7E+01
Sr-85	9.1E+04	1.5E+03	1.4E+04	2.2E+04	4.5E+03	4.5E+03	6.4E+03	6.4E+03
Sr-89	8.6E+04	1.2E+03	1.3E+04	2.0E+04	4.0E+03	4.0E+03	5.7E+03	5.7E+03
Sr-90	2.6E+05	1.5E+05	2.8E+04	3.5E+05	7.4E+04	7.4E+04	4.5E+04	4.5E+04
Y-90	1.7E+04	2.9E-01	1.2E+03	1.3E+02	1.2E+00	1.2E+01	1.5E+00	1.5E+01
Zr-89	2.0E+04	6.6E-01	1.5E+03	2.7E+01	2.8E+00	2.3E+01	3.1E+01	3.1E+01
Zr-95	9.0E+04	8.7E+01	1.4E+04	9.0E+01	2.7E+01	2.2E+02	4.3E+02	4.3E+02

Radio-nuclide	50th year activity concentrations in foods per unit deposition rate (Bq/kg or Bq/l per Bq/m^2/s)							
	Green vegetables	Root vegetables	Fruit	Cow milk	Cow meat	Cow liver	Sheep Meat	Sheep liver
Nb-95	7.7E+04	7.0E+01	1.1E+04	9.4E+00	1.4E+00	5.5E+01	9.3E+01	9.3E+01
Mo-99	1.7E+04	3.3E+01	1.3E+03	7.3E+03	4.6E+02	4.6E+04	3.0E+03	6.1E+04
Tc-94m	3.9E+02	5.2E+01	3.1E+01	5.5E+02	6.7E+00	2.7E+01	4.8E+00	1.4E+01
Tc-99	1.4E+07	9.1E+06	9.4E+06	2.1E+07	2.1E+07	8.5E+07	6.9E+08	2.1E+09
Tc-99m	2.7E+03	3.7E+02	2.2E+02	1.3E+04	1.1E+03	4.2E+03	9.3E+02	2.8E+03
Ru-103	7.7E+04	2.0E+01	5.3E+03	2.2E+02	1.0E+04	3.1E+03	1.1E+03	5.1E+03
Ru-106	1.0E+05	1.8E+02	7.0E+03	2.8E+02	5.3E+04	1.6E+04	4.9E+03	2.3E+04
Ag-110m	1.1E+05	1.6E+02	3.2E+04	1.5E+06	4.2E+04	1.7E+07	3.2E+03	2.0E+07
In-111	1.8E+04	1.5E-01	1.3E+03	1.3E+03	4.1E+01	4.1E+01	5.4E+01	5.4E+01
In-113m	5.1E+02	9.2E-04	3.6E+01	5.6E+00	4.2E-03	4.2E-03	4.9E-03	4.9E-03
Sb-125	1.1E+05	2.0E+02	2.4E+04	1.3E+03	3.9E+04	3.2E+06	6.7E+04	6.7E+06
I-123	4.0E+03	1.4E+01	3.2E+02	1.5E+03	4.2E+02	4.2E+02	2.3E+02	2.3E+02
I-124	2.5E+04	2.4E+03	9.5E+03	3.4E+04	1.3E+04	1.3E+04	1.3E+04	1.3E+04
I-125	1.0E+05	7.3E+04	2.1E+05	1.2E+05	7.3E+04	7.3E+04	1.7E+05	1.7E+05
I-129	1.9E+05	1.8E+05	3.6E+05	1.7E+05	1.1E+05	1.1E+05	3.9E+05	3.9E+05
I-131	4.1E+04	8.6E+03	2.9E+04	5.8E+04	2.5E+04	2.5E+04	3.2E+04	3.2E+04
I-132	7.1E+02	3.9E-01	4.9E+01	1.6E+01	3.6E+00	3.6E+00	1.7E+00	1.7E+00
I-133	6.2E+03	4.7E+01	5.9E+02	3.8E+03	1.1E+03	1.1E+03	6.8E+02	6.8E+02
I-134	2.7E+02	1.3E-01	1.9E+01	7.1E-01	1.5E-01	1.5E-01	6.6E-02	6.6E-02
I-135	2.0E+03	2.6E+00	1.5E+02	3.1E+02	7.8E+01	7.8E+01	3.8E+01	3.8E+01
Cs-134	1.3E+05	1.2E+05	3.4E+05	1.8E+05	9.1E+05	9.1E+05	1.7E+06	1.7E+06
Cs-136	5.6E+04	1.9E+04	5.9E+04	6.4E+04	1.4E+05	1.4E+05	2.8E+05	2.8E+05
Cs-137	1.4E+05	1.4E+05	3.6E+05	2.1E+05	1.1E+06	1.1E+06	2.1E+06	2.1E+06
Ba-140	5.1E+04	8.7E+00	5.0E+03	2.8E+03	6.7E+02	2.4E+03	3.8E+03	3.8E+03
La-140	1.1E+04	1.2E-01	7.9E+02	8.0E+01	2.4E-01	3.7E+02	1.2E+01	4.6E+02
Ce-141	7.3E+04	1.0E+01	5.1E+03	4.9E+02	2.1E+02	4.2E+04	8.5E+00	6.8E+04
Ce-144	1.0E+05	8.4E+01	6.9E+03	8.4E+02	2.6E+03	5.2E+05	6.7E+01	5.4E+05
Pm-147	1.1E+05	2.1E+03	1.5E+04	6.1E+02	2.1E+04	1.7E+05	1.8E+04	1.1E+05
Sm-153	1.3E+04	4.3E-01	8.8E+02	9.4E+01	2.5E+00	5.0E+02	8.0E-02	6.4E+02
Eu-152	1.1E+05	3.3E+03	1.1E+04	6.7E+02	4.1E+04	3.2E+05	2.5E+04	1.5E+05
Eu-154	1.1E+05	2.4E+03	9.7E+03	6.6E+02	3.6E+04	2.9E+05	2.4E+04	1.4E+05
Eu-155	1.1E+05	1.4E+03	8.7E+03	6.4E+02	2.9E+04	2.4E+05	2.1E+04	1.3E+05
Er-169	4.2E+04	2.5E+00	2.9E+03	3.1E+02	3.9E+01	7.8E+03	1.5E+00	1.2E+04
Lu-177	3.4E+04	1.7E+00	2.3E+03	2.6E+02	2.4E+01	4.7E+03	8.5E-01	6.8E+03
Re-188	7.5E+03	1.1E+03	7.2E+02	5.0E+04	9.8E+03	3.9E+04	1.0E+04	3.0E+04
Au-198	1.7E+04	1.8E+00	1.2E+03	3.7E+01	1.6E+04	1.6E+04	2.0E+03	2.0E+03
Tl-201	1.9E+04	1.1E+03	5.2E+03	1.6E+04	7.6E+04	7.6E+04	9.8E+04	9.8E+04
Pb-210	1.2E+05	4.8E+03	3.8E+04	2.4E+04	7.3E+04	2.1E+05	6.3E+04	1.8E+05
Pb-212	3.2E+03	2.3E-01	2.2E+02	1.4E+02	8.6E-01	2.5E+00	1.0E+00	2.9E+00
Bi-213	2.4E+02	5.3E-03	1.6E+01	3.2E+00	3.4E-02	3.4E-02	4.9E-02	2.9E-02
Po-210	1.2E+05	9.7E+04	2.8E+05	6.1E+03	6.8E+04	1.8E+06	2.1E+05	2.5E+06
At-211	2.2E+03	3.1E+00	1.6E+02	2.1E+03	2.2E-01	6.5E-02	1.1E-01	1.8E-01
Ra-223	4.8E+04	4.1E+01	4.6E+03	6.3E+03	8.7E+03	2.6E+03	4.0E+03	4.0E+03
Ra-226	1.4E+05	4.1E+04	5.2E+04	3.3E+04	1.4E+05	4.2E+04	6.4E+04	6.4E+04
Ac-225	4.4E+04	2.2E+00	3.0E+03	4.7E+01	4.2E+00	8.4E+02	6.4E+00	1.3E+03
Th-227	6.0E+04	7.4E-01	4.1E+03	1.0E+02	1.1E+02	4.9E+02	7.9E+01	7.9E+02
Th-230	1.1E+05	4.7E+02	9.2E+03	3.7E+02	1.1E+04	4.9E+04	3.3E+03	3.3E+04
Th-232	1.1E+05	4.7E+02	9.2E+03	3.7E+02	1.1E+04	4.9E+04	3.3E+03	3.3E+04
Th-234	6.6E+04	9.8E-01	4.6E+03	1.1E+02	1.6E+02	6.8E+02	1.1E+02	1.1E+03

Radio-nuclide	50th year activity concentrations in foods per unit deposition rate (Bq/kg or Bq/l per Bq/m^2/s)							
	Green vegetables	Root vegetables	Fruit	Cow milk	Cow meat	Cow liver	Sheep Meat	Sheep liver
U-234	1.1E+05	5.0E+03	1.1E+04	9.2E+04	2.0E+04	1.0E+04	2.0E+04	2.0E+04
U-235	1.1E+05	5.0E+03	1.1E+04	9.2E+04	2.0E+04	1.0E+04	2.0E+04	2.0E+04
U-238	1.1E+05	5.0E+03	1.1E+04	9.2E+04	2.0E+04	1.0E+04	2.0E+04	2.0E+04
Np-237	1.1E+05	1.3E+04	1.4E+04	1.4E+02	7.9E+03	9.6E+05	4.9E+03	3.5E+05
Pu-238	1.1E+05	1.9E+02	7.6E+03	7.9E+01	4.4E+03	5.4E+05	3.6E+03	2.6E+05
Pu-239	1.1E+05	2.3E+02	7.7E+03	8.2E+01	4.6E+03	5.6E+05	3.7E+03	2.6E+05
Pu-240	1.1E+05	2.3E+02	7.7E+03	8.2E+01	4.6E+03	5.6E+05	3.7E+03	2.6E+05
Pu-241	1.0E+05	9.2E+01	7.4E+03	6.7E+01	3.7E+03	4.5E+05	3.3E+03	2.4E+05
Pu-242	1.1E+05	2.3E+02	7.7E+03	8.2E+01	4.6E+03	5.6E+05	3.7E+03	2.6E+05
Am-241	1.1E+05	3.7E+02	7.7E+03	1.1E+02	6.3E+03	7.7E+05	4.3E+03	3.1E+05
Am-242	4.8E+03	1.5E-02	3.3E+02	2.6E-02	6.0E-01	2.9E+01	9.1E-01	2.6E+01
Am-243	1.1E+05	3.8E+02	7.7E+03	1.2E+02	6.3E+03	7.8E+05	4.3E+03	3.1E+05
Cm-242	9.6E+04	6.7E+00	6.7E+03	1.0E+01	5.7E+02	6.9E+04	1.1E+03	7.8E+04
Cm-243	1.1E+05	3.0E+02	7.6E+03	7.4E+01	4.1E+03	5.0E+05	3.5E+03	2.5E+05
Cm-244	1.1E+05	2.3E+02	7.5E+03	7.0E+01	3.9E+03	4.7E+05	3.4E+03	2.4E+05

*Bq/kg per Bq/m^3 in air – from the Specific Activity Model (see Section D.5.3)
^ data taken from the original version of IRAT Part 2 report [D.7] and based on PC-CREAM 98.
^^ activity concentrations of P-32 and P-33 in cow milk per unit deposition rate were derived by taking the ratio of activity concentrations of phosphorus isotopes in cow liver:cow milk from data in the original version of IRAT and applying this ratio to cow liver in IRAT2.

Table D.12. Factors relating concentrations of tritium and ^{14}C in foodstuffs and soil to concentrations in air

Foodstuff	Water content (fraction)	Carbon of dry matter (fraction)	Total carbon (fraction)	Conversion factor *F** (Bq/kg per Bq/m^3)	
				H-3^	C-14
Green vegetables	0.8	0.4	0.08	100	533
Root vegetables	0.8	0.4	0.08	100	533
Fruit	0.8	0.4	0.08	100	533
Cow milk	0.9	0.4	0.04	112.5	267
Cow/sheep meat	0.7	0.4	0.12	87.5	800
Soil	0.05*	0.07	0.1	6.3	47

* includes a factor of 0.3 to account for the fraction of soil water that is atmospherically derived [D.13].
^this includes organically bound tritium.

Table D.13. Activity concentration in terrestrial foodstuffs per unit release rate

Radio-nuclide	Activity concentration (Bq/kg per Bq/y)*							
	Green veg	Root veg	Fruit	Cow milk	Cow meat	Cow liver	Sheep meat	Sheep liver
H-3	1.4E-11	1.4E-11	1.4E-11	1.6E-11	1.2E-11	1.2E-11	1.2E-11	1.2E-11
H-3 org.^	1.4E-11	1.4E-11	1.4E-11	1.6E-11	1.2E-11	1.2E-11	1.2E-11	1.2E-11
C-11	6.8E-11	6.8E-11	6.8E-11	3.4E-11	1.0E-10	1.0E-10	1.0E-10	1.0E-10
C-14	7.5E-11	7.5E-11	7.5E-11	3.7E-11	1.1E-10	1.1E-10	1.1E-10	1.1E-10
Na-22	2.0E-11	1.8E-11	5.2E-11	3.2E-11	1.7E-10	1.7E-10	2.9E-10	2.9E-10
Na-24	6.8E-13	2.7E-15	5.6E-14	1.7E-13	6.2E-14	6.2E-14	3.5E-13	3.5E-13
P-32	8.9E-12	3.2E-12	1.0E-11	6.8E-12	1.1E-10	5.7E-12	1.4E-11	5.7E-12
P-33	1.2E-11	6.2E-12	1.9E-11	6.2E-12	1.7E-10	9.1E-12	2.4E-11	9.4E-12
S-35	1.8E-11	1.5E-11	3.9E-11	5.9E-11	9.6E-10	9.6E-10	7.6E-10	9.0E-10
Cl-36	8.9E-10	7.5E-10	1.4E-09	5.3E-10	2.7E-09	2.7E-09	3.2E-09	3.2E-09
Ca-45	2.7E-11	4.3E-13	3.2E-12	8.4E-11	9.4E-11	1.4E-11	2.2E-10	2.2E-10
Ca-47	4.2E-12	9.5E-15	3.0E-13	1.6E-11	3.1E-12	4.8E-13	6.5E-12	6.5E-12
V-48	8.6E-12	3.5E-15	9.2E-13	1.2E-15	9.4E-17	3.6E-15	5.8E-15	5.8E-15
Cr-51	1.0E-11	2.1E-16	7.2E-13	1.4E-12	7.4E-12	7.4E-12	1.3E-11	1.3E-11
Mn-52	4.5E-12	1.4E-14	4.0E-13	7.2E-14	2.1E-13	6.3E-11	4.5E-13	8.9E-11
Mn-54	1.6E-11	1.0E-12	7.7E-12	3.3E-13	4.5E-12	1.5E-09	1.1E-11	2.3E-09
Mn-56	1.2E-13	2.2E-16	8.6E-15	4.0E-16	2.9E-17	8.2E-15	5.1E-17	9.7E-15
Fe-55	1.8E-11	3.3E-14	3.3E-12	1.6E-13	1.5E-11	4.4E-09	1.0E-12	3.1E-11
Fe-59	1.2E-11	8.2E-15	1.8E-12	1.3E-13	1.2E-12	3.3E-10	1.4E-13	4.1E-12
Co-56	1.4E-11	7.7E-14	2.3E-12	4.4E-13	5.0E-13	1.2E-10	2.3E-12	1.9E-10
Co-57	1.6E-11	2.4E-13	3.0E-12	5.1E-13	1.1E-12	2.6E-10	4.7E-12	3.9E-10
Co-58	1.4E-11	7.0E-14	2.2E-12	4.3E-13	4.5E-13	1.1E-10	2.1E-12	1.8E-10
Co-60	1.8E-11	1.7E-12	3.3E-12	6.9E-13	2.2E-12	5.2E-10	8.6E-12	7.1E-10
Ni-63	3.1E-11	3.8E-12	7.1E-12	1.4E-11	4.7E-14	4.7E-13	1.3E-14	1.3E-13
Cu-61	1.6E-13	5.7E-16	1.1E-14	4.8E-14	1.4E-15	1.7E-17	4.1E-17	1.8E-17
Cu-64	5.7E-13	2.2E-15	4.0E-14	4.1E-13	4.3E-14	5.4E-16	1.4E-15	6.1E-16
Zn-62	4.2E-13	5.9E-16	3.3E-14	2.5E-13	2.0E-14	2.5E-16	6.1E-16	2.7E-16
Zn-65	1.8E-11	5.6E-13	1.2E-11	2.4E-11	6.1E-10	7.6E-12	2.0E-11	8.7E-12
Ga-67	3.0E-12	3.1E-17	2.2E-13	2.3E-14	3.3E-14	6.5E-12	2.2E-14	2.2E-14
Ga-68	5.1E-14	9.2E-20	3.5E-15	3.9E-17	8.5E-19	1.7E-16	4.9E-19	4.9E-19
Se-75	2.2E-11	1.8E-11	4.5E-11	4.9E-11	4.0E-10	9.9E-09	6.8E-10	1.4E-08
Br-76	7.3E-13	3.6E-15	6.3E-14	4.3E-12	9.9E-16	9.9E-15	1.1E-15	1.1E-14
Br-77	2.3E-12	9.1E-14	4.7E-13	1.8E-11	1.4E-14	1.4E-13	1.7E-14	1.7E-13
Br-82	1.5E-12	2.8E-14	2.0E-13	1.1E-11	5.6E-15	5.5E-14	6.5E-15	6.5E-14
Rb-81	2.1E-13	9.4E-16	1.5E-14	3.0E-13	1.5E-15	1.5E-15	1.7E-15	1.7E-15
Rb-82	2.7E-16	1.0E-18	1.9E-17	2.5E-18	6.1E-23	6.1E-23	6.2E-23	6.2E-23
Rb-83	1.7E-11	1.3E-11	3.7E-11	4.5E-11	3.1E-11	3.1E-11	5.4E-11	5.4E-11
Sr-83	1.4E-12	3.2E-15	9.7E-14	1.4E-13	1.0E-14	1.0E-14	1.5E-14	1.5E-14
Sr-85	1.4E-11	2.3E-13	2.1E-12	3.3E-12	6.8E-13	6.8E-13	9.6E-13	9.6E-13
Sr-89	1.3E-11	1.8E-13	1.9E-12	3.0E-12	6.0E-13	6.0E-13	8.5E-13	8.5E-13
Sr-90	3.8E-11	2.3E-11	4.2E-12	5.2E-11	1.1E-11	1.1E-11	6.8E-12	6.8E-12
Y-90	2.5E-12	4.4E-17	1.8E-13	1.9E-14	1.7E-16	1.7E-15	2.3E-16	2.3E-15
Zr-89	3.0E-12	9.9E-17	2.2E-13	4.1E-15	4.2E-16	3.5E-15	4.7E-15	4.7E-15
Zr-95	1.3E-11	1.3E-14	2.1E-12	1.4E-14	4.0E-15	3.4E-14	6.4E-14	6.4E-14

Radio-nuclide	Activity concentration (Bq/kg per Bq/y)*							
	Green veg	Root veg	Fruit	Cow milk	Cow meat	Cow liver	Sheep meat	Sheep liver
Nb-95	1.2E-11	1.0E-14	1.6E-12	1.4E-15	2.1E-16	8.2E-15	1.4E-14	1.4E-14
Mo-99	2.6E-12	5.0E-15	1.9E-13	1.1E-12	6.9E-14	6.9E-12	4.5E-13	9.1E-12
Tc-94m	5.6E-14	7.5E-15	4.5E-15	7.9E-14	9.6E-16	3.9E-15	6.9E-16	2.1E-15
Tc-99	2.1E-09	1.4E-09	1.4E-09	3.2E-09	3.2E-09	1.3E-08	1.0E-07	3.1E-07
Tc-99m	4.0E-13	5.5E-14	3.3E-14	2.0E-12	1.6E-13	6.2E-13	1.4E-13	4.2E-13
Ru-103	1.2E-11	3.0E-15	8.0E-13	3.3E-14	1.5E-12	4.6E-13	1.6E-13	7.7E-13
Ru-106	1.5E-11	2.8E-14	1.0E-12	4.2E-14	7.9E-12	2.4E-12	7.4E-13	3.5E-12
Ag-110m	1.6E-11	2.3E-14	4.9E-12	2.2E-10	6.3E-12	2.5E-09	4.7E-13	3.0E-09
In-111	2.7E-12	2.2E-17	1.9E-13	2.0E-13	6.2E-15	6.2E-15	8.1E-15	8.1E-15
In-113m	7.6E-14	1.4E-19	5.2E-15	8.2E-16	6.2E-19	6.2E-19	7.2E-19	7.2E-19
Sb-125	1.6E-11	3.0E-14	3.7E-12	1.9E-13	5.8E-12	4.8E-10	1.0E-11	1.0E-09
I-123	4.3E-12	1.5E-14	3.4E-13	1.6E-12	4.5E-13	4.5E-13	2.5E-13	2.5E-13
I-124	2.7E-11	2.5E-12	1.0E-11	3.6E-11	1.3E-11	1.3E-11	1.4E-11	1.4E-11
I-125	1.1E-10	7.8E-11	2.3E-10	1.3E-10	7.8E-11	7.8E-11	1.8E-10	1.8E-10
I-129	2.0E-10	1.9E-10	3.9E-10	1.8E-10	1.2E-10	1.2E-10	4.2E-10	4.2E-10
I-131	4.4E-11	9.2E-12	3.1E-11	6.2E-11	2.6E-11	2.6E-11	3.4E-11	3.4E-11
I-132	7.6E-13	4.2E-16	5.2E-14	1.7E-14	3.9E-15	3.9E-15	1.7E-15	1.7E-15
I-133	6.6E-12	5.0E-14	6.3E-13	4.0E-12	1.2E-12	1.2E-12	7.3E-13	7.3E-13
I-134	2.8E-13	1.3E-16	1.9E-14	7.3E-16	1.5E-16	1.5E-16	6.8E-17	6.8E-17
I-135	2.2E-12	2.7E-15	1.6E-13	3.3E-13	8.3E-14	8.3E-14	4.1E-14	4.1E-14
Cs-134	2.0E-11	1.8E-11	5.2E-11	2.7E-11	1.4E-10	1.4E-10	2.5E-10	2.5E-10
Cs-136	8.4E-12	2.8E-12	8.8E-12	9.6E-12	2.1E-11	2.1E-11	4.3E-11	4.3E-11
Cs-137	2.1E-11	2.1E-11	5.4E-11	3.2E-11	1.6E-10	1.6E-10	3.1E-10	3.1E-10
Ba-140	7.6E-12	1.3E-15	7.5E-13	4.1E-13	1.0E-13	3.6E-13	5.7E-13	5.7E-13
La-140	1.7E-12	1.8E-17	1.2E-13	1.2E-14	3.6E-17	5.5E-14	1.7E-15	6.9E-14
Ce-141	1.1E-11	1.5E-15	7.6E-13	7.3E-14	3.2E-14	6.3E-12	1.3E-15	1.0E-11
Ce-144	1.5E-11	1.3E-14	1.0E-12	1.3E-13	3.9E-13	7.7E-11	1.0E-14	8.0E-11
Pm-147	1.6E-11	3.1E-13	2.2E-12	9.2E-14	3.2E-12	2.5E-11	2.7E-12	1.6E-11
Sm-153	1.9E-12	6.4E-17	1.3E-13	1.4E-14	3.8E-16	7.5E-14	1.2E-17	9.6E-14
Eu-152	1.6E-11	5.0E-13	1.6E-12	1.0E-13	6.1E-12	4.9E-11	3.7E-12	2.3E-11
Eu-154	1.6E-11	3.6E-13	1.5E-12	9.9E-14	5.4E-12	4.4E-11	3.6E-12	2.1E-11
Eu-155	1.6E-11	2.1E-13	1.3E-12	9.6E-14	4.4E-12	3.5E-11	3.2E-12	1.9E-11
Er-169	6.3E-12	3.7E-16	4.3E-13	4.6E-14	5.9E-15	1.2E-12	2.2E-16	1.7E-12
Lu-177	5.1E-12	2.5E-16	3.5E-13	3.9E-14	3.5E-15	7.1E-13	1.3E-16	1.0E-12
Re-188	1.1E-12	1.6E-13	1.1E-13	7.5E-12	1.5E-12	5.9E-12	1.5E-12	4.5E-12
Au-198	2.5E-12	2.7E-16	1.8E-13	5.6E-15	2.4E-12	2.4E-12	3.0E-13	3.0E-13
Tl-201	2.9E-12	1.7E-13	7.8E-13	2.4E-12	1.1E-11	1.1E-11	1.5E-11	1.5E-11
Pb-210	1.8E-11	7.2E-13	5.7E-12	3.6E-12	1.1E-11	3.1E-11	9.4E-12	2.6E-11
Pb-212	4.8E-13	3.4E-17	3.3E-14	2.0E-14	1.3E-16	3.7E-16	1.5E-16	4.4E-16
Bi-213	3.4E-14	7.6E-19	2.3E-15	4.6E-16	4.9E-18	4.9E-18	7.0E-18	4.2E-18
Po-210	1.8E-11	1.5E-11	4.2E-11	9.2E-13	1.0E-11	2.7E-10	3.1E-11	3.7E-10
At-211	3.3E-13	4.6E-16	2.4E-14	3.2E-13	3.2E-17	9.7E-18	1.6E-17	2.7E-17
Ra-223	7.2E-12	6.1E-15	6.8E-13	9.5E-13	1.3E-12	3.8E-13	6.0E-13	6.0E-13
Ra-226	2.1E-11	6.1E-12	7.8E-12	4.9E-12	2.2E-11	6.4E-12	9.7E-12	9.7E-12
Ac-225	6.5E-12	3.3E-16	4.5E-13	7.0E-15	6.3E-16	1.3E-13	9.6E-16	1.9E-13
Th-227	9.0E-12	1.1E-16	6.2E-13	1.5E-14	1.7E-14	7.4E-14	1.2E-14	1.2E-13

Radio-nuclide	Activity concentration (Bq/kg per Bq/y)*							
	Green veg	Root veg	Fruit	Cow milk	Cow meat	Cow liver	Sheep meat	Sheep liver
Th-230	1.6E-11	7.0E-14	1.4E-12	5.5E-14	1.7E-12	7.4E-12	5.0E-13	5.0E-12
Th-232	1.6E-11	7.0E-14	1.4E-12	5.5E-14	1.7E-12	7.4E-12	5.0E-13	5.0E-12
Th-234	9.9E-12	1.5E-16	6.9E-13	1.6E-14	2.3E-14	1.0E-13	1.7E-14	1.7E-13
U-234	1.7E-11	7.5E-13	1.6E-12	1.4E-11	3.0E-12	1.5E-12	3.0E-12	3.0E-12
U-235	1.7E-11	7.5E-13	1.6E-12	1.4E-11	3.0E-12	1.5E-12	3.0E-12	3.0E-12
U-238	1.7E-11	7.5E-13	1.6E-12	1.4E-11	3.0E-12	1.5E-12	3.0E-12	3.0E-12
Np-237	1.7E-11	1.9E-12	2.0E-12	2.1E-14	1.2E-12	1.4E-10	7.3E-13	5.2E-11
Pu-238	1.6E-11	2.9E-14	1.1E-12	1.2E-14	6.6E-13	8.1E-11	5.4E-13	3.9E-11
Pu-239	1.6E-11	3.4E-14	1.2E-12	1.2E-14	6.8E-13	8.4E-11	5.5E-13	3.9E-11
Pu-240	1.6E-11	3.4E-14	1.2E-12	1.2E-14	6.8E-13	8.4E-11	5.5E-13	3.9E-11
Pu-241	1.6E-11	1.4E-14	1.1E-12	1.0E-14	5.6E-13	6.8E-11	5.0E-13	3.6E-11
Pu-242	1.6E-11	3.4E-14	1.2E-12	1.2E-14	6.8E-13	8.4E-11	5.5E-13	3.9E-11
Am-241	1.6E-11	5.5E-14	1.2E-12	1.7E-14	9.4E-13	1.2E-10	6.5E-13	4.6E-11
Am-242	7.2E-13	2.2E-18	4.9E-14	3.8E-18	8.9E-17	4.4E-15	1.4E-16	3.9E-15
Am-243	1.6E-11	5.7E-14	1.2E-12	1.7E-14	9.5E-13	1.2E-10	6.5E-13	4.6E-11
Cm-242	1.4E-11	1.0E-15	1.0E-12	1.6E-15	8.6E-14	1.0E-11	1.7E-13	1.2E-11
Cm-243	1.6E-11	4.5E-14	1.1E-12	1.1E-14	6.2E-13	7.5E-11	5.3E-13	3.8E-11
Cm-244	1.6E-11	3.5E-14	1.1E-12	1.0E-14	5.8E-13	7.1E-11	5.1E-13	3.6E-11

*for a release at ground level
^assumed the values for carbon-14

Table D.14. Soil activity concentration from deposited radionuclides per unit deposition rate used in the wildlife assessments

Radionuclide	Soil activity concentration (for a 50 y integration time) (Bq/kg per Bq/m^2/s)
H-3	6.3E+00
H-3 organic	6.3E+00
C-11	4.7E+01
C-14	4.7E+01
N-13	1.9E+00
O-15	3.9E-01
F-18	2.1E+01
Na-22	2.8E+05
Na-24	1.7E+02
P-32	4.2E+03
P-33	7.7E+03
S-35	3.1E+04
Cl-36	2.1E+06
Ca-45	5.8E+04
Ca-47	1.3E+03
V-48	4.8E+03
Cr-51	8.5E+03
Mn-52	1.6E+03
Mn-54	1.1E+05
Mn-56	3.0E+01
Fe-55	3.0E+05
Fe-59	1.4E+04
Co-56	2.7E+04
Co-57	9.4E+04
Co-58	2.4E+04
Co-60	5.4E+05
Ni-63	2.5E+06
Cu-61	3.9E+01
Cu-64	1.5E+02
Zn-62	1.1E+02
Zn-65	8.5E+04
Ga-67	9.2E+02
Ga-68	1.3E+01
Se-75	4.3E+04
Br-76	1.9E+02
Br-77	6.5E+02
Br-82	4.1E+02
Rb-81	5.3E+01
Rb-82	2.5E-01
Rb-83	3.0E+04
Sr-83	3.8E+02
Sr-85	2.2E+04
Sr-89	1.7E+04

Radionuclide	Soil activity concentration (for a 50 y integration time) (Bq/kg per Bq/m^2/s)
Sr-90	1.8E+06
Y-90	7.5E+02
Zr-89	9.2E+02
Zr-95	2.2E+04
Nb-95	1.1E+04
Mo-99	7.7E+02
Tc-94m	1.0E+01
Tc-99	1.0E+06
Tc-99m	7.0E+01
Ru-103	1.3E+04
Ru-106	1.2E+05
Ag-110m	8.7E+04
In-111	7.9E+02
In-113m	1.9E+01
Sb-125	3.0E+05
I-123	1.5E+02
I-124	1.2E+03
I-125	2.0E+04
I-129	2.9E+06
I-131	2.3E+03
I-132	2.7E+01
I-133	2.4E+02
I-134	1.0E+01
I-135	7.6E+01
Cs-134	2.3E+05
Cs-136	3.8E+03
Cs-137	1.8E+06
Ba-140	3.7E+03
La-140	4.7E+02
Ce-141	1.0E+04
Ce-144	9.8E+04
Pm-147	2.9E+05
Sm-153	5.4E+02
Eu-152	1.2E+06
Eu-154	8.4E+05
Eu-155	5.1E+05
Er-169	2.7E+03
Lu-177	1.9E+03
Re-188	2.0E+02
Au-198	7.6E+02
Tl-201	8.5E+02
Pb-210	1.6E+06
Pb-212	1.2E+02
Bi-213	8.8E+00
Po-210	4.9E+04

Radionuclide	Soil activity concentration (for a 50 y integration time) (Bq/kg per Bq/m^2/s)
At-211	8.3E+01
Ra-223	3.3E+03
Ra-226	2.9E+06
Ac-225	2.9E+03
Th-227	5.6E+03
Th-230	3.0E+06
Th-232	3.0E+06
Th-234	7.3E+03
U-234	3.0E+06
U-235	3.0E+06
U-238	3.0E+06
Np-237	3.0E+06
Pu-238	2.5E+06
Pu-239	3.0E+06
Pu-240	3.0E+06
Pu-241	1.2E+06
Pu-242	3.0E+06
Am-241	2.9E+06
Am-242	1.9E+02
Am-243	3.0E+06
Cm-242	5.8E+04
Cm-243	1.8E+06
Cm-244	1.4E+06

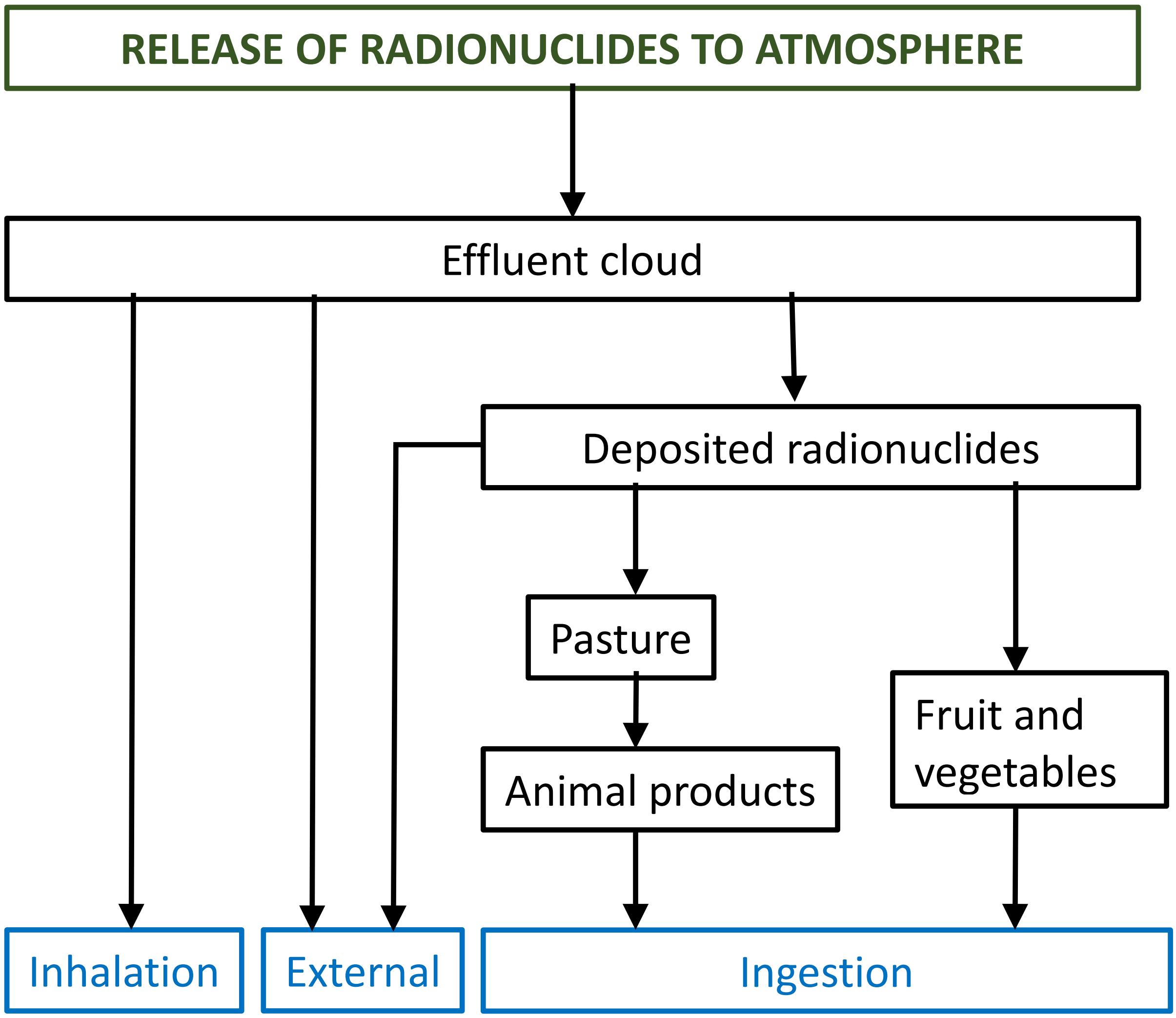

Figure D.1. Flow diagram of exposurepathways considered for atmospheric releases of radionuclides

Appendix E: Input data and calculation of DPUR factors for coastal discharges scenario

E.1 Source term

The source term for releases to the estuarine or coastal environment is either direct discharges to an estuary or into coastal water, or the discharge of treated effluent from a sewage treatment works. DPUR factors were not calculated for any radionuclides with half-lives of less than 3 hours, because of the relative timescales involved for the radionuclides to disperse and reach equilibrium with sediments and biota. The radionuclides considered for releases to the estuarine or coastal environment are shown in Table 1.

E.2 Exposed group for assessments to public

The following exposed group was considered. This was taken to be representative of people exposed to liquid discharges into the sea around the UK.

Fishing family

Pathways included are:

- internal radiation from the consumption of seafood contaminated with radionuclides;
- external radiation from radionuclides in beach and shore sediment.

Figure E.1 shows the matrix of pathways that were evaluated. Inhalation of seaspray, inhalation of resuspended sediment, inadvertent ingestion of seawater and external radiation from the handling of fishing gear were not included, since the resulting doses are much smaller than doses from the pathways listed above [E.1].

It was assumed that the members of the fishing family exposure group consume fish, molluscs and crustaceans at high consumption rates. Occupancy times above beach sediments and consumption rates are listed in Table E.1.

Radionuclides with half-lives of less than 3 hours were not considered for this exposed group.

E.3 Activity concentrations in filtered seawater and seabed sediments

E.3.1 Marine dispersion modelling

The transfer and dispersion of radionuclides between the discharge site and the points at which exposure occurs were determined by the marine dispersion model DORIS, which is part of the PC-CREAM 08 suite of models [E.2]. DORIS is a compartment model designed to model the dispersion of radionuclides in North

European coastal water. The model consists of a water dispersion model and a sedimentation model, which are described in detail elsewhere [E.2]. A brief summary of the model's main characteristics is given below.

Dispersion is modelled using the concept of a local marine compartment, which sits within one of the compartments of the regional model. Discharge occurs directly into the local compartment where it is assumed that it gets uniformly distributed instantly. From there water and suspended sediment exchange takes place with the adjacent regional compartment, characterised by volumetric exchange rates.

Activity concentrations in filtered seawater are calculated from activity concentrations in unfiltered seawater using the equation:

$$C_{filt} = \frac{C_{unf}}{1 + Kd \times SSL}$$

where C_{filt} is concentration in filtered seawater (Bq/l)
C_{unf} is concentration in unfiltered seawater (Bq/l)
K_d is seawater sediment partition coefficient (Bq/kg per Bq/l)
SSL is suspended sediment load (kg/l)

Partitioning between the water and sediment phases was calculated using published sediment partition coefficients (K_d) and it was assumed that the two phases are in equilibrium. The removal of activity to bottom sediments was evaluated using a particle scavenging approach, which is part of a three-compartment sediment model. Radionuclide concentrations in beach material were taken to be the same as those in the top layer of bed sediment (an assumption that is generally cautious, as beach materials are often of much coarser texture than that assumed for bed sediments).

Where data are available, coastal sediment partition coefficients, rather than deep ocean sediment partition coefficients, have been used, as most of the marine compartments around the UK can be classified as coastal [E.2]. The sediment partition coefficients are the same as those used to derive the wildlife dose factors (which are listed in Table A.2) and for clarity are repeated in this appendix in Table E.2.

E.3.2 Characterisation of coastal compartment

DORIS includes data for a number of specified sites around the UK coastline. A representative coastal location and regional compartment needed to be selected to carry out the model runs for this study. In addition, parameters had to be selected to characterise the local compartment into which the discharge takes place and in which most of the dose to the exposure group occurs.

For the purposes of this study it is important not to underestimate exposure, therefore a low volumetric exchange rate has been chosen as a default value. A volumetric exchange rate of 100 m^3/s (about 3.2E+09 m^3/y) was selected for the local compartment, as this is the lowest rate for which there is a linear relationship between dose and volumetric exchange rate. As a result the DPUR factors can be scaled by larger volumetric exchanges corresponding to different coastal locations. If scaling for lower exchange rates below 100 m^3/s to about 30 m^3/s then the dose ~~rate~~ will be cautious by a factor of about 2. Dewar *et al.* [E.3] and Smith [E.4] provides information that can be used to characterise local compartment properties for a wide range of locations around the UK coastline.

Cautiously, Heysham was chosen as the representative site, with default values for local compartment volume and suspended sediment load. Table E.3 lists the parameters characterising the local compartment.

E.3.3 DORIS modelling approach

DORIS fully incorporates radioactive decay and ingrowth of radioactive progeny by modelling the distribution of parent and progeny separately at each step. The concentration of the parent and first progeny were used in the calculations of DPUR factors. The parent/progeny pairs are shown in Table E.4.

DORIS was run to derive filtered seawater and seabed sediment activity concentrations in the local and regional compartments for a unit discharge of 1 Bq/y for all radionuclides. The resulting activity concentrations in seawater and beach sediment (Bq/l for seawater or Bq/kg for sediment) per unit release (Bq/y) are shown in Table E.4. Activity concentrations in seabed sediments are reported as dry mass of sediment but including the fraction of activity within the pore water. This was deemed appropriate as external doses are normally delivered above wet sediment containing pore water [E.5].

E.4 Dose rates for external exposure

E.4.1 External exposure from beach sediments

The activity concentrations in beach sediment calculated by DORIS consist of the top seabed sediment layer, which has a depth of 10 cm [E.3, E.6]. The sediment layer was assumed to be uniformly contaminated. External dose factors for a soil depth of 15 cm listed in Eckerman and Leggett and Eckerman and Ryman [E.7, E.8], using ICRP 60 dosimetry, were applied and converted from a volume source (Bq/m^3) to a source per unit mass basis (Bq/kg), applying a soil density of 1,600 kg/m^3 [E.8]. It was assumed that the spatial extent of tidally exposed sediments is large enough to assume an infinite slab geometry for the external dose factors.

Decay and ingrowth of progeny has been considered explicitly for a number of radionuclides by the DORIS code (see Section E.3.3) and external dose rates are presented for the progeny radionuclides for which sediment concentrations have been calculated. In addition, for the purpose of calculating external dose, dose coefficients for progeny which can be considered to be in secular equilibrium with their parent or which will decay significantly during the timescale considered have been added to their parent's dose coefficients. The resulting dose rates for external exposure above contaminated beach sediments per unit activity concentration in sediments are shown in Table E.5.

E.4.2 External dose rates per unit release

The effective dose rates from external exposure to beach sediments per unit release were calculated as follows:

$$DR_{ext\_bch} = DR_{ext\_bch(u)} A_{sed}$$

where DR_{ext_bch} is external dose rate from radionuclides in beach sediments per unit release rate (µSv/h per Bq/y)

$DR_{ext\_bch(u)}$ is external dose rate per unit activity concentration in beach sediments (µSv/h per Bq/kg)

A_{sed} is activity concentration in sediments per unit release rate (Bq/kg per Bq/y)

The resulting external dose rates per unit release are shown in Table E.6.

E.5 Activity concentrations in seafood

Activity concentrations in fish, crustaceans and molluscs per unit release rate were derived as follows:

$$A_{seafood} = A_{seawater} CF_{seafood}$$

where $A_{seafood}$ is activity concentration in the seafood under consideration per unit release rate (Bq/kg per Bq/y)

$A_{seawater}$ is activity concentration in filtered seawater per unit release rate (Bq/l per Bq/y)(see Table E.4)

$CF_{seafood}$ is the concentration factor for the seafood under consideration (Bq/kg per Bq/l)

The seafood concentration factors are shown in Table E.7. The activity concentrations of the seafoods per unit discharge rate are shown in Table E.8.

E.6 Method to calculate DPUR factors for people

The DPUR factors for the external exposure pathway for each age group were calculated as follows:

$$DPUR_{ext\_bch} = H_{occ,a} \ DR_{ext\_bch}$$

where $DPUR_{ext\_bch}$ is dose per unit release factor from external exposure to activity in beach sediments for the age group considered (µSv/y per Bq/y)

DR_{ext_bch} is external dose rate from activity in beach sediments adjacent to the local compartment per unit release rate (µSv/h per Bq/y)

$H_{occ,a}$ is total occupancy for the age group considered (h/y)

The DPUR factors for ingestion of seafoods were calculated as follows:

$$DPUR_{food,a} = (A_{food\_loc}\ f_{food\_loc} + A_{food\_reg} f_{food\_reg}) I_{food,a}\ DF_{ing,a}$$

where $DPUR_{food,a}$ is dose per unit release factor from the ingestion of a seafood type for the age group considered (µSv/y per Bq/y)

A_{food_loc} is activity concentration in the seafood type considered in the local compartment (Bq/kg per Bq/y)

A_{food_reg} is activity concentration in the seafood considered in the regional compartment (Bq/kg per Bq/y)

f_{food_loc} is the fraction of the seafood type considered from the local compartment

f_{food_reg} is fraction of the seafood type considered from the regional compartment

$I_{food,a}$ is ingestion rate of the seafood type for the age group considered (kg/y)

$DF_{ing,a}$ is ingestion dose coefficient for the age group considered (µSv/Bq)

The DPUR factors are shown in the main report: Tables 9-13 for the members of the fishing family exposure group.

E.7 Method to calculate DPUR factors for Wildlife

The exposed group for coastal releases to wildlife are the reference organisms for the marine environment, as described in the ERICA approach (see Appendix A). The dose factors (DPUC) for wildlife were calculated using the ERICA tool and are presented in Appendix A, Table A.8.

Activity concentrations in filtered seawater and seabed sediments used to calculate the DPUR for wildlife are the same as that for the public, as described in Section E.3. The wildlife DPUR are based on reference organisms being located in the local compartment. Local compartment parameters are shown in Table E.3. Activity concentrations in filtered seawater and seabed sediments are shown in Table E.4.

DPUR factors for marine wildlife were calculated from the seawater activity concentrations in the local compartment using the following equation:

$$DPUR_{wildlife} = A_{seawater}\ DF_{wildlife}$$

$DPUR_{wildlife}$ is the dose rate per unit release factor for wildlife (µGy/h per Bq/y)

$A_{seawater}$ is activity concentration in filtered seawater per unit release rate (Bq/l per Bq/y) (Table E.4)

$DF_{wildlife}$ is the dose factor for wildlife per unit concentration in water (µGy/h per Bq/l) (See Appendix A, Table A.8)

The DPUR factors for wildlife exposed to coastal releases are shown in Tables 14 and 15 in the main report. Radionuclides with half-lives of less than 3 hours were not considered.

E.8 References

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E.7 Eckerman, K F and Leggett, R W (2002). DCFPAK: Dose Coefficient File Package for Sandia National Laboratory. Dosimetry Research Group, Oak Ridge National Laboratory.

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E.13 Tröjbom M, Grolander S, Rensfeldt V and Nordén S (2013) K_d and CR used for transport calculations in the biosphere in SR-PSU. SKB Report R-13-01.

E.14 IAEA (2001). Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment. Safety Reports Series No 19. International Atomic Energy Agency, Vienna.

Table E.1. Habit data for fishing family exposure group

	Infant	Child	Adult	Comment	Fraction in compartment	
					Local	Regional
Food consumption rates (kg /y)				[E.9]		
Fish	5	20	100		0.5	0.5
Crustaceans	0	5	20		1	0
Molluscs	0	5	20		1	0
Occupancy on beach (h/y)	30	300	2,000	[E.9]	1	0

Table E.2. Coastal water/sediment K_d

Element	Marine K_d (l/kg)	Reference
Ac	2000000	[E.10]
Ag	10000	[E.10]
Am	2000000	[E.10]
At	70	Iodine used as analogue*
Au	10000	Silver used as analogue*
Ba	2000	[E.10]
Br	0.03	Chlorine used as analogue*
C	1000	[E.10]
Ca	500	[E.10]
Ce	3000000	[E.10]
Cl	0.03	[E.10]
Cm	2000000	[E.10]
Co	300000	[E.10]
Cr	50000	[E.10]
Cs	4000	[E.10]
Cu	70000	Zinc used as analogue*
Er	3000000	Cerium used as analogue*
Eu	2000000	[E.10]
Fe	3E+08	[E.10]
Ga	300	Use value for soil in [E.11]*
H	1	[E.10]
H-3 org.	1000	Carbon used as analogue*
I	70	[E.10]
In	50000	[E.10]
La	1200000	[E.12]
Lu	3000000	Cerium used as analogue*

Mn	2000000	[E.10]
Mo	2300	[E.13]
Na	0.1	[E.10]
Nb	800000	[E.10]
Ni	20000	[E.10]
Np	1000	[E.10]
P	100	[E.2]
Pb	100000	[E.10]
Pm	2000000	[E.10]
Po	20000000	[E.10]
Pu	100000	[E.10]
Ra	2000	[E.10]
Rb	4000	Caesium used as analogue*
Re	110	[E.13]
Ru	40000	[E.10]
S	0.5	[E.10]
Sb	2000	[E.10]
Se	3000	[E.10]
Sm	3000000	[E.10]
Sr	8	[E.10]
Tc	100	[E.10]
Th	3000000	[E.10]
Tl	20000	[E.10]
U	1000	[E.10]
V	800000	Niobium used as analogue*
Y	900000	[E.10]
Zn	70000	[E.10]
Zr	2000000	[E.10]

*See Table C.4.

Table E.3. Parameters characterising the local compartment

	Value	Comment
Volume (m^3)	1.0E+08	[E.2]
Depth (m)	10	[E.2]
Coastline length (km)	10	[E.2]
Volumetric exchange (m^3 /y)	3.2E+09	see Section E.3.2
Suspended sediment load (te /m^3)	1.0E-05	[E.2]
Sedimentation rate (te per m^2 /y)	4.9E-03	[E.2]
Density of dry sediment particles (te /m^3)	2.6	[E.2]
Diffusion rate (sediment diffusion coefficient) (m^2 /y)	3.15E-02	[E.2]

Table E.4. Filtered seawater and beach sediment concentrations per unit release rate

Radionuclide		Filtered seawater concentration (Bq/l per Bq/y)*				Beach sediment concentration (Bq/kg per Bq/y)*+#			
		Local compartment		Regional compart.		Local compartment		Regional compart.	
Parent	Progeny	Parent	Progeny	Parent	Progeny	Parent	Progeny	Parent	Progeny
H-3		3.2E-13		7.5E-15		5.5E-13		1.3E-14	
H-3 org.		3.1E-13		6.8E-15		3.0E-10		6.6E-12	
C-14		3.1E-13		6.8E-15		3.0E-10		6.6E-12	
Na-22		3.2E-13		6.9E-15		2.8E-13		6.1E-15	
Na-24		2.3E-14		5.6E-18		3.3E-16		8.1E-20	
P-32		2.0E-13		8.8E-16		2.1E-13		9.9E-16	
P-33		2.4E-13		1.6E-15		4.4E-13		3.2E-15	
S-35		2.9E-13		3.8E-15		2.0E-13		2.7E-15	
Cl-36		3.2E-13		7.8E-15		3.8E-13		9.2E-15	
Ca-45		3.0E-13		4.6E-15		1.2E-11		2.1E-13	
Ca-47	Sc-47	1.1E-13	1.5E-15	1.8E-16	6.3E-18	1.4E-13	7.5E-12	2.5E-16	3.6E-14
V-48		9.3E-15		1.3E-17		5.9E-11		9.5E-14	
Cr-51		9.8E-14		2.8E-16		6.6E-11		2.2E-13	
Mn-52		3.1E-15		3.6E-18		1.7E-11		2.3E-14	
Mn-54		4.5E-15		6.8E-18		1.2E-09		2.0E-12	
Fe-55		3.2E-17		5.1E-20		3.2E-09		5.4E-12	
Fe-59		2.8E-17		3.8E-20		1.8E-10		2.8E-13	
Co-56		2.6E-14		4.6E-17		3.0E-10		5.9E-13	
Co-57		2.7E-14		5.1E-17		9.7E-10		2.0E-12	
Co-58		2.6E-14		4.6E-17		2.7E-10		5.3E-13	
Co-60		3.1E-14		6.7E-17		4.5E-09		1.0E-11	
Ni-63		2.1E-13		1.7E-15		3.9E-09		3.3E-11	
Cu-61		3.2E-15		2.5E-19		1.6E-14		1.4E-18	
Cu-64		1.1E-14		2.9E-18		2.0E-13		6.0E-17	
Zn-62	Cu-62	8.2E-15	8.1E-15	1.6E-18	1.7E-18	1.1E-13	1.1E-13	2.5E-17	2.5E-17
Zn-65		9.0E-14		2.8E-16		6.8E-10		2.4E-12	
Ga-67		9.1E-14		1.1E-16		5.1E-14		6.9E-17	
Se-75		2.7E-13		3.1E-15		4.6E-11		5.9E-13	
Br-76		2.5E-14		6.5E-18		3.9E-16		1.0E-19	
Br-77		7.1E-14		6.3E-17		3.7E-15		3.2E-18	
Br-82		4.9E-14		2.8E-17		1.6E-15		9.2E-19	
Rb-81	Kr-81	7.1E-15	7.8E-22	5.4E-19	1.9E-23	2.7E-15	2.6E-21	2.4E-19	2.2E-23
Rb-83		2.6E-13		2.5E-15		4.2E-11		4.7E-13	
Sr-83	Rb-83	4.6E-14	3.4E-15	2.4E-17	4.0E-17	1.7E-15	5.7E-13	9.0E-19	7.5E-15
Sr-85		2.8E-13		3.2E-15		3.9E-13		4.5E-15	
Sr-89		2.7E-13		2.8E-15		3.1E-13		3.2E-15	
Sr-90		3.2E-13		7.6E-15		2.2E-12		5.3E-14	
Y-90		5.0E-15		5.0E-18		5.9E-12		6.7E-15	
Zr-89		2.6E-15		2.7E-18		8.2E-12		9.8E-15	
Zr-95	Nb-95	4.2E-15	7.2E-16	6.0E-18	1.7E-18	2.6E-10	2.7E-10	4.2E-13	4.4E-13
Nb-95		1.0E-14		1.5E-17		1.4E-10		2.3E-13	
Mo-99	Tc-99m	7.8E-14	7.7E-14	8.0E-17	8.8E-17	2.5E-13	2.5E-13	2.9E-16	2.9E-16
Tc-99		3.2E-13		7.6E-15		2.8E-11		6.8E-13	0.0E+00
Tc-99m	Tc-99	9.6E-15	1.0E-21	9.5E-19	2.5E-23	1.8E-16	9.0E-20	1.9E-20	2.2E-21
Ru-103		1.2E-13		4.0E-16		8.9E-11		3.4E-13	0.0E+00

Radionuclide		Filtered seawater concentration (Bq/l per Bq/y)*				Beach sediment concentration (Bq/kg per Bq/y)*+#			
		Local compartment		Regional compart.		Local compartment		Regional compart.	
Parent	Progeny	Parent	Progeny	Parent	Progeny	Parent	Progeny	Parent	Progeny
Ru-106		1.3E-13		5.6E-16		8.1E-10		3.8E-12	0.0E+00
Ag-110m		2.3E-13		2.0E-15		2.5E-10		2.4E-12	
In-111		4.5E-14		4.7E-17		3.2E-12		3.7E-15	
Sb-125	Te-125m	3.0E-13	4.0E-14	5.1E-15	3.0E-15	2.0E-10	2.0E-10	3.7E-12	3.7E-12
I-123	Te-123	2.0E-14	4.4E-29	4.4E-18	1.0E-30	6.5E-16	4.3E-26	1.5E-19	1.0E-27
I-124		1.1E-13		1.6E-16		2.6E-14		4.3E-17	
I-125		2.8E-13		3.1E-15		9.2E-13		1.1E-14	
I-129		3.2E-13		7.7E-15		1.9E-11		4.7E-13	
I-131	Xe-131m	1.6E-13	6.3E-14	4.3E-16	5.9E-16	7.3E-14	6.6E-14	2.2E-16	2.8E-16
I-133	Xe-133	3.1E-14	1.9E-14	1.0E-17	4.4E-17	1.6E-15	3.3E-15	5.7E-19	5.2E-18
I-135	Xe-135	1.1E-14	1.0E-14	1.1E-18	2.6E-18	1.7E-16	2.6E-16	2.0E-20	4.3E-20
Cs-134		2.8E-13		3.9E-15		3.0E-10		4.6E-12	
Cs-136		1.8E-13		6.7E-16		4.6E-12		2.0E-14	
Cs-137		2.9E-13		4.7E-15		9.6E-10		1.6E-11	
Ba-140	La-140	1.8E-13	8.4E-15	7.1E-16	7.5E-17	2.4E-12	1.1E-11	1.0E-14	9.5E-14
La-140		3.0E-15		2.5E-18		3.0E-12		2.8E-15	
Ce-141		2.7E-15		3.8E-18		1.3E-10		2.0E-13	
Ce-144		3.0E-15		4.4E-18		1.1E-09		1.8E-12	
Pm-147	Sm-147	4.8E-15	2.1E-26	7.8E-18	8.8E-29	3.1E-09	2.2E-19	5.5E-12	5.1E-22
Sm-153		1.3E-15		1.2E-18		3.9E-12		3.9E-15	
Eu-152	Gd-152	5.4E-15	7.6E-29	1.0E-17	3.4E-31	7.7E-09	5.3E-22	1.5E-11	1.3E-24
Eu-154		5.3E-15		9.7E-18		6.5E-09		1.3E-11	
Eu-155		5.0E-15		8.7E-18		4.7E-09		8.8E-12	
Er-169		2.3E-15		3.0E-18		3.2E-11		4.6E-14	
Lu-177		2.2E-15		2.6E-18		2.2E-11		3.0E-14	
Re-188		2.6E-14		7.1E-18		1.4E-15		4.3E-19	
Au-198		6.8E-14		6.9E-17		9.2E-13		1.1E-15	
Tl-201		6.5E-14		7.2E-17		2.0E-12		2.5E-15	
Pb-210	Po-210	8.4E-14	1.0E-16	2.9E-16	5.9E-19	6.7E-09	6.4E-09	2.4E-11	2.3E-11
Pb-212	Bi-212	7.8E-15	1.5E-14	1.9E-18	2.7E-18	1.7E-13	1.7E-13	4.7E-17	4.7E-17
Po-210		4.4E-16		6.2E-19		5.7E-10		9.0E-13	
At-211		1.1E-14		1.4E-18		2.0E-16		2.6E-20	
Ra-223	Pb-211	1.8E-13	8.9E-14	6.2E-16	4.8E-16	2.0E-12	2.1E-12	8.1E-15	8.8E-15
Ra-226^	Pb-210^	3.0E-13	2.7E-16	6.0E-15	1.4E-17	6.0E-10	1.8E-10	1.2E-11	4.2E-12
Ac-225	Bi-213	3.5E-15	7.3E-14	4.5E-18	3.3E-17	3.5E-11	3.5E-11	5.1E-14	5.1E-14
Th-227	Ra-223	2.6E-15	3.2E-14	3.5E-18	1.4E-16	7.2E-11	7.2E-11	1.1E-13	1.1E-13
Th-230	Ra-226	4.1E-15	4.2E-16	8.7E-18	1.2E-17	1.2E-08	4.0E-11	2.6E-11	9.7E-14
Th-232	Ra-228	4.1E-15	6.0E-14	8.7E-18	1.7E-15	1.2E-08	5.8E-09	2.6E-11	1.3E-11
Th-234	U-234	2.7E-15	3.0E-20	3.6E-18	8.4E-22	9.4E-11	2.0E-15	1.5E-13	3.5E-18
U-234	Th-230	3.1E-13	4.0E-21	6.8E-15	1.3E-22	3.0E-10	3.3E-14	6.6E-12	7.8E-16
U-235	Pa-231	3.1E-13	2.7E-20	6.8E-15	9.0E-22	3.0E-10	7.7E-14	6.6E-12	1.9E-15
U-238	U-234	3.1E-13	1.2E-19	6.8E-15	2.0E-20	3.0E-10	6.5E-15	6.6E-12	1.4E-16
Np-237	U-233	3.1E-13	1.8E-19	6.8E-15	3.1E-20	3.0E-10	1.0E-14	6.6E-12	2.2E-16
Pu-238	U-234	8.7E-14	2.0E-18	3.2E-16	8.0E-20	8.2E-09	1.7E-13	3.0E-11	6.4E-16
Pu-239	U-235	8.9E-14	7.4E-22	3.4E-16	3.0E-23	8.8E-09	6.5E-17	3.3E-11	2.4E-19
Pu-240	U-236	8.8E-14	2.2E-20	3.4E-16	9.0E-22	8.8E-09	1.9E-15	3.3E-11	7.3E-18
Pu-241	Am-241	8.2E-14	1.4E-17	2.8E-16	9.0E-20	5.9E-09	1.0E-10	2.1E-11	4.0E-13

Radionuclide		Filtered seawater concentration (Bq/l per Bq/y)*				Beach sediment concentration (Bq/kg per Bq/y)*+#			
		Local compartment		Regional compart.		Local compartment		Regional compart.	
Parent	Progeny	Parent	Progeny	Parent	Progeny	Parent	Progeny	Parent	Progeny
Pu-242	U-238	8.9E-14	1.2E-22	3.4E-16	4.7E-24	8.8E-09	1.0E-17	3.3E-11	3.8E-20
Am-241	Np-237	6.0E-15	3.2E-19	1.3E-17	1.0E-20	1.2E-08	2.8E-14	2.5E-11	6.3E-17
Am-242	Cm-242	9.8E-16	1.4E-17	5.0E-19	2.4E-20	6.5E-13	2.7E-12	3.7E-16	4.4E-15
Am-243	Pu-239	6.0E-15	7.6E-18	1.3E-17	5.2E-20	1.2E-08	3.4E-12	2.6E-11	9.9E-15
Cm-242	Pu-238	4.4E-15	1.2E-16	6.4E-18	7.0E-19	6.5E-10	4.9E-11	1.1E-12	1.2E-13
Cm-243	Pu-239	5.7E-15	6.1E-18	1.2E-17	4.1E-20	9.5E-09	2.7E-12	2.0E-11	7.8E-15
Cm-244	Pu-240	5.5E-15	2.0E-17	1.1E-17	1.4E-19	8.5E-09	9.0E-12	1.7E-11	2.5E-14

*for a water exchange rate of 100 m^3/s
+activity concentrations in sediments contain fraction of activity in pore water
^not an output from DORIS. Based on a ratio of Ra-226:Pb-210 from IRAT1 and applied to Ra-226 in IRAT2 to generate the value for Pb-210 in IRAT2.
beach sediment is also seabed sediment.

Table E.5. External dose rates per unit concentration in sediment

Radionuclide	Dose rate above sediment (µSv/h per Bq/kg)			Progeny considered explicitly in assessment	Dose rate above sediment (µSv/h per Bq/kg)		
	Dose rate parent	Dose rate including all progeny	Comments		Dose rate	Dose rate including all progeny	Comments
H-3	0.0E+00	0.0E+00					
H-3 organic	0.0E+00	0.0E+00					
C-14	3.4E-10	3.4E-10					
Na-22	3.4E-04	3.4E-04					
Na-24	6.6E-04	6.6E-04					
P-32	6.1E-07	6.1E-07					
P-33	1.5E-09	1.5E-09					
S-35	3.8E-10	3.8E-10					
Cl-36	7.4E-08	7.4E-08					
Ca-45	1.6E-09	1.6E-09					
Ca-47	1.7E-04	1.7E-04		Sc-47	1.4E-05	1.4E-05	
V-48	4.6E-04	4.6E-04					
Cr-51	4.7E-06	4.7E-06					
Mn-52	5.5E-04	5.5E-04					
Mn-54	1.3E-04	1.3E-04					
Fe-55	0.0E+00	0.0E+00					
Fe-59	1.9E-04	1.9E-04					
Co-56	5.7E-04	5.7E-04					
Co-57	1.4E-05	1.4E-05					
Co-58	1.5E-04	1.5E-04					
Co-60	4.0E-04	4.0E-04					
Ni-63	0.0E+00	0.0E+00					
Cu-61	1.3E-04	1.3E-04					
Cu-64	2.9E-05	2.9E-05					

Radionuclide	Dose rate above sediment (μSv/h per Bq/kg)			Progeny considered explicitly in assessment	Dose rate above sediment (μSv/h per Bq/kg)		
	Dose rate parent	Dose rate including all progeny	Comments		Dose rate	Dose rate including all progeny	Comments
Zn-62	6.6E-05	6.6E-05		Cu-62	1.6E-04	1.6E-04	
Zn-65	9.2E-05	9.2E-05					
Ga-67	2.0E-05	2.0E-05					
Se-75	5.4E-05	5.4E-05					
Br-76	4.1E-04	4.1E-04					
Br-77	4.8E-05	4.8E-05					
Br-82	4.1E-04	4.1E-04					
Rb-81	9.3E-05	9.3E-05		Kr-81	8.1E-07	8.1E-07	
Rb-83	7.7E-05	7.7E-05					
Sr-83	1.2E-04	1.2E-04		Rb-83	7.7E-05	7.7E-05	
Sr-85	7.7E-05	7.7E-05					
Sr-89	4.5E-07	4.5E-07					
Sr-90	2.0E-08	1.2E-06	Y-90 included				
Y-90	1.2E-06	1.2E-06					
Zr-89	1.8E-04	1.8E-04					
Zr-95	1.2E-04	1.2E-04		Nb-95	1.2E-04	1.2E-04	
Nb-95	1.2E-04	1.2E-04					
Mo-99	2.3E-05	2.3E-05		Tc-99m	1.5E-05	1.5E-05	
Tc-99	3.3E-09	3.3E-09					
Tc-99m	1.5E-05	1.5E-05		Tc-99	3.3E-09	3.3E-09	
Ru-103	7.2E-05	7.2E-05					
Ru-106	0.0E+00	3.4E-05	Rh-106 included				
Ag-110m	4.3E-04	4.3E-04					
In-111	5.4E-05	5.4E-05					
Sb-125	6.4E-05	6.4E-05		Te-125m	3.4E-07	3.4E-07	
I-123	1.9E-05	1.9E-05		Te-123	1.4E-07	1.4E-07	
I-124	1.7E-04	1.7E-04					

Radionuclide	Dose rate above sediment (µSv/h per Bq/kg)			Progeny considered explicitly in assessment	Dose rate above sediment (µSv/h per Bq/kg)		
	Dose rate parent	Dose rate including all progeny	Comments		Dose rate	Dose rate including all progeny	Comments
I-125	3.7E-07	3.7E-07					
I-129	2.9E-07	2.9E-07					
I-131	5.7E-05	5.7E-05		Xe-131m	5.8E-07	5.8E-07	
I-133	9.4E-05	9.4E-05		Xe-133	2.7E-06	2.7E-06	
I-135	4.1E-04	4.1E-04		Xe-135	3.6E-05	3.6E-05	
Cs-134	4.8E-05	4.8E-05					
Cs-136	4.1E-04	4.1E-04					
Cs-137	9.3E-05	9.3E-05	Ba-137m included				
Ba-140	2.7E-05	2.7E-05		La-140	3.7E-04	3.7E-04	
La-140	3.7E-04	3.7E-04					
Ce-141	8.8E-06	8.8E-06					
Ce-144	2.0E-06	8.9E-06	Pr-144 included				
Pm-147	1.3E-09	1.3E-09		Sm-147	0.0E+00	0.0E+00	
Sm-153	4.3E-06	4.3E-06					
Eu-152	1.8E-04	1.8E-04		Gd-152	0.0E+00	0.0E+00	
Eu-154	1.9E-04	1.9E-04					
Eu-155	5.0E-06	5.0E-06					
Er-169	3.7E-09	3.7E-09					
Lu-177	4.3E-06	4.3E-06					
Re-188	8.8E-06	8.8E-06					
Au-198	6.1E-05	6.1E-05					
Tl-201	7.5E-06	7.5E-06					
Pb-210	6.1E-08	2.3E-07	Bi-210 only (Po-210 treated explicitly)	Po-210	1.3E-09	1.3E-09	
Pb-212	1.9E-05	1.9E-05		Bi-212	2.9E-05	2.9E-05	
Po-210	1.3E-09	1.3E-09					

Radionuclide	Dose rate above sediment (µSv/h per Bq/kg)			Progeny considered explicitly in assessment	Dose rate above sediment (µSv/h per Bq/kg)		
	Dose rate parent	Dose rate including all progeny	Comments		Dose rate	Dose rate including all progeny	Comments
At-211	3.1E-06	3.1E-06					
Ra-223	1.6E-05	4.0E-05	Rn-219 through to Tl-207 included				
Ra-226	8.7E-07	2.8E-04	Rn-222 through to Po-214 included	Pb-210	6.1E-08	2.3E-07	Bi-210 only
Ac-225	1.7E-06	6.0E-06	Fr-221 and At-217 included	Bi-213	2.0E-05	2.0E-05	Po-213 and Pb-209 included
Th-227	1.4E-05	1.4E-05		Ra-223	1.6E-05	4.0E-05	Rn-219 to Tl-207 included
Th-230	3.3E-08	3.3E-08		Ra-226	8.7E-07	2.8E-04	Rn-222 to Po-214 included
Th-232	1.4E-08	1.4E-08		Ra-228	0.0E+00	3.9E-04	Ac-228 to Tl-208 are included
Th-234	6.6E-07	3.4E-06	Pa-234m only included	U-234	1.1E-08	1.1E-08	
U-234	1.1E-08	1.1E-08		Th-230	3.3E-08	3.3E-08	
U-235	2.0E-05	2.1E-05	Th-231 included	Pa-231	5.1E-06	5.1E-06	
U-238	2.5E-09	3.8E-06	Th-234 to U-234 included	U-234	1.1E-08	1.1E-08	
Np-237	2.1E-06	3.0E-05	Pa-233 included	U-233	3.8E-08	3.8E-08	
Pu-238	3.6E-09	3.6E-09		U-234	1.1E-08	1.1E-08	
Pu-239	7.8E-09	7.8E-09		U-235	2.0E-05	2.1E-05	Th-231 included
Pu-240	3.5E-09	3.5E-09		U-236	5.5E-09	5.5E-09	
Pu-241	1.6E-10	1.6E-10		Am-241	1.1E-06	1.1E-06	
Pu-242	3.1E-09	3.1E-09		U-238	2.5E-09	3.4E-06	Th-234 to U-234 included
Am-241	1.1E-06	1.1E-06		Np-237	2.1E-06	3.0E-05	Pa-233 included
Am-242	1.4E-06	1.4E-06		Cm-242	3.9E-09	3.9E-09	
Am-243	3.8E-06	2.4E-05	Np-239 only included	Pu-239	7.8E-09	7.8E-09	
Cm-242	3.9E-09	3.9E-09		Pu-238	3.6E-09	3.6E-09	
Cm-243	1.6E-05	1.6E-05		Pu-239	7.8E-09	7.8E-09	

Radionuclide	Dose rate above sediment (µSv/h per Bq/kg)			Progeny considered explicitly in assessment	Dose rate above sediment (µSv/h per Bq/kg)		
	Dose rate parent	Dose rate including all progeny	Comments		Dose rate	Dose rate including all progeny	Comments
Cm-244	2.8E-09	2.8E-09		Pu-240	3.5E-09	3.5E-09	

Table E.6. External dose rates per unit release rate

Radionuclide		Dose rate per unit release (µSv/h per Bq/y)*			
		Local compartment		Regional compartment	
Parent	Progeny	Parent	Progeny	Parent	Progeny
H-3		0.0E+00		0.0E+00	
H-3 organic		0.0E+00		0.0E+00	
C-14		1.0E-19		2.3E-21	
Na-22		9.4E-17		2.1E-18	
Na-24		2.2E-19		5.4E-23	
P-32		1.3E-19		6.1E-22	
P-33		6.5E-22		4.7E-24	
S-35		7.7E-23		1.0E-24	
Cl-36		2.8E-20		6.8E-22	
Ca-45		1.9E-20		3.3E-22	
Ca-47	Sc-47	2.3E-17	1.1E-16	4.3E-20	5.0E-19
V-48		2.7E-14		4.4E-17	
Cr-51		3.1E-16		1.0E-18	
Mn-52		9.4E-15		1.3E-17	
Mn-54		1.6E-13		2.6E-16	
Fe-55		0.0E+00		0.0E+00	
Fe-59		3.5E-14		5.3E-17	
Co-56		1.7E-13		3.4E-16	
Co-57		1.4E-14		2.8E-17	
Co-58		4.0E-14		7.9E-17	
Co-60		1.8E-12		4.2E-15	
Ni-63		0.0E+00		0.0E+00	
Cu-61		2.0E-18		1.8E-22	
Cu-64		5.8E-18		1.8E-21	
Zn-62	Cu-62	7.2E-18	1.7E-17	1.6E-21	4.0E-21
Zn-65		6.3E-14		2.2E-16	
Ga-67		1.0E-18		1.4E-21	
Se-75		2.5E-15		3.2E-17	
Br-76		1.6E-19		4.1E-23	
Br-77		1.8E-19		1.6E-22	
Br-82		6.7E-19		3.8E-22	
Rb-81	Kr-81	2.5E-19	2.1E-27	2.2E-23	1.8E-29
Rb-83		3.2E-15		3.6E-17	
Sr-83	Rb-83	2.1E-19	4.4E-17	1.1E-22	5.8E-19
Sr-85		3.0E-17		3.5E-19	
Sr-89		1.4E-19		1.4E-21	
Sr-90		2.7E-18		6.4E-20	
Y-90		7.1E-18		8.0E-21	
Zr-89		1.5E-15		1.8E-18	
Zr-95	Nb-95	3.1E-14	3.2E-14	5.0E-17	5.3E-17
Nb-95		1.6E-14		2.8E-17	
Mo-99	Tc-99m	5.7E-18	3.8E-18	6.6E-21	4.4E-21
Tc-99		9.2E-20		2.2E-21	

Radionuclide		Dose rate per unit release (µSv/h per Bq/y)*			
		Local compartment		Regional compartment	
Parent	Progeny	Parent	Progeny	Parent	Progeny
Tc-99m	Tc-99	2.6E-21	3.0E-28	2.9E-25	7.2E-30
Ru-103		6.4E-15		2.5E-17	
Ru-106		2.8E-14		1.3E-16	
Ag-110m		1.1E-13		1.0E-15	
In-111		1.7E-16		2.0E-19	
Sb-125	Te-125m	1.3E-14	6.6E-17	2.4E-16	1.3E-18
I-123	Te-123	1.2E-20	6.1E-33	2.9E-24	1.4E-34
I-124		4.5E-18		7.3E-21	
I-125		3.4E-19		4.0E-21	
I-129		5.5E-18		1.4E-19	
I-131	Xe-131m	4.2E-18	3.8E-20	1.2E-20	1.6E-22
I-133	Xe-133	1.5E-19	8.9E-21	5.3E-23	1.4E-23
I-135	Xe-135	4.2E-20	9.2E-21	5.0E-24	1.5E-24
Cs-134		7.3E-14		1.1E-15	
Cs-136		1.6E-15		6.7E-18	
Cs-137		8.5E-14		1.4E-15	
Ba-140	La-140	6.4E-17	4.0E-15	2.8E-19	3.5E-17
La-140		1.1E-15		1.0E-18	
Ce-141		1.1E-15		1.8E-18	
Ce-144		9.9E-15		1.6E-17	
Pm-147	Sm-147	4.0E-18		7.1E-21	
Sm-153		1.7E-17		1.7E-20	
Eu-152	Gd-152	1.4E-12		2.7E-15	
Eu-154		1.2E-12		2.4E-15	
Eu-155		2.4E-14		4.4E-17	
Er-169		1.2E-19		1.7E-22	
Lu-177		9.3E-17		1.3E-19	
Re-188		1.2E-20		3.8E-24	
Au-198		5.6E-17		6.4E-20	
Tl-201		1.5E-17		1.9E-20	
Pb-210	Po-210	1.5E-15	8.3E-18	5.5E-18	3.0E-20
Pb-212	Bi-212	3.3E-18	5.0E-18	9.1E-22	1.4E-21
Po-210		7.4E-19		1.2E-21	
At-211		6.3E-22		8.1E-26	
Ra-223		8.2E-17		3.3E-19	
Ra-226	Pb-210	1.7E-13	4.2E-17	3.3E-15	9.7E-19
Ac-225	Bi-213	2.1E-16	7.1E-16	3.0E-19	1.0E-18
Th-227	Ra-223	1.0E-15	2.9E-15	1.5E-18	4.4E-18
Th-230	Ra-226	4.0E-16	1.1E-14	8.5E-19	2.7E-17
Th-232	Ra-228	1.7E-16	2.3E-12	3.6E-19	5.2E-15
Th-234	U-234	3.2E-16	2.2E-23	4.9E-19	3.9E-26
U-234	Th-230	3.3E-18	1.1E-21	7.3E-20	2.6E-23
U-235	Pa-231	6.4E-15	3.9E-19	1.4E-16	9.4E-21
U-238	U-234	1.2E-15	7.2E-23	2.5E-17	1.6E-24
Np-237	U-233	9.1E-15	3.8E-22	2.0E-16	8.4E-24
Pu-238	U-234	2.9E-17	1.9E-21	1.1E-19	7.0E-24

Radionuclide		Dose rate per unit release (µSv/h per Bq/y)*			
		Local compartment		Regional compartment	
Parent	**Progeny**	**Parent**	**Progeny**	**Parent**	**Progeny**
Pu-239	U-235	6.9E-17	1.4E-21	2.6E-19	5.1E-24
Pu-240	U-236	3.1E-17	1.1E-23	1.2E-19	4.0E-26
Pu-241	Am-241	9.5E-19	1.1E-16	3.3E-21	4.4E-19
Pu-242	U-238	2.7E-17	3.4E-23	1.0E-19	1.3E-25
Am-241	Np-237	1.3E-14	8.5E-19	2.8E-17	1.9E-21
Am-242	Cm-242	9.0E-19	1.0E-20	5.2E-22	1.7E-23
Am-243	Pu-239	2.9E-13	2.6E-20	6.2E-16	7.7E-23
Cm-242	Pu-238	2.5E-18	1.8E-19	4.2E-21	4.4E-22
Cm-243	Pu-239	1.5E-13	2.1E-20	3.1E-16	6.1E-23
Cm-244	Pu-240	2.4E-17	3.2E-20	4.8E-20	8.9E-23

*for a water exchange rate of 100 m^3/s

Table E.7. Concentration factors for seafoods

Radio-nuclide	Seafood/water concentration factor (Bq/kg per Bq/l)					
	Fish	Comment#	Mollusc	Comment#	Crustaceans	Comment#
H-3	1		1		1	
H-3 org.	20,000	as C-14*	20,000	as C-14*	20,000	as C-14*
C-14	20,000		20,000		20,000	
Na-22	1		0.3		0.07	
Na-24	1		0.3		0.07	
P-32	30,000	[E.14]	20,000	[E.14]	20,000	[E.14]
P-33	30,000	[E.14]	20,000	[E.14]	20,000	[E.14]
S-35	1		3		1	
Cl-36	0.06		0.05		0.06	
Ca-45	2		3		5	
Ca-47	2		3		5	
V-48	30	as Nb*	1,000	as Nb*	200	as Nb*
Cr-51	200		2,000		100	
Mn-52	1,000		50,000		5,000	
Mn-54	1,000		50,000		5,000	
Fe-55	30,000		500,000		500,000	
Fe-59	30,000		500,000		500,000	
Co-56	700		20,000		7,000	
Co-57	700		20,000		7,000	
Co-58	700		20,000		7,000	
Co-60	700		20,000		7,000	
Ni-63	1,000		2,000		1,000	
Cu-61	1,000	as Zn*	80,000	as Zn*	300,000	as Zn*
Cu-64	1,000	as Zn*	80,000	as Zn*	300,000	as Zn*
Zn-62	1,000		80,000		300,000	
Zn-65	1,000		80,000		300,000	
Ga-67	700	[E.14]	700	[E.14]	700	[E.14]
Se-75	10,000		9,000		10,000	
Br-76	3	[E.14]	10	[E.14]	10	[E.14]
Br-77	3	[E.14]	10	[E.14]	10	[E.14]
Br-82	3	[E.14]	10	[E.14]	10	[E.14]
Rb-81	100	[E.14]	20	[E.14]	20	[E.14]
Rb-83	100	[E.14]	20	[E.14]	20	[E.14]
Sr-83	3		10		5	
Sr-85	3		10		5	
Sr-89	3		10		5	
Sr-90	3		10		5	
Y-90	20		1,000		1,000	
Zr-89	20		5,000		200	
Zr-95	20		5,000		200	
Nb-95	30		1,000		200	
Mo-99	10	[E.14]	100	[E.14]	100	[E.14]
Tc-99	80		500		1,000	
Tc-99m	80		500		1,000	
Ru-103	2		500		100	

Radio-nuclide	Seafood/water concentration factor (Bq/kg per Bq/l)					
	Fish	Comment#	Mollusc	Comment#	Crustaceans	Comment#
Ru-106	2		500		100	
Ag-110m	10,000		60,000		200,000	
In-111	500		10,000		10,000	
Sb-125	600		300		300	
I-123	9		10		3	
I-124	9		10		3	
I-125	9		10		3	
I-129	9		10		3	
I-131	9		10		3	
I-133	9		10		3	
I-135	9		10		3	
Cs-134	100		60		50	
Cs-136	100		60		50	
Cs-137	100		60		50	
Ba-140	10		10		0.7	
La-140	50	as Ce*	2,000	as Ce*	1,000	as Ce*
Ce-141	50		2,000		1,000	
Ce-144	50		2,000		1,000	
Pm-147	300		7,000		4,000	
Sm-153	300		7,000		4,000	
Eu-152	300		7,000		4,000	
Eu-154	300		7,000		4,000	
Eu-155	300		7,000		4,000	
Er-169	50	as Ce*	2,000	as Ce*	1,000	as Ce*
Lu-177	50	as Ce*	2,000	as Ce*	1,000	as Ce*
Re-188	80	as Tc*	500	as Tc*	1,000	as Tc*
Au-198	100	[E.14]	1,000	[E.14]	1,000	[E.14]
Tl-201	5,000		6,000		1,000	
Pb-210	200		50,000		90,000	
Pb-212	200		50,000		90,000	
Po-210	2,000		20,000		20,000	
At-211	9	as I*	10	as I*	3	as I*
Ra-223	100		100		100	
Ra-226	100		100		100	
Ac-225	50		1,000		1,000	
Th-227	600		1,000		1,000	
Th-230	600		1,000		1,000	
Th-232	600		1,000		1,000	
Th-234	600		1,000		1,000	
U-234	1		30		10	
U-235	1		30		10	
U-238	1		30		10	
Np-237	1		400		100	
Pu-238	100		3,000		200	
Pu-239	100		3,000		200	
Pu-240	100		3,000		200	
Pu-241	100		3,000		200	

Radio-nuclide	Seafood/water concentration factor (Bq/kg per Bq/l)					
	Fish	Comment#	Mollusc	Comment#	Crustaceans	Comment#
Pu-242	100		3,000		200	
Am-241	100		1,000		400	
Am-242	100		1,000		400	
Am-243	100		1,000		400	
Cm-242	100		1,000		400	
Cm-243	100		1,000		400	
Cm-244	100		1,000		400	

where no comment made, value taken from IAEA [E.10]
* see Table C.4 for details

Table E.8. Activity concentrations in seafoods per unit release rate

Radionuclide		Activity concentration in fish (Bq/kg per Bq/y)*		Activity concentration in crustaceans (Bq/kg per Bq/y)*		Activity concentration in molluscs (Bq/kg per Bq/y)*	
Parent	Progeny	Parent	Progeny	Parent	Progeny	Parent	Progeny
H-3		1.6E-13		3.2E-13		3.2E-13	
H-3 org.		3.2E-09		6.2E-09		6.2E-09	
C-14		3.2E-09		6.2E-09		6.2E-09	
Na-22		1.6E-13		2.2E-14		9.5E-14	
Na-24		1.1E-14		1.6E-15		6.9E-15	
P-32		3.0E-09		4.0E-09		4.0E-09	
P-33		3.6E-09		4.8E-09		4.8E-09	
S-35		1.5E-13		2.9E-13		8.7E-13	
Cl-36		9.8E-15		1.9E-14		1.6E-14	
Ca-45		3.0E-13		1.5E-12		8.9E-13	
Ca-47	Sc-47	1.1E-13	1.5E-15	5.7E-13	7.4E-15	3.4E-13	4.4E-15
V-48		1.4E-13		1.9E-12		9.3E-12	
Cr-51		9.8E-12		9.8E-12		2.0E-10	
Mn-52		1.5E-12		1.5E-11		1.5E-10	
Mn-54		2.2E-12		2.2E-11		2.2E-10	
Fe-55		4.9E-13		1.6E-11		1.6E-11	
Fe-59		4.2E-13		1.4E-11		1.4E-11	
Co-56		9.2E-12		1.8E-10		5.2E-10	
Co-57		9.6E-12		1.9E-10		5.5E-10	
Co-58		9.2E-12		1.8E-10		5.2E-10	
Co-60		1.1E-11		2.1E-10		6.1E-10	
Ni-63		1.0E-10		2.1E-10		4.1E-10	
Cu-61		1.6E-12		9.5E-10		2.5E-10	
Cu-64		5.4E-12		3.2E-09		8.6E-10	
Zn-62	Cu-62	4.1E-12	4.1E-12	2.4E-09	2.4E-09	6.5E-10	6.5E-10
Zn-65		4.5E-11		2.7E-08		7.2E-09	
Ga-67		3.2E-11		6.4E-11		6.4E-11	
Se-75		1.4E-09		2.7E-09		2.4E-09	
Br-76		3.7E-14		2.5E-13		2.5E-13	
Br-77		1.1E-13		7.1E-13		7.1E-13	
Br-82		7.4E-14		4.9E-13		4.9E-13	
Rb-81	Kr-81	3.5E-13	4.0E-20	1.4E-13	1.6E-20	1.4E-13	1.6E-20
Rb-83		1.3E-11		5.1E-12		5.1E-12	
Sr-83	Rb-83	6.8E-14	5.2E-15	2.3E-13	1.7E-14	4.6E-13	3.4E-14
Sr-85		4.3E-13		1.4E-12		2.8E-12	
Sr-89		4.1E-13		1.4E-12		2.7E-12	
Sr-90		4.9E-13		1.6E-12		3.2E-12	
Y-90		5.0E-14		5.0E-12		5.0E-12	
Zr-89		2.6E-14		5.1E-13		1.3E-11	
Zr-95	Nb-95	4.2E-14	7.2E-15	8.5E-13	1.4E-13	2.1E-11	3.6E-12
Nb-95		1.5E-13		2.0E-12		1.0E-11	
Mo-99	Tc-99m	3.9E-13	3.8E-13	7.8E-12	7.7E-12	7.8E-12	7.7E-12
Tc-99		1.3E-11		3.2E-10		1.6E-10	

Radionuclide		Activity concentration in fish (Bq/kg per Bq/y)*		Activity concentration in crustaceans (Bq/kg per Bq/y)*		Activity concentration in molluscs (Bq/kg per Bq/y)*	
Parent	Progeny	Parent	Progeny	Parent	Progeny	Parent	Progeny
Tc-99m	Tc-99	3.8E-13	4.1E-20	9.6E-12	1.0E-18	4.8E-12	5.0E-19
Ru-103		1.2E-13		1.2E-11		5.8E-11	
Ru-106		1.3E-13		1.3E-11		6.6E-11	
Ag-110m		1.1E-09		4.6E-08		1.4E-08	
In-111		1.1E-11		4.5E-10		4.5E-10	
Sb-125	Te-125m	9.0E-11	1.3E-11	8.9E-11	1.2E-11	8.9E-11	1.2E-11
I-123	Te-123	9.1E-14	2.0E-28	6.1E-14	1.3E-28	2.0E-13	4.4E-28
I-124		4.9E-13		3.2E-13		1.1E-12	
I-125		1.3E-12		8.3E-13		2.8E-12	
I-129		1.5E-12		9.6E-13		3.2E-12	
I-131	Xe-131m	7.1E-13	2.9E-13	4.7E-13	1.9E-13	1.6E-12	6.3E-13
I-133	Xe-133	1.4E-13	8.4E-14	9.2E-14	5.6E-14	3.1E-13	1.9E-13
I-135	Xe-135	4.7E-14	4.5E-14	3.2E-14	3.0E-14	1.1E-13	1.0E-13
Cs-134		1.4E-11		1.4E-11		1.7E-11	
Cs-136		8.9E-12		8.9E-12		1.1E-11	
Cs-137		1.5E-11		1.4E-11		1.7E-11	
Ba-140	La-140	9.2E-13	4.3E-14	1.3E-13	5.9E-15	1.8E-12	8.4E-14
La-140		7.5E-14		3.0E-12		6.0E-12	
Ce-141		6.8E-14		2.7E-12		5.5E-12	
Ce-144		7.5E-14		3.0E-12		6.0E-12	
Pm-147	Sm-147	7.2E-13	3.2E-24	1.9E-11	8.4E-23	3.3E-11	1.5E-22
Sm-153		2.0E-13		5.4E-12		9.4E-12	
Eu-152	Gd-152	8.1E-13	1.1E-26	2.2E-11	3.0E-25	3.8E-11	5.3E-25
Eu-154		7.9E-13		2.1E-11		3.7E-11	
Eu-155		7.5E-13		2.0E-11		3.5E-11	
Er-169		5.9E-14		2.3E-12		4.7E-12	
Lu-177		5.4E-14		2.2E-12		4.3E-12	
Re-188		1.0E-12		2.6E-11		1.3E-11	
Au-198		3.4E-12		6.8E-11		6.8E-11	
Tl-201		1.6E-10		6.5E-11		3.9E-10	
Pb-210	Po-210	8.4E-12	1.0E-14	7.5E-09	9.3E-12	4.2E-09	5.2E-12
Pb-212	Bi-212	7.8E-13	1.5E-12	7.0E-10	1.4E-09	3.9E-10	7.7E-10
Po-210		4.4E-13		8.8E-12		8.8E-12	
At-211		5.1E-14		3.4E-14		1.1E-13	
Ra-223	Pb-211	8.8E-12	4.5E-12	1.8E-11	8.9E-12	1.8E-11	8.9E-12
Ra-226	Pb-210	1.5E-11	1.4E-14	3.0E-11	2.7E-14	3.0E-11	2.7E-14
Ac-225	Bi-213	8.8E-14	1.8E-12	3.5E-12	7.3E-11	3.5E-12	7.3E-11
Th-227	Ra-223	7.8E-13	9.6E-12	2.6E-12	3.2E-11	2.6E-12	3.2E-11
Th-230	Ra-226	1.2E-12	1.3E-13	4.1E-12	4.2E-13	4.1E-12	4.2E-13
Th-232	Ra-228	1.2E-12	1.9E-11	4.1E-12	6.0E-11	4.1E-12	6.0E-11
Th-234	U-234	8.0E-13	9.3E-18	2.7E-12	3.0E-17	2.7E-12	3.0E-17
U-234	Th-230	1.6E-13	2.0E-21	3.1E-12	4.0E-20	9.3E-12	1.2E-19
U-235	Pa-231	1.6E-13	1.4E-20	3.1E-12	2.7E-19	9.3E-12	8.2E-19
U-238	U-234	1.6E-13	6.9E-20	3.1E-12	1.2E-18	9.3E-12	3.5E-18

Radionuclide		Activity concentration in fish (Bq/kg per Bq/y)*		Activity concentration in crustaceans (Bq/kg per Bq/y)*		Activity concentration in molluscs (Bq/kg per Bq/y)*	
Parent	Progeny	Parent	Progeny	Parent	Progeny	Parent	Progeny
Np-237	U-233	1.6E-13	1.1E-19	3.1E-11	1.8E-17	1.2E-10	7.2E-17
Pu-238	U-234	4.4E-12	1.0E-16	1.7E-11	4.0E-16	2.6E-10	5.9E-15
Pu-239	U-235	4.4E-12	3.9E-20	1.8E-11	1.5E-19	2.7E-10	2.2E-18
Pu-240	U-236	4.4E-12	1.2E-18	1.8E-11	4.4E-18	2.7E-10	6.7E-17
Pu-241	Am-241	4.1E-12	7.2E-16	1.6E-11	2.9E-15	2.5E-10	4.3E-14
Pu-242	U-238	4.4E-12	6.1E-21	1.8E-11	2.3E-20	2.7E-10	3.5E-19
Am-241	Np-237	3.0E-13	1.7E-17	2.4E-12	1.3E-16	6.0E-12	3.2E-16
Am-242	Cm-242	4.9E-14	7.0E-16	3.9E-13	5.6E-15	9.8E-13	1.4E-14
Am-243	Pu-239	3.0E-13	3.8E-16	2.4E-12	3.0E-15	6.0E-12	7.6E-15
Cm-242	Pu-238	2.2E-13	5.8E-15	1.7E-12	4.6E-14	4.4E-12	1.2E-13
Cm-243	Pu-239	2.9E-13	3.1E-16	2.3E-12	2.5E-15	5.7E-12	6.1E-15
Cm-244	Pu-240	2.8E-13	1.0E-15	2.2E-12	8.1E-15	5.5E-12	2.0E-14

*for a water exchange rate of 100 m^3/s

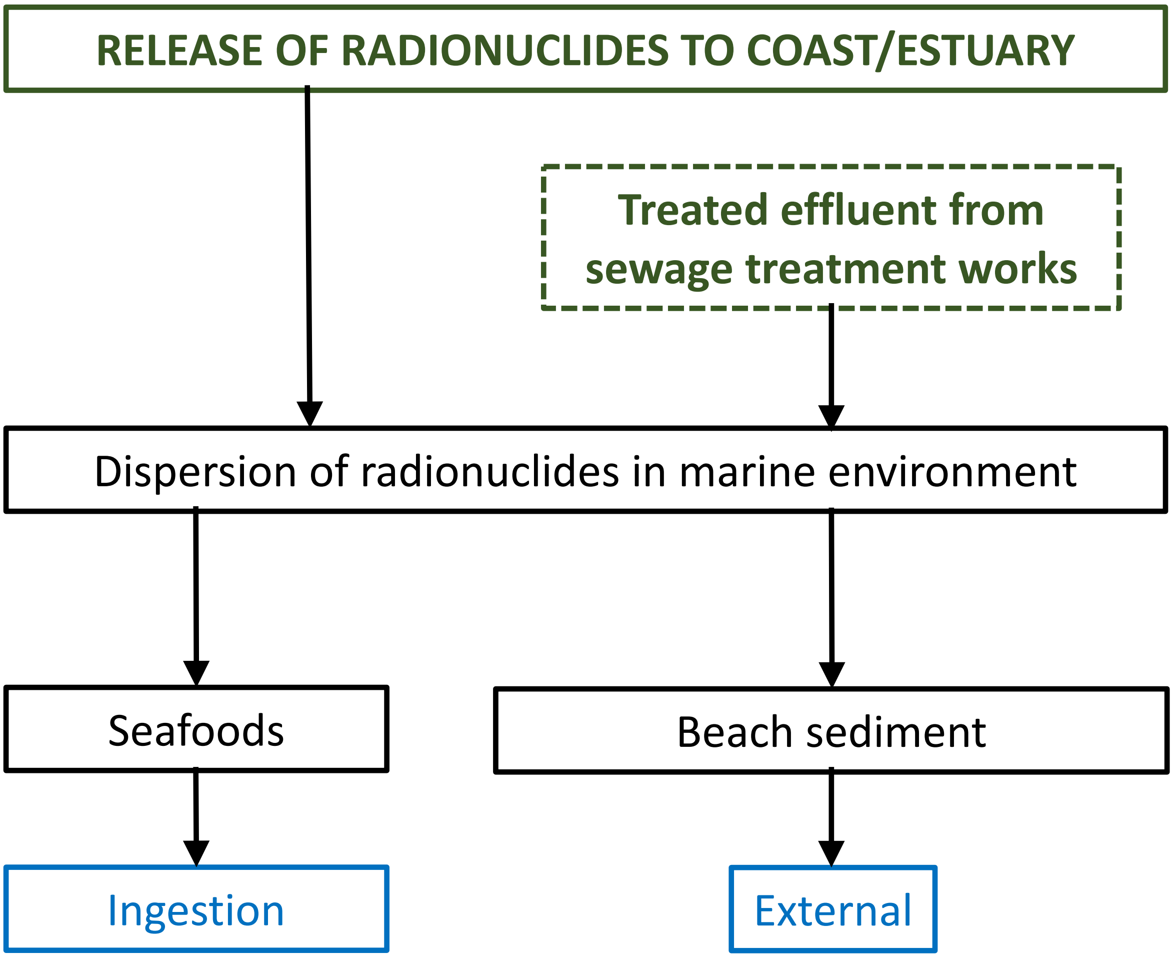

Figure E.1. Flow diagram of exposure pathways considered for releases to coast/estuary

Appendix F: Input data and calculation of DPUR factors for river discharges scenario

F.1 Source term

The source term for releases to river is made up from direct discharges and/or the discharge of treated effluent from a sewage treatment works. DPUR factors were not calculated for any radionuclides with half-lives of less than 3 hours, because of the relative timescales involved for the radionuclides to disperse and reach equilibrium with sediments and biota, and in the treatment and distribution of drinking water. The radionuclides considered for releases to a freshwater river are listed in Table 1.

F.2 Exposed groups for assessments to public

The following exposed groups were considered. They are taken to be representative of people exposed to liquid radioactive discharges into freshwater rivers across the UK.

Angler family

Pathways included are:

- internal radiation from the consumption of drinking water, assuming commercial abstraction from the river or a well on the bank;
- internal radiation from the consumption of freshwater fish;
- external radiation from radionuclides in bank sediments.

The angler exposure group was assumed to consume fish at high rates and abstracted drinking water at normal rates. A freshwater fish consumption rate of 20 kg /y was taken for adults, from generalised data published by PHE (now UK HSA) [F.1]. Drinking water treatment practices were assumed to have no effect on radionuclide concentrations; however, it was assumed that the water had been filtered to remove suspended sediments. Relevant habit data including consumption rates and occupancy times are shown in Table F.1. Radionuclides with half-lives of less than 3 hours were not considered for this exposed group.

Irrigated food consumer family

Pathways included are:

- external radiation from radionuclides in contaminated soil;
- internal radiation from the consumption of appropriate terrestrial food types incorporating radionuclides from irrigation water;
- consumption of drinking water containing radionuclides.

The irrigated food consumer family exposure group was assumed to consume green vegetables, root vegetables and fruit at high rates. A water irrigation rate of 0.3 m^3 per m^2 /y was used which is representative of the highest rates used for vegetables and fruit in the UK [F.2] and irrigation carried out with unfiltered river water. The irrigated food consumer was assumed to consume water at the same rate as the Angler family. Habit data for the irrigated food consumer family exposure group are shown in Table F.2. Radionuclides with half-lives of less than 3 hours were not considered for this exposed group.

Figure F.1 shows the matrix of pathways that were evaluated. Inadvertent ingestion of river bank sediments, inhalation of river water and resuspended bank sediments were not included as resulting doses are much smaller than those resulting from above pathways [F.3].

F.3 Activity concentrations in river water, bank sediments and freshwater fish

Activity concentrations of radionuclides discharged into a river were calculated using a simple dilution model [F.4]. A river flow rate of 1 m^3/s was adopted, which is representative of a relatively small river, but which can support drinking water abstraction and a sizeable edible fish population. The following assumptions were made:

- radionuclides are released at a uniform rate of 1 Bq/y;
- all flow rates remain constant;
- instantaneous and complete dilution of the radionuclides in river water at the discharge point;
- there is no further dilution and no radioactive decay between the point of release and point of extraction of the water;
- concentrations in river bank sediments were taken to be equal to concentrations in suspended sediments;
- loss of suspended sediment to riverbed sediment and other sinks was ignored;
- the concentration of radionuclides in sediments are in equilibrium with those in river water.

The activity concentration of radionuclides in unfiltered river water is given by:

$$C_{unf} = \frac{Q}{V}$$

where C_{unf} is activity concentration in *unfiltered* river water (Bq/l)
Q is discharge rate (Bq/s)
V is river volumetric flow rate (l/s)

Partitioning between the water and sediment phases was calculated by applying published freshwater sediment partition coefficients (K_d). Activity concentration for river sediments is given by:

$$C_{Sed} = K_d \times C_{filt}$$

where C_{Sed} is activity concentration in sediments (Bq/kg)
C_{filt} is activity concentration in *filtered* river water (Bq/l)
K_d is freshwater sediment distribution coefficient (Bq/kg per Bq/l)

And for freshwater fish by:

$$C_{fish} = CF \times C_{filt}$$

where C_{fish} is activity concentration in fish (Bq/kg)
C_{filt} is activity concentration in *filtered* river water (Bq/l)
CF is freshwater fish concentration factor (see Table F.4) (Bq/kg per Bq/l)

The concentration in filtered water is related to the concentration in unfiltered water by:

$$C_{filt} = \frac{C_{unf}}{1 + K_d \times S}$$

where S is suspended sediment load (kg/l)

Concentrations of radionuclides in water abstracted for drinking are likely to be affected by water treatment processes. A number of treatments can be applied with varying radionuclide removal efficiencies. River water is also likely to be stored in reservoirs prior to use, where radionuclides may decay. Both of these are likely to affect the concentration of some radionuclides. For this study, any water treatment processes apart from filtering to remove suspended sediments were ignored. However, if site-specific information exists, this should be considered when making a more refined assessment.

Parameters characterising the river are presented in Table F.3. Values for sediment distribution coefficients are the same as those used to derive the wildlife dose factors, (listed in Table A.2) and are shown in Table F.4 together with fish/freshwater concentration factors.

The resulting activity concentrations in river water, bank sediment and freshwater fish per unit release are shown in Table F.5.

F.4 Dose rates for external exposure

F.4.1 External exposure from river bank sediments

To calculate the dose rates from external exposure above contaminated river bank sediments, effective dose coefficients above contaminated soil listed in Eckerman and Leggett and Eckerman and Ryman [F.5, F.6], using ICRP 60 dosimetry, were applied. A well-mixed profile to infinite depth was assumed, except for radionuclides with half-lives of less than 3 weeks, where it was assumed that activity is present in the top 1 cm only. Dose rates were converted from a volume source (Bq/m^3) to a source per unit mass basis (Bq/kg), applying a soil density of 1,600 kg/m^3 [F.6]. Since the external dose rates are based on a source region with infinite horizontal extent, a dose reduction factor of 0.2, as recommended for river banks, was applied [F.6].

For the purpose of calculating external dose rates, dose coefficients for progeny which can be considered to be in secular equilibrium with their parent or which will decay significantly during the timescale considered, have been added to their parent's dose rates. The resulting dose rates for external exposure above contaminated bank sediments per unit activity concentration in sediments are shown in Table F.6, together with the parent/progeny combinations considered.

F.4.2 External dose rates per unit discharge

The effective dose rates from external exposure to river bank sediments per unit release were calculated as follows:

$$DR_{ext\_river} = DR_{ext\_river(u)} A_{sed}$$

where DR_{ext_river} is external dose rate from radionuclides in river-bank sediments per unit release rate (μSv/h per Bq/y)

$DR_{ext\_river(u)}$ is external dose rate per unit activity concentration in river bank sediments (μSv/h per Bq/kg)

A_{sed} is activity concentration in river bank sediments per unit release rate (Bq/kg per Bq/y)

The resulting external dose rates per unit release are shown in Table F.7.

F.4.3 External exposure from deposited radionuclides by spray irrigation of soil by river water

The PC-CREAM 08 module GRANIS was used to calculate gamma dose rates above soil from radionuclides deposited onto the ground by spray irrigation of river water. An undisturbed soil profile consisting of 'generic wet soil' was assumed, represented by five compartments to a total depth of 1 m. GRANIS includes full decay chains when calculating transfer between soil compartments and the contributions of progeny are included in the resulting dose rate of the parent. The doses arising from external gamma radiation exposure to deposited radionuclides in undisturbed soil were calculated for an integration time of 50 years. The effective dose rate per unit deposition rate (Bq/m^2/s) is listed in Table D.5.

F.5 Activity concentrations in fish consumed by the angler family exposed group

Activity concentrations in fish per unit release rate were derived as follows:

$$A_{fish} = A_{water} CF_{fish}$$

where A_{fish} is activity concentration in freshwater fish per unit release rate (Bq/kg per Bq/y)

A_{water} is activity concentration in filtered river water per unit release rate (Bq/l per Bq/y)

CF_{fish} is the concentration factor for freshwater fish (Bq/kg per Bq/l)

Values for freshwater fish concentration factors are listed in Table F.4. The activity concentrations in fish per unit discharge rate are shown in Table F.5.

F.6 Activity concentrations in terrestrial foodstuffs

F.6.1 Deposition from irrigation and terrestrial foodchain modelling

It was assumed that irrigation is via spray irrigation at a rate of 0.3 m^3/y per m^2 of irrigated land. This irrigation rate is cautiously selected; it is the upper end of the range used for UK climate and soil conditions and is sustainable regarding a volumetric flow rate of the river of 1 m^3/s [F.2]. It was further assumed that spray irrigation at the rate applied here may be treated as an atmospheric source with corresponding deposition onto plants' surfaces and soil [F.7]. The activity concentrations in food products were derived as follows.

Only food crops (green vegetables, root vegetables and fruit) were assumed to be irrigated and not pasture. Activity concentrations in terrestrial foodstuffs (Bq/kg per Bq/m^2/s) grown on irrigated soil have been calculated using the PC-CREAM 08 module FARMLAND. The same method and input data as for atmospheric releases were applied (see Appendix D, Section D.5.2).

Activity concentrations in terrestrial foodstuffs per unit deposition rate from irrigation are listed in Table F.8.

F.6.2 Equilibrium modelling for tritium (H-3) and carbon-14 (C-14)

For tritium (H-3) and carbon-14 (C-14) the activity concentrations in green vegetables and root vegetables resulting from spray irrigation were taken from Jones *et al*. [F.8]. Activity concentrations for tritium were calculated using the TRIF model assuming that the activity concentration in the plant was in equilibrium with that in the water and the initial concentration of tritiated water in the plants was the same as the soil water with some of this converted to organically bound tritium (OBT) within the plant. To calculate activity concentrations for C-14, the interception by plants of C-14 in water, translocation through the leaves, root uptake and direct uptake of C-14 in air were included [F.8]. In the absence of more specific data, the activity concentrations of tritium and C-14 in green vegetables were also applied to fruit.

F.6.3 Activity concentrations in terrestrial foodstuffs per unit release

Activity concentrations in terrestrial foodstuffs per unit release were calculated as follows:

$$A_{food} = A_{food(u)} I_{app} C_{unf}$$

where A_{food} is activity concentration in food products grown on land irrigated by river water per unit discharge into the river (Bq/kg per Bq/y)

$A_{food(u)}$ is activity concentration in food products per unit deposition rate (Bq/kg per Bq/m^2/s)

I_{app} is irrigation water application rate (l/s per m^2)

C_{unf} is activity concentration in unfiltered river water per unit discharge into the river (Bq/l per Bq/y)

The activity concentrations in terrestrial foodstuffs are shown in Table F.9.

F.7 Method to calculate DPUR factors for people

The DPUR factors for external exposure pathways for each age group were calculated as follows:

$$DPUR_{ext,a} = DR_{ext}\ H_{occ,a}$$

where $DPUR_{ext,a}$ is dose per unit release factor from external exposure to activity in the bank sediments or irrigated soil for the age group considered (µSv/y per Bq/y) (see Table F.7).

DR_{ext} is external dose rate from river bank sediments or irrigated soil (µSv/h per Bq/y)

$H_{occ,a}$ is total occupancy on the river banks or on irrigated soil for the age group considered (h/y)

The DPUR factors for ingestion of fish, water and terrestrial foodstuffs were calculated as follows:

$$DPUR_{food,a} = A_{food}\ I_{food,a}\ DF_{ing,a}$$

where $DPUR_{food,a}$ is dose per unit release factor from the ingestion of a foodstuff or water for the age group considered (µSv/y per Bq/y)

A_{food} is activity concentration in the foodstuff or water considered (Bq/kg per Bq/y or Bq/l per Bq/y)

$I_{food,a}$ is ingestion rate of the foodstuff or water for the age group considered (kg/y or l/y)

$DF_{ing,a}$ is ingestion dose coefficient for the age group considered (µSv/Bq)

The DPUR factors are shown in the main report: Tables 16–20 for the angler family exposure group and Tables 21–25 for the irrigated food consumer family exposure group.

F.8 Method to calculate DPUR factors for Wildlife

The exposed group for river releases to wildlife are the reference organisms for the freshwater environment, as described in the ERICA approach (see Appendix A). The dose factors (DPUC) for wildlife were calculated using the ERICA tool and are presented in Appendix A, Table A.9.

Activity concentrations in filtered river water used to calculate the DPUR for wildlife are the same as that for the public, as described in Section F.3. The wildlife DPUR are based on reference organisms being located in the river to which the radionuclides are released. River parameters are shown in Table F.3. Activity concentrations in filtered river water are shown in Table F.5.

DPUR factors for river wildlife were calculated from the filtered river water concentrations using the following equation:

$$DPUR_{wildlife} = A_{water}\ DF_{wildlife}$$

$DPUR_{wildlife}$	is the dose rate per unit release factor for wildlife (µGy/h per Bq/y)
$DF_{wildlife}$	is the dose factor for non-human species per unit concentration in water (µGy/h per Bq/l) (see Table A.9 in Appendix A).
A_{water}	is activity concentration in filtered river water per unit release rate (Bq/l per Bq/y) (Table F.5)

DPUR factors for wildlife exposed to river releases are presented in Tables 26 and 27 in the main report. Radionuclides with half-lives of less than 3 hours were not considered.

F.9 References

F.1 Smith, K R and Jones, A L (2003). Generalised Habit Data for Radiological Assessments. NRPB-W41.

F.2 Rees, B, Cessford, F, Connelly, R, Cowan, J, Bowell, R, Weatherhead E K, Knox, J W, Twite C L and Morris J (2003). Optimum Use of Water for Industry and Agriculture: Phase 3, Best Practice Manual, Environment Agency R&D Technical Report W6-056/TR2, September 2002.

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Table F.1. Habit data of river angler family exposure group

	Infant	Child	Adult	Comment
Consumption rates				
Freshwater fish (kg/y)	1	5	20	[F.1]
Water (l/y)	260	350	600	[F.1]
Occupancy on bank sediments (h/y)	30	500	1,000	[F.1]

Table F.2. Habit data of irrigated food consumer family exposure group

	Infant	Child	Adult	Comment
Food consumption rates (kg/y)				[F.1]
Green vegetables	15	35	80	
Root vegetables	45	95	130	
Fruit	35	50	75	
Breathing rates (m^3/h)	0.22	0.64	0.92	[F.1]
Occupancy at habitation (h/y)	8,760	8,760	8,760	100%
Fraction of time spent indoors	0.9	0.8	0.5	[F.1]
Shielding factor for deposited radionuclides	0.1	0.1	0.1	[F.7]

Drinking water consumption as Table F.1.

Table F.3. Parameters characterising the river

	Value	Comment
River flow rate (m^3/s)	1	[F.7]
Suspended sediment load (kg/l)	4.0E-05	[F.7]
Irrigation rate (m^3 per m^2/y)	0.3	[F.2]

Table F.4. Freshwater/sediment K_d and fish foodstuff concentration factors

Element	Freshwater K_d (l/kg)	Comment	Fish/freshwater concentration factor (CF) (Bq/kg per Bq/l)	
			Concentration factors	Comment#
Ac	91000	Samarium used as analogue*	15	[F.12]
Ag	270000	Average of values in [F.11]	110	
Am	120000	[F.11]	240	
At	4400	Iodine used as analogue*	15	[F.12]
Au	270000	Silver used as analogue*	240	
Ba	2000	[F.11]	1.2	
Br	2300	[F.16]	91	
C	2000	[F.7]	400,000	
Ca	1100	[F.16]	12	
Ce	220000	[F.11]	25	
Cl	98	[F.15]	47	
Cm	5000	[F.11]	30	[F.12]
Co	44000	[F.11]	76	
Cr	20000	[F.7]	40	
Cs	29000	[F.11]	2,500	
Cu	500	Zinc used as analogue*	230	
Er	220000	Cerium used as analogue*	25	[F.4]
Eu	500	[F.11]	130	
Fe	5000	[F.11]	170	
Ga	300	Use value for soil in [F.11]	400	[F.12]
H	0.03	[F.7]	1	[F.7]
H-3 org	2000	Carbon used as analogue*	400,000	Carbon used as analogue*
I	4400	[F.11]	30	
In	50000	Use ocean margin value in [F.17]*	10,000	[F.12]
La	60000	[F.7]	37	
Lu	220000	Cerium used as analogue*	30	Promethium used as analogue*
Mn	79000	[F.11]	240	
Mo	12000	[F.16]	1.9	

Na	0.1	Use ocean margin value in [F.17]*	76	
Nb	100	[F.7]	300	[F.12]
Ni	10000	[F.7]	21	
Np	10	[F.11]	30	[F.12]
P	50	[F.7]	140,000	
Pb	10000	[F.7]	25	
Pm	5000	[F.11]	30	[F.12]
Po	40000	[F.7]	36	
Pu	240000	[F.11]	21,000	
Ra	7400	[F.11]	4	
Rb	29000	Caesium used as analogue*	4,900	
Re	430	[F.16]	20	Technetium used as analogue*
Ru	32000	[F.11]	55	
S	200	[F.7]	800	[F.12]
Sb	5000	[F.11]	37	
Se	4000	[F.7]	6,000	
Sm	91000	[F.16]	30	Promethium used as analoguem*
Sr	1200	[F.11]	2.9	
Tc	5	[F.11]	20	[F.12]
Th	190000	[F.11]	6	
Tl	20000	Use ocean margin value from [F.17]*	900	
U	50	[F.11]	0.96	
V	100	Niobium used as analogue*	97	
Y	1000	Zirconium used as an analogue*	40	
Zn	500	[F.11]	3,400	
Zr	1000	[F.11]	22	

where no comment made, value taken from IAEA compilation [F.11]
* see Table C.5 for details

Table F.5. Activity concentrations in unfiltered water, filtered water, river bank sediment and freshwater fish per unit release rate

Radionuclide	Activity concentration*			
	Unfiltered water (Bq/l per Bq/y)	Filtered water (Bq/l per Bq/y)	Bank sediment (Bq/kg per Bq/y)	Freshwater fish (Bq/kg per Bq/y)
H-3	3.2E-11	3.2E-11	9.5E-13	3.2E-11
H-3 organic	3.2E-11	2.9E-11	5.9E-08	1.2E-05
C-14	3.2E-11	2.9E-11	5.9E-08	1.2E-05
Na-22	3.2E-11	3.2E-11	3.2E-12	2.4E-09
Na-24	3.2E-11	3.2E-11	3.2E-12	2.4E-09
P-32	3.2E-11	3.2E-11	1.6E-09	4.4E-06
P-33	3.2E-11	3.2E-11	1.6E-09	4.4E-06
S-35	3.2E-11	3.1E-11	6.3E-09	2.5E-08
Cl-36	3.2E-11	3.2E-11	3.1E-09	1.5E-09
Ca-45	3.2E-11	3.0E-11	3.3E-08	3.6E-10
Ca-47	3.2E-11	3.0E-11	3.3E-08	3.6E-10
V-48	3.2E-11	3.2E-11	3.2E-09	3.1E-09
Cr-51	3.2E-11	1.8E-11	3.5E-07	7.0E-10
Mn-52	3.2E-11	7.6E-12	6.0E-07	1.8E-09
Mn-54	3.2E-11	7.6E-12	6.0E-07	1.8E-09
Fe-55	3.2E-11	2.6E-11	1.3E-07	4.5E-09
Fe-59	3.2E-11	2.6E-11	1.3E-07	4.5E-09
Co-56	3.2E-11	1.1E-11	5.1E-07	8.7E-10
Co-57	3.2E-11	1.1E-11	5.1E-07	8.7E-10
Co-58	3.2E-11	1.1E-11	5.1E-07	8.7E-10
Co-60	3.2E-11	1.1E-11	5.1E-07	8.7E-10
Ni-63	3.2E-11	2.3E-11	2.3E-07	4.8E-10
Cu-61	3.2E-11	3.1E-11	1.6E-08	7.1E-09
Cu-64	3.2E-11	3.1E-11	1.6E-08	7.1E-09
Zn-62	3.2E-11	3.1E-11	1.6E-08	1.1E-07
Zn-65	3.2E-11	3.1E-11	1.6E-08	1.1E-07
Ga-67	3.2E-11	3.1E-11	9.4E-09	1.3E-08
Se-75	3.2E-11	2.7E-11	1.1E-07	1.6E-07
Br-76	3.2E-11	2.9E-11	6.7E-08	2.6E-09
Br-77	3.2E-11	2.9E-11	6.7E-08	2.6E-09
Br-82	3.2E-11	2.9E-11	6.7E-08	2.6E-09
Rb-81	3.2E-11	1.5E-11	4.3E-07	7.2E-08
Rb-83	3.2E-11	1.5E-11	4.3E-07	7.2E-08
Sr-83	3.2E-11	3.0E-11	3.6E-08	8.8E-11
Sr-85	3.2E-11	3.0E-11	3.6E-08	8.8E-11
Sr-89	3.2E-11	3.0E-11	3.6E-08	8.8E-11
Sr-90	3.2E-11	3.0E-11	3.6E-08	8.8E-11
Y-90	3.2E-11	3.0E-11	3.0E-08	1.2E-09
Zr-89	3.2E-11	3.0E-11	3.0E-08	6.7E-10
Zr-95	3.2E-11	3.0E-11	3.0E-08	6.7E-10
Nb-95	3.2E-11	3.2E-11	3.2E-09	9.5E-09

Radionuclide	Activity concentration*			
	Unfiltered water (Bq/l per Bq/y)	Filtered water (Bq/l per Bq/y)	Bank sediment (Bq/kg per Bq/y)	Freshwater fish (Bq/kg per Bq/y)
Mo-99	3.2E-11	2.1E-11	2.6E-07	4.1E-11
Tc-99	3.2E-11	3.2E-11	1.6E-10	6.3E-10
Tc-99m	3.2E-11	3.2E-11	1.6E-10	6.3E-10
Ru-103	3.2E-11	1.4E-11	4.4E-07	7.6E-10
Ru-106	3.2E-11	1.4E-11	4.4E-07	7.6E-10
Ag-110m	3.2E-11	2.7E-12	7.3E-07	3.0E-10
In-111	3.2E-11	6.3E-12	6.3E-07	6.3E-08
Sb-125	3.2E-11	2.6E-11	1.3E-07	9.8E-10
I-123	3.2E-11	2.7E-11	1.2E-07	8.1E-10
I-124	3.2E-11	2.7E-11	1.2E-07	8.1E-10
I-125	3.2E-11	2.7E-11	1.2E-07	8.1E-10
I-129	3.2E-11	2.7E-11	1.2E-07	8.1E-10
I-131	3.2E-11	2.7E-11	1.2E-07	8.1E-10
I-133	3.2E-11	2.7E-11	1.2E-07	8.1E-10
I-135	3.2E-11	2.7E-11	1.2E-07	8.1E-10
Cs-134	3.2E-11	1.5E-11	4.3E-07	3.7E-08
Cs-136	3.2E-11	1.5E-11	4.3E-07	3.7E-08
Cs-137	3.2E-11	1.5E-11	4.3E-07	3.7E-08
Ba-140	3.2E-11	2.9E-11	5.9E-08	3.5E-11
La-140	3.2E-11	9.3E-12	5.6E-07	3.4E-10
Ce-141	3.2E-11	3.2E-12	7.1E-07	8.1E-11
Ce-144	3.2E-11	3.2E-12	7.1E-07	8.1E-11
Pm-147	3.2E-11	2.6E-11	1.3E-07	7.9E-10
Sm-153	3.2E-11	6.8E-12	6.2E-07	2.0E-10
Eu-152	3.2E-11	3.1E-11	1.6E-08	4.0E-09
Eu-154	3.2E-11	3.1E-11	1.6E-08	4.0E-09
Eu-155	3.2E-11	3.1E-11	1.6E-08	4.0E-09
Er-169	3.2E-11	3.2E-12	7.1E-07	8.1E-11
Lu-177	3.2E-11	3.2E-12	7.1E-07	9.7E-11
Re-188	3.2E-11	3.1E-11	1.3E-08	6.2E-10
Au-198	3.2E-11	2.7E-12	7.3E-07	6.4E-10
Tl-201	3.2E-11	1.8E-11	3.5E-07	1.6E-08
Pb-210	3.2E-11	2.3E-11	2.3E-07	5.7E-10
Pb-212	3.2E-11	2.3E-11	2.3E-07	5.7E-10
Po-210	3.2E-11	1.2E-11	4.9E-07	4.4E-10
At-211	3.2E-11	2.7E-11	1.2E-07	4.0E-10
Ra-223	3.2E-11	2.4E-11	1.8E-07	9.8E-11
Ra-226	3.2E-11	2.4E-11	1.8E-07	9.8E-11
Ac-225	3.2E-11	6.8E-12	6.2E-07	1.0E-10
Th-227	3.2E-11	3.7E-12	7.0E-07	2.2E-11
Th-230	3.2E-11	3.7E-12	7.0E-07	2.2E-11
Th-232	3.2E-11	3.7E-12	7.0E-07	2.2E-11
Th-234	3.2E-11	3.7E-12	7.0E-07	2.2E-11
U-234	3.2E-11	3.2E-11	1.6E-09	3.0E-11

Radionuclide	Activity concentration*			
	Unfiltered water (Bq/l per Bq/y)	Filtered water (Bq/l per Bq/y)	Bank sediment (Bq/kg per Bq/y)	Freshwater fish (Bq/kg per Bq/y)
U-235	3.2E-11	3.2E-11	1.6E-09	3.0E-11
U-238	3.2E-11	3.2E-11	1.6E-09	3.0E-11
Np-237	3.2E-11	3.2E-11	3.2E-10	9.5E-10
Pu-238	3.2E-11	3.0E-12	7.2E-07	6.3E-08
Pu-239	3.2E-11	3.0E-12	7.2E-07	6.3E-08
Pu-240	3.2E-11	3.0E-12	7.2E-07	6.3E-08
Pu-241	3.2E-11	3.0E-12	7.2E-07	6.3E-08
Pu-242	3.2E-11	3.0E-12	7.2E-07	6.3E-08
Am-241	3.2E-11	5.5E-12	6.6E-07	1.3E-09
Am-242	3.2E-11	5.5E-12	6.6E-07	1.3E-09
Am-243	3.2E-11	5.5E-12	6.6E-07	1.3E-09
Cm-242	3.2E-11	2.6E-11	1.3E-07	7.9E-10
Cm-243	3.2E-11	2.6E-11	1.3E-07	7.9E-10
Cm-244	3.2E-11	2.6E-11	1.3E-07	7.9E-10

*for a river flow rate of 1 m^3/s

Table F.6. External dose rates from river bank sediments per unit activity concentration in sediments

Radio-nuclide	Dose rate above sediment (µSv/h per Bq/kg)			
	Dose rate parent	Dose rate including all progeny	Comments	Dose rate after application of river bank scaling factor
H-3	0.0E+00	0.0E+00		0.0E+00
H-3 org.	0.0E+00	0.0E+00		0.0E+00
C-14	3.4E-10	3.4E-10		6.8E-11
Na-22	4.0E-04	4.0E-04		8.0E-05
Na-24	1.3E-04	1.3E-04		2.7E-05
P-32	3.8E-07	3.8E-07		7.6E-08
P-33	1.5E-09	1.5E-09		3.1E-10
S-35	3.8E-10	3.8E-10		7.5E-11
Cl-36	7.7E-08	7.7E-08		1.5E-08
Ca-45	1.6E-09	1.6E-09		3.3E-10
Ca-47	3.6E-05	4.0E-05	Sc-47 included, since all will decay in 1 year	8.0E-06
V-48	1.0E-04	1.0E-04		2.0E-05
Cr-51	5.0E-06	5.0E-06		1.0E-06
Mn-52	1.2E-04	1.2E-04		2.4E-05
Mn-54	1.5E-04	1.5E-04		3.0E-05
Fe-55	0.0E+00	0.0E+00		0.0E+00
Fe-59	2.2E-04	2.2E-04		4.5E-05
Co-56	6.9E-04	6.9E-04		1.4E-04
Co-57	1.4E-05	1.4E-05		2.8E-06
Co-58	1.7E-04	1.7E-04		3.5E-05
Co-60	4.8E-04	4.8E-04		9.5E-05
Ni-63	0.0E+00	0.0E+00		0.0E+00
Cu-61	2.9E-05	2.9E-05		5.8E-06
Cu-64	6.6E-06	6.6E-06		1.3E-06
Zn-62	1.5E-05	5.1E-05	Cu-62 included	1.0E-05
Zn-65	1.1E-04	1.1E-04		2.2E-05
Ga-67	5.1E-06	5.1E-06		1.0E-06
Se-75	5.6E-05	5.6E-05		1.1E-05
Br-76	8.9E-05	8.9E-05		1.8E-05
Br-77	1.1E-05	1.1E-05		2.2E-06
Br-82	9.1E-05	9.1E-05		1.8E-05
Rb-81	2.1E-05	2.1E-05	Kr-81m not included as gaseous	4.3E-06
Rb-83	8.5E-05	8.5E-05		1.7E-05
Sr-83	2.7E-05	2.7E-05		5.5E-06
Sr-85	8.5E-05	8.5E-05	Rb-83 not included as longer half life	1.7E-05
Sr-89	4.7E-07	4.7E-07		9.3E-08
Sr-90	2.0E-08	1.3E-06	Y-90 included	2.5E-07
Y-90	7.3E-07	7.3E-07		1.5E-07

Radio-nuclide	Dose rate above sediment (µSv/h per Bq/kg)			
	Dose rate parent	Dose rate including all progeny	Comments	Dose rate after application of river bank scaling factor
Zr-89	4.0E-05	4.0E-05		8.0E-06
Zr-95	1.3E-04	2.7E-04	Nb-95 included as significant decay in 1 year	5.3E-05
Nb-95	1.4E-04	1.4E-04		2.7E-05
Mo-99	5.3E-06	8.9E-06	Tc-99m included but Tc-99 not as longer half-life	1.8E-06
Tc-99	3.3E-09	3.3E-09		6.7E-10
Tc-99m	4.2E-06	4.2E-06		8.3E-07
Ru-103	7.9E-05	7.9E-05		1.6E-05
Ru-106	0.0E+00	3.8E-05	Rh-106 included	7.7E-06
Ag-110m	5.0E-04	5.0E-04		1.0E-04
In-111	1.3E-05	1.3E-05		2.6E-06
Sb-125	7.0E-05	7.0E-05		1.4E-05
I-123	5.2E-06	5.2E-06		1.0E-06
I-124	3.7E-05	3.7E-05		7.5E-06
I-125	3.7E-07	3.7E-07		7.3E-08
I-129	2.9E-07	2.9E-07		5.9E-08
I-131	1.3E-05	1.3E-05		2.7E-06
I-133	2.1E-05	2.1E-05		4.3E-06
I-135	5.3E-05	5.3E-05		1.1E-05
Cs-134	2.7E-04	2.7E-04		5.5E-05
Cs-136	7.4E-05	7.4E-05		1.5E-05
Cs-137	2.6E-08	9.9E-05	Ba-137m included	2.0E-05
Ba-140	6.3E-06	8.5E-05	La-140 included	1.7E-05
La-140	7.8E-05	7.8E-05		1.6E-05
Ce-141	8.9E-06	8.9E-06		1.8E-06
Ce-144	2.0E-06	1.0E-05	Pr-144 included	2.0E-06
Pm-147	1.3E-09	1.3E-09		2.6E-10
Sm-153	1.6E-06	1.6E-06		3.2E-07
Eu-152	2.0E-04	2.0E-04		4.1E-05
Eu-154	2.2E-04	2.2E-04		4.5E-05
Eu-155	5.0E-06	5.0E-06		1.0E-06
Er-169	1.5E-09	1.5E-09		3.1E-10
Lu-177	1.2E-06	1.2E-06		2.3E-07
Re-188	2.4E-06	2.4E-06		4.9E-07
Au-198	1.4E-05	1.4E-05		2.8E-06
Tl-201	2.6E-06	2.6E-06		5.3E-07
Pb-210	6.1E-08	2.3E-07	Bi-210 and Po-210 included	4.6E-08
Pb-212	4.9E-06	5.1E-05	Bi-212, Po-212 and Tl-208 included	1.0E-05
Po-210	1.5E-09	1.5E-09		3.0E-10
At-211	1.1E-06	1.3E-06	Po-211 included	2.5E-07

Radio-nuclide	Dose rate above sediment (µSv/h per Bq/kg)			
	Dose rate parent	Dose rate including all progeny	Comments	Dose rate after application of river bank scaling factor
Ra-223	4.3E-06	1.0E-05	Rn-219 through to Tl-207 included	2.0E-06
Ra-226	9.0E-07	3.3E-04	Rn-222 through to Pb-210 included	6.5E-05
Ac-225	5.1E-07	7.7E-06	Fr-221 through to Pb-209	1.5E-06
Th-227	3.5E-06	1.4E-05	Ra-223 through to Tl-207 included	2.7E-06
Th-230	3.3E-08	3.3E-08		6.6E-09
Th-232	1.4E-08	4.7E-04	Ra-228 through to Tl-208 included	9.5E-05
Th-234	6.6E-07	4.2E-06	Pa-234m, Pa-234, U-234 included, rest of chain:long half-life	8.4E-07
U-234	1.1E-08	1.1E-08		2.1E-09
U-235	2.0E-05	2.1E-05	Th-231 only included	4.3E-06
U-238	2.5E-09	4.2E-06	Th-234 to U-234 included	8.4E-07
Np-237	2.1E-06	3.1E-05	Pa-233 only included	6.2E-06
Pu-238	3.6E-09	3.6E-09		7.2E-10
Pu-239	8.1E-09	8.1E-09		1.6E-09
Pu-240	3.5E-09	3.5E-09		6.9E-10
Pu-241	1.6E-10	1.6E-10		3.3E-11
Pu-242	3.1E-09	3.1E-09		6.1E-10
Am-241	1.1E-06	1.1E-06		2.3E-07
Am-242	4.3E-07	4.3E-07	Cm-242 included: significant decay in 1 year. Pu-242: half-life too long	8.7E-08
Am-243	3.8E-06	2.5E-05	Np-239 only included	5.0E-06
Cm-242	4.0E-09	4.0E-09		7.9E-10
Cm-243	1.6E-05	1.6E-05		3.3E-06
Cm-244	2.8E-09	2.8E-09		5.5E-10

Table F.7. External dose rates per unit release rate

Radionuclide	Dose rate per unit release from riverbank sediments (µSv/h per Bq/y)*	Dose rate per unit release from irrigated soil (µSv/h per Bq/y)^
H-3	0.0E+00	0.0E+00
H-3 organic	0.0E+00	0.0E+00
C-14	4.0E-18	0.0E+00
Na-22	2.5E-16	1.3E-13
Na-24	8.5E-17	2.0E-16
P-32	1.2E-16	0.0E+00
P-33	4.9E-19	0.0E+00
S-35	4.7E-19	0.0E+00
Cl-36	4.7E-17	5.0E-17
Ca-45	1.1E-17	5.5E-24
Ca-47	2.7E-13	4.8E-16
V-48	6.3E-14	4.0E-15
Cr-51	3.5E-13	7.6E-17
Mn-52	1.4E-11	1.7E-15
Mn-54	1.8E-11	2.0E-14
Fe-55	0.0E+00	1.7E-19
Fe-59	5.9E-12	4.4E-15
Co-56	7.0E-11	2.2E-14
Co-57	1.4E-12	2.3E-15
Co-58	1.7E-11	5.8E-15
Co-60	4.8E-11	2.5E-13
Ni-63	0.0E+00	0.0E+00
Cu-61	9.0E-14	1.0E-17
Cu-64	2.1E-14	8.9E-18
Zn-62	1.6E-13	5.0E-17
Zn-65	3.4E-13	1.1E-14
Ga-67	9.7E-15	4.2E-17
Se-75	1.2E-12	3.8E-15
Br-76	1.2E-12	1.5E-16
Br-77	1.5E-13	6.5E-17
Br-82	1.2E-12	3.4E-16
Rb-81	1.8E-12	1.0E-17
Rb-83	7.2E-12	3.6E-15
Sr-83	2.0E-13	3.8E-15
Sr-85	6.2E-13	2.8E-15
Sr-89	3.4E-15	3.5E-19
Sr-90	9.1E-15	2.7E-21
Y-90	4.4E-15	1.4E-23
Zr-89	2.4E-13	3.3E-16
Zr-95	1.6E-12	1.1E-14
Nb-95	8.6E-14	2.3E-15
Mo-99	4.6E-13	6.6E-17
Tc-99	1.1E-19	0.0E+00
Tc-99m	1.3E-16	2.6E-18

Radionuclide	Dose rate per unit release from riverbank sediments (µSv/h per Bq/y)*	Dose rate per unit release from irrigated soil (µSv/h per Bq/y)^
Ru-103	7.1E-12	1.6E-15
Ru-106	3.4E-12	5.7E-15
Ag-110m	7.2E-11	5.4E-14
In-111	1.4E-12	9.4E-17
Sb-125	1.9E-12	2.7E-14
I-123	1.2E-13	4.5E-16
I-124	8.8E-13	3.9E-16
I-125	8.7E-15	5.0E-17
I-129	7.0E-15	8.8E-16
I-131	3.2E-13	2.7E-16
I-133	5.1E-13	4.8E-17
I-135	1.3E-12	4.2E-17
Cs-134	2.3E-11	7.8E-14
Cs-136	6.3E-12	2.4E-15
Cs-137	8.4E-12	1.4E-13
Ba-140	9.9E-13	3.0E-15
La-140	8.8E-12	3.2E-16
Ce-141	1.3E-12	1.9E-16
Ce-144	1.5E-12	1.0E-15
Pm-147	3.5E-17	2.1E-19
Sm-153	2.0E-13	7.6E-18
Eu-152	6.3E-13	2.0E-13
Eu-154	7.0E-13	1.7E-13
Eu-155	1.5E-14	4.1E-15
Er-169	2.2E-16	1.7E-23
Lu-177	1.6E-13	1.9E-17
Re-188	6.5E-15	3.4E-18
Au-198	2.1E-12	9.7E-17
Tl-201	1.9E-13	1.9E-17
Pb-210	1.0E-14	1.4E-16
Pb-212	2.3E-12	1.3E-17
Po-210	1.5E-16	9.6E-20
At-211	3.0E-14	3.9E-13
Ra-223	3.6E-13	2.8E-16
Ra-226	1.2E-11	5.8E-13
Ac-225	9.6E-13	1.6E-16
Th-227	1.9E-12	8.9E-16
Th-230	4.6E-15	5.9E-13
Th-232	6.6E-11	4.1E-13
Th-234	5.9E-13	8.2E-17
U-234	3.4E-18	4.4E-15
U-235	6.7E-15	4.4E-14
U-238	1.3E-15	7.0E-15
Np-237	2.0E-15	6.3E-14
Pu-238	5.2E-16	3.6E-17

Radionuclide	Dose rate per unit release from riverbank sediments (µSv/h per Bq/y)*	Dose rate per unit release from irrigated soil (µSv/h per Bq/y)^
Pu-239	1.2E-15	4.4E-14
Pu-240	5.0E-16	2.6E-17
Pu-241	2.3E-17	3.0E-15
Pu-242	4.4E-16	7.2E-15
Am-241	1.5E-13	6.6E-14
Am-242	5.7E-14	1.9E-16
Am-243	3.3E-12	5.3E-14
Cm-242	1.0E-16	1.1E-17
Cm-243	4.4E-13	7.8E-14
Cm-244	7.3E-17	5.2E-17

*for a river flow rate of 1 m^3/s , ^for an irrigation rate of 0.3 m^3 per m^2/y .

Table F.8. Activity concentrations in terrestrial foods per unit deposition rate for irrigation

Radionuclide	50th year activity concentrations in foods per unit deposition rate (Bq/kg per Bq/m^2/s)		
	Green vegetables	Root vegetables	Fruit
H-3	5.1E+04	5.1E+04	5.1E+04
H-3 organic	1.1E+04	1.1E+04	1.1E+04
C-14	2.3E+06	1.8E+06	2.3E+06
Na-22	1.3E+05	1.2E+05	3.5E+05
Na-24	4.5E+03	1.8E+01	3.8E+02
P-32	5.9E+04	2.2E+04	6.8E+04
P-33	7.9E+04	4.1E+04	1.3E+05
S-35	1.2E+05	9.8E+04	2.6E+05
Cl-36	5.9E+06	5.0E+06	9.4E+06
Ca-45	1.8E+05	2.9E+03	2.1E+04
Ca-47	2.8E+04	6.3E+01	2.0E+03
V-48	5.7E+04	2.3E+01	6.1E+03
Cr-51	7.0E+04	1.4E+00	4.8E+03
Mn-52	3.0E+04	9.6E+01	2.7E+03
Mn-54	1.1E+05	6.6E+03	5.1E+04
Fe-55	1.2E+05	2.2E+02	2.2E+04
Fe-59	8.3E+04	5.4E+01	1.2E+04
Co-56	9.3E+04	5.1E+02	1.5E+04
Co-57	1.1E+05	1.6E+03	2.0E+04
Co-58	9.2E+04	4.7E+02	1.5E+04
Co-60	1.2E+05	1.1E+04	2.2E+04
Ni-63	2.1E+05	2.5E+04	4.8E+04
Cu-61	1.1E+03	3.8E+00	7.3E+01
Cu-64	3.8E+03	1.4E+01	2.6E+02
Zn-62	2.8E+03	3.9E+00	2.2E+02
Zn-65	1.2E+05	3.7E+03	8.1E+04
Ga-67	2.0E+04	2.1E-01	1.5E+03
Se-75	1.5E+05	1.2E+05	3.0E+05
Br-76	4.9E+03	2.4E+01	4.2E+02
Br-77	1.5E+04	6.1E+02	3.2E+03
Br-82	1.0E+04	1.9E+02	1.4E+03
Rb-81	1.4E+03	6.3E+00	1.0E+02
Rb-83	1.1E+05	8.8E+04	2.5E+05
Sr-83	9.3E+03	2.1E+01	6.5E+02
Sr-85	9.1E+04	1.5E+03	1.4E+04
Sr-89	8.6E+04	1.2E+03	1.3E+04
Sr-90	2.6E+05	1.5E+05	2.8E+04
Y-90	1.7E+04	2.9E-01	1.2E+03
Zr-89	2.0E+04	6.6E-01	1.5E+03
Zr-95	9.0E+04	8.7E+01	1.4E+04
Nb-95	7.7E+04	7.0E+01	1.1E+04
Mo-99	1.7E+04	3.3E+01	1.3E+03

Radionuclide	50th year activity concentrations in foods per unit deposition rate (Bq/kg per Bq/m²/s)		
	Green vegetables	Root vegetables	Fruit
Tc-99	1.4E+07	9.1E+06	9.4E+06
Tc-99m	2.7E+03	3.7E+02	2.2E+02
Ru-103	7.7E+04	2.0E+01	5.3E+03
Ru-106	1.0E+05	1.8E+02	7.0E+03
Ag-110m	1.1E+05	1.6E+02	3.2E+04
In-111	1.8E+04	1.5E-01	1.3E+03
Sb-125	1.1E+05	2.0E+02	2.4E+04
I-123	4.0E+03	1.4E+01	3.2E+02
I-124	2.5E+04	2.4E+03	9.5E+03
I-125	1.0E+05	7.3E+04	2.1E+05
I-129	1.9E+05	1.8E+05	3.6E+05
I-131	4.1E+04	8.6E+03	2.9E+04
I-133	6.2E+03	4.7E+01	5.9E+02
I-135	2.0E+03	2.6E+00	1.5E+02
Cs-134	1.3E+05	1.2E+05	3.4E+05
Cs-136	5.6E+04	1.9E+04	5.9E+04
Cs-137	1.4E+05	1.4E+05	3.6E+05
Ba-140	5.1E+04	8.7E+00	5.0E+03
La-140	1.1E+04	1.2E-01	7.9E+02
Ce-141	7.3E+04	1.0E+01	5.1E+03
Ce-144	1.0E+05	8.4E+01	6.9E+03
Pm-147	1.1E+05	2.1E+03	1.5E+04
Sm-153	1.3E+04	4.3E-01	8.8E+02
Eu-152	1.1E+05	3.3E+03	1.1E+04
Eu-154	1.1E+05	2.4E+03	9.7E+03
Eu-155	1.1E+05	1.4E+03	8.7E+03
Er-169	4.2E+04	2.5E+00	2.9E+03
Lu-177	3.4E+04	1.7E+00	2.3E+03
Re-188	7.5E+03	1.1E+03	7.2E+02
Au-198	1.7E+04	1.8E+00	1.2E+03
Tl-201	1.9E+04	1.1E+03	5.2E+03
Pb-210	1.2E+05	4.8E+03	3.8E+04
Pb-212	3.2E+03	2.3E-01	2.2E+02
Po-210	1.2E+05	9.7E+04	2.8E+05
At-211	2.2E+03	3.1E+00	1.6E+02
Ra-223	4.8E+04	4.1E+01	4.6E+03
Ra-226	1.4E+05	4.1E+04	5.2E+04
Ac-225	4.4E+04	2.2E+00	3.0E+03
Th-227	6.0E+04	7.4E-01	4.1E+03
Th-230	1.1E+05	4.7E+02	9.2E+03
Th-232	1.1E+05	4.7E+02	9.2E+03
Th-234	6.6E+04	9.8E-01	4.6E+03
U-234	1.1E+05	5.0E+03	1.1E+04
U-235	1.1E+05	5.0E+03	1.1E+04
U-238	1.1E+05	5.0E+03	1.1E+04

Radionuclide	50th year activity concentrations in foods per unit deposition rate (Bq/kg per Bq/m^2/s)		
	Green vegetables	Root vegetables	Fruit
Np-237	1.1E+05	1.3E+04	1.4E+04
Pu-238	1.1E+05	1.9E+02	7.6E+03
Pu-239	1.1E+05	2.3E+02	7.7E+03
Pu-240	1.1E+05	2.3E+02	7.7E+03
Pu-241	1.0E+05	9.2E+01	7.4E+03
Pu-242	1.1E+05	2.3E+02	7.7E+03
Am-241	1.1E+05	3.7E+02	7.7E+03
Am-242	4.8E+03	1.5E-02	3.3E+02
Am-243	1.1E+05	3.8E+02	7.7E+03
Cm-242	9.6E+04	6.7E+00	6.7E+03
Cm-243	1.1E+05	3.0E+02	7.6E+03
Cm-244	1.1E+05	2.3E+02	7.5E+03

Table F.9. Activity concentration in terrestrial foodstuffs irrigated with river water per unit release rate

Radionuclide	Activity concentration (Bq/kg per Bq/y)*		
	Green vegetables	Root vegetables	Fruit
H-3	1.5E-11	1.5E-11	1.5E-11
H-3 organic	3.3E-12	3.3E-12	3.3E-12
C-14	6.9E-10	5.4E-10	6.9E-10
Na-22	3.9E-11	3.6E-11	1.0E-10
Na-24	1.4E-12	5.5E-15	1.1E-13
P-32	1.8E-11	6.5E-12	2.0E-11
P-33	2.4E-11	1.2E-11	3.8E-11
S-35	3.7E-11	2.9E-11	7.8E-11
Cl-36	1.8E-09	1.5E-09	2.8E-09
Ca-45	5.4E-11	8.7E-13	6.4E-12
Ca-47	8.3E-12	1.9E-14	6.1E-13
V-48	1.7E-11	7.0E-15	1.8E-12
Cr-51	2.1E-11	4.3E-16	1.4E-12
Mn-52	9.1E-12	2.9E-14	8.1E-13
Mn-54	3.3E-11	2.0E-12	1.5E-11
Fe-55	3.6E-11	6.5E-14	6.6E-12
Fe-59	2.5E-11	1.6E-14	3.6E-12
Co-56	2.8E-11	1.5E-13	4.6E-12
Co-57	3.2E-11	4.8E-13	6.0E-12
Co-58	2.8E-11	1.4E-13	4.4E-12
Co-60	3.6E-11	3.3E-12	6.7E-12
Ni-63	6.3E-11	7.5E-12	1.4E-11
Cu-61	3.2E-13	1.1E-15	2.2E-14
Cu-64	1.2E-12	4.3E-15	8.0E-14
Zn-62	8.5E-13	1.2E-15	6.7E-14
Zn-65	3.6E-11	1.1E-12	2.5E-11
Ga-67	6.0E-12	6.3E-17	4.4E-13

Radionuclide	Activity concentration (Bq/kg per Bq/y)*		
	Green vegetables	Root vegetables	Fruit
Se-75	4.4E-11	3.7E-11	9.1E-11
Br-76	1.5E-12	7.2E-15	1.3E-13
Br-77	4.6E-12	1.8E-13	9.5E-13
Br-82	3.0E-12	5.7E-14	4.1E-13
Rb-81	4.2E-13	1.9E-15	3.0E-14
Rb-83	3.3E-11	2.7E-11	7.5E-11
Sr-83	2.8E-12	6.4E-15	1.9E-13
Sr-85	2.7E-11	4.5E-13	4.3E-12
Sr-89	2.6E-11	3.6E-13	3.9E-12
Sr-90	7.7E-11	4.6E-11	8.5E-12
Y-90	5.1E-12	8.7E-17	3.7E-13
Zr-89	6.0E-12	2.0E-16	4.4E-13
Zr-95	2.7E-11	2.6E-14	4.3E-12
Nb-95	2.3E-11	2.1E-14	3.2E-12
Mo-99	5.2E-12	1.0E-14	3.9E-13
Tc-99	4.3E-09	2.7E-09	2.8E-09
Tc-99m	8.1E-13	1.1E-13	6.7E-14
Ru-103	2.3E-11	6.1E-15	1.6E-12
Ru-106	3.1E-11	5.5E-14	2.1E-12
Ag-110m	3.2E-11	4.7E-14	9.8E-12
In-111	5.3E-12	4.5E-17	3.9E-13
Sb-125	3.3E-11	5.9E-14	7.4E-12
I-123	1.2E-12	4.2E-15	9.6E-14
I-124	7.6E-12	7.1E-13	2.8E-12
I-125	3.1E-11	2.2E-11	6.4E-11
I-129	5.7E-11	5.5E-11	1.1E-10
I-131	1.2E-11	2.6E-12	8.8E-12
I-133	1.9E-12	1.4E-14	1.8E-13
I-135	6.1E-13	7.7E-16	4.4E-14
Cs-134	3.9E-11	3.6E-11	1.0E-10
Cs-136	1.7E-11	5.6E-12	1.8E-11
Cs-137	4.3E-11	4.3E-11	1.1E-10
Ba-140	1.5E-11	2.6E-15	1.5E-12
La-140	3.4E-12	3.6E-17	2.4E-13
Ce-141	2.2E-11	3.0E-15	1.5E-12
Ce-144	3.0E-11	2.5E-14	2.1E-12
Pm-147	3.2E-11	6.2E-13	4.4E-12
Sm-153	3.9E-12	1.3E-16	2.7E-13
Eu-152	3.3E-11	1.0E-12	3.2E-12
Eu-154	3.2E-11	7.2E-13	2.9E-12
Eu-155	3.2E-11	4.2E-13	2.6E-12
Er-169	1.3E-11	7.4E-16	8.7E-13
Lu-177	1.0E-11	5.1E-16	7.0E-13
Re-188	2.3E-12	3.3E-13	2.2E-13
Au-198	5.1E-12	5.5E-16	3.5E-13
Tl-201	5.8E-12	3.4E-13	1.6E-12
Pb-210	3.7E-11	1.5E-12	1.1E-11

Radionuclide	Activity concentration (Bq/kg per Bq/y)*		
	Green vegetables	Root vegetables	Fruit
Pb-212	9.7E-13	6.8E-17	6.7E-14
Po-210	3.6E-11	2.9E-11	8.5E-11
At-211	6.7E-13	9.4E-16	4.8E-14
Ra-223	1.4E-11	1.2E-14	1.4E-12
Ra-226	4.1E-11	1.2E-11	1.6E-11
Ac-225	1.3E-11	6.7E-16	9.1E-13
Th-227	1.8E-11	2.2E-16	1.2E-12
Th-230	3.2E-11	1.4E-13	2.8E-12
Th-232	3.2E-11	1.4E-13	2.8E-12
Th-234	2.0E-11	2.9E-16	1.4E-12
U-234	3.3E-11	1.5E-12	3.2E-12
U-235	3.3E-11	1.5E-12	3.2E-12
U-238	3.3E-11	1.5E-12	3.2E-12
Np-237	3.4E-11	3.9E-12	4.1E-12
Pu-238	3.2E-11	5.8E-14	2.3E-12
Pu-239	3.2E-11	6.9E-14	2.3E-12
Pu-240	3.2E-11	6.8E-14	2.3E-12
Pu-241	3.1E-11	2.8E-14	2.2E-12
Pu-242	3.2E-11	6.9E-14	2.3E-12
Am-241	3.2E-11	1.1E-13	2.3E-12
Am-242	1.4E-12	4.5E-18	9.9E-14
Am-243	3.2E-11	1.1E-13	2.3E-12
Cm-242	2.9E-11	2.0E-15	2.0E-12
Cm-243	3.2E-11	9.0E-14	2.3E-12
Cm-244	3.2E-11	7.0E-14	2.3E-12

*for a river flow rate of 1 m^3/s

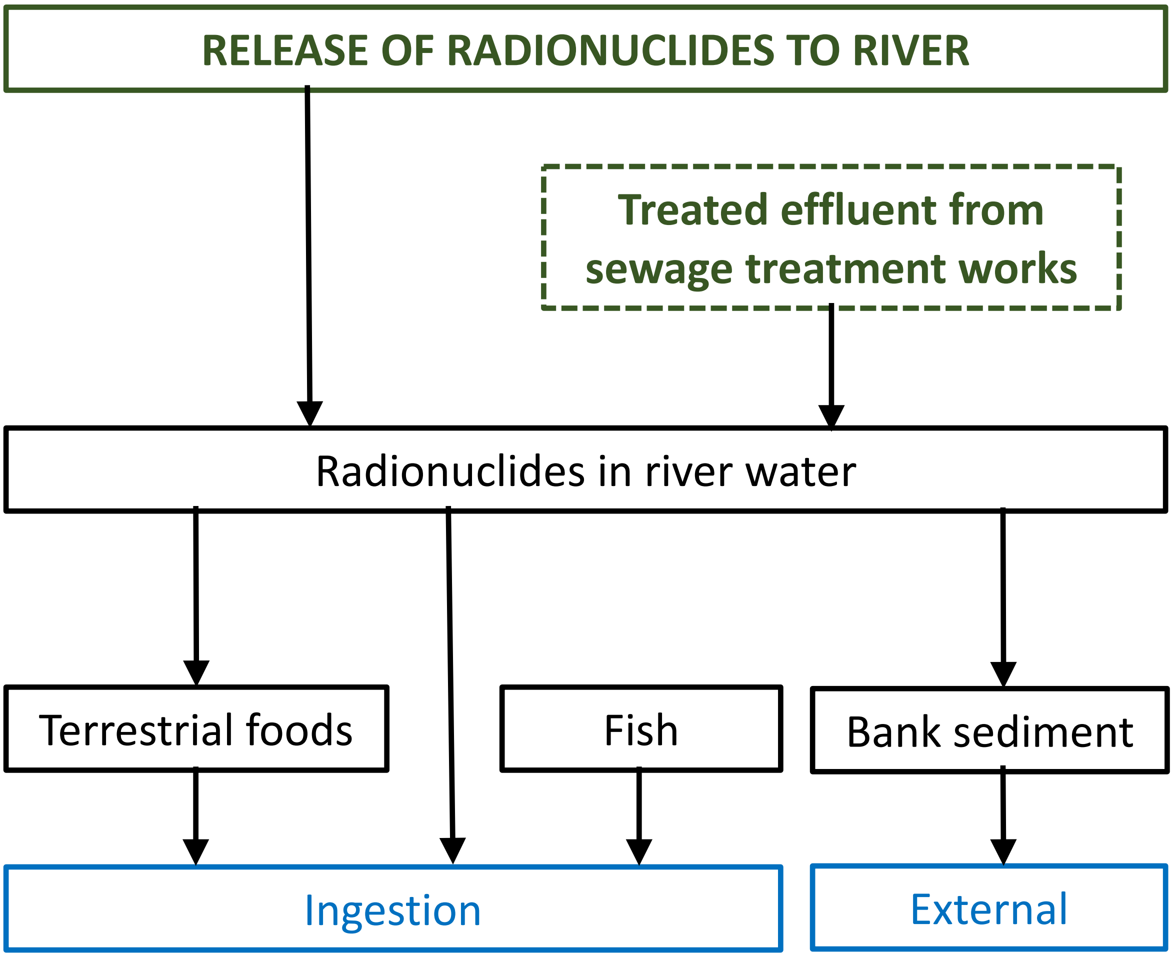

Figure F.1. Flow diagram of exposure pathways considered for releases to rivers

Appendix G: Input data and calculation of DPUR factors for sewage discharges scenario

G.1 Source term

Discharges of liquid radioactive wastes can take place directly to a public sewer. At sewage treatment works and waste water treatment works, a variety of treatment processes can occur. The wastes are predominantly water containing low levels of suspended and dissolved solids. The treatment processes result in separation of solids into sludges and liquid effluent with low suspended solid load. Radionucldies partition between the liquid effluent and sewage sludge.

Treated sewage sludge may be used for soil conditioning in agriculture which could lead to radionuclide transfer into the soils, crops and grazing animals. Therefore there is a requirement for assessment of the potential radiological impact which is covered in this appendix. Sewage sludge may be dewatered and incinerated (see Appendix H) resulting in discharges of radionuclides to air which may need to be assessed.

The treated liquid effluent can be discharged into estuarine and coastal environments, either directly, or via freshwater streams and rivers. As a result, the impact on coastal and river exposure groups (see Appendices E and F) may need to be assessed in addition to the exposure groups particular to discharges to sewers. The radionuclides considered for releases to public sewers are listed in Table 1.

G.2 Exposed groups for assessments to public

The following exposure groups were considered.

<u>Sewage treatment workers (adult only)</u>
Pathways included are:

- external radiation from radionuclides in raw sewage and sewage sludge;
- internal radiation from the inadvertent inhalation of raw sewage and sewage sludge;
- internal radiation from the inadvertent ingestion of raw sewage and sewage sludge.

Members of the sewage treatment worker exposure group were assumed to spend a working year (2,000 h/y) at the sewage treatment works, approximately 25% of which is spent in the vicinity of sewage sludge tanks [G.1], and the exposure was calculated accordingly. Time-integrated concentrations in raw sewage and sludge were used, to account for decay during transit times through the treatment works. Table G.1 lists the relevant habit data.

Farming family exposed to sludge used for agriculture and soil conditioning (not considered for radionuclides with half-lives of less than 4 days)
Pathways included are:

- external radiation from radionuclides in sludge conditioned soil;
- internal radiation from the inadvertent inhalation of resuspended soil;
- internal radiation from the inadvertent ingestion of soil;
- internal radiation from the consumption of appropriate food types produced on sludge conditioned land (radionuclides with half-lives of less than 30 days were not considered for consumption of vegetables).

The farming family was assumed to live on land treated repeatedly with sewage sludge and to consume the relevant foodstuffs produced at high rates [G.2]. Decay of any radionuclides present in the treated sludge, up the point of the sludge leaving the sewage treatment works, was included. Habit data relevant to the farming family, including ingestion rates and occupancy times, are listed in Table G.2.

Children playing in brook carrying treated effluent (children only) (not considered for radionuclides with half-lives of less than 3 hours)
Pathways included are:

- external radiation from radionuclides in river bank sediments;
- internal radiation from the inadvertent ingestion of brook water;
- internal radiation from the inadvertent ingestion of sediments.

Members of the children playing in brook exposure group are exposed to the liquid effluents from the sewage treatment works. Exposure was determined based on radionuclide concentration in brook water and brook bank sediments, which were derived following the method, data and assumptions detailed in Appendix F. This exposure group was considered for all radionuclides, although some of the radionuclides with very short half-lives will have decayed significantly during the transit time through the treatment works; radionuclides with a half life of less than 3 hours were not considered for this pathway. A representative occupancy rate of 500 h/y and inadvertent sediment ingested rate of 10 mg/h were adopted [G.3]. A value of 10 ml/h was assumed for the inadvertent ingestion of brook water, based on a value of 0.7 ml/h for the inadvertent ingestion of seawater [G.3] and allowing for a possibly higher ingestion rate of freshwater. Habit data for the children playing in brook exposure group are listed in Table G.3.

Fishing family in the estuarine and coastal environment receiving treated effluent
Pathways and habits are the same as that for fishing family as detailed in Appendix E. This exposure group was considered for all radionuclides, although some of the radionuclides with very short half-lives will have decayed significantly during the transit time through the treatment works; radionuclides with a half life of less than 3 hours were not considered for this pathway.

Angler family making use of rivers receiving treated effluent
Pathways and habits are the same as that for angler family as detailed in Appendix F. This exposure group was considered for all radionuclides, although some of the radionuclides with very short half-lives will have decayed significantly during the

transit time through the treatment works; radionuclides with a half life of less than 3 hours were not considered for this pathway.

Irrigated food comsumer family making use of rivers receiving treated effluent
Pathways and habits are the same as that for irrigated food consumer family as detailed in Appendix F. This exposure group was considered for all radionuclides, although some of the radionuclides with very short half-lives will have decayed significantly during the transit time through the treatment works; radionuclides with a half life of less than 3 hours were not considered for this pathway.

Local resident family affected by releases to air from incinerated sludge
Pathways and habits are the same as that for local resident family as detailed in Appendix H. This exposure group was considered for all radionuclides, although some of the radionuclides with very short half-lives will have decayed significantly during the transit time through the treatment works; radionuclides with a half life of less than 3 hours were not considered for this pathway.

Figure G.1 shows the matrix of pathways that were evaluated.

G.3 Activity concentrations in liquid effluent and sewage sludge

Activity concentration of radionuclides released into effluent in the sewer were calculated using a simple volume dilution approach. In the sewage treatment works, the following processes were considered: flow of effluent through settling tanks, separation of suspended solids from the liquid effluent and subsequent treatment of the remaining liquid effluent and sludge produced from the suspended solids.

Assuming simple dilution of the discharge at the sewage treatment works, the activity concentration of radionuclides in raw sewage is given by:

$$C_{raw} = \frac{Q}{V\rho_{raw}}$$

where	C_{raw}	is activity concentration in unfiltered raw sewage per unit discharge rate to the sewage treatment works (Bq/kg per Bq/y)
	Q	is discharge rate to sewage treatment works (Bq/y)
	V	is volumetric flow rate of the sewage treatment works (l/y)
	ρ_{raw}	is density of raw sewage (kg/l)

A representative flow rate of 60 m^3/d (2.2E+07 l/y) of effluent through the sewage treatment works was applied, which corresponds to a small rural installation, serving approximately 500 people [G.2]. A transition time of 15 hours was assumed for liquid effluent and 17 days (408 hours) for conditioned sewage sludge [G.2]. Data characterising the sewage treatment works are listed in Table G.4. The dilution approach results in activity concentrations in raw sewage of 4.6E-08 Bq/kg per Bq/y. This is for all radionuclides discharged, assuming a density of 1 kg/l of raw sewage. This assumes instant arrival of sewage at the sewage treatment works and does not include any decay or losses en route. This is the basecase; assessments can be refined by scaling by the flow rate of sewage effluent.

For the partitioning of the radionuclides between the sewage sludge and liquid effluent, experimental or field study data was used where available, in particular drawing on research by the Environment Agency [G.4]. The remaining radionuclides' partitioning was approximated by creating three categories based on partition coefficients for organic soil:

- radionuclides with a low partition coefficient (<1,000 l/kg) were assumed to remain mainly in the liquid effluent (90% liquid, 10% sludge);
- radionuclides with a high partition coefficient (>5,000 l/kg) were assumed to concentrate in the sewage sludge (10% liquid, 90% sludge);
- a 50/50 split was assumed for radionuclides with an intermediate partition coefficient.

Partition coefficients for sewage are listed in Table G.5, together with relevant data sources.

To calculate activity concentrations in liquid effluent at the point of discharge from the sewage treatment works, decay during the 15-hour residence time was included.

The activity concentration in treated liquid effluent on leaving the sewage treatment works (including the 15 hour residence time) per unit discharge to the sewage treatment works is given by:

$$C_{eff} = C_{raw}\, F_{eff}\, e^{-\lambda t}$$

where	C_{eff}	is activity concentration in the liquid effluent per unit discharge (Bq/l per Bq/y)
	C_{raw}	is activity concentration in unfiltered raw sewage per unit discharge (Bq/kg per Bq/y) (assuming 1 kg = 1 l of raw sewage).
	F_{eff}	is fraction of activity which remains in the liquid effluent (see Table G.5)
	λ	is decay constant (/h)
	t	is residency time of effluent (h)

The production of sewage sludge involves separating and concentrating some of the suspended solids present in the sewage sludge. To calculate activity concentrations in the sewage sludge (for agriculture and soil conditioning), at the point of discharge from the sewage treatment works, decay during the 408 h residence time was included. It is assumed that the production rate of sludge is proportional to the input rate of raw sewage and indicated by the relative suspended solid contents. Thus, the activity concentration in sewage sludge, at the point of discharge from the sewage treatment works, per unit discharge into the sewage treatment works, is given by:

$$C_{slu} = C_{raw}\, F_{slu}\, \frac{SS_{slu}}{SS_{raw}}\, e^{-\lambda t}$$

where	C_{slu}	is activity concentration in the sludge per unit discharge rate (Bq/kg per Bq/y)
	C_{raw}	is activity concentration in unfiltered raw sewage per unit discharge (Bq/kg per Bq/y)
	F_{slu}	is fraction of activity in the sludge (see Table G.5)
	SS_{slu}	is suspended solid content of the treated sludge (%) (see Table G.4)
	SS_{raw}	is suspended solid content of the raw sewage (%) (see Table G.4)
	λ	is decay contant (/h)
	t	is residency time of sludge (h)

For sewage sludge for incineration, a residence time of 96 hours was applied for the calculation of activities in sewage sludge, see Appendix H.

For pathways resulting from exposure to raw sewage and sewage sludge at the sewage treatment works, time-integrated concentrations were derived as follows:

given that $\overline{C} = \frac{\int_{t_0}^{t_1} f(t)}{t_1 - t_0}$ it follows that $\overline{C} = \frac{C_0 (1 - e^{(-\lambda\, t_1)})}{\lambda\, t_1}$

where	$\overline{C}$	is average time-integrated activity concentration (Bq/kg)
	$f(t)$	$= C_0\ e^{-\lambda\, t}$
	t_0	is time = 0
	t_1	is residency time of the effluent or sludge (h)
	C_0	is initial activity concentration at t_0 (Bq/kg)
	λ	is decay constant (/h)

Table G.6 and Table G.7 list the activity concentrations in the raw sewage, liquid effluent and sewage sludge (both at the treatment works and at the time of leaving the treatment works) per unit release.

The activity concentration resulting from the discharge of the effluent into a small brook was derived in a similar way as that for the river release scenario river (see Appendix F). The parameters characterising the brook are shown in Table G.8. Water and sediment concentrations in the brook per unit release into the sewage treatment works are shown in Table G.9. These values do not include any partitioning of activity or decay in the sewage treatment works; this is accounted for later using the factor Q_{eff} (defined below).

Activity concentrations in the liquid effluent from the sewage treatment works are also used as input into river and coastal radiological impact calculations (see Appendices E and F). In order to assess pathways resulting from the discharge of the liquid effluent into a brook, a river or coastal water, a partitioning and decay factor, which can be expressed as a discharge rate of activity in the liquid effluent per unit discharge into the sewage treatment works, was calculated as follows:

$$Q_{eff} = C_{eff}\ V$$

where Q_{eff} is discharge rate of activity from the sewage treatment works in liquid effluent per unit discharge into the sewage treatment works (Bq/y per Bq/y)

C_{eff} is activity concentration in the liquid effluent per unit discharge rate (Bq/l per Bq/y)

V is volumetric flow rate of the sewage treatment works (l/y)

Partitioning and decay factors (Q_{eff}), expressed as discharge rates of activity in the liquid effluent per unit release are shown in Table G.10.

G.4 External dose rates

G.4.1 External exposure from sewage and sludge tanks

To derive the dose rates for external exposure from raw sewage and sewage sludge at the treatment works, effective dose coefficients above soil contaminated to an infinite depth listed in Eckerman and Leggett and Eckerman and Ryman [G.5, G.6], using ICRP dosimetry, were used and converted from a volume source (Bq/m^3) to a source per unit mass basis (Bq/kg), applying a soil density of 1,600 kg/m^3 [G.6]. Although the density of sewage sludge is somewhat lower than that of soil it was taken that the effect on the calculated dose factors will not be significant, as long as the activity is assessed per unit sewage/sludge mass rather than per unit volume [G.7]. It was cautiously assumed that an exposure geometry of an infinite horizontal extent could be applied.

Dose coefficients for progeny which can be considered to exist in secular equilibrium with their parent or which will decay significantly during the timescale considered, were added to their parent's dose rate. Here the sludge residency time of 408 hours was taken as a benchmark, rather than the effluent residency time of 15 hours. The dose rates for external exposure above raw sewage and sludge per unit activity concentration in raw sewage or sludge, together with the progeny considered are shown in Table G.11.

External exposures from raw sewage and raw sewage sludge were calculated separately and then added to give a total dose to sewage treatment workers. For the dose from the sewage tanks an exposure time of 1,500 h/y, for which the average integrated activity concentration over the transit time of the liquid effluent (15 hours) has been calculated, was assumed. The sewage tanks were cautiously assumed to contain all of the activity received by the STW. For the dose from the sludge tanks, an exposure time of 500 h/y was assumed. The average integrated activity concentration in sludge over the time for digestion and storage (408 hours) has been calculated. The sludge was assumed to contain only the activity left after partitioning from the liquid phase.

G.4.2 External exposure from sludge conditioned soil

The dose rate from external exposure above agricultural soil conditioned with sewage sludge will depend on the agricultural use of the soil. Pasture is undisturbed, therefore radionuclides deposited on the surface migrate gradually downwards through the soil primarily by leaching (although bioturbation will also mix soils). In contrast, land used for crops is ploughed annually which assumes instant mixing of deposited radionuclides through the ploughed depth of soil (generally assumed to be 30 cm). As a result, the concentrations in well mixed soil are lower at the surface than in undisturbed pasture. For external dose pathways it is conservatively assumed that the soil is undisturbed, which will result in higher concentrations and higher external dose rates at the surface. The external dose model used is therefore exactly the same as used for the external dose from radionuclides deposited following atmospheric releases of radionuclides (see Section D.4.2 and Table D.5).

G.4.3 External dose rates per unit release

The effective dose rates from external exposure to raw sewage, sludge tanks, above conditioned soil or brook bank sediments per unit release were calculated as follows:

$$DR_{ext\_sewage} = DR_{ext\_sewage(u)} A$$

where	DR_{ext_sewage}	is external dose rate from radionuclides in raw sewage, sludge, conditioned soil or sediments (µSv/h per Bq/y)
	$DR_{ext\_sewage(u)}$	is external dose rate per unit activity concentration in raw sewage, sludge, conditioned soil or sediments (µSv/h per Bq/kg)
	A	is activity concentration per unit release rate in raw sewage (C_{raw}), sludge (C_{slu}), conditioned soil (C_{soil}) or sediments (C_{sed}) (Bq/kg per Bq/y)

The calculation of C_{raw} and C_{slu} are presented in the preceding section. C_{soil} is calculated as described in the Section G.5, termed C_{food}. C_{sed} is calculated as described in Appendix F.

The resulting external dose rates per unit release are shown in Table G.12.

G.5 Activity concentrations in terrestrial foodstuffs produced on sewage sludge conditioned soil

G.5.1 Terrestrial foodchain transfer modelling

Activity concentrations in the terrestrial foodstuffs produced on land conditioned with sewage sludge were calculated for animal products (cow meat, liver and milk and sheep meat and liver) and green and root vegetables. Two situations were considered. One is application of sludge to the surface of undisturbed pasture followed by animal grazing; milk production and animal products. The second was application of sludge to arable soil – well mixed to 30 cm and then production of fruit and vegetables. Activity concentrations in terrestrial foodstuffs and conditioned soil were derived using a similar method to the one used to derive the Generalised Derived Constraints (GDCs) and Generalised Derived Limits (GDLs) for discharges to sewers [G.2, G.8, G.9].

Conditioning of the soil was assumed to occur annually and 3 weeks before grazing animals were allowed on the pasture or 10 months before vegetables were harvested [G.10]. Decay of radionuclides during these delay times were taken into account. Activity concentrations in vegetables were not calculated for radionuclides with half-lives of less than 30 days. FARMLAND (as implemented in PC-CREAM 08) [G.11, G.12] was used to derive concentration factors in terrestrial foodstuffs per unit deposition rate, as a consequence of applying sewage sludge to agricultural land.

For the application of sewage sludge to soil, no direct contamination of the pasture or vegetables was assumed. In order to model deposition of radionuclides to soil only, the plant interception factor for pasture and vegetables was set to its lowest value of 1% (compared with the default for atmospheric deposition and leaf interception onto pasture, which is 25% and for green and root vegetables 30% and 40%, respectively). All other model settings and input data were as described in Appendix D. The resulting terrestrial food concentration factors are higher than the factors calculated for the sewage GDCs and GDLs in virtually all cases, so were used. The exceptions are tritium (H-3) and isotopes of carbon (see Section G.5.2).

Table G.13 lists the activity concentrations in foodstuffs in the 50th year per unit application rate of sewage sludge.

Activity concentrations per unit deposition rate in agricultural soil treated with sewage sludge were predicted using the soil module of FARMLAND, which allows for migration down the soil profile. Relevant parameters are listed in Table G.14. The resulting soil concentrations in the 50th year are shown in Table G.15 and these were used to calculate doses from inadvertent ingestion and inhalation of conditioned soil. These values relate to arable farmland rather than the pasture assumed for the calculation of external doses. Arable farming involves ploughing and can leave bare earth between the farmed plants, circumstance that are much more likely to raise dust than would be the case in grassed pasture land. The assumption of arable land is therefore used as it is conservative with respect to inadvertent ingestion and inhalation pathways, just as the assumption of pasture land is conservative for external exposure.

The soil concentrations in the 50th year were also used to calculate doses to wildlife, see Section G.7.

G.5.2 Equilibrium modelling for tritium (H-3) and carbon-14 (C-14)

For tritium (H-3) and carbon-14 (C-14) the activity concentrations in soil and animal products resulting from the application of sewage sludge were taken from Jones *et al*. [G.9]. Activity concentrations per unit deposition rate for tritium were calculated using the TRIF model [G.13], assuming that all of the tritium in the sludge is in the form of tritiated water. In the absence of more specific data, the activity concentrations of tritiated water in soil were also applied to organically bound tritium

(OBT). This is likely to be cautious because of the timescale involved for the OBT to be converted to tritated water by soil microbes, which in turn will be converted to OBT after plant uptake. Activity concentrations per unit deposition rate for C-14 were calculated including degassing losses resulting from the application of wet sewage sludge and soil root uptake [G.9]. The activity concentrations for H-3 in green vegetables and root vegetables were taken to be zero as it can be assumed that in 10 months, all of the tritiated water in the soil will have leached away and that any OBT present will not be available for plant uptake. For C-14, in the absence of any better data, the specific activity concentrations per unit deposition rate from the irrigated water pathway (Appendix F) have been applied. This is likely to be conservative, as for irrigation a continuous application is assumed.

G.5.3 Activity concentrations in terrestrial foodstuffs and soil per unit release

The activity concentrations in food products and soil per unit discharge rate were derived as follows:

$$C_{food} = C_{food(u)} I_{app} C_{slu}$$

where C_{food} is activity concentration in soil or food products grown on land conditioned with treated sewage sludge per unit discharge into the sewage treatment works (Bq/kg per Bq/y)

$C_{food(u)}$ is activity concentration in food products or soil per unit deposition rate (Bq/kg per Bq/m^2/s)

I_{app} is application rate of sewage sludge (kg/s per m^2)

C_{slu} is activity concentration in sewage sludge per unit discharge into the sewage treatment works (Bq/kg per Bq/y)

The resulting activity concentrations in terrestrial foodstuffs are shown in Table G.16 and in conditioned soil in Table G.17.

G.6 Method to calculate DPUR factors for people

The DPUR factors for external exposure pathways for each age group were calculated as follows:

$$DPUR_{ext,a} = DR_{ext}\ H_{occ,a}$$

where $DPUR_{ext,a}$ is dose per unit release factor from external exposure to activity in raw sewage, sludge, or brook sediments for the age group considered (μSv/y per Bq/y)

DR_{ext} is external dose rate from the relevant material (μSv/h per Bq/y)

$H_{occ,a}$ is occupancy for the age group considered above the relevant material (h/y)

The DPUR factors for external radiation above sludge conditioned soil were calculated as follows:

$$DPUR_{soil\_ext,a} = DR_{ext}\ H_{occ,a}\ (F_{ind,a}\,T_{ind} + F_{out,a}T_{out})$$

where	$DPUR_{soil\_ext,a}$	is dose per unit release factor from external exposure to activity in conditioned soil for the age group considered (µSv/y per Bq/y)
	DR_{ext}	is external dose rate from activity in conditioned soil (µSv/h per Bq/y)
	$H_{occ,a}$	is total occupancy time for the age group considered (h/y)
	$F_{ind,a}$	is fraction spent indoors for the age group considered
	$T_{ind,a}$	is indoor shielding factor for ground shine
	$F_{out,a}$	is fraction spent outdoors for age group considered = 1– $F_{ind,a}$
	$T_{out,a}$	is outdoor shielding factor for ground shine (no shielding assumed so set to 1)

The DPUR factors for ingestion of terrestrial foodstuffs were calculated as follows:

$$DPUR_{food,a} = A_{food}\ I_{food,a}\ DF_{ing,a}$$

where	$DPUR_{food,a}$	is dose per unit release factor from the ingestion of a terrestrial foodstuff for the age group considered (µSv/y per Bq/y)
	A_{food}	is the activity concentration in the foodstuff per unit discharge rate to the sewage treatment works (Bq/kg per Bq/y), this is the same as C_{food}.
	$I_{food,a}$	is the ingestion rate of the foodstuff for the age group considered (kg/y)
	$DF_{ing,a}$	is the ingestion dose coefficient for the age group considered (µSv/Bq)

The DPUR factors for inadvertent ingestion of brook water or sediments were calculated as follows:

$$DPUR_{brook} = A_{brook}\ Q_{eff}\ I_{brook}\ H_{occ}\ DF_{ing}$$

where	$DPUR_{brook}$	is the dose per unit release factor from the inadvertent ingestion of brook water or sediment for a child (µSv/y per Bq/y)
	A_{brook}	is the activity concentration in the brook sediment or water per unit discharge to the sewage treatment works (Bq/kg or Bq/l per Bq/y)
	I_{brook}	is the inadvertent ingestion rate of the brook sediment or water for a child (kg/h or l/h)
	H_{occ}	is occupancy time of a child by the brook (h/y)
	DF_{ing}	is ingestion dose coefficient for a child (µSv/Bq)

The DPUR factors for inadvertent ingestion of raw sewage or sewage sludge were calculated as follows:

$$DPUR_{sew\_ing,a} = A_{sew}\ I_{sew}\ H_{occ}\ DF_{ing,a}$$

where $DPUR_{sew\_ing,a}$ is the dose per unit release factor from the inadvertent ingestion of raw sewage or sludge for an adult (µSv/y per Bq/y)

A_{sew} is the time integrated activity concentration in the raw sewage or sludge per unit discharge to sewage treatment works, C_{raw} or C_{slu} (Bq/kg per Bq/y)

I_{sew} is the inadvertent ingestion rate of raw sewage or sludge (kg/h)

H_{occ} is the occupancy time by either the raw sewage tanks or the sludge tank (h/y)

$DF_{ing,a}$ is the ingestion dose coefficient for an adult (µSv/Bq)

The DPUR factors for the inhalation of raw sewage or sewage sludge suspended in air were calculated as follows:

$$DPUR_{sew\_inh,a} = A_{sew}\ B_{work}\ C_{air\_sew}\ H_{occ}\ DF_{inh,a}$$

where $DPUR_{sew\_inh,a}$ is the dose per unit release factor from the inadvertent inhalation of raw sewage or sludge for an adult (µSv/y per Bq/y)

B_{work} is the breathing rate of an adult sewage worker (m^3/h)

C_{air_sew} is the airborne concentration of raw sewage or sludge (kg/m^3)

H_{occ} is the occupancy time by either the raw sewage tanks or the sludge tank (h/y)

$DF_{inh,a}$ is the inhalation dose coefficient for an adult (µSv/Bq)

The DPUR factors for inadvertent ingestion of sludge conditioned soil were calculated as follows:

$$DPUR_{soil\_ing,a} = A_{soil}\ I_{soil\_ing,a}\ (1 - F_{ind,a})H_{occ,a}\ DF_{ing,a}$$

where $DPUR_{soil\_ing,a}$ is the dose per unit release factor from the inadvertent ingestion of conditioned soil (well mixed arable soil) for the age group considered (µSv/y per Bq/y)

A_{soil} is the activity concentration in the sludge conditioned soil per unit concentration released to STW (Bq/kg per Bq/y)

$I_{soil\_ing,a}$ is the inadvertent ingestion rate of conditioned soil for the age group considered (kg/h)

$F_{ind,a}$ is the fraction of time spent indoors for age group considered

$H_{occ,a}$ is the total occupancy time for the age group considered (h/y)

$DF_{ing,a}$	is the ingestion dose coefficient for the age group considered (μSv/Bq)

The DPUR factors for the inhalation of sludge conditioned soil suspended in air were calculated as follows:

$$DPUR_{soil\_inh,a} = A_{soil}\ B_a\ C_{air\_soil}\ (1 - F_{ind,a})H_{occ,a}\ DF_{inh,a}$$

where	$DPUR_{soil\_inh,a}$	is the dose per unit release factor from the inadvertent inhalation of sludge conditioned soil (well mixed arable soil) for the age group considered (μSv/y per Bq/y)
	B_a	is the breathing rate of the age group considered (m^3/h)
	C_{air_soil}	is the airborne concentration of soil (kg/m^3, see Table G.2)
	$F_{ind,a}$	is the fraction of time spent indoors for age group considered
	$H_{occ,a}$	is the total occupancy time for the age group considered (h/y)
	$DF_{inh,a}$	is the inhalation dose coefficient for the age group considered (μSv/Bq)

The resulting DPUR factors are listed in the main report: Table 28 for the sewage treatment works exposure group; Table 29 for the children playing in brook exposure group; and Tables 30-34 for the farming family exposure group for soil conditioned with sludge.

G.7 Method to calculate DPUR factors for terrestrial wildlife

The dose factors for wildlife were calculated using the ERICA tool and are presented in Appendix A. Dose factors (DPUC) used to calculate dose rates to wildlife from soil conditioned with sludge are the same as those used in the release to air scenario, and are shown in Appendix A, Table A.7. The DPUC factors for isotopes of H, C, S and P are derived for concentrations in air (μGy/h per Bq/m^3). For IRAT2, we have assumed a ratio of 1 for Bq/m^3 to Bq/kg to enable soil concentrations for these isotopes to be included.

The DPUR factors for wildlife were calculated as follows:

$$DPUR_{wildlife} = R_{Depos} A_{soil}\ DF_{wildlife}$$

$DPUR_{wildlife}$	is the dose rate per unit release factor for wildlife (μGy/h per Bq/y)
R_{depos}	is deposition rate at 100 m from application of sludge to soil (Bq/m^2/s per Bq/y)
A_{soil}	is activity concentration in conditioned soil per unit sludge application rate (Bq/kg per Bq/m^2/s)
$DF_{wildlife}$	is the DPUC factor for terrestrial wildlife (μGy/h per Bq/kg)

The soil activity concentrations in the 50th year (represented by $A_{soil} \times R_{depos}$ in the equation above), used to calculate the terrestrial wildlife DPUR factors are shown in Table G.15. These values relate to arable farmland rather than pasture.

When the DPURs are calculated, radionuclides with a half life of less than 4 days are excluded to account for the time taken for radionuclides to move through the sewage treatement works.

DPUR values for wildlife exposed to soil conditioned with sewage sludge are shown in Tables 35 and 36.

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Table G.1. Habit data for sewage treatment works worker exposure group

	Adult sewage worker	Comment
Occupancy adjacent sewage tanks (h/y)	1,500	see Section G.2
Occupancy adjacent sludge tanks (h/y)	500	see Section G.2
Sewage worker inhalation rate (m^3/h)	1.2	[G.12]
Inadvertent sludge ingestion rate (kg/h)	5.0E-06	[G.2]

Table G.2. Habit data for farming family exposure group

	Infant	Child	Adult	Comment
Food consumption rates (kg/y)*				[G.12]
Cow meat	10	30	45	
Cow milk	320	240	240	
Cow liver	2.75	5	10	
Sheep meat	3	10	25	
Sheep liver	2.75	5	10	
Green vegetables	15	35	80	
Root vegetables	45	95	130	
Breathing rate (m^3/h)	0.22	0.64	0.92	[G.12]
Airborne concentration of soil (kg/m^3)	1.0E-07	1.0E-07	1.0E-07	[G.14]
Inadvertent ingestion rate (kg/h)	8.4E-08	3.4E-08	1.6E-08	[G.8]
Occupancy (h/y)	8,760	8,760	8,760	100%
Fraction of time spent indoors	0.9	0.8	0.5	[G.12]
Indoor shielding factor	0.1	0.1	0.1	[G.8]

* Values are rates for the 97.5 percentile of consumers [G.3].

Table G.3. Habit data for children playing in brook exposure group

	Child playing in brook	Comment
Occupancy (h/y)	500	[G.3]
Inadvertent ingestion rate of water (ml/h)	10	see Section G.2
Inadvertent ingestion rate of sediment (mg/h)	10	[G.3]

Table G.4. Parameters characterising the sewage treatment works*

	Value	Comment
Flow rate raw sewage (m^3/d)	60	[G.2]
Effluent residence time (h)	15	[G.2]
Residence time for sludge that is incinerated (h)	96	See Appendix H
Total sludge residence time (h)	408	[G.2]
%solid content of raw sewage	0.05	[G.2]
%solid content of treated sludge	5	[G.2]
Density of raw sewage and treated sludge (kg/l)	1	[G.2]
Airborne concentration of sewage or sludge at sewage treatment works (kg/m^3)	1.0E-07	[G.2]

*The activity concentration in raw sewage per unit discharge rate to the sewage treatment works was calculated as 4.6E-08 Bq/kg per Bq/y (see Section G.3).

Table G.5. Partitioning coefficients for sewage

Radio-nuclide	Fraction of activity concentration			K_d for organic soil (l/kg)	
	Sludge	Effluent	Comment	K_d	Comment
H-3	0.15	0.85	[G.12]		
H-3 org.	0.15	0.85	[G.15]		
C-11	0.15	0.85	[G.12]		
C-14	0.15	0.85	[G.12]		
F-18	0.1	0.9	[G.16]		
Na-22	0.1	0.9	[G.12]		
Na-24	0.1	0.9	[G.12]		
P-32	0.8	0.2	[G.4]		
P-33	0.8	0.2	[G.4]		
S-35	0.1	0.9	[G.4]		
Cl-36	0.1	0.9	[G.12]		
Ca-45	0.4	0.6	[G.4]		
Ca-47	0.4	0.6	[G.4]		
V-48	0.9	0.1	[G.4]		
Cr-51	0.9	0.1	[G.12]		
Mn-52	0.95	0.05	[G.4]^		
Mn-54	0.95	0.05	[G.4]^		
Mn-56	0.95	0.05	[G.4]^		
Fe-55	0.9	0.1	[G.4]		
Fe-59	0.9	0.1	[G.4]		
Co-56	0.9	0.1	[G.4]		
Co-57	0.9	0.1	[G.4]		
Co-58	0.9	0.1	[G.4]		
Co-60	0.9	0.1	[G.4]		
Ni-63	0.9	0.1	[G.4]		
Cu-61	0.95	0.05	[G.4]^		
Cu-64	0.95	0.05	[G.4]^		
Zn-62	0.1	0.9	Based on organic soil	560	[G.17]
Zn-65	0.1	0.9	Based on organic soil	560	[G.17]
Ga-67	0.9	0.1	[G.4]		
Ga-68	0.9	0.1	[G.4]		
Se-75	0.5	0.5	[G.12]		
Br-76	0.1	0.9	[G.4]		
Br-77	0.1	0.9	[G.4]		
Br-82	0.1	0.9	[G.4]		
Rb-81	0.1	0.9	[G.12]		
Rb-82	0.1	0.9	[G.12]		
Rb-83	0.1	0.9	[G.12]		
Sr-83	0.4	0.6	[G.4]		
Sr-85	0.4	0.6	[G.4]		
Sr-89	0.4	0.6	[G.4]		
Sr-90	0.4	0.6	[G.4]		
Y-90	0.95	0.05	[G.4]^		

Radio-nuclide	Fraction of activity concentration			K_d for organic soil (l/kg)	
	Sludge	Effluent	Comment	K_d	Comment
Zr-89	0.5	0.5	Based on organic soil	3,700	[G.17]
Zr-95	0.5	0.5	Based on organic soil	3,700	[G.17]
Nb-95	0.5	0.5	Based on organic soil	2,000	[G.17]
Mo-99	0.1	0.9	Based on all soils	40	[G.17]
Tc-94m	0.1	0.9	[G.4]		
Tc-99	0.1	0.9	[G.4]		
Tc-99m	0.1	0.9	[G.4]		
Ru-103	0.1	0.9	[G.12]		
Ru-106	0.1	0.9	[G.12]		
Ag-110m	0.9	0.1	Based on organic soil	9,700	[G.17]
In-111	0.9	0.1	[G.4]		
In-113m	0.9	0.1	[G.4]		
Sb-125	0.1	0.9	Based on organic soil	75	[G.17]
I-123	0.2	0.8	[G.12]		
I-124	0.2	0.8	[G.12]		
I-125	0.2	0.8	[G.12]		
I-129	0.2	0.8	[G.12]		
I-131	0.2	0.8	[G.12]		
I-132	0.2	0.8	[G.12]		
I-133	0.2	0.8	[G.12]		
I-134	0.2	0.8	[G.12]		
I-135	0.2	0.8	[G.12]		
Cs-134	0.1	0.9	Based on organic soil	270	[G.17]
Cs-136	0.1	0.9	Based on organic soil	270	[G.17]
Cs-137	0.1	0.9	Based on organic soil	270	[G.17]
Ba-140	0.4	0.6	As Sr*		
La-140	0.7	0.3	[G.4]		
Ce-141	0.5	0.5	Based on organic soil	3,000	[G.17]
Ce-144	0.5	0.5	Based on organic soil	3,000	[G.17]
Pm-147	0.5	0.5	Based on organic soil	3,000	As Ce*
Sm-153	0.5	0.5	Based on organic soil	3,000	[G.17]
Eu-152	0.5	0.5	As Ce*		
Eu-154	0.5	0.5	As Ce*		
Eu-155	0.5	0.5	As Ce*		
Er-169	0.5	0.5	As Ce*		

Radio-nuclide	Fraction of activity concentration			K_d for organic soil (l/kg)	
	Sludge	Effluent	Comment	K_d	Comment
Lu-177	0.5	0.5	Based on organic soil	3000	As Ce*
Re-188	0.1	0.9	[G.4]		
Au-198	0.5	0.5	As Ce*		
Tl-201	0.5	0.5	As Sm*		
Pb-210	0.9	0.1	[G.12]		
Pb-212	0.9	0.1	[G.12]		
Bi-213	0.5	0.5	Based on organic soil	1,500	[G.17]
Po-210	0.9	0.1	Based on organic soil	6,600	[G.17]
At-211	0.2	0.8	As I*		
Ra-223	0.5	0.5	Based on organic soil	1,300	[G.17]
Ra-226	0.5	0.5	Based on organic soil	1,300	[G.17]
Ac-225	0.9	0.1	Based on organic soil	5,400	[G.17]
Th-227	0.9	0.1	[G.4]		
Th-230	0.9	0.1	[G.4]		
Th-232	0.9	0.1	[G.4]		
Th-234	0.9	0.1	[G.4]		
U-234	0.1	0.9	[G.4]		
U-235	0.1	0.9	[G.4]		
U-238	0.1	0.9	[G.4]		
Np-237	0.1	0.9	Based on organic soil	810	[G.17]
Pu-238	0.1	0.9	Based on organic soil	760	[G.17]
Pu-239	0.1	0.9	Based on organic soil	760	[G.17]
Pu-240	0.1	0.9	Based on organic soil	760	[G.17]
Pu-241	0.1	0.9	Based on organic soil	760	[G.17]
Pu-242	0.1	0.9	Based on organic soil	760	[G.17]
Am-241	0.5	0.5	Based on organic soil	2,500	[G.17]
Am-242	0.5	0.5	Based on organic soil	2,500	[G.17]
Am-243	0.5	0.5	Based on organic soil	2,500	[G.17]
Cm-242	0.9	0.1	Based on all soils	9,300	[G.17]
Cm-243	0.9	0.1	Based on all soils	9,300	[G.17]
Cm-244	0.9	0.1	Based on all soils	9,300	[G.17]

*see Table C.3
^ For these elements [G.4] recommends 100% remains in sludge. In order to ensure that the liquid release pathway, it is assumed here that 95% is retained in sludge and 5% is released into effluent.

Table G.6. Activity concentrations in raw sewage and raw sludge at the sewage treatment works per unit release rate

Radionuclide	Activity concentration of raw sewage: Average time-integrated decay (Bq/kg per Bq/y)*	Activity concentration of sludge: Average time-integrated decay (Bq/kg per Bq/y)*
H-3	4.6E-08	6.8E-07
H-3 organic	4.6E-08	6.8E-07
C-11	1.5E-09	8.2E-10
C-14	4.6E-08	6.8E-07
F-18	8.0E-09	3.0E-09
Na-22	4.6E-08	4.5E-07
Na-24	3.3E-08	2.4E-08
P-32	4.5E-08	2.5E-06
P-33	4.5E-08	2.9E-06
S-35	4.6E-08	4.3E-07
Cl-36	4.6E-08	4.6E-07
Ca-45	4.6E-08	1.8E-06
Ca-47	4.4E-08	6.5E-07
V-48	4.5E-08	2.9E-06
Cr-51	4.5E-08	3.3E-06
Mn-52	4.4E-08	1.8E-06
Mn-54	4.6E-08	4.3E-06
Mn-56	1.1E-08	4.0E-08
Fe-55	4.6E-08	4.1E-06
Fe-59	4.5E-08	3.6E-06
Co-56	4.6E-08	3.8E-06
Co-57	4.6E-08	4.0E-06
Co-58	4.5E-08	3.8E-06
Co-60	4.6E-08	4.1E-06
Ni-63	4.6E-08	4.1E-06
Cu-61	1.4E-08	5.2E-08
Cu-64	3.1E-08	1.9E-07
Zn-62	2.7E-08	1.5E-08
Zn-65	4.6E-08	4.5E-07
Ga-67	4.3E-08	1.1E-06
Ga-68	4.9E-09	1.6E-08
Se-75	4.6E-08	2.2E-06
Br-76	3.4E-08	2.6E-08
Br-77	4.2E-08	9.0E-08
Br-82	4.0E-08	5.7E-08
Rb-81	1.8E-08	7.4E-09
Rb-82	9.3E-11	3.4E-11
Rb-83	4.6E-08	4.3E-07
Sr-83	3.9E-08	2.1E-07
Sr-85	4.5E-08	1.7E-06
Sr-89	4.5E-08	1.6E-06

Radionuclide	Activity concentration of raw sewage: Average time-integrated decay (Bq/kg per Bq/y)*	Activity concentration of sludge: Average time-integrated decay (Bq/kg per Bq/y)*
Sr-90	4.6E-08	1.8E-06
Y-90	4.2E-08	9.7E-07
Zr-89	4.3E-08	6.2E-07
Zr-95	4.5E-08	2.1E-06
Nb-95	4.5E-08	1.9E-06
Mo-99	4.2E-08	1.0E-07
Tc-94m	3.8E-09	1.4E-09
Tc-99	4.6E-08	4.6E-07
Tc-99m	2.2E-08	9.7E-09
Ru-103	4.5E-08	3.9E-07
Ru-106	4.6E-08	4.5E-07
Ag-110m	4.6E-08	4.0E-06
In-111	4.2E-08	9.6E-07
In-113m	7.3E-09	2.4E-08
Sb-125	4.6E-08	4.5E-07
I-123	3.2E-08	4.3E-08
I-124	4.3E-08	3.0E-07
I-125	4.5E-08	8.3E-07
I-129	4.6E-08	9.1E-07
I-131	4.4E-08	4.8E-07
I-132	1.0E-08	7.4E-09
I-133	3.6E-08	6.7E-08
I-134	3.8E-09	2.8E-09
I-135	2.3E-08	2.1E-08
Cs-134	4.6E-08	4.5E-07
Cs-136	4.5E-08	3.0E-07
Cs-137	4.6E-08	4.6E-07
Ba-140	4.5E-08	1.2E-06
La-140	4.0E-08	4.5E-07
Ce-141	4.5E-08	1.9E-06
Ce-144	4.6E-08	2.2E-06
Pm-147	4.6E-08	2.3E-06
Sm-153	4.1E-08	3.7E-07
Eu-152	4.6E-08	2.3E-06
Eu-154	4.6E-08	2.3E-06
Eu-155	4.6E-08	2.3E-06
Er-169	4.5E-08	1.3E-06
Lu-177	4.4E-08	1.1E-06
Re-188	3.4E-08	2.7E-08
Au-198	4.2E-08	5.2E-07
Tl-201	4.3E-08	5.8E-07
Pb-210	4.6E-08	4.1E-06
Pb-212	2.9E-08	1.5E-07
Bi-213	3.3E-09	6.1E-09

Radionuclide	Activity concentration of raw sewage: Average time-integrated decay (Bq/kg per Bq/y)*	Activity concentration of sludge: Average time-integrated decay (Bq/kg per Bq/y)*
Po-210	4.6E-08	3.9E-06
At-211	2.4E-08	2.3E-08
Ra-223	4.5E-08	1.4E-06
Ra-226	4.6E-08	2.3E-06
Ac-225	4.5E-08	2.4E-06
Th-227	4.5E-08	3.0E-06
Th-230	4.6E-08	4.1E-06
Th-232	4.6E-08	4.1E-06
Th-234	4.5E-08	3.5E-06
U-234	4.6E-08	4.6E-07
U-235	4.6E-08	4.6E-07
U-238	4.6E-08	4.6E-07
Np-237	4.6E-08	4.6E-07
Pu-238	4.6E-08	4.6E-07
Pu-239	4.6E-08	4.6E-07
Pu-240	4.6E-08	4.6E-07
Pu-241	4.6E-08	4.6E-07
Pu-242	4.6E-08	4.6E-07
Am-241	4.6E-08	2.3E-06
Am-242	3.4E-08	1.3E-07
Am-243	4.6E-08	2.3E-06
Cm-242	4.6E-08	4.0E-06
Cm-243	4.6E-08	4.1E-06
Cm-244	4.6E-08	4.1E-06

*for a raw sewage flow rate into the sewage treatment works of 60 m^3/d

Table G.7. Activity concentrations in liquid effluent and treated sewage sludge per unit release rate allowing for radioactive decay

Radionuclide	Treated effluent*	Treated sludge*		
	Decay to leaving sewage works (15 hrs)^ (Bq/l discharged from sewage works per Bq/y)	Decay to leaving sewage works 17 days^ (Bq/kg per Bq/y)	Decay to animals grazing 21 days^ (Bq/kg per Bq/y)	Decay to vegetable harvest 10 months^ (Bq/kg per Bq/y)
H-3	3.9E-08	6.8E-07	6.8E-07	6.5E-07
H-3 organic	3.9E-08	6.8E-07	6.8E-07	6.5E-07
C-11	nc	nc	nc	nc
C-14	3.9E-08	6.8E-07	6.8E-07	6.8E-07
F-18	nc	nc	nc	nc
Na-22	4.1E-08	4.5E-07	4.4E-07	3.6E-07
Na-24	2.0E-08	2.8E-15	nc	nc
P-32	8.9E-09	1.6E-06	5.8E-07	nc
P-33	9.0E-09	2.3E-06	1.3E-06	nc
S-35	4.1E-08	4.0E-07	3.4E-07	3.6E-08
Cl-36	4.1E-08	4.6E-07	4.6E-07	4.6E-07
Ca-45	2.7E-08	1.7E-06	1.6E-06	4.6E-07
Ca-47	2.5E-08	1.4E-07	5.4E-09	nc
V-48	4.4E-09	2.0E-06	8.1E-07	nc
Cr-51	4.5E-09	2.7E-06	1.6E-06	nc
Mn-52	2.1E-09	5.3E-07	3.9E-08	nc
Mn-54	2.3E-09	4.2E-06	4.0E-06	2.1E-06
Mn-56	nc	nc	nc	nc
Fe-55	4.6E-09	4.1E-06	4.0E-06	3.3E-06
Fe-59	4.5E-09	3.2E-06	2.3E-06	2.7E-08
Co-56	4.5E-09	3.5E-06	2.9E-06	2.3E-07
Co-57	4.6E-09	3.9E-06	3.7E-06	1.8E-06
Co-58	4.5E-09	3.5E-06	2.8E-06	1.8E-07
Co-60	4.6E-09	4.1E-06	4.1E-06	3.7E-06
Ni-63	4.6E-09	4.1E-06	4.1E-06	4.1E-06
Cu-61	1.0E-10	1.4E-42	nc	nc
Cu-64	1.0E-09	9.3E-16	nc	nc
Zn-62	1.3E-08	2.5E-20	nc	nc
Zn-65	4.1E-08	4.3E-07	4.1E-07	1.8E-07
Ga-67	4.0E-09	1.1E-07	nc	nc
Ga-68	nc	nc	nc	nc
Se-75	2.3E-08	2.1E-06	1.8E-06	3.6E-07
Br-76	2.2E-08	1.2E-14	nc	nc
Br-77	3.4E-08	2.9E-09	nc	nc
Br-82	3.1E-08	1.5E-10	nc	nc
Rb-81	4.2E-09	7.0E-34	nc	nc

Radionuclide	Treated effluent*	Treated sludge*		
	Decay to leaving sewage works (15 hrs)^ (Bq/l discharged from sewage works per Bq/y)	Decay to leaving sewage works 17 days^ (Bq/kg per Bq/y)	Decay to animals grazing 21 days^ (Bq/kg per Bq/y)	Decay to vegetable harvest 10 months^ (Bq/kg per Bq/y)
Rb-82	nc	nc	nc	nc
Rb-83	4.1E-08	4.0E-07	3.4E-07	3.4E-08
Sr-83	2.0E-08	3.0E-10	nc	nc
Sr-85	2.7E-08	1.5E-06	1.2E-06	5.9E-08
Sr-89	2.7E-08	1.4E-06	1.1E-06	2.2E-08
Sr-90	2.7E-08	1.8E-06	1.8E-06	1.8E-06
Y-90	1.9E-09	5.2E-08	nc	nc
Zr-89	2.0E-08	6.2E-08	nc	nc
Zr-95	2.3E-08	1.9E-06	1.5E-06	7.0E-08
Nb-95	2.3E-08	1.6E-06	1.1E-06	3.9E-09
Mo-99	3.5E-08	6.3E-09	nc	nc
Tc-94m	nc	nc	nc	nc
Tc-99	4.1E-08	4.6E-07	4.6E-07	4.6E-07
Tc-99m	7.3E-09	1.6E-27	nc	nc
Ru-103	4.1E-08	3.4E-07	2.3E-07	1.6E-09
Ru-106	4.1E-08	4.4E-07	4.3E-07	2.5E-07
Ag-110m	4.6E-09	3.9E-06	3.7E-06	1.7E-06
In-111	3.9E-09	6.2E-08	nc	nc
In-113m	nc	nc	nc	nc
Sb-125	4.1E-08	4.5E-07	4.4E-07	3.7E-07
I-123	1.7E-08	4.7E-16	nc	nc
I-124	3.3E-08	5.4E-08	1.7E-09	nc
I-125	3.6E-08	7.5E-07	5.9E-07	2.1E-08
I-129	3.7E-08	9.1E-07	9.1E-07	9.1E-07
I-131	3.5E-08	2.1E-07	3.4E-08	nc
I-132	nc	nc	nc	nc
I-133	2.2E-08	1.2E-12	nc	nc
I-134	nc	nc	nc	nc
I-135	7.6E-09	2.4E-25	nc	nc
Cs-134	4.1E-08	4.5E-07	4.4E-07	3.4E-07
Cs-136	4.0E-08	1.9E-07	6.1E-08	nc
Cs-137	4.1E-08	4.6E-07	4.6E-07	4.5E-07
Ba-140	2.6E-08	7.2E-07	2.3E-07	nc
La-140	1.1E-08	2.9E-09	nc	nc
Ce-141	2.3E-08	1.6E-06	1.0E-06	2.4E-09
Ce-144	2.3E-08	2.2E-06	2.1E-06	1.0E-06
Pm-147	2.3E-08	2.3E-06	2.2E-06	1.8E-06
Sm-153	1.8E-08	5.1E-09	nc	nc
Eu-152	2.3E-08	2.3E-06	2.3E-06	2.2E-06

Radionuclide	Treated effluent*	Treated sludge*		
	Decay to leaving sewage works (15 hrs)^ (Bq/l discharged from sewage works per Bq/y)	Decay to leaving sewage works 17 days^ (Bq/kg per Bq/y)	Decay to animals grazing 21 days^ (Bq/kg per Bq/y)	Decay to vegetable harvest 10 months^ (Bq/kg per Bq/y)
Eu-154	2.3E-08	2.3E-06	2.3E-06	2.1E-06
Eu-155	2.3E-08	2.3E-06	2.2E-06	2.0E-06
Er-169	2.2E-08	6.5E-07	1.4E-07	nc
Lu-177	2.1E-08	3.9E-07	4.3E-08	nc
Re-188	2.2E-08	2.7E-14	nc	nc
Au-198	1.9E-08	2.9E-08	nc	nc
Tl-201	2.0E-08	4.7E-08	nc	nc
Pb-210	4.6E-09	4.1E-06	4.1E-06	4.0E-06
Pb-212	1.7E-09	1.2E-17	nc	nc
Bi-213	nc	nc	nc	nc
Po-210	4.5E-09	3.8E-06	3.4E-06	8.2E-07
At-211	8.6E-09	8.7E-24	nc	nc
Ra-223	2.2E-08	8.1E-07	2.3E-07	nc
Ra-226	2.3E-08	2.3E-06	2.3E-06	2.3E-06
Ac-225	4.4E-09	1.3E-06	2.9E-07	nc
Th-227	4.5E-09	2.2E-06	1.0E-06	nc
Th-230	4.6E-09	4.1E-06	4.1E-06	4.1E-06
Th-232	4.6E-09	4.1E-06	4.1E-06	4.1E-06
Th-234	4.5E-09	2.9E-06	1.9E-06	5.0E-09
U-234	4.1E-08	4.6E-07	4.6E-07	4.6E-07
U-235	4.1E-08	4.6E-07	4.6E-07	4.6E-07
U-238	4.1E-08	4.6E-07	4.6E-07	4.6E-07
Np-237	4.1E-08	4.6E-07	4.6E-07	4.6E-07
Pu-238	4.1E-08	4.6E-07	4.6E-07	4.5E-07
Pu-239	4.1E-08	4.6E-07	4.6E-07	4.6E-07
Pu-240	4.1E-08	4.6E-07	4.6E-07	4.6E-07
Pu-241	4.1E-08	4.6E-07	4.5E-07	4.4E-07
Pu-242	4.1E-08	4.6E-07	4.6E-07	4.6E-07
Am-241	2.3E-08	2.3E-06	2.3E-06	2.3E-06
Am-242	1.2E-08	4.9E-14	nc	nc
Am-243	2.3E-08	2.3E-06	2.3E-06	2.3E-06
Cm-242	4.6E-09	3.8E-06	3.5E-06	1.0E-06
Cm-243	4.6E-09	4.1E-06	4.1E-06	4.0E-06
Cm-244	4.6E-09	4.1E-06	4.1E-06	4.0E-06

nc = not considered due to short half-life.

Radionuclides with half-lives of less than 3 hours were not considered for treated effluent leaving the sewage treatment works; radionuclides with half-lives of less than 4 days were not considered for treated sludge leaving the sewage treatment

works; radionuclides with half-lives of less than 30 days were not considerd for vegetables harvested from sludge-conditioned soil.
*for a raw sewage flow rate into the sewage treatment works of 60 m^3/d
^assumed decay times: 15 hours for treated effluent to leave the sewage treatment works; 17 days for sludge to leave sewage treatment works; 21 days for animals after the sludge has left the sewage treatment works (38 days in total); 10 months for vegetable harvest after sludge has left the sewage treatment works (10.5 months in total). For incineration of sludge, see Appendix H.

Table G.8. Parameters characterising the brook

	Value	Comment
Brook flow rate (m^3/s)	0.1	
Suspended sediment load (kg/l)	4.0E-05	[G.2]

Table G.9. Activity concentration in brook bank sediments per unit release rate into sewage treatment works

Radionuclide	Activity concentration in unfiltered brook water[#] (Bq/l per Bq/y of discharge into a brook)*	Activity concentration in brook bank sediments[#] (Bq/kg per Bq/y of discharge into brook)*
H-3	3.2E-10	9.5E-12
H-3 organic	3.2E-10	5.9E-07
C-11	nc	nc
C-14	3.2E-10	5.9E-07
F-18	nc	nc
Na-22	3.2E-10	3.2E-11
Na-24	3.2E-10	3.2E-11
P-32	3.2E-10	1.6E-08
P-33	3.2E-10	1.6E-08
S-35	3.2E-10	6.3E-08
Cl-36	3.2E-10	3.1E-08
Ca-45	3.2E-10	3.3E-07
Ca-47	3.2E-10	3.3E-07
V-48	3.2E-10	3.2E-08
Cr-51	3.2E-10	3.5E-06
Mn-52	3.2E-10	6.6E-06
Mn-54	3.2E-10	6.6E-06
Mn-56	nc	nc
Fe-55	3.2E-10	1.3E-06
Fe-59	3.2E-10	1.3E-06
Co-56	3.2E-10	5.1E-06
Co-57	3.2E-10	5.1E-06
Co-58	3.2E-10	5.1E-06
Co-60	3.2E-10	5.1E-06
Ni-63	3.2E-10	2.3E-06
Cu-61	3.2E-10	1.6E-07
Cu-64	3.2E-10	1.6E-07
Zn-62	3.2E-10	1.6E-07
Zn-65	3.2E-10	1.6E-07
Ga-67	3.2E-10	9.4E-08
Ga-68	nc	nc
Se-75	3.2E-10	1.1E-06
Br-76	3.2E-10	6.7E-07
Br-77	3.2E-10	6.7E-07
Br-82	3.2E-10	6.7E-07
Rb-81	3.2E-10	4.3E-06
Rb-82	nc	nc
Rb-83	3.2E-10	4.3E-06
Sr-83	3.2E-10	3.6E-07
Sr-85	3.2E-10	3.6E-07

Radionuclide	Activity concentration in unfiltered brook water# (Bq/l per Bq/y of discharge into a brook)*	Activity concentration in brook bank sediments# (Bq/kg per Bq/y of discharge into brook)*
Sr-89	3.2E-10	3.6E-07
Sr-90	3.2E-10	3.6E-07
Y-90	3.2E-10	3.0E-07
Zr-89	3.2E-10	3.0E-07
Zr-95	3.2E-10	3.0E-07
Nb-95	3.2E-10	3.2E-08
Mo-99	3.2E-10	2.6E-06
Tc-94m	nc	nc
Tc-99	3.2E-10	1.6E-09
Tc-99m	3.2E-10	1.6E-09
Ru-103	3.2E-10	4.4E-06
Ru-106	3.2E-10	4.4E-06
Ag-110m	3.2E-10	7.2E-06
In-111	3.2E-10	5.3E-06
In-113m	nc	nc
Sb-125	3.2E-10	1.3E-06
I-123	3.2E-10	1.2E-06
I-124	3.2E-10	1.2E-06
I-125	3.2E-10	1.2E-06
I-129	3.2E-10	1.2E-06
I-131	3.2E-10	1.2E-06
I-132	nc	nc
I-133	3.2E-10	1.2E-06
I-134	nc	nc
I-135	3.2E-10	1.2E-06
Cs-134	3.2E-10	4.3E-06
Cs-136	3.2E-10	4.3E-06
Cs-137	3.2E-10	4.3E-06
Ba-140	3.2E-10	5.9E-07
La-140	3.2E-10	5.6E-06
Ce-141	3.2E-10	7.1E-06
Ce-144	3.2E-10	7.1E-06
Pm-147	3.2E-10	1.3E-06
Sm-153	3.2E-10	6.2E-06
Eu-152	3.2E-10	1.6E-07
Eu-154	3.2E-10	1.6E-07
Eu-155	3.2E-10	1.6E-07
Er-169	3.2E-10	7.1E-06
Lu-177	3.2E-10	7.1E-06
Re-188	3.2E-10	1.3E-07
Au-198	3.2E-10	7.3E-06
Tl-201	3.2E-10	3.5E-06
Pb-210	3.2E-10	2.3E-06

Radionuclide	Activity concentration in unfiltered brook water# (Bq/l per Bq/y of discharge into a brook)*	Activity concentration in brook bank sediments# (Bq/kg per Bq/y of discharge into brook)*
Pb-212	3.2E-10	2.3E-06
Bi-213	nc	nc
Po-210	3.2E-10	4.9E-06
At-211	3.2E-10	1.2E-06
Ra-223	3.2E-10	1.8E-06
Ra-226	3.2E-10	1.8E-06
Ac-225	3.2E-10	6.2E-06
Th-227	3.2E-10	7.0E-06
Th-230	3.2E-10	7.0E-06
Th-232	3.2E-10	7.0E-06
Th-234	3.2E-10	7.0E-06
U-234	3.2E-10	1.6E-08
U-235	3.2E-10	1.6E-08
U-238	3.2E-10	1.6E-08
Np-237	3.2E-10	3.2E-09
Pu-238	3.2E-10	7.2E-06
Pu-239	3.2E-10	7.2E-06
Pu-240	3.2E-10	7.2E-06
Pu-241	3.2E-10	7.2E-06
Pu-242	3.2E-10	7.2E-06
Am-241	3.2E-10	6.6E-06
Am-242	3.2E-10	6.6E-06
Am-243	3.2E-10	6.6E-06
Cm-242	3.2E-10	1.3E-06
Cm-243	3.2E-10	1.3E-06
Cm-244	3.2E-10	1.3E-06

The values in Table G.9 do not account for partitioning and decay of radionuclides in the STW. A partioning and decay factors (Qeff), detailed in Table G.10, must be applied to calculate activity concentrations in the brook following discharge from a STW.

nc = not considered due to half-life of less than 3 hours.

*for a raw sewage flow rate into the sewage treatment works of 60 m^3/d and a brook flow rate of 0.1 m^3/s

Table G.10. Discharge rate of radionuclides from the sewage treatment works in treated effluent per unit release rate into sewage treatment works

Radionuclide	Partitioning and decay factor, expressed as a discharge rate (*Qeff*) (Bq/y discharge from STW in treated effluent per Bq/y of discharge into STW)
H-3	8.5E-01
H-3 organic	8.5E-01
C-11	nc
C-14	8.5E-01
F-18	nc
Na-22	9.0E-01
Na-24	4.5E-01
P-32	1.9E-01
P-33	2.0E-01
S-35	9.0E-01
Cl-36	9.0E-01
Ca-45	6.0E-01
Ca-47	5.5E-01
V-48	9.7E-02
Cr-51	9.8E-02
Mn-52	4.6E-02
Mn-54	5.0E-02
Mn-56	nc
Fe-55	1.0E-01
Fe-59	9.9E-02
Co-56	9.9E-02
Co-57	1.0E-01
Co-58	9.9E-02
Co-60	1.0E-01
Ni-63	1.0E-01
Cu-61	2.3E-03
Cu-64	2.2E-02
Zn-62	2.9E-01
Zn-65	9.0E-01
Ga-67	8.8E-02
Ga-68	nc
Se-75	5.0E-01
Br-76	4.7E-01
Br-77	7.5E-01
Br-82	6.7E-01
Rb-81	9.3E-02
Rb-82	nc
Rb-83	9.0E-01
Sr-83	4.4E-01

Radionuclide	Partitioning and decay factor, expressed as a discharge rate (*Qeff*) (Bq/y discharge from STW in treated effluent per Bq/y of discharge into STW)
Sr-85	6.0E-01
Sr-89	5.9E-01
Sr-90	6.0E-01
Y-90	4.3E-02
Zr-89	4.4E-01
Zr-95	5.0E-01
Nb-95	4.9E-01
Mo-99	7.7E-01
Tc-94m	nc
Tc-99	9.0E-01
Tc-99m	1.6E-01
Ru-103	8.9E-01
Ru-106	9.0E-01
Ag-110m	1.0E-01
In-111	8.6E-02
In-113m	nc
Sb-125	9.0E-01
I-123	3.6E-01
I-124	7.2E-01
I-125	7.9E-01
I-129	8.0E-01
I-131	7.6E-01
I-132	nc
I-133	4.9E-01
I-134	nc
I-135	1.7E-01
Cs-134	9.0E-01
Cs-136	8.7E-01
Cs-137	9.0E-01
Ba-140	5.8E-01
La-140	2.3E-01
Ce-141	4.9E-01
Ce-144	5.0E-01
Pm-147	5.0E-01
Sm-153	4.0E-01
Eu-152	5.0E-01
Eu-154	5.0E-01
Eu-155	5.0E-01
Er-169	4.8E-01
Lu-177	4.7E-01
Re-188	4.9E-01
Au-198	4.3E-01
Tl-201	4.3E-01

Radionuclide	Partitioning and decay factor, expressed as a discharge rate (*Qeff*) (Bq/y discharge from STW in treated effluent per Bq/y of discharge into STW)
Pb-210	1.0E-01
Pb-212	3.8E-02
Bi-213	nc
Po-210	1.0E-01
At-211	1.9E-01
Ra-223	4.8E-01
Ra-226	5.0E-01
Ac-225	9.6E-02
Th-227	9.8E-02
Th-230	1.0E-01
Th-232	1.0E-01
Th-234	9.9E-02
U-234	9.0E-01
U-235	9.0E-01
U-238	9.0E-01
Np-237	9.0E-01
Pu-238	9.0E-01
Pu-239	9.0E-01
Pu-240	9.0E-01
Pu-241	9.0E-01
Pu-242	9.0E-01
Am-241	5.0E-01
Am-242	2.6E-01
Am-243	5.0E-01
Cm-242	1.0E-01
Cm-243	1.0E-01
Cm-244	1.0E-01

nc = not considered due to half-life of less than 3 hours.

Table G.11. External dose rates above tanks per unit activity concentration

Radionuclide	External dose rate per unit concentration (µSv/h per Bq/kg)		
	Parent	Parent and all progeny	Comments
H-3	0.0E+00	0.0E+00	
H-3 organic	0.0E+00	0.0E+00	
C-11	1.7E-04	1.7E-04	
C-14	3.4E-10	3.4E-10	
F-18	1.7E-04	1.7E-04	
Na-22	4.0E-04	4.0E-04	
Na-24	8.4E-04	8.4E-04	
P-32	6.3E-07	6.3E-07	
P-33	1.5E-09	1.5E-09	
S-35	3.8E-10	3.8E-10	
Cl-36	7.7E-08	7.7E-08	
Ca-45	1.6E-09	1.6E-09	
Ca-47	2.0E-04	2.2E-04	Sc-47 included, since all will decay in 1 year
V-48	5.4E-04	5.4E-04	
Cr-51	5.0E-06	5.0E-06	
Mn-52	6.4E-04	6.4E-04	
Mn-54	1.5E-04	1.5E-04	
Mn-56	3.2E-04	3.2E-04	
Fe-55	0.0E+00	0.0E+00	
Fe-59	2.2E-04	2.2E-04	
Co-56	6.9E-04	6.9E-04	
Co-57	1.4E-05	1.4E-05	
Co-58	1.7E-04	1.7E-04	
Co-60	4.8E-04	4.8E-04	
Ni-63	0.0E+00	0.0E+00	
Cu-61	1.4E-04	1.4E-04	
Cu-64	3.2E-05	3.2E-05	
Zn-62	7.3E-05	2.5E-04	Cu-62 included
Zn-65	1.1E-04	1.1E-04	
Ga-67	2.1E-05	2.1E-05	
Ga-68	1.6E-04	1.6E-04	
Se-75	5.6E-05	5.6E-05	
Br-76	5.0E-04	5.0E-04	
Br-77	5.2E-05	5.2E-05	
Br-82	4.8E-04	4.8E-04	
Rb-81	1.0E-04	1.0E-04	Kr-81m not included as gaseous
Rb-82	1.9E-04	1.9E-04	
Rb-83	8.5E-05	8.5E-05	
Sr-83	1.4E-04	1.4E-04	Rb-83 not included as longer half life
Sr-85	8.5E-05	8.5E-05	
Sr-89	4.7E-07	4.7E-07	
Sr-90	2.0E-08	1.3E-06	Y-90 included
Y-90	1.2E-06	1.2E-06	
Zr-89	2.1E-04	2.1E-04	

Radionuclide	External dose rate per unit concentration (µSv/h per Bq/kg)		
	Parent	Parent and all progeny	Comments
Zr-95	1.3E-04	1.3E-04	
Nb-95	1.4E-04	1.4E-04	
Mo-99	2.6E-05	3.9E-05	Tc-99m included but Tc-99 not as longer half-life
Tc-94m	3.4E-04	3.4E-04	
Tc-99	3.3E-09	3.3E-09	
Tc-99m	1.5E-05	1.5E-05	
Ru-103	7.9E-05	7.9E-05	
Ru-106	0.0E+00	3.8E-05	Rh-106 included
Ag-110m	5.0E-04	5.0E-04	
In-111	5.6E-05	5.6E-05	
In-113m	4.1E-05	4.1E-05	
Sb-125	7.0E-05	7.0E-05	
I-123	2.0E-05	2.0E-05	
I-124	2.0E-04	2.0E-04	
I-125	3.7E-07	3.7E-07	
I-129	2.9E-07	2.9E-07	
I-131	6.2E-05	6.2E-05	
I-132	4.1E-04	4.1E-04	
I-133	1.1E-04	1.1E-04	
I-134	4.8E-04	4.8E-04	
I-135	3.0E-04	3.0E-04	
Cs-134	2.7E-04	2.7E-04	
Cs-136	3.9E-04	3.9E-04	
Cs-137	2.6E-08	9.9E-05	Ba-137m included
Ba-140	3.0E-05	4.7E-04	La-140 included
La-140	4.4E-04	4.4E-04	
Ce-141	8.9E-06	8.9E-06	
Ce-144	2.0E-06	1.0E-05	Pr-144 included
Pm-147	1.3E-09	1.3E-09	
Sm-153	4.3E-06	4.3E-06	
Eu-152	2.0E-04	2.0E-04	
Eu-154	2.2E-04	2.2E-04	
Eu-155	5.0E-06	5.0E-06	
Er-169	3.7E-09	3.7E-09	
Lu-177	4.5E-06	4.5E-06	
Re-188	9.6E-06	9.6E-06	
Au-198	6.7E-05	6.7E-05	
Tl-201	7.5E-06	7.5E-06	
Pb-210	6.1E-08	2.3E-07	Bi-210 and Po-210 included
Pb-212	2.0E-05	3.0E-04	Bi-212, Po-212 and Tl-208 included
Bi-213	2.2E-05	3.0E-05	Po-213, Pb-209 and Tl-209 included
Po-210	1.5E-09	1.5E-09	
At-211	3.2E-06	4.0E-06	Po-211 included

Radionuclide	External dose rate per unit concentration (µSv/h per Bq/kg)		
	Parent	Parent and all progeny	Comments
Ra-223	1.7E-05	4.3E-05	Rn-219 through to Tl-207 included
Ra-226	9.0E-07	3.3E-04	Rn-222 through to Pb-210 included
Ac-225	1.8E-06	3.6E-05	Fr-221 through to Pb-209
Th-227	1.5E-05	5.8E-05	Ra-223 through to Tl-207 included
Th-230	3.3E-08	3.3E-08	
Th-232	1.4E-08	1.4E-08	
Th-234	6.6E-07	4.2E-06	Pa-234m, Pa-234 included, rest of chain: half-life too long
U-234	1.1E-08	1.1E-08	
U-235	2.0E-05	2.1E-05	Th-231 only included
U-238	2.5E-09	4.2E-06	Th-234, Pa-234m and Pa-234 included
Np-237	2.1E-06	2.1E-06	
Pu-238	3.6E-09	3.6E-09	
Pu-239	8.1E-09	8.1E-09	
Pu-240	3.5E-09	3.5E-09	
Pu-241	1.6E-10	1.6E-10	
Pu-242	3.1E-09	3.1E-09	
Am-241	1.1E-06	1.1E-06	
Am-242	1.4E-06	1.4E-06	
Am-243	3.8E-06	2.5E-05	Np-239 only included
Cm-242	4.0E-09	4.0E-09	
Cm-243	1.6E-05	1.6E-05	
Cm-244	2.8E-09	2.8E-09	

Table G.12. External dose rates per unit release rate

Radionuclide	External dose rates (µSv/h per Bq/y)*		
	Raw sewage tanks	Sludge tanks	Brook bank sediments +
H-3	0.0E+00	0.0E+00	0.0E+00
H-3 organic	0.0E+00	0.0E+00	0.0E+00
C-11	2.6E-13	1.4E-13	nc
C-14	1.5E-17	2.3E-16	4.0E-17
F-18	1.4E-12	5.1E-13	nc
Na-22	1.8E-11	1.8E-10	2.5E-15
Na-24	2.8E-11	2.0E-11	8.5E-16
P-32	2.8E-14	1.6E-12	1.2E-15
P-33	7.0E-17	4.5E-15	4.9E-18
S-35	1.7E-17	1.6E-16	4.7E-18
Cl-36	3.5E-15	3.5E-14	4.7E-16
Ca-45	7.5E-17	2.9E-15	1.1E-16
Ca-47	9.4E-12	1.4E-10	2.7E-12
V-48	2.4E-11	1.6E-09	6.3E-13
Cr-51	2.3E-13	1.7E-11	3.5E-12
Mn-52	2.8E-11	1.2E-09	1.4E-10
Mn-54	6.8E-12	6.4E-10	1.8E-10
Mn-56	3.6E-12	1.3E-11	nc
Fe-55	0.0E+00	0.0E+00	0.0E+00
Fe-59	1.0E-11	8.1E-10	5.9E-11
Co-56	3.1E-11	2.6E-09	7.0E-10
Co-57	6.4E-13	5.6E-11	1.4E-11
Co-58	7.9E-12	6.5E-10	1.7E-10
Co-60	2.2E-11	1.9E-09	4.8E-10
Ni-63	0.0E+00	0.0E+00	0.0E+00
Cu-61	2.0E-12	7.3E-12	9.0E-13
Cu-64	1.0E-12	6.3E-12	2.1E-13
Zn-62	6.7E-12	3.7E-12	1.6E-12
Zn-65	4.9E-12	4.8E-11	3.4E-12
Ga-67	9.0E-13	2.3E-11	9.7E-14
Ga-68	8.0E-13	2.6E-12	nc
Se-75	2.6E-12	1.2E-10	1.2E-11
Br-76	1.7E-11	1.3E-11	1.2E-11
Br-77	2.2E-12	4.7E-12	1.5E-12
Br-82	1.9E-11	2.7E-11	1.2E-11
Rb-81	1.8E-12	7.4E-13	1.8E-11
Rb-82	1.7E-14	6.4E-15	nc
Rb-83	3.9E-12	3.6E-11	7.2E-11
Sr-83	5.4E-12	2.9E-11	2.0E-12
Sr-85	3.9E-12	1.4E-10	6.2E-12
Sr-89	2.1E-14	7.6E-13	3.4E-14

Radionuclide	External dose rates (µSv/h per Bq/y)*		
	Raw sewage tanks	Sludge tanks	Brook bank sediments +
Sr-90	5.7E-14	2.3E-12	9.1E-14
Y-90	5.2E-14	1.2E-12	4.4E-14
Zr-89	8.9E-12	1.3E-10	2.4E-12
Zr-95	5.9E-12	2.7E-10	1.6E-11
Nb-95	6.2E-12	2.6E-10	8.6E-13
Mo-99	1.7E-12	4.1E-12	4.6E-12
Tc-94m	1.3E-12	4.7E-13	nc
Tc-99	1.5E-16	1.5E-15	1.1E-18
Tc-99m	3.4E-13	1.5E-13	1.3E-15
Ru-103	3.6E-12	3.1E-11	7.1E-11
Ru-106	1.8E-12	1.7E-11	3.4E-11
Ag-110m	2.3E-11	2.0E-09	7.2E-10
In-111	2.4E-12	5.4E-11	1.4E-11
In-113m	3.0E-13	9.9E-13	nc
Sb-125	3.2E-12	3.2E-11	1.9E-11
I-123	6.4E-13	8.6E-13	1.2E-12
I-124	8.5E-12	6.0E-11	8.8E-12
I-125	1.7E-14	3.0E-13	8.7E-14
I-129	1.3E-14	2.7E-13	7.0E-14
I-131	2.8E-12	3.0E-11	3.2E-12
I-132	4.1E-12	3.0E-12	nc
I-133	3.8E-12	7.1E-12	5.1E-12
I-134	1.8E-12	1.4E-12	nc
I-135	6.9E-12	6.4E-12	1.3E-11
Cs-134	1.3E-11	1.2E-10	2.3E-10
Cs-136	1.7E-11	1.2E-10	6.3E-11
Cs-137	4.5E-12	4.5E-11	8.4E-11
Ba-140	2.1E-11	5.6E-10	9.9E-12
La-140	1.8E-11	2.0E-10	8.8E-11
Ce-141	4.0E-13	1.7E-11	1.3E-11
Ce-144	4.7E-13	2.3E-11	1.5E-11
Pm-147	6.0E-17	3.0E-15	3.5E-16
Sm-153	1.8E-13	1.6E-12	2.0E-12
Eu-152	9.3E-12	4.6E-10	6.3E-12
Eu-154	1.0E-11	5.1E-10	7.0E-12
Eu-155	2.3E-13	1.1E-11	1.5E-13
Er-169	1.7E-16	4.8E-15	2.2E-15
Lu-177	2.0E-13	4.8E-12	1.6E-12
Re-188	3.3E-13	2.6E-13	6.5E-14
Au-198	2.8E-12	3.4E-11	2.1E-11
Tl-201	3.2E-13	4.4E-12	1.9E-12
Pb-210	1.1E-14	9.5E-13	1.0E-13
Pb-212	8.6E-12	4.6E-11	2.3E-11

Radionuclide	External dose rates (μSv/h per Bq/y)*		
	Raw sewage tanks	Sludge tanks	Brook bank sediments +
Bi-213	9.9E-14	1.8E-13	nc
Po-210	6.9E-17	6.0E-15	1.5E-15
At-211	9.6E-14	9.3E-14	3.0E-13
Ra-223	1.9E-12	6.1E-11	3.6E-12
Ra-226	1.5E-11	7.5E-10	1.2E-10
Ac-225	1.6E-12	8.7E-11	9.6E-12
Th-227	2.6E-12	1.8E-10	1.9E-11
Th-230	1.5E-15	1.4E-13	4.6E-14
Th-232	6.4E-16	5.8E-14	6.6E-10
Th-234	1.9E-13	1.5E-11	5.9E-12
U-234	4.8E-16	4.8E-15	3.4E-17
U-235	9.7E-13	9.7E-12	6.7E-14
U-238	1.9E-13	1.9E-12	1.3E-14
Np-237	9.8E-14	9.8E-13	2.0E-14
Pu-238	1.6E-16	1.6E-15	5.2E-15
Pu-239	3.7E-16	3.7E-15	1.2E-14
Pu-240	1.6E-16	1.6E-15	5.0E-15
Pu-241	7.5E-18	7.5E-17	2.3E-16
Pu-242	1.4E-16	1.4E-15	4.4E-15
Am-241	5.2E-14	2.6E-12	1.5E-12
Am-242	4.6E-14	1.8E-13	5.7E-13
Am-243	1.1E-12	5.7E-11	3.3E-11
Cm-242	1.8E-16	1.6E-14	1.0E-15
Cm-243	7.5E-13	6.8E-11	4.4E-12
Cm-244	1.3E-16	1.1E-14	7.3E-16

nc = not considered due to half-life of less than 3 hours.
*for a raw sewage flow rate into the sewage treatment works of 60 m^3/d
+for a brook flow rate of 0.1 m^3/s. These values do not take into account partitioning and decay in the sewage treatment works. This is applied later using the factor Q_{eff} (see Section G.3).

Table G.13. Activity concentrations in terrestrial foodstuffs per unit application rate of sludge

Radio-nuclide	Activity concentration in foodstuffs produced on soil conditioned with sewage sludge in 50th year (Bq/kg or Bq/l per Bq/m²/s)*						
	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	Green veg.	Root veg.
H-3	2.4E+04	2.4E+04	1.6E+04	1.6E+04	1.8E+04	0.0E+00	0.0E+00
H-3 organic	1.8E+03	1.8E+03	1.2E+03	1.2E+03	9.6E+02	0.0E+00	0.0E+00
C-11	nc	nc	nc	nc	nc	nc	nc
C-14	1.3E+06	1.3E+06	8.3E+05	8.3E+05	4.0E+05	2.3E+06	1.8E+06
F-18	nc	nc	nc	nc	nc	nc	nc
Na-22	6.7E+05^	6.7E+05^	4.1E+05^	4.1E+05^	8.3E+04^	5.1E+03	4.5E+03
Na-24	nc	nc	nc	nc	nc	nc	nc
P-32	1.8E+04	7.1E+03	1.6E+05	8.8E+03	1.03E+04^^	nc	nc
P-33	3.7E+04	1.5E+04	3.3E+05	1.8E+04	1.73E+04^^	nc	nc
S-35	2.1E+06	2.5E+06	3.4E+06	3.4E+06	2.1E+05	1.7E+04	1.6E+04
Cl-36	2.0E+07^	2.7E+07^	1.7E+07^	1.7E+07^	3.4E+06^	5.9E+06	4.9E+06
Ca-45	6.4E+05	6.4E+05	3.5E+05	5.4E+04	3.2E+05	8.4E+04	2.9E+03
Ca-47	4.8E+03	4.8E+03	2.4E+03	3.8E+02	1.3E+04	nc	nc
V-48	2.1E+00	2.1E+00	2.9E-02	1.1E+00	3.6E-01	nc	nc
Cr-51	4.8E+03	4.8E+03	2.2E+03	2.2E+03	4.3E+02	nc	nc
Mn-52	2.4E+02	4.8E+04	1.2E+02	3.5E+04	4.0E+01	nc	nc
Mn-54	3.0E+04	6.5E+06	1.6E+04	5.2E+06	1.2E+03	6.8E+03	6.6E+03
Mn-56	nc	nc	nc	nc	nc	nc	nc
Fe-55	1.5E+03	4.5E+04	1.2E+04	3.4E+06	1.2E+02	1.3E+04	5.6E+01
Fe-59	5.7E+01	1.7E+03	3.7E+02	1.1E+05	4.0E+01	3.2E+03	3.8E+00
Co-56	1.4E+03	1.2E+05	2.8E+02	6.5E+04	2.5E+02	3.5E+03	4.6E+02
Co-57	5.4E+03	4.5E+05	1.2E+03	2.7E+05	5.3E+02	4.7E+03	1.5E+03
Co-58	1.3E+03	1.1E+05	2.5E+02	5.7E+04	2.3E+02	3.4E+03	4.2E+02
Co-60	2.1E+04	1.8E+06	5.5E+03	1.3E+06	1.7E+03	1.2E+04	1.1E+04
Ni-63	5.6E+01	5.6E+02	2.3E+02	2.3E+03	6.7E+04	1.0E+05	2.5E+04
Cu-61	nc	nc	nc	nc	nc	nc	nc
Cu-64	nc	nc	nc	nc	nc	nc	nc
Zn-62	nc	nc	nc	nc	nc	nc	nc
Zn-65	6.1E+04	2.7E+04	2.4E+06	2.9E+04	9.5E+04	1.8E+04	3.7E+03
Ga-67	nc	nc	nc	nc	nc	nc	nc
Ga-68	nc	nc	nc	nc	nc	nc	nc
Se-75	2.7E+06	5.4E+07	1.9E+06	4.7E+07	2.3E+05	3.4E+04	3.2E+04
Br-76	nc	nc	nc	nc	nc	nc	nc
Br-77	nc	nc	nc	nc	nc	nc	nc
Br-82	nc	nc	nc	nc	nc	nc	nc
Rb-81	nc	nc	nc	nc	nc	nc	nc
Rb-82	nc	nc	nc	nc	nc	nc	nc
Rb-83	5.7E+04	5.7E+04	3.9E+04	3.9E+04	5.7E+04	5.1E+03	6.2E+03
Sr-83	nc	nc	nc	nc	nc	nc	nc
Sr-85	1.2E+03	1.2E+03	1.1E+03	1.1E+03	5.4E+03	4.5E+03	1.5E+03
Sr-89	9.6E+02	9.6E+02	8.6E+02	8.6E+02	4.2E+03	4.0E+03	1.2E+03
Sr-90	3.8E+04	3.8E+04	6.8E+04	6.8E+04	3.2E+05	1.5E+05	1.5E+05
Y-90	nc	nc	nc	nc	nc	nc	nc

Radio-nuclide	Activity concentration in foodstuffs produced on soil conditioned with sewage sludge in 50th year (Bq/kg or Bq/l per Bq/m²/s)*						
	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	Green veg.	Root veg.
Zr-89	nc	nc	nc	nc	nc	nc	nc
Zr-95	3.1E+01	3.1E+01	1.4E+00	1.2E+01	4.8E+00	3.0E+03	1.6E+01
Nb-95	5.7E+00	5.7E+00	7.2E-02	2.8E+00	4.8E-01	2.6E+03	3.5E+01
Mo-99	nc	nc	nc	nc	nc	nc	nc
Tc-94m	nc	nc	nc	nc	nc	nc	nc
Tc-99	6.9E+08	2.1E+09	2.1E+07	8.5E+07	2.1E+07	1.4E+07	9.0E+06
Tc-99m	nc	nc	nc	nc	nc	nc	nc
Ru-103	7.1E+01	3.4E+02	5.6E+02	1.7E+02	1.2E+01	2.7E+03	2.2E+01
Ru-106	8.4E+02	4.0E+03	6.8E+03	2.1E+03	3.6E+01	4.2E+03	1.9E+02
Ag-110m	1.2E+03	7.8E+06	2.1E+04	8.2E+06	7.2E+05	3.5E+03	2.0E+01
In-111	nc	nc	nc	nc	nc	nc	nc
In-113m	nc	nc	nc	nc	nc	nc	nc
Sb-125	1.7E+04	1.7E+06	7.8E+03	6.5E+05	2.5E+02	3.8E+03	3.6E+01
I-123	nc	nc	nc	nc	nc	nc	nc
I-124	6.0E+02	6.0E+02	5.2E+02	5.2E+02	1.4E+03	nc	nc
I-125	1.2E+04	1.2E+04	3.7E+03	3.7E+03	6.1E+03	3.7E+03	2.2E+03
I-129	1.4E+05	1.4E+05	2.4E+04	2.4E+04	3.5E+04	6.3E+04	6.2E+04
I-131	1.5E+03	1.5E+03	1.1E+03	1.1E+03	2.5E+03	nc	nc
I-132	nc	nc	nc	nc	nc	nc	nc
I-133	nc	nc	nc	nc	nc	nc	nc
I-134	nc	nc	nc	nc	nc	nc	nc
I-135	nc	nc	nc	nc	nc	nc	nc
Cs-134	4.9E+05	4.9E+05	2.7E+05	2.7E+05	5.4E+04	5.5E+03	5.1E+03
Cs-136	2.0E+04	2.0E+04	9.7E+03	9.7E+03	4.4E+03	nc	nc
Cs-137	8.6E+05	8.6E+05	4.1E+05	4.1E+05	7.9E+04	1.6E+04	2.3E+04
Ba-140	2.0E+02	2.0E+02	3.1E+01	1.1E+02	1.3E+02	nc	nc
La-140	nc	nc	nc	nc	nc	nc	nc
Ce-141	8.8E-01	7.0E+03	2.5E+01	5.0E+03	5.7E+01	2.5E+03	1.1E+01
Ce-144	2.1E+01	1.7E+05	9.9E+02	2.0E+05	3.2E+02	3.4E+03	8.6E+01
Pm-147	4.1E+03	2.5E+04	2.9E+03	2.3E+04	8.5E+01	7.7E+03	2.1E+03
Sm-153	nc	nc	nc	nc	nc	nc	nc
Eu-152	8.1E+03	4.9E+04	8.6E+03	6.9E+04	1.4E+02	6.9E+03	3.3E+03
Eu-154	7.3E+03	4.4E+04	7.1E+03	5.7E+04	1.3E+02	5.9E+03	2.4E+03
Eu-155	5.8E+03	3.5E+04	5.0E+03	4.0E+04	1.1E+02	4.9E+03	1.4E+03
Er-169	1.1E-01	8.4E+02	2.9E+00	5.8E+02	2.3E+01	nc	nc
Lu-177	5.8E-02	4.7E+02	1.6E+00	3.2E+02	1.8E+01	nc	nc
Re-188	nc	nc	nc	nc	nc	nc	nc
Au-198	nc	nc	nc	nc	nc	nc	nc
Tl-201	nc	nc	nc	nc	nc	nc	nc
Pb-210	4.4E+04	1.2E+05	5.8E+04	1.7E+05	1.9E+04	1.6E+04	4.7E+03
Pb-212	nc	nc	nc	nc	nc	nc	nc
Bi-213	nc	nc	nc	nc	nc	nc	nc
Po-210	2.8E+04	3.4E+05	9.4E+03	2.5E+05	8.4E+02	4.0E+03	2.5E+03
At-211	nc	nc	nc	nc	nc	nc	nc
Ra-223	2.4E+02	2.4E+02	4.9E+02	1.4E+02	3.5E+02	nc	nc

Radio-nuclide	Activity concentration in foodstuffs produced on soil conditioned with sewage sludge in 50th year (Bq/kg or Bq/l per Bq/m²/s)*						
	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	Green veg.	Root veg.
Ra-226	4.0E+04	4.0E+04	1.0E+05	2.9E+04	2.3E+04	3.0E+04	4.1E+04
Ac-225	3.2E-01	6.3E+01	1.8E-01	3.6E+01	2.0E+00	nc	nc
Th-227	4.9E+00	4.9E+01	6.5E+00	2.8E+01	5.8E+00	nc	nc
Th-230	1.9E+03	1.9E+04	7.2E+03	3.1E+04	2.4E+02	4.0E+03	4.7E+02
Th-232	1.9E+03	1.9E+04	7.2E+03	3.1E+04	2.4E+02	4.0E+03	4.7E+02
Th-234	7.2E+00	7.2E+01	9.5E+00	4.1E+01	6.6E+00	2.2E+03	1.1E+00
U-234	9.5E+03	9.5E+03	9.5E+03	4.9E+03	4.4E+04	9.5E+03	5.0E+03
U-235	9.5E+03	9.5E+03	9.5E+03	4.9E+03	4.4E+04	9.5E+03	5.0E+03
U-238	9.5E+03	9.5E+03	9.5E+03	4.9E+03	4.4E+04	9.5E+03	5.0E+03
Np-237	2.5E+03	1.8E+05	4.1E+03	5.1E+05	7.5E+01	1.2E+04	1.3E+04
Pu-238	1.2E+03	8.7E+04	7.8E+02	9.5E+04	1.4E+01	3.6E+03	1.9E+02
Pu-239	1.3E+03	9.0E+04	8.2E+02	1.0E+05	1.5E+01	3.6E+03	2.3E+02
Pu-240	1.3E+03	9.0E+04	8.2E+02	1.0E+05	1.5E+01	3.6E+03	2.3E+02
Pu-241	1.0E+03	7.3E+04	5.9E+02	7.2E+04	1.1E+01	3.5E+03	9.2E+01
Pu-242	1.3E+03	9.0E+04	8.3E+02	1.0E+05	1.5E+01	3.6E+03	2.3E+02
Am-241	1.9E+03	1.4E+05	2.6E+03	3.1E+05	4.6E+01	3.7E+03	3.7E+02
Am-242	nc	nc	nc	nc	nc	nc	nc
Am-243	1.9E+03	1.4E+05	2.6E+03	3.2E+05	4.7E+01	3.7E+03	3.8E+02
Cm-242	1.1E+02	7.8E+03	3.6E+01	4.3E+03	6.5E-01	3.2E+03	6.9E+00
Cm-243	1.1E+03	8.1E+04	7.1E+02	8.7E+04	1.3E+01	3.8E+03	3.0E+02
Cm-244	1.1E+03	7.7E+04	6.4E+02	7.9E+04	1.2E+01	3.7E+03	2.3E+02

* animal food concentration factors for tritium and carbon radionuclides taken from [G.9]. Other values obtained primarily from [G.11] and [G.17]. Values are presented in Tables D.7 and D.8.

nc = not considered due to short half-life. Radionuclides with half-lives of less than 4 days were not considered for pathways resulting application of sewage sludge to soil; radionuclides with half-lives of less than 30 days were not considered for consumption of vegetables grown in sludge-conditioned soil.

^ data taken from the original version of IRAT Part 2 report [G.18] and based on PC-CREAM 98.

^^ activity concentrations of P-32 and P-33 in cow milk per unit deposition rate were derived by taking the ratio of activity concentrations of phosphorus isotopes in cow liver:cow milk from data in the original version of IRAT, and applying this ratio to cow liver in IRAT2.

Table G.14. Parameters characterising the application of treated sewage sludge to agricultural land

	Value	Comment
Delay between spreading of sludge and animal grazing (d)	21	[G.2]
Delay between spreading of sludge and crop harvest (d)	304	[G.10]
Spreading rate of sludge to land ($kg/m^2/y$)	8	[G.2]
Density of soil (kg/m^3)	1,250	
Transfer of strontium to next soil layer (/y)	0.464	[G.11]
Transfer of other radionuclides to next soil layer (/y)	0.243	[G.11]
Airborne soil concentration (kg/m^3)	1.0E-07	[G.11]

Table G.15. Activity concentrations in soil per unit deposition rate of sewage sludge (arable well-mixed soil)

Radionuclide	Soil concentration in 50th year (Bq/kg per Bq/m^2/s)
H-3	8.5E+03
H-3 organic	9.7E+05
C-11	0.0E+00
C-14	9.7E+05
F-18	2.1E+01
Na-22	2.9E+05
Na-24	1.7E+02
P-32	4.2E+03
P-33	7.7E+03
S-35	3.1E+04
Cl-36	2.1E+06
Ca-45	5.8E+04
Ca-47	1.3E+03
V-48	4.8E+03
Cr-51	8.5E+03
Mn-52	1.6E+03
Mn-54	1.1E+05
Mn-56	3.0E+01
Fe-55	3.0E+05
Fe-59	1.4E+04
Co-56	2.7E+04
Co-57	9.4E+04
Co-58	2.4E+04
Co-60	5.4E+05
Ni-63	2.5E+06
Cu-61	3.9E+01
Cu-64	1.5E+02
Zn-62	1.1E+02
Zn-65	8.5E+04
Ga-67	9.2E+02
Ga-68	1.3E+01
Se-75	4.3E+04
Br-76	1.9E+02
Br-77	6.5E+02
Br-82	4.1E+02
Rb-81	5.3E+01
Rb-82	2.5E-01
Rb-83	3.0E+04
Sr-83	3.8E+02
Sr-85	2.2E+04
Sr-89	1.7E+04
Sr-90	1.8E+06
Y-90	7.5E+02

Radionuclide	Soil concentration in 50th year (Bq/kg per Bq/m^2/s)
Zr-89	9.2E+02
Zr-95	2.2E+04
Nb-95	1.1E+04
Mo-99	7.7E+02
Tc-94m	1.0E+01
Tc-99	1.0E+06
Tc-99m	7.0E+01
Ru-103	1.3E+04
Ru-106	1.2E+05
Ag-110m	8.7E+04
In-111	7.9E+02
In-113m	1.9E+01
Sb-125	3.0E+05
I-123	1.5E+02
I-124	1.2E+03
I-125	2.0E+04
I-129	3.0E+06
I-131	2.3E+03
I-132	2.7E+01
I-133	2.4E+02
I-134	1.0E+01
I-135	7.6E+01
Cs-134	2.3E+05
Cs-136	3.8E+03
Cs-137	1.8E+06
Ba-140	3.7E+03
La-140	4.7E+02
Ce-141	1.0E+04
Ce-144	9.8E+04
Pm-147	2.9E+05
Sm-153	5.4E+02
Eu-152	1.2E+06
Eu-154	8.4E+05
Eu-155	5.1E+05
Er-169	2.7E+03
Lu-177	1.9E+03
Re-188	2.0E+02
Au-198	7.6E+02
Tl-201	8.5E+02
Pb-210	1.6E+06
Pb-212	1.2E+02
Bi-213	8.8E+00
Po-210	5.0E+04
At-211	8.3E+01
Ra-223	3.3E+03

Radionuclide	Soil concentration in 50^{th} year (Bq/kg per Bq/m^2/s)
Ra-226	2.9E+06
Ac-225	2.9E+03
Th-227	5.6E+03
Th-230	3.0E+06
Th-232	3.0E+06
Th-234	7.3E+03
U-234	3.0E+06
U-235	3.0E+06
U-238	3.0E+06
Np-237	3.0E+06
Pu-238	2.5E+06
Pu-239	3.0E+06
Pu-240	3.0E+06
Pu-241	1.2E+06
Pu-242	3.0E+06
Am-241	2.9E+06
Am-242	1.9E+02
Am-243	3.0E+06
Cm-242	5.8E+04
Cm-243	1.8E+06
Cm-244	1.4E+06

Table G.16. Activity concentration in terrestrial foodstuffs grown in or raised on soil conditioned with sludge per unit release rate

Radio-nuclide	Activity concentration (Bq/kg per Bq/y)*						
	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow Milk	Green veg.	Root veg.
H-3	4.1E-09	4.1E-09	2.7E-09	2.7E-09	3.2E-09	0.0E+00	0.0E+00
H-3 organic	3.1E-10	3.1E-10	2.1E-10	2.1E-10	1.7E-10	0.0E+00	0.0E+00
C-11	nc	nc	nc	nc	nc	nc	nc
C-14	2.3E-07	2.3E-07	1.4E-07	1.4E-07	7.0E-08	3.9E-07	3.2E-07
F-18	nc	nc	nc	nc	nc	nc	nc
Na-22	7.5E-08	7.5E-08	4.6E-08	4.6E-08	9.3E-09	4.7E-10	4.1E-10
Na-24	nc	nc	nc	nc	nc	nc	nc
P-32	2.6E-09	1.0E-09	2.4E-08	1.3E-09	1.5E-09	nc	nc
P-33	1.2E-08	4.9E-09	1.1E-07	6.0E-09	5.7E-09	nc	nc
S-35	1.8E-07	2.2E-07	2.9E-07	2.9E-07	1.8E-08	1.6E-10	1.4E-10
Cl-36	2.3E-06	3.1E-06	2.0E-06	2.0E-06	3.9E-07	6.8E-07	5.7E-07
Ca-45	2.5E-07	2.5E-07	1.4E-07	2.1E-08	1.2E-07	9.9E-09	3.4E-10
Ca-47	6.6E-12	6.6E-12	3.4E-12	5.2E-13	1.7E-11	nc	nc
V-48	4.2E-13	4.2E-13	5.9E-15	2.3E-13	7.3E-14	nc	nc
Cr-51	1.9E-09	1.9E-09	9.0E-10	9.0E-10	1.7E-10	nc	nc
Mn-52	2.4E-12	4.7E-10	1.2E-12	3.5E-10	4.0E-13	nc	nc
Mn-54	3.0E-08	6.5E-06	1.6E-08	5.2E-06	1.2E-09	3.6E-09	3.6E-09
Mn-56	nc	nc	nc	nc	nc	nc	nc
Fe-55	1.5E-09	4.6E-08	1.2E-08	3.5E-06	1.2E-10	1.1E-08	4.7E-11
Fe-59	3.3E-11	9.9E-10	2.1E-10	6.1E-08	2.3E-11	2.2E-11	2.7E-14
Co-56	1.1E-09	8.8E-08	2.1E-10	4.8E-08	1.8E-10	2.0E-10	2.7E-11
Co-57	5.1E-09	4.2E-07	1.1E-09	2.5E-07	5.0E-10	2.1E-09	6.9E-10
Co-58	9.0E-10	7.5E-08	1.8E-10	4.1E-08	1.7E-10	1.5E-10	1.9E-11
Co-60	2.2E-08	1.8E-06	5.7E-09	1.3E-06	1.8E-09	1.1E-08	1.0E-08
Ni-63	5.9E-11	5.9E-10	2.4E-10	2.4E-09	7.0E-08	1.1E-07	2.6E-08
Cu-61	nc	nc	nc	nc	nc	nc	nc
Cu-64	nc	nc	nc	nc	nc	nc	nc
Zn-62	nc	nc	nc	nc	nc	nc	nc
Zn-65	6.3E-09	2.8E-09	2.4E-07	3.1E-09	9.8E-09	8.4E-10	1.7E-10
Ga-67	nc	nc	nc	nc	nc	nc	nc
Ga-68	nc	nc	nc	nc	nc	nc	nc
Se-75	1.2E-06	2.5E-05	8.7E-07	2.2E-05	1.1E-07	3.1E-09	2.9E-09
Br-76	nc	nc	nc	nc	nc	nc	nc
Br-77	nc	nc	nc	nc	nc	nc	nc
Br-82	nc	nc	nc	nc	nc	nc	nc
Rb-81	nc	nc	nc	nc	nc	nc	nc
Rb-82	nc	nc	nc	nc	nc	nc	nc
Rb-83	4.8E-09	4.8E-09	3.3E-09	3.3E-09	4.8E-09	4.4E-11	5.4E-11
Sr-83	nc	nc	nc	nc	nc	nc	nc
Sr-85	3.8E-10	3.8E-10	3.4E-10	3.4E-10	1.7E-09	6.7E-11	2.3E-11
Sr-89	2.6E-10	2.6E-10	2.4E-10	2.4E-10	1.2E-09	2.3E-11	7.0E-12
Sr-90	1.8E-08	1.8E-08	3.1E-08	3.1E-08	1.5E-07	6.8E-08	7.0E-08
Y-90	nc	nc	nc	nc	nc	nc	nc

Radio-nuclide	Activity concentration (Bq/kg per Bq/y)*						
	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow Milk	Green veg.	Root veg.
Zr-89	nc	nc	nc	nc	nc	nc	nc
Zr-95	1.2E-11	1.2E-11	5.5E-13	4.6E-12	1.9E-12	5.3E-11	2.8E-13
Nb-95	1.6E-12	1.6E-12	2.0E-14	7.6E-13	1.3E-13	2.6E-12	3.5E-14
Mo-99	nc	nc	nc	nc	nc	nc	nc
Tc-94m	nc	nc	nc	nc	nc	nc	nc
Tc-99	8.0E-05	2.4E-04	2.5E-06	9.8E-06	2.5E-06	1.7E-06	1.0E-06
Tc-99m	nc	nc	nc	nc	nc	nc	nc
Ru-103	4.2E-12	2.0E-11	3.3E-11	9.9E-12	7.2E-13	1.1E-12	8.9E-15
Ru-106	9.0E-11	4.3E-10	7.3E-10	2.2E-10	3.9E-12	2.7E-10	1.2E-11
Ag-110m	1.2E-09	7.3E-06	1.9E-08	7.7E-06	6.8E-07	1.5E-09	8.4E-12
In-111	nc	nc	nc	nc	nc	nc	nc
In-113m	nc	nc	nc	nc	nc	nc	nc
Sb-125	1.9E-09	1.9E-07	8.8E-10	7.3E-08	2.9E-11	3.6E-10	3.3E-12
I-123	nc	nc	nc	nc	nc	nc	nc
I-124	2.5E-13	2.5E-13	2.2E-13	2.2E-13	6.0E-13	nc	nc
I-125	1.7E-09	1.7E-09	5.5E-10	5.5E-10	9.0E-10	2.0E-11	1.2E-11
I-129	3.2E-08	3.2E-08	5.5E-09	5.5E-09	8.1E-09	1.5E-08	1.4E-08
I-131	1.3E-11	1.3E-11	9.1E-12	9.1E-12	2.1E-11	nc	nc
I-132	nc	nc	nc	nc	nc	nc	nc
I-133	nc	nc	nc	nc	nc	nc	nc
I-134	nc	nc	nc	nc	nc	nc	nc
I-135	nc	nc	nc	nc	nc	nc	nc
Cs-134	5.5E-08	5.5E-08	3.0E-08	3.0E-08	6.0E-09	4.8E-10	4.4E-10
Cs-136	3.0E-10	3.0E-10	1.5E-10	1.5E-10	6.8E-11	nc	nc
Cs-137	9.9E-08	9.9E-08	4.7E-08	4.7E-08	9.1E-09	1.8E-09	2.6E-09
Ba-140	1.2E-11	1.2E-11	1.8E-12	6.5E-12	7.5E-12	nc	nc
La-140	nc	nc	nc	nc	nc	nc	nc
Ce-141	2.3E-13	1.8E-09	6.4E-12	1.3E-09	1.5E-11	1.5E-12	6.9E-15
Ce-144	1.1E-11	8.9E-08	5.2E-10	1.0E-07	1.7E-10	9.1E-10	2.3E-11
Pm-147	2.3E-09	1.4E-08	1.6E-09	1.3E-08	4.8E-11	3.5E-09	9.6E-10
Sm-153	nc	nc	nc	nc	nc	nc	nc
Eu-152	4.7E-09	2.8E-08	5.0E-09	4.0E-08	8.3E-11	3.8E-09	1.8E-09
Eu-154	4.2E-09	2.5E-08	4.1E-09	3.3E-08	7.5E-11	3.2E-09	1.3E-09
Eu-155	3.3E-09	2.0E-08	2.8E-09	2.3E-08	6.2E-11	2.5E-09	7.1E-10
Er-169	3.7E-15	3.0E-11	1.0E-13	2.0E-11	8.0E-13	nc	nc
Lu-177	6.4E-16	5.1E-12	1.8E-14	3.6E-12	1.9E-13	nc	nc
Re-188	nc	nc	nc	nc	nc	nc	nc
Au-198	nc	nc	nc	nc	nc	nc	nc
Tl-201	nc	nc	nc	nc	nc	nc	nc
Pb-210	4.5E-08	1.3E-07	6.0E-08	1.7E-07	2.0E-08	1.6E-08	4.7E-09
Pb-212	nc	nc	nc	nc	nc	nc	nc
Bi-213	nc	nc	nc	nc	nc	nc	nc
Po-210	2.4E-08	2.9E-07	8.0E-09	2.1E-07	7.2E-10	8.2E-10	5.1E-10
At-211	nc	nc	nc	nc	nc	nc	nc
Ra-223	1.4E-11	1.4E-11	2.8E-11	8.3E-12	2.0E-11	nc	nc
Ra-226	2.3E-08	2.3E-08	5.8E-08	1.7E-08	1.3E-08	1.7E-08	2.3E-08

Radio-nuclide	Activity concentration (Bq/kg per Bq/y)*						
	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow Milk	Green veg.	Root veg.
Ac-225	2.4E-14	4.7E-12	1.3E-14	2.7E-12	1.5E-13	nc	nc
Th-227	1.2E-12	1.2E-11	1.7E-12	7.2E-12	1.5E-12	nc	nc
Th-230	2.0E-09	2.0E-08	7.5E-09	3.3E-08	2.4E-10	4.1E-09	4.9E-10
Th-232	2.0E-09	2.0E-08	7.5E-09	3.3E-08	2.4E-10	4.1E-09	4.9E-10
Th-234	3.4E-12	3.4E-11	4.5E-12	1.9E-11	3.1E-12	2.8E-12	1.4E-15
U-234	1.1E-09	1.1E-09	1.1E-09	5.6E-10	5.1E-09	1.1E-09	5.7E-10
U-235	1.1E-09	1.1E-09	1.1E-09	5.6E-10	5.1E-09	1.1E-09	5.7E-10
U-238	1.1E-09	1.1E-09	1.1E-09	5.6E-10	5.1E-09	1.1E-09	5.7E-10
Np-237	2.8E-10	2.0E-08	4.8E-10	5.9E-08	8.6E-12	1.3E-09	1.5E-09
Pu-238	1.4E-10	1.0E-08	9.0E-11	1.1E-08	1.6E-12	4.1E-10	2.2E-11
Pu-239	1.5E-10	1.0E-08	9.5E-11	1.2E-08	1.7E-12	4.2E-10	2.6E-11
Pu-240	1.5E-10	1.0E-08	9.5E-11	1.2E-08	1.7E-12	4.2E-10	2.6E-11
Pu-241	1.2E-10	8.4E-09	6.8E-11	8.3E-09	1.2E-12	3.9E-10	1.0E-11
Pu-242	1.5E-10	1.0E-08	9.5E-11	1.2E-08	1.7E-12	4.2E-10	2.6E-11
Am-241	1.1E-09	7.8E-08	1.5E-09	1.8E-07	2.7E-11	2.1E-09	2.1E-10
Am-242	nc	nc	nc	nc	nc	nc	nc
Am-243	1.1E-09	7.9E-08	1.5E-09	1.9E-07	2.7E-11	2.1E-09	2.2E-10
Cm-242	9.8E-11	6.9E-09	3.2E-11	3.8E-09	5.8E-13	8.5E-10	1.8E-12
Cm-243	1.2E-09	8.4E-08	7.3E-10	9.0E-08	1.3E-11	3.9E-09	3.0E-10
Cm-244	1.1E-09	7.9E-08	6.7E-10	8.2E-08	1.2E-11	3.7E-09	2.3E-10

nc = not considered due to short half-life. Radionuclides with half-lives of less than 4 days were not considered for pathways resulting application of sewage sludge to soil; radionuclides with half-lives of less than 30 days were not considered for consumption of vegetables grown in sludge-conditioned soil.
*for a raw sewage flow rate into the sewage treatment works of 60 m^3/d

Table G.17. Activity concentration in soil conditioned with sludge per unit release rate (arable well-mixed soil) [for undisturbed soil, see Table D.6 in Appendix D].

Radionuclide	Activity concentration (Bq/kg per Bq/y)*
H-3	1.5E-09
H-3 organic	1.7E-07
C-11	nc
C-14	1.7E-07
F-18	nc
Na-22	3.3E-08
Na-24	nc
P-32	1.7E-09
P-33	4.5E-09
S-35	3.1E-09
Cl-36	2.4E-07
Ca-45	2.5E-08
Ca-47	4.5E-11
V-48	2.4E-09
Cr-51	5.8E-09
Mn-52	2.1E-10
Mn-54	1.2E-07
Mn-56	nc
Fe-55	3.1E-07
Fe-59	1.1E-08
Co-56	2.4E-08
Co-57	9.4E-08
Co-58	2.1E-08
Co-60	5.6E-07
Ni-63	2.6E-06
Cu-61	nc
Cu-64	nc
Zn-62	nc
Zn-65	9.4E-09
Ga-67	nc
Ga-68	nc
Se-75	2.3E-08
Br-76	nc
Br-77	nc
Br-82	nc
Rb-81	nc
Rb-82	nc
Rb-83	3.0E-09
Sr-83	nc
Sr-85	8.5E-09
Sr-89	6.2E-09
Sr-90	8.3E-07
Y-90	nc

Radionuclide	Activity concentration (Bq/kg per Bq/y)*
Zr-89	nc
Zr-95	1.1E-08
Nb-95	4.5E-09
Mo-99	nc
Tc-94m	nc
Tc-99	1.2E-07
Tc-99m	nc
Ru-103	1.1E-09
Ru-106	1.3E-08
Ag-110m	8.6E-08
In-111	nc
In-113m	nc
Sb-125	3.4E-08
I-123	nc
I-124	1.7E-11
I-125	3.8E-09
I-129	6.9E-07
I-131	1.2E-10
I-132	nc
I-133	nc
I-134	nc
I-135	nc
Cs-134	2.6E-08
Cs-136	1.8E-10
Cs-137	2.1E-07
Ba-140	6.8E-10
La-140	nc
Ce-141	4.0E-09
Ce-144	5.4E-08
Pm-147	1.7E-07
Sm-153	nc
Eu-152	6.9E-07
Eu-154	4.8E-07
Eu-155	2.9E-07
Er-169	4.5E-10
Lu-177	1.9E-10
Re-188	nc
Au-198	nc
Tl-201	nc
Pb-210	1.7E-06
Pb-212	nc
Bi-213	nc
Po-210	4.8E-08
At-211	nc
Ra-223	6.8E-10
Ra-226	1.7E-06
Ac-225	9.3E-10

Radionuclide	Activity concentration (Bq/kg per Bq/y)*
Th-227	3.1E-09
Th-230	3.1E-06
Th-232	3.1E-06
Th-234	5.3E-09
U-234	3.5E-07
U-235	3.5E-07
U-238	3.5E-07
Np-237	3.5E-07
Pu-238	2.9E-07
Pu-239	3.5E-07
Pu-240	3.5E-07
Pu-241	1.4E-07
Pu-242	3.5E-07
Am-241	1.7E-06
Am-242	nc
Am-243	1.7E-06
Cm-242	5.6E-08
Cm-243	1.9E-06
Cm-244	1.5E-06

*for a raw sewage flow rate into the sewage treatment works of 60 m^3/d
nc = not considered due to half-life of less than 4 days.

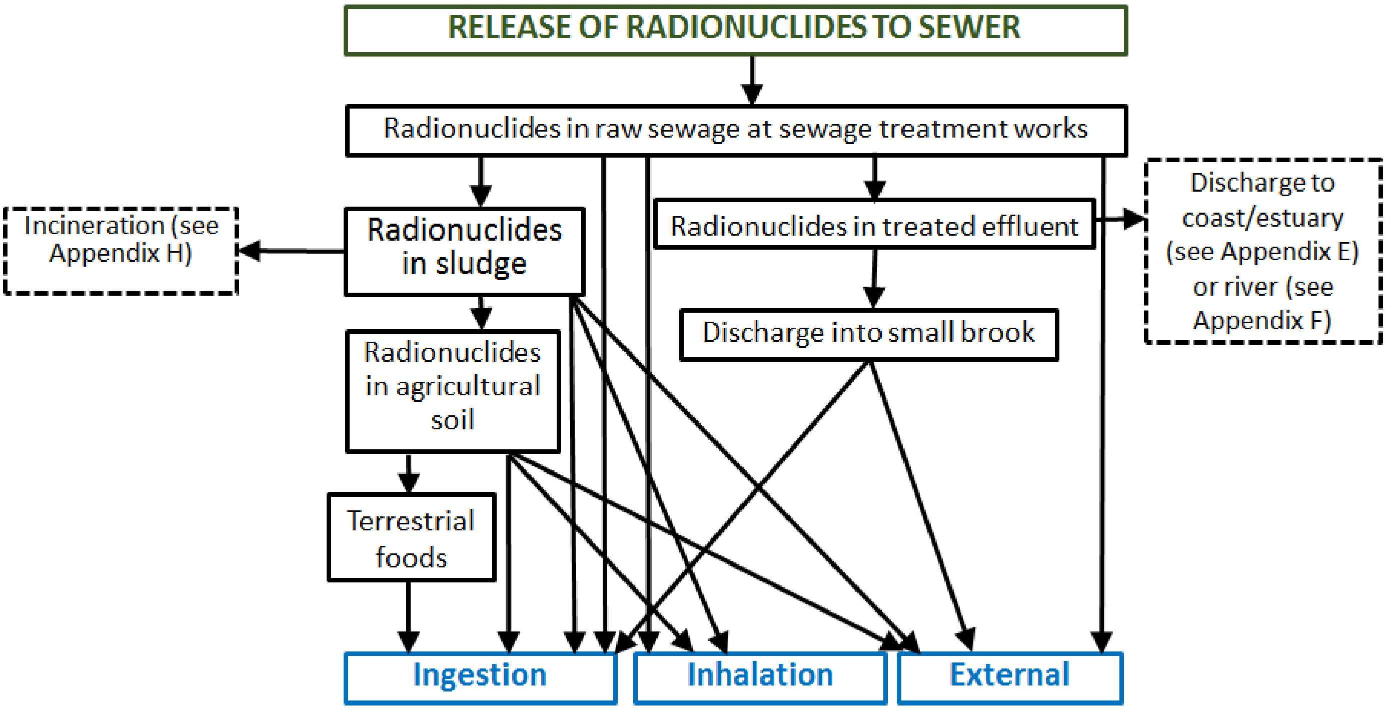

Figure G.1. Flow diagram of exposure pathways considered for releases to sewer

Appendix H: Input data and calculation of doses from incineration of radioactive waste

H.1 Source term

The source term for incinerator discharges can be either the amounts of radioactive waste received by the incinerator (feedstock) for heat treatment or the flue gas atmospheric discharges following combustion of mixed radioactive wastes (permit limits). In some cases an incinerator may have a permit expressed in terms of solid waste received and in some cases for discharges from the stack. The incinerator 'feedstock' may be comprised of low level high volume combustible waste originating from small users and some nuclear sites. Some incinerators also receive de-watered sludge from sewage treatment works, which can contain radioactive material originating from small user disposals to sewers.

This appendix applies to a source term of radionuclides in waste received at and disposed of to the incinerator. Partitioning factors can be applied that represent the behaviour of radionuclides during the combustion process. Radionuclides may be exhausted from the stack or be retained in bottom ash or abatement products, or a proportion may transfer between these phases.

For the radionuclides that are discharged in the exhaust gases, DPUR factors for exposure from releases to air are used. The DPUR factors are the same as those applied in the initial atmospheric assessments (see Appendix D). For initial assessment to atmosphere the assumed dispersion parameters and concentration factors are the same. The radionuclides considered for an atmospheric assessment are the same as those considered for incinerator discharges.

For assessment of the disposal of waste to the incinerator – as feedstock – data in this appendix can be used. The baseline initial assessment assumes that 100% of the radionuclides in the feedstock combusted are discharged to air. General incinerator partition factors for radionuclides are presented and can be applied to refine the assessment. The use of partitioning factors will yield a more representative atmospheric discharge from the combustion process. Sets of radionuclide specific partitioning factors for general assessment are presented in this appendix and can be selected in the atmospheric discharges IRAT2 spreadsheet tool.

H.2 Exposed groups for the public and wildlife

The exposed groups considered for public and wildlife are the same as for the atmospheric assessment presented in Appendix D.

H.3 Activity concentrations in air and deposition rates

Activity concentrations per unit discharge to air are the same as those for the atmospheric assessment presented in Appendix D.

H.4 Partitioning behaviour in incinerators

When waste containing radioactive material is combusted, a portion of the radioactivity from the feedstock partitions to the gas phase and is discharged from the incinerator stack to the atmosphere (flue gas). The remaining radioactivity is retained in the incineration chamber as bottom ash or as air pollution control residues (filter ash, fly ash) or process water effluent (aqueous wastes from wet abatement equipment). The partitioning is radionuclide dependent. The releases to atmosphere during incineration are mostly of radionuclides that are gaseous at the temperature of incineration or attached to fine particles which are not abated by air pollution control systems.

Partitioning can also be affected by the type of abatement equipment used in the incinerator to remove chemicals and particulates from flue gases prior to discharge. Generally, these methods can either be dry gas cleaning methods, such as filtration, or wet gas cleaning methods such as a liquid quench. Depending on the radionuclides in the waste being incinerated, the type of gas cleaning method can significantly affect partitioning. For example, tritium follows the mass balance of water in an incinerator, meaning that in a dry gas cleaned incinerator, it will partition to water vapour and be mostly discharged with flue gases. The converse is true for tritium discharges from a wet gas cleaned incinerator, as it partitions almost entirely to water used in the incinerator's abatement equipment – leading to very low gaseous discharges. Tritiated water is produced as an aqueous waste by-product from this process.

General partitioning factors are presented in Table H.1 (dry gas abatement) and Table H.2 (wet abatement) and are included in the IRAT2 atmospheric spreadsheet tool. The factors can be applied to the annual incinerator feedstock activity (D_{incin}) to calculate the annual atmospheric discharge from the incinerator stack for a specific radionuclide (D_{air}) and can be described as follows:

$$D_{air} = D_{incin} \times pf_{flue}$$

When:

D_{air} = Activity of radionuclide discharged to air (Bq/y)

D_{incin} =Activity of radionuclide in waste fed to incinerator (Bq/y) (e.g. a permit limit)

pf_{flue} = Radionuclide partition factor to flue gases (Tables H.1 or H.2).

Each radionuclide in the IRAT2 Releases to Air spreadsheet tool has been assigned a general partition factor (pf_{air}) for each of the general abatement types:

- Dry-gas cleaned incinerators (dry abatement equipment)
- Wet-gas cleaned incinerators (wet abatement equipment, produces aqueous discharges).

The general partition factors for the main incinerator abatement types can be very similar or identical for some radionuclides (e.g. carbon-14). For other nuclides, the type of abatement equipment used can significantly impact on the resulting discharges, as the partition factors for the abatement techniques differ significantly from each other (e.g. tritium, caesium-137).

Generalised partition factors have been derived for each radionuclide from experimental data and peer reviewed literature. Where insufficient data are available for a radionuclide, it has been assigned an appropriate analogue.

The experimental data used to determine the generalised partition factors are based on information from a variety of incinerators combusting a range of mixed waste. Incinerator operating conditions feature a range of variables which could impact radionuclide partitioning behaviour; these include physical properties such as kiln temperature, and chemical properties such as halogenic content and oxygen availability. In addition, abatement systems in some incinerators feature a range of cleaning methods rather than a simple wet or dry gas cleaned system. Consequently, partitioning behaviour is often complex and inconsistent. Partitioning of volatile metals, for example, often exhibit variation due to minor alterations to the incinerator feedstock. For this reason, the generalised partition factors selected are cautious in favour of atmospheric discharge.

For a site-specific detailed assessment, it may be appropriate to use incinerator operator information on partitioning specific to their incinerator (if available).

The permit may be expressed in terms of discharges from the incinerator stack or the activity in the incinerator feedstock. For the former it would not be necessary to apply partitioning factors to dose calculations, as partitioning will already have been taken into account. In the latter case partitioning and the factors presented can be used.

Some permits may contain 2 different discharge limits for radionuclides; one for discharges from the stack and the other for the feedstock. In this event, two separate assessments may be conducted. The partitioning factors can be used to inform on the appropriateness of the permit and the consistency of the proposed permit limits.

H.5 Determination of source term in incineration of sewage sludge following discharge to sewers

Some incinerators may combust sludge from sewage treatment works. Sewage sludge is separated from raw sewage during the treatment of raw sewage (see Appendix G). Where the sludge is to be incinerated (rather than applied to farmland as soil conditioner), anaerobic digestion of the sludge is not normally undertaken (as the need for toxicity reduction has been removed). The residence time of sludge in a sewage works before incineration may therefore be shorter than when sludge is to be applied to soil. For IRAT2, the residence time of sludge for incineration is 4 days. Sewage sludge is generally combusted following de-watering to around 30% solid content.

Incineration of sewage sludge containing radioactivity may be an exposure route to local residents and wildlife following disposal of radioactive waste to sewers. This means that an initial dose assessment of permitted disposal limits to sewers by ‘small users’ may need to be undertaken if the sludge is incinerated.

In order to assess doses arising from sewage sludge incineration, the annual activity in the incinerator sludge feedstock for each radionuclide must be calculated. This will be based on the annual activity discharged to the sewer (such as a proposed permit limit). The amount in the sludge to be incinerated is then calculated using radionuclide-specific partitioning and decay factors (Q_{slu}), which is the proportion of the activity discharged to sewers which remains in the sludge incinerator feedstock.

Partitioning factors during sewage treatment are radionuclide dependent and are shown in Table G.5 of Appendix G. The activity of each radionuclide will decrease due to any radioactive decay which occurs before the sludge is incinerated and discharged to the atmosphere. This reduction can be significant for radionuclides with a short half life. Prior to calculating doses from incineration, decay to the point of incineration must be considered by applying a decay constant which is specific to the radionuclide being assessed, and the average time from discharge to incineration, equivalent to the sludge residence time at the sewage treatment works. For initial assessment purposes for incineration of sludge, this has been determined as 4 days (96 hours) [H.1]. This is likely to represent the shortest time and assumes sludge is extracted straight after dewatering. Radioactive decay will significantly reduce or remove the presence of short lived radionuclides, such as technetium-99m.

The assessment here combines partitioning to sludge at the works and radioactive decay. The resulting partitioning and decay factors (Q_{slu}) are shown in Table H.3 and were calculated as follows:

$$Q_{slu} = F_{slu}\, e^{-\lambda t}$$

Q_{slu}	is partitioning and decay factor (unitless)
F_{slu}	is fraction of activity in sewage transferred to sludge (see Table G.5)

λ is decay contant (/h)
t is residency time of sludge before incineration (h) (96 hours)

For incineration assessment of sludge the partitioning and decay factors for each radionuclide are used with annual discharge information to sewer in the IRAT2 Releases to Sewer spreadsheet tool. An outcome of this are values representing the annual amount of radionuclides (originally discharged to sewer) that are exported in sludge for incineration (taking into account partitioning at the works and radioactive decay).

These values (annual amount of radionuclides exported in sludge for incineration) can be used as incinerator feedstock source term in the IRAT2 Releases to Air spreadsheet tool. This is a manual copy of data from the IRAT2 Releases to Sewer spreadsheet tool into the appropriate part of the IRAT2 Releases to Air spreadsheet tool.

The appropriate incinerator partition factors described in Section H.4, are then combined with the atmospheric dispersion parameters and adjustments for stack height (see Appendix D). The resulting doses to local residents and dose rates to wildlife can be calculated.

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Table H.1. Partitioning factors for bottom ash, air pollution control residue and flue gas for radionuclides in a dry gas cleaned incinerator

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Reference	Derivation
Tritium		0	0	1	McDonnell et al 1997 [H.2], USEPA 1991 [H.3]	Tritium follows mass balance of water.
Carbon		0.01	0	0.99	Belevi and Moench 2000 [H.4], Brunner and Moench 1986 [H.5], DoE 1991 [H.6], Kyle and Bellinger 1988 [H.7], McDonnell et al 1997 [H.2], McDonnell 2008 [H.8], USEPA 1991 [H.3]	Average of 4 values in bottom ash 1%, rest to flue.
Fluorine		0.5	0.4	0.1	Belevi and Moench 2000 [H.4], Brunner and Moench 1986 [H.5], Cetin et al 2004 [H.9]	Average of 4 values for bottom ash 53.1%, air pollution control residue 39.9% and flue gas 9.25%.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Reference	Derivation
Sodium		0.9	0.099	0.001	Belevi and Moench 2000 [H.4], Kyle and Bellinger 1988 [H.7], Pedersen et al 2009 [H.10].	Average of 3 values for bottom ash and air pollution control residue. Minimum value for flue gas.
Aluminium		0.89	0.109	0.001	Belevi and Moench 2000 [H.4], Jung et al 2004 [H.11], Kuo et al 2007 [H.12].	Average of 3 values for bottom ash and air pollution control residue. Minimum value for flue gas.
Phosphorus		0.8	0.1	0.1	Belevi and Moench 2000 [H.4], DoE 1991 [H.6], Kyle and Bellinger 1998 [H.7], McDonnell et al 1997 [H.2], McDonnell 2008 [H.8].	Average of 4 values for bottom ash 83%. Average of 2 values for air pollution control residue 12%. 'Some in flue'.
Sulphur		0.3	0.5	0.2	Belevi and Moench 2000 [H.4], Brunner and Moench 1986 [H.5], Kyle and Bellinger 1998	Average of 5 values for bottom ash 38%, 3 values for air pollution

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Reference	Derivation
					[H.7], McDonnell et al 1997 [H.2], Pedersen et al 2009 [H.10].	control residue 48%, 2 values for flue 27% - equals more than one so rounded down.
Chlorine		0.35	0.35	0.3	Belevi and Moench 2000 [H.4], Brunner and Moench 1986 [H.5], Cetin et al 2004 [H.9], Pedersen et al 2009 [H.10].	Average of 4 values for each component. Variable measured data.
Calcium		0.9	0.099	0.001	Belevi and Moench 2000 [H.4], Kyle and Bellinger 1988 [H.7]	Average of 3 values for bottom ash and 2 values for air pollution control residue. Flue gas <0.001, so minimum used.
Vanadium		0.94	0	0.06	Kyle and Bellinger 1988 [H.7]	Average of 2 values in bottom ash. Assume rest in flue gas.
Chromium		0.9	0.095	0.005	Abanades et al 2002 [H.13], Barton et al 1990 [H.14], Belevi	13 data sets, good range agreement.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Reference	Derivation
					and Moench 2000 [H.4], Binner at al 1997 [H.15], Corella and Toledo 2000 [H.16], DoE 1991 [H.6], Jung et al 2004 [H.11], Kuo et al 1999 [H.17] and 2007 [H.12], Kyle and Bellinger 1988 [H.7], McDonnell 2008 [H.8], Wang et al 1999 [H.18], Zhao et al 2008 [H.19].	Bottom ash 83-98%; air pollution control residue 5-15%, flue gas <1%.
Manganese		0.8	0.199	0.001	Bakoglu et al 2003 [H.20], Belevi and Moench 2000 [H.4], Kyle and Bellinger 1988 [H.7].	Average of 3 values in bottom ash 84%, minimum in flue gas, mass balance in air pollution control residue.
Iron		0.95	0.049	0.001	Belevi and Moench 2000 [H.4], Brunner and Moench 1986 [H.5], Jung et al 2004 [H.11], Kuo et al 2007 [H.12], Kyle and	Average of 6 values in bottom ash 94.3%, minimum in flue gas, mass balance for air pollution control residue.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Reference	Derivation
					Bellinger 1988 [H.7], USEPA 1991 [H.3].	
Cobalt		0.7	0.299	0.001	Abanades et al 2002 [H.13], Bakoglu et al 2003 [H.20], Belevi and Moench 2000 [H.4], Kyle and Bellinger 1988 [H.7], USEPA 1991 [H.3], Yang et al 2002 [H.21].	Average of 3 values for bottom ash 70%, average of 3 low values in flue gas so 0.1% minimum, air pollution control residue has variable data so mass balance used.
Nickel		0.7	0.299	0.001	Abanades et al 2002 [H.13], Bakaglu et al 2003 [H.20], Belevi and Moench 2000 [H.4], Binner et al 1997 [H.15], Corella and Toledo 2000 [H.16], Kuo et al 1999 [H.17], Nasserzadeh et al 1995 [H.22], USEPA 1991 [H.3], Zhao et al 2008 [H.19]	Average of 4 values in bottom ash 70.7%, minimum in flue gas and mass balance in air pollution control residue.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Reference	Derivation
Copper		0.95	0.04	0.01	Abanades et al 2002 [H.13], Bakoglu et al 2003 [H.20], Barton et al 1990 [H.14], Belevi and Moench 2000 [H.4], Binner et al 1997 [H.15], Brunner and Moench 1986 [H.5], Corella and Toledo 2000 [H.16], Jung et al 2004 [H.11], Kuo et al 2007 [H.12], Kyle and Bellinger 1988 [H.7], Nasserzadeh et al 1995 [H.22], Verhulst et al 1996 [H.23], Wang et al 1999 [H.18], Waterland et al 1991 [H.24].	Many data 90-100% in bottom ash, minimum to flue and mass balance to air pollution control residue.
Zinc		0.6	0.38	0.02	Abanades et al 2002 [H.13] Bakoglu et al 2003 [H.20], Belevi and Moench 2000 [H.4], Binner et al 1997 [H.15], Brunner and Moench 1986 [H.5], Corella and Toledo 2000 [H.16], Jung et al 2004 [H.11],	Average of 10 values for bottom ash 61%, 5 values for flue gas 2%, and mass balance for air pollution control residue.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Reference	Derivation
					Kuo et al 2007 [H.12], Kyle and Bellinger 1988 [H.7], Nasserzadeh et al 1995 [H.22], Pedersen et al 2009 [H.10], Verhulst et al 1996 [H.23], Wang et al 1999 [H.18], Yang et al 1998 [H.25], Zhao et al 2008 [H.19].	
Gallium		0.63	0.369	0.001	Kyle and Bellinger 1988 [H.7]	One value for 63% in bottom ash. Assume rest in air pollution control residue, minimum in flue gas.
Selenium		0.77	0.229	0.001	Jung et al 2004 [H.11]	One value for 77% in bottom ash. Assume rest in air pollution control residue, minimum in flue gas.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Reference	Derivation
Bromine		0.5	0.499	0.001	Belevi and Moench 2000 [H.4], Cetin et al 2004 [H.9]	Average of 2 values in bottom ash 52%. Variable. Minimum in flue gas, mass balance in air pollution control residue.
Rubidium		0.7	0	0.3	Kyle and Bellinger 1988 [H.7]	Average of 2 values in bottom ash 72%. Assume rest in flue gas.
Strontium		0.8	0.19	0.01	Barton et al 1990 [H.14], Kyle and Belinger 1988 [H.7], USEPA 1991 [H.3], Yang et al 1998 [H.25]	Two values of 80% in bottom ash, one value of <1% in flue gas, mass balance for air pollution control residue.
Yttrium	Promethium	0.93	0	0.07	No data found. Promethium used as surrogate.	Promethium used as yttrium is above lanthanides in periodic table.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Reference	Derivation
Zirconium		0.94	0	0.06	Kyle and Bellinger 1988 [H.7]	Average of 2 values in bottom ash 94%. Assume rest in flue gas.
Niobium	Vanadium	0.94	0	0.06	No data found. Vanadium used as surrogate.	Vanadium used as adjacent to niobium in periodic table.
Molybdenum		0.9	0.09	0.01	Belevi and Moench 2000 [H.4], Kyle and Bellinger 1988 [H.7]	Average of 4 values to bottom ash 90.5%, 2 values to air pollution control residues 9.2%, mass balance used for 1% to flue.
Technetium	Manganese	0.8	0.199	0.001	No data found. Manganese used as surrogate.	Manganese used as above technetium in periodic table.
Ruthenium		0.9	0.09	0.01	Kyle and Bellinger 1988 [H.7], USEPA 1991 [H.3].	One value of 90% in ash, 0.2 to 1% in flue gas, 1% chosen. Air

Element	**Surrogate element**	**Partition factor – Bottom ash (for reference)**	**Partition factor – Air pollution control residue (for reference)**	**Partition factor – Flue gas^ (pf_{flue}) (General Assessment)**	**Reference**	**Derivation**
						pollution control residue mass balance.
Silver		0.4	0.5	0.1	Kyle and Bellinger 1988 [H.7], Zhao et al 2008 [H.19]	Two references with different partitioning. Most in bottom ash and air pollution control residues. Judgement used.
Indium		0.36	0.639	0.001	Kyle and Bellinger 1988 [H.7]	One value in bottom ash 35.7%, Minimum in flue gas, mass balance for air pollution control residue.
Antimony		0.3	0.69	0.01	Belevi and Moench 2000 [H.4], Jung et al 2004 [H.11], USEPA 1991 [H.3]	Average of 3 values for bottom ash and air pollution control residue. <1% in flue gas.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Reference	Derivation
Iodine		0.01	0.98	0.01	Alexander and Doty 1983 [H.26], McDonnell et al 1997 [H.2], Kyle and Bellinger 1988 [H.7], USEPA 1991 [H.3], Cetin et al 2004 [H.9].	Variable data. Little in bottom ash or flue gas in most references. 1% for both from McDonnell et al 1997 [H.2].
Caesium		0.8	0.19	0.01	Kyle and Bellinger 1988 [H.7], USEPA 1991 [H.3], Yang et al 2002 [H.21].	81% average of 5 variable data in bottom ash, 80% used. Minimum value in flue gas. Mass balance for air pollution control residue.
Barium		0.85	0.14	0.01	Barton et al 1990 [H.14], Belevi and Moench 2000 [H.4], Waterland et al 1991 [H.24], Zhao et al 2008 [H.19]	Average of 3 values in bottom ash 84%, 0 to <5% in flue gas 1% chosen, mass balance in air pollution control residue.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Reference	Derivation
Lanthanum	Promethium	0.93	0	0.07	No data found. Promethium used as surrogate.	Promethium used as both elements are lanthanides.
Cerium	Promethium	0.93	0	0.07	No data found. Promethium used as surrogate.	Promethium used as both elements are lanthanides.
Promethium		0.93	0	0.07	Kyle and Bellinger 1988 [H.7]	Average of 2 values in bottom ash. Assume rest in flue gas.
Samarium	Promethium	0.93	0	0.07	No data found. Promethium used as surrogate.	Promethium used as both elements are lanthanides.
Europium	Promethium	0.93	0	0.07	No data found. Promethium used as surrogate.	Promethium used as both elements are lanthanides.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Reference	Derivation
Erbium	Promethium	0.93	0	0.07	No data found. Promethium used as surrogate.	Promethium used as both elements are lanthanides.
Lutetium	Promethium	0.93	0	0.07	No data found. Promethium used as surrogate.	Promethium used as both elements are lanthanides.
Rhenium	Manganese	0.8	0.199	0.001	No data found. Manganese used as surrogate.	Manganese used as in same group as rhenium in periodic table.
Gold		0.76	0	0.24	Kyle and Bellinger 1988 [H.7]	Average of 2 values in bottom ash. Assume rest in flue gas.
Mercury		0.01	0.4	0.59	Abanades et al 2002 [H.13], Belevi and Moench 2000 [H.4], Brunner and Moench 1986 [H.5], Kyle and Bellinger 1988 [H.7], Nassezadeh et al 1995	Average of 4 values in bottom ash 1%, air pollution control residues 40%, flue gas ~60% mass balance.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Reference	Derivation
					[H.22], Verhulst et al 1996 [H.23].	
Thallium		0.02	0	0.98	Kyle and Bellinger 1988 [H.7]	Average of 3 values in bottom ash 1.87%. Assume rest in flue gas.
Lead		0.55	0.44	0.01	Abanades et al 2002 [H.13], Bakoglu et al 2003 [H.20], Barton et al 1990 [H.14], Belevi and Moench 2000 [H.4], Binner et al 1997 [H.15], Brunner and Moench 1986 [H.5], Corella and Toledo 2000 [H.16], Durlak et al 1997 [H.27], Jung et al 2004 [H.11], Kauppinen and Pakkanen 1990 [H.28], Kuo et al 2007 [H.12], Nasserzadeh et al 1995 [H.22], Pedersen et al 2009 [H.10], Rio et al 2007 [H.29], USEPA 1991 [H.3], Waterland et al 1991 [H.24],	Average of 10 values for bottom ash 54%, 7 values for flue gas 1.4%, mass balance for air pollution control residue.

Element	**Surrogate element**	**Partition factor – Bottom ash (for reference)**	**Partition factor – Air pollution control residue (for reference)**	**Partition factor – Flue gas^ (pf_{flue}) (General Assessment)**	**Reference**	**Derivation**
					Yang et al 1998 [H.25], Zhao et al 2008 [H.19].	
Bismuth		0.4	0.59	0.01	Jung et al 2004 [H.11], Waterland et al 1991 [H.24], Yang et al 1998 [H.25].	Average of 3 data sets, 40% bottom ash, 60% air pollution control residues, <1% flue gas.
Polonium	Selenium	0.77	0.229	0.001	No data found. Selenium used as surrogate.	Selenium used as same group as polonium in periodic table.
Astatine	Iodine	0.01	0.98	0.01	No data found. Iodine used as surrogate.	Iodine used as in the same group as astatine in periodic table.
Radium	Barium	0.85	0.14	0.01	No data found. Barium used as surrogate.	Barium used as above radium in periodic table.
Actinium	Uranium	0.99	0.009	0.001	No data found. Uranium used as surrogate.	Uranium used as both elements are actinides.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Reference	Derivation
Thorium	Uranium	0.99	0.009	0.001	No data found. Uranium used as surrogate	Uranium used as both elements are actinides.
Uranium		0.99	0.009	0.001	Yang et al 2002 [H.21], USEPA 1991 [H.3]	No measured data. 'Most alpha radionuclides partition to bottom ash'. 99% in bottom ash as judgement. Flue gas as minimum value. Air pollution control residue as mass balance.
Neptunium	Uranium	0.99	0.009	0.001	No data found. Uranium used as surrogate.	Uranium used as both elements are actinides.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Reference	Derivation
Plutonium		0.99	0.009	0.001	Yang et al 2002 [H.21], USEPA 1991 [H.3]	No measured data. 'Most alpha radionuclides partition to bottom ash'. 99% in bottom ash as judgement. Flue gas as minimum value. Air pollution control residue as mass balance.
Americium		0.99	0.009	0.001	Yang et al 2002 [H.21], USEPA 1991 [H.3]	No measured data. 'Most alpha radionuclides partition to bottom ash'. 99% in bottom ash as judgement. Flue gas as minimum value. Air pollution control residue as mass balance.
Curium		0.99	0.009	0.001	Yang et al 2002 [H.21], USEPA 1991 [H.3]	No measured data. 'Most alpha radionuclides partition to

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Reference	Derivation
						bottom ash'. 99% in bottom ash as judgement. Flue gas as minimum value. Air pollution control residue as mass balance.

^Where flue gas value is zero or no data from the literature, a value of 0.001 used rather than zero. For other alpha-emitting radionuclides and other beta/gamma-emitting radionuclides, for initial assessment assume a partition factor of 1 to flue gas.

Table H.2. Partitioning factors for bottom ash, air pollution control residue and flue gas for radionuclides in a wet gas cleaned incinerator

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
Tritium		0	0	0.001	0.999	McDonnell et al 1997 [H.2], USEPA 1991 [H.3]	Tritium follows mass balance of water
Carbon		0.01	0	0.98	0.01	Belevi and Moench 2000 [H.4], Brunner and Moench 1986 [H.5], DoE 1991 [H.6], Kyle and Bellinger 1988 [H.7], McDonnell et al 1997 [H.2], McDonnell 2008 [H.8], USEPA 1991 [H.3]	Average of 4 values in bottom ash 1%, rest to flue, several references.
Fluorine		0.5	0.4	0.1	No data	Belevi and Moench 2000 [H.4], Brunner and Moench 1986	Average of 4 values for bottom ash 53.1%, air pollution control residue

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
						[H.5] Cetin et al 2004 [H.9]	39.9% and flue gas 9.25%
Sodium		0.9	0.099	0.001	No data	Belevi and Moench, 2000 [H.4], Kyle and Bellinger 1988 [H.7], Pedersen et al 2009 [H.10].	Average of 3 values for bottom ash and air pollution control residue and minimum value for flue gas.
Aluminium		0.89	0.109	0.001	No data	Belevi and Moench 2000 [H.4], Jung et al 2004 [H.11], Kuo et al 2007 [H.12].	Average of 3 values for bottom ash and air pollution control residue and minimum value for flue gas.
Phosphorus		0.8	0.09	0.1	0.01	Belevi and Moench 2000 [H.4], DoE 1991 [H.6], Kyle and Bellinger 1998 [H.7],	Average of 4 values for bottom ash 83%. Average of 2 values for air pollution

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
						McDonnell et al 1997 [H.2], McDonnell 2008 [H.8].	control residue 12%. 'Some in flue'.
Sulphur		0.3	0.49	0.2	0.01	Belevi and Moench 2000 [H.4], Brunner and Moench 1986 [H.5], Kyle and Bellinger 1998 [H.7], McDonnell et al 1997 [H.2], Pedersen 2009 [H.10].	Average of 5 values for bottom ash 38%, 3 values for air pollution control residue 48%, 2 values for flue 27% - equals more than one so rounded down.
Chlorine		0.35	0.35	0.3	No data	Belevi and Moench 2000 [H.4], Brunner and Moench 1986 [H.5], Cetin et al 2004 [H.9], Pedersen et al 2009 [H.10].	Average of 4 values for each component. Variable measured data.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
Calcium		0.9	0.099	0.001	No data	Belevi and Moench 2000 [H.4], Kyle and Bellinger 1988 [H.7]	Average of 3 values for bottom ash and 2 values for air pollution control residue. Flue gas <0.001, so minimum used.
Vanadium		0.94	0	0.06	No data	Kyle and Bellinger 1988 [H.7]	Average of 2 values in bottom ash. Assume rest in flue gas.
Chromium		0.9	0.095	0.005	No data	Abanades et al 2002 [H.13], Barton et al 1990 [H.14], Belevi and Moench 2000 [H.4], Binner at al 1997 [H.15], Corella and Toledo 2000 [H.16], DoE 1991 [H.6], Jung	13 data sets, good range agreement. Bottom ash 83-98%, air pollution control residue 5-15%, flue gas <1%.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
						et al 2004 [H.11], Kuo et al 1999 [H.17] and 2007 [H.12], Kyle and Bellinger 1988 [H.7], McDonnell 2008 [H.8], Wang et al 1999 [H.18], Zhao et al 2008 [H.19].	
Manganese		0.8	0.199	0.001	No data	Bakoglu et al 2003 [H.20], Belevi and Moench 2000 [H.4], Kyle and Bellinger 1988 [H.7].	Average of 3 values in bottom ash 84%, minimum in flue gas, mass balance in air pollution control residue.
Iron		0.95	0.049	0.001	No data	Belevi and Moench 2000 [H.4], Brunner and Moench 1986 [H.5], Jung et al 2004 [H.11], Kuo et al 2007 [H.12], Kyle and	Average of 6 values in bottom ash 94.3%, minimum in flue gas, mass balance for air

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
						Bellinger 1988 [H.7], USEPA 1991 [H.3].	pollution control residue.
Cobalt		0.7	0.298	0.001	0.001	Abanades et al 2002 [H.13], Bakoglu et al 2003 [H.20], Belevi and Moench 2000 [H.4], Kyle and Bellinger 1988 [H.7], USEPA 1991 [H.3], Yang et al 2002 [H.21].	Average of 3 values for bottom ash 70%, average of 3 low values in flue gas so 0.1% minimum, air pollution control residues variable data so mass balance used.
Nickel		0.7	0.299	0.001	No data	Abanades et al 2002 [H.13], Bakaglu et al 2003 [H.20], Belevi and Moench 2000 [H.4], Binner et al 1997 [H.15], Corella and Toledo 2000 [H.16], Kuo et al 1999 [H.17],	Average of 4 values in bottom ash 70.7%, minimum in flue gas and mass balance in air pollution control residues.

Element	**Surrogate element**	**Partition factor – Bottom ash (for reference)**	**Partition factor – Air pollution control residue (for reference)**	**Partition factor – Flue gas^ (pf_{flue}) (General Assessment)**	**Partition factor – Process water effluent* (for reference)**	**Reference**	**Derivation**
						Nasserzadeh et al 1995 [H.22], USEPA 1991 [H.3], Zhao et al 2008 [H.19].	
Copper		0.95	0.04	0.01	No data	Abanades et al 2002 [H.13], Bakoglu et al 2003 [H.20], Barton et al 1990 [H.14], Belevi and Moench 2000 [H.4], Binner et al 1997 [H.15], Brunner and Moench 1986 [H.5], Corella and Toledo 2000 [H.16], Jung et al 2004 [H.11], Kuo et al 2007 [H.12], Kyle and Bellinger 1988 [H.7], Nasserzadeh et al 1995 [H.22], Verhulst et al 1996 [H.23], Wang et al 1999	Many data 90-100% in bottom ash, minimum to flue and mass balance to air pollution control residue.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
						[H.18], Waterland et al 1991 [H.24].	
Zinc		0.6	0.38	0.02	No data	Abanades et al 2002 [H.13], Bakoglu et al 2003 [H.20], Belevi and Moench 2000 [H.4], Binner et al 1997 [H.15], Brunner and Moench 1986 [H.5], Corella and Toledo 2000 [H.16], Jung et al 2004 [H.11], Kuo et al 2007 [H.12], Kyle and Bellinger 1988 [H.7], Nasserzadeh et al 1995 [H.22], Pedersen et al 2009 [H.10], Verhulst et al 1996 [H.23], Wang et al 1999 [H.18], Yang et al	Average of 10 values for bottom ash 61%, 5 values for flue gas 2% and mass balance for air pollution control residue.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
						1998 [H.25], Zhao et al 2008 [H.19].	
Gallium		0.63	0.369	0.001	No data	Kyle and Bellinger 1988 [H.7]	One value for 63% in ash. Assume rest in air pollution control residue, minimum in flue gas.
Selenium		0.77	0.229	0.001	No data	Jung et al 2004 [H.11]	One value for 77% in bottom ash. Assume rest in air pollution control residue, minimum in flue gas.
Bromine		0.5	0.499	0.001	No data	Belevi and Moench 2000 [H.4], Cetin et al 2004 [H.9]	Average of 2 values in bottom ash 52%. Variable. Minimum in flue gas, mass balance in air

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
							pollution control residue.
Rubidium		0.7	0	0.3	No data	Kyle and Bellinger 1988 [H.7]	Average of 2 values in bottom ash 72%. Assume rest in flue gas.
Strontium		0.8	0.18	0.01	0.01	Barton et al 1990 [H.14], Kyle and Bellinger 1988 [H.7], USEPA 1991 [H.3], Yang et al 1998 [H.25]	Two values of 80% in bottom ash, one value of <1% in flue gas, mass balance for air pollution control residue.
Yttrium	Promethium	0.93	0	0.07	No data	No data found. Promethium used as surrogate.	Promethium used as yttrium is above lanthanides in periodic table.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
Zirconium		0.94	0	0.06	No data	Kyle and Bellinger 1988 [H.7]	Average of 2 values in bottom ash 94%. Assume rest in flue gas.
Niobium	Vanadium	0.94	0	0.06	No data	No data found. Vanadium used as surrogate.	Vanadium used as adjacent to niobium in periodic table.
Molybdenum		0.9	0.09	0.01	No data	Belevi and Moench 2000 [H.4], Kyle and Bellinger 1988 [H.7].	Average of 4 values to bottom ash 90.5%, 2 values to air pollution control residues 9.2 %. Mass balance used for 1% to flue.
Technetium	Manganese	0.8	0.199	0.001	No data	No data found. Manganese used as surrogate.	Manganese used as above technetium in periodic table.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
Ruthenium		0.9	0.09	0.01	No data	Kyle and Bellinger 1988 [H.7], USEPA 1991 [H.3].	One value of 90% in bottom ash, 0.2 to 1% in flue gas, 1% chosen. Air pollution control residue mass balance.
Silver		0.4	0.5	0.1	No data	Kyle and Bellinger 1988 [H.7], Zhao et al 2008 [H.19]	Two references with different partitioning. Most in bottom ash and air pollution control residues. Judgement used.
Indium		0.36	0.639	0.001	No data	Kyle and Bellinger 1988 [H.7]	One value in bottom ash 35.7%. Minimum in flue gas, mass balance for air pollution control residue.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
Antimony		0.3	0.69	0.01	No data	Belevi and Moench 2000 [H.4], Jung et al 2004 [H.11], USEPA 1991 [H.3]	Average of 3 values for bottom ash and air pollution control residue. <1% in flue gas.
Iodine		0.01	0.93	0.01	0.05	Alexander and Doty 1983 [H.26], McDonnell et al 1997 [H.2], Kyle and Bellinger 1988 [H.7], USEPA 1991 [H.3], Cetin et al 2004 [H.9].	Variable data. Little in bottom ash or flue gas in most references. 1% for both from McDonnell et al 1997 [H.2].
Caesium		0.8	0.09	0.01	0.1	Kyle and Bellinger 1988 [H.7], USEPA 1991 [H.3], Yang et al 2002 [H.21].	81% average of 5 variable data in bottom ash, 80% used. Minimum value in flue gas. Mass balance for air

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
							pollution control residue.
Barium		0.85	0.14	0.01	No data	Barton et al 1990 [H.14], Belevi and Moench 2000 [H.4], Waterland et al 1991 [H.24], Zhao et al 2008 [H.19]	Average of 3 values in bottom ash 84%, 0 to <5% in flue gas 1% chosen, mass balance in air pollution control residue.
Lanthanum	Promethium	0.93	0	0.07	No data	No data found. Promethium used as surrogate.	Promethium used both elements are lanthanides.
Cerium	Promethium	0.93	0	0.07	No data	No data found. Promethium used as surrogate.	Promethium used both elements are lanthanides.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
Promethium		0.93	0	0.07	No data	Kyle and Bellinger 1988 [H.7]	Average of 2 values in bottom ash. Assume rest in flue gas.
Samarium	Promethium	0.93	0	0.07	No data	No data found. Promethium used as surrogate.	Promethium used both elements are lanthanides.
Europium	Promethium	0.93	0	0.07	No data	No data found. Promethium used as surrogate.	Promethium used both elements are lanthanides.
Erbium	Promethium	0.93	0	0.07	No data	No data found. Promethium used as surrogate.	Promethium used both elements are lanthanides.
Lutetium	Promethium	0.93	0	0.07	No data	No data found. Promethium used as surrogate.	Promethium used both elements are lanthanides.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
Rhenium	Manganese	0.8	0.199	0.001	No data	No data found. Manganese used as surrogate.	Manganese used as in same group as rhenium in periodic table.
Gold		0.76	0	0.24	No data	Kyle and Bellinger 1988 [H.7]	Average of 2 values in bottom ash. Assume rest in flue gas.
Mercury		0.01	0.3999	0.59	0.0001	Abanades et al 2002 [H.13], Belevi and Moench 2000 [H.4], Brunner and Moench 1986 [H.5], Kyle and Bellinger, 1988 [H.7], Nassezadeh et al 1995 [H.22], Verhulst et al 1996 [H.23].	Average of 4 values in bottom ash 1%, air pollution control residues 40%, flue gas ~60% mass balance.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
Thallium		0.02	0	0.98	No data	Kyle and Bellinger 1988 [H.7]	Average of 3 values in bottom ash 1.87%. Assume rest in flue gas.
Lead		0.55	0.44	0.01	No data	Abanades et al 2002 [H.13], Bakoglu et al 2003 [H.20] Barton et al 1990 [H.14], Belevi and Moench 2000 [H.4], Binner et al 1997 [H.15], Brunner and Moench 1986 [H.5], Corella and Toledo 2000 [H.16], Durlak et al 1997 [H.27], Jung et al 2004 [H.11], Kauppinen and Pakkanen 1990 [H.28], Kuo et al 2007 [H.12], Nasserzadeh et al 1995 [H.22], Pedersen	Average of 10 values for bottom ash 54%, 7 values for flue gas 1.4%, mass balance for air pollution control residue.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
						et al 2009 [H.10], Rio et al 2007 [H.29], USEPA 1991 [H.3], Waterland et al 1991 [H.24], Yang et al 1998 [H.25], Zhao et al 2008 [H.19]	
Bismuth		0.4	0.59	0.01	No data	Jung et al 2004 [H.11], Waterland et al 1991 [H.24], Yang et al 1998 [H.25]	Average of 3 data sets, 40% bottom ash, 60% air pollution control residues, <1% flue gas.
Polonium	Selenium	0.77	0.229	0.001	No data	No data found. Selenium used as surrogate.	Selenium used in the same group as polonium in periodic table.

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
Astatine	Iodine	0.01	0.98	0.01	No data	No data found. Iodine used as surrogate.	Iodine used as in the same group as astatine in periodic table.
Radium	Barium	0.85	0.14	0.01	No data	No data found. Barium used as surrogate.	Barium used as same group as radium in periodic table.
Actinium	Uranium	0.99	0.009	0.001	No data	No data found. Uranium used as surrogate.	Uranium used as both elements are actinides.
Thorium	Uranium	0.99	0.0089	0.001	0.0001	No data found. Uranium used as surrogate.	Uranium used as both elements are actinides.
Uranium		0.99	0.0089	0.001	0.0001	Yang et al 2002 [H.21], USEPA 1991 [H.3]	No measured data. 'Most alpha radionuclides partition to bottom

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
							ash'. 99% in bottom ash as judgement. Flue gas as minimum value. Air pollution control residue as mass balance.
Neptunium	Uranium	0.99	0.009	0.001	No data	No data found. Uranium used as surrogate.	Uranium used as both elements are actinides.
Plutonium		0.99	0.009	0.001	No data	Yang et al 2002 [H.21], USEPA 1991 [H.3]	No measured data. 'Most alpha radionuclides partition to bottom ash'. 99% in bottom ash as judgement. Flue gas as minimum value. Air pollution control

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
							residue as mass balance.
Americium		0.99	0.0089	0.001	0.0001	Yang et al 2002 [H.21], USEPA 1991 [H.3]	No measured data. 'Most alpha radionuclides partition to bottom ash'. 99% in bottom ash as judgement. Flue gas as minimum value. Air pollution control residue as mass balance.
Curium		0.99	0.009	0.001	No data	Yang et al 2002 [H.21], USEPA 1991 [H.3]	No measured data. 'Most alpha radionuclides

Element	Surrogate element	Partition factor – Bottom ash (for reference)	Partition factor – Air pollution control residue (for reference)	Partition factor – Flue gas^ (pf_{flue}) (General Assessment)	Partition factor – Process water effluent* (for reference)	Reference	Derivation
							partition to bottom ash'. 99% in bottom ash as judgement. Flue gas as minimum value. Air pollution control residue as mass balance.

^Where flue gas value is zero or no data from the literature, a value of 0.001 used rather than zero. For other alpha-emitting radionuclides and other beta/gamma-emitting radionuclides, for initial assessment assume a partition factor of 1 to flue gas.
*Process water discharge value is from operator information.

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Table H.3. Partitioning and decay factor for sludge prior to incineration

Radionuclide*	Partitioning and decay factor (Q_{slu})
H-3	1.5E-01
H-3 organic	1.5E-01
C-14	1.5E-01
Na-22	1.0E-01
Na-24	1.2E-03
P-32	6.6E-01
P-33	7.2E-01
S-35	9.7E-02
Cl-36	1.0E-01
Ca-45	3.9E-01
Ca-47	2.2E-01
V-48	7.6E-01
Cr-51	8.1E-01
Mn-52	5.8E-01
Mn-54	9.4E-01
Fe-55	9.0E-01
Fe-59	8.5E-01
Co-56	8.7E-01
Co-57	8.9E-01
Co-58	8.7E-01
Co-60	9.0E-01
Ni-63	9.0E-01
Cu-61	2.5E-09
Cu-64	5.0E-03

Zn-62	7.6E-05
Zn-65	9.9E-02
Ga-67	3.8E-01
Se-75	4.9E-01
Br-76	1.6E-03
Br-77	3.0E-02
Br-82	1.5E-02
Rb-81	4.9E-08
Rb-83	9.7E-02
Sr-83	5.1E-02
Sr-85	3.8E-01
Sr-89	3.8E-01
Sr-90	4.0E-01
Y-90	3.4E-01
Zr-89	2.1E-01
Zr-95	4.8E-01
Nb-95	4.6E-01
Mo-99	3.6E-02
Tc-99	1.0E-01
Tc-99m	1.5E-06
Ru-103	9.3E-02
Ru-106	9.9E-02
Ag-110m	8.9E-01
In-111	3.3E-01
Sb-125	1.0E-01
I-123	1.3E-03

I-124	1.0E-01
I-125	1.9E-01
I-129	2.0E-01
I-131	1.4E-01
I-133	8.2E-03
I-135	8.5E-06
Cs-134	1.0E-01
Cs-136	8.1E-02
Cs-137	1.0E-01
Ba-140	3.2E-01
La-140	1.3E-01
Ce-141	4.6E-01
Ce-144	5.0E-01
Pm-147	5.0E-01
Sm-153	1.2E-01
Eu-152	5.0E-01
Eu-154	5.0E-01
Eu-155	5.0E-01
Er-169	3.7E-01
Lu-177	3.3E-01
Re-188	2.0E-03
Au-198	1.8E-01
Tl-201	2.0E-01
Pb-210	9.0E-01
Pb-212	1.7E-03
Po-210	8.8E-01

At-211	2.0E-05
Ra-223	3.9E-01
Ra-226	5.0E-01
Ac-225	6.8E-01
Th-227	7.8E-01
Th-230	9.0E-01
Th-232	9.0E-01
Th-234	8.3E-01
U-234	1.0E-01
U-235	1.0E-01
U-238	1.0E-01
Np-237	1.0E-01
Pu-238	1.0E-01
Pu-239	1.0E-01
Pu-240	1.0E-01
Pu-241	1.0E-01
Pu-242	1.0E-01
Am-241	5.0E-01
Am-242	7.8E-03
Am-243	5.0E-01
Cm-242	8.8E-01
Cm-243	9.0E-01
Cm-244	9.0E-01

* not considered for radionuclides with half-lives of less than 3 hours

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