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Initial radiological assessment methodology – part 2 methods and input data

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Steve Killeen

Head of Science

Executive summary

The Radioactive Substances Act 1993 (RSA 93) 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. In particular, RSA 93 requires prior authorisation for the disposal or discharge of radioactive waste to the environment. The UK Environment Agencies are required to ensure that doses to critical groups of the public do not exceed specified dose constraints, as part of the process of authorising such disposals or discharges. An initial radiological assessment methodology has been developed to calculate doses from authorised releases in a simple, cautious (but not unrealistic) and consistent manner.

Two reports have been produced describing the initial assessment methodology. This report includes a review of methods and data, describes the proposed methodology in detail and lists all of the relevant input data, intermediate data and data sources. The other report ('Initial Radiological Assessment Methodology – Part 1 User Report') presents the data needed to carry out initial assessments, guidance on how to apply the data, and a number of example case studies.

The methodology is based on dose per unit release (DPUR) data, which are combined with authorisation limits to calculate doses to members of the public. The following release scenarios are specified in discharge authorisations for various sites and were therefore included in the methodology: release to air; release to estuary/coastal water; release to a river, and, release to public sewer. Consequent upon such releases, there are a number of pathways that lead to the exposure of members of the public.

A short review of methods and data sources was carried out. Although numerous biosphere models are available, none of them fulfilled the complete requirements of this study. In particular, the set of radionuclides to be addressed was beyond the scope of existing models. However, for the purposes of generic analyses, the biosphere calculations required can be expressed through simple analytic equations. Therefore, rather than using existing models as they stand, either the datasets underpinning those models were extracted or the models were used to compute input data for use in simple analytical calculations. Where data gaps were found, in particular for environmental transfer data, it was deemed preferable to use the best input data available, rather than selecting a uniform set of data for all radionuclides. The advantage of this approach is that the calculations are based on the best available data for each radionuclide. In addition, as new and better data are published, they can easily be updated.

A comprehensive set of data has been compiled in this report to enable the calculation of DPUR factors for the four discharge scenarios, 100 radionuclides and seven candidate critical groups, including a total of 41 exposure pathways. Four age groups have been considered, including the fetus.

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1. Introduction

1.1 Background

Currently, organisations that have a requirement to discharge radioactive wastes to the environment must apply to the Environment Agency for a discharge authorisation under the Radioactive Substances Act 1993 (RSA 93). The Environment Agency is required to ensure that doses from discharges do not exceed the Euratom Basic Safety Standards (BSS) directive public dose limit of 1 mSv y^{-1} [1] and have regard for a maximum dose constraint of 0.3 mSv y^{-1} 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 authorisation is required to submit a radiological assessment of the impact of their discharges. The Euratom BSS 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 authorisations 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 of the small users have short half-lives and are often released at lower quantities, in comparison with radionuclides discharged by the nuclear industry. Effective doses are therefore often relatively small. Undertaking realistic assessments involves significant resources, which may not be appropriate when assessed doses are low or very low.

The Environment Agencies, in collaboration with the Food Standards Agency and the National Radiological Protection Board (NRPB, now Health Protection Agency), have 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 critical group doses for authorisation purposes is recommended, as shown in Figure 1. The first stage consists of a simple and cautious assessment of the critical group dose rate (initial radiological assessment). If the resulting effective dose rate is less than 0.02 mSv y^{-1} then no further assessment would be warranted for the purpose of authorising the discharge of radioactive waste to the environment. Further investigation using more realistic data should be undertaken when effective dose rates exceed 0.02 mSv y^{-1} [3], in particular if a regulatory decision is dependent on the outcome of the assessment.

The initial assessment needs to be simple, cautious (but not unrealistic), consistent and supported by the most appropriate data. This will provide a robust and acceptable screen to identify where further resource should be expended to look in more detail at the predicted doses (i.e. including detailed source and site assessment, short-term release assessment, collective dose assessment and variability and uncertainty assessments).

The Environment Agency has prepared a first version of an initial assessment system for making screening assessments [4]. This has been reviewed, further developed and updated by staff at Serco Assurance under contract to the Environment Agency.

Two reports have been produced describing the Initial Assessment Methodology. This report includes a review of methods and data, describes the proposed methodology in detail and lists all of the relevant input data, intermediate data and data sources. The second report (‘Initial Radiological Assessment Methodology – User Report’ [5]) presents the data needed to carry out initial assessments, guidance on how to apply the data, and a number of example case studies.

1.2 Objectives

The main requirements for any initial assessment methodology are:
- a minimum of required input data;
- a minimum of modelling effort;
- a robust methodology;
- consistent radionuclide-specific data.

The method employed currently by the majority of small users and Environment Agency staff to assess discharge authorisations is based on that developed by the NRPB in 1996 [6] and its recent replacement [7]. The approach is well focused on the needs of small users and by providing detailed equations for the assessment process enables realistic assessments to be made using site-specific data. However, it has a number of shortcomings, including the following: gaps in available data for some required radionuclides, doses to adults only are considered and not all relevant pathways and radionuclides are represented. In addition, the methodology has not been implemented consistently. Each user of the methodology has implemented it individually, which, in many cases, has led to considerable expenditure of effort to resolve resulting discrepancies.

The main objectives of this project can be summarised as follows:
1. Review the existing Environment Agency approach to initial assessments against other methodologies in use to ensure that it covers the most important release scenarios and that the list of radionuclides considered is sufficiently comprehensive.
2. Fill gaps in radionuclide and pathway data from information that has already been published.
3. Provide justification for one consistent and coherent set of data to be used.
4. Ensure that the method is quick and user friendly, so that it can be applied efficiently by non-experts.
5. Retain transparency of data used and sufficient flexibility of the methodology to ensure future adaptability.
6. Advertise and publish the agreed dataset and methodology to allow for maximum accessibility.

2 Methods

2.1 Review of available assessment methodologies

A detailed review of available assessment methodologies was carried out. The findings of the review are detailed in Appendix A.

In assessing the radiological impact of discharges of radionuclides, any methodology must give consideration to the scenarios for release, the pathways for transport through the environment and the modes of exposure of the receptor (humans). Thus, a source–pathway–receptor analysis is appropriate. For the current application, the sources are atmospheric and liquid discharges, with the liquid discharges being routed to streams and rivers, sewage treatment works, or estuarine and coastal environments. All these routes of discharge have been extensively studied over many years (though discharges via sewage treatment works have been given rather less attention than the other routes). 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.

The main distinctions between available models do not arise at the level of selecting pathways or modes of exposure for inclusion. Rather they arise at the level of defining how those pathways and modes of exposure should be represented mathematically and in associating parameter values with those mathematical representations.

Although numerous biosphere models are available, as discussed in Appendix A, none of them fulfil the requirements of this study. In particular, the set of radionuclides to be addressed is beyond the scope of existing models. However, for the purposes of generic analyses, the biosphere calculations required can be expressed through simple analytic equations. Therefore, rather than using existing models as they stand, either the datasets underpinning those models can be extracted or the models can be used to compute input data for use in simple analytical calculations. Although the extracted or computed datasets will be incomplete, it is relatively straightforward to use a variety of techniques to generate the missing data. In addition, where comprehensive up-to-date datasets exist independently of the existing models, those can be used in preference to earlier or incomplete datasets within the models. External dose factors and intake-to-dose factors are good examples of such independently available datasets.

This approach of abstracting information from existing models or data compilations and using that information in transparent analytical calculations forms the basis of the method adopted in this study and is described in detail in the following sections.

3 Initial assessment methodology

3.1 Introduction to dose per unit release factors

For the purpose of setting discharge authorisations, future effective doses from the discharges at the proposed limits have to be assessed. All prospective assessments require assumptions to be made regarding the behaviour of radionuclides in the environment and the habits of the people who might be exposed to the radionuclides discharged. An initial assessment using simple cautious assumptions is required to provide a quick screen of the proposed discharges. The quick screen should include sufficient caution to ensure that the dose is very unlikely to be underestimated. However, the degree of caution should not be too large, or the initial assessment methodology will be inefficient in screening out those discharge authorisations that do not need more detailed consideration.

The simplest way to undertake such an assessment consists of multiplying the quantity of radionuclide discharged by an appropriate dose per unit release (DPUR) factor. In the first instance, cautious, non-site-specific, DPUR data can be used, so a single DPUR factor is provided for each radionuclide, critical group and discharge scenario.

It should be possible for the assessment to be refined with the use of more site-specific DPUR data. This refinement of the initial assessment can be achieved by the augmentation of the methodology using very simple models. Here the key factor is the degree of dispersion and dilution that is included. For example, for discharges to a river, linear, radionuclide-independent scaling factors, representing different river flow rates can be applied.

An advantage of such a tiered assessment is that a first cautious assessment can be carried out where only a quick and simple scoping calculation is required or where relevant site-specific data are not immediately to hand. The tiered approach could also be applied to refine an assessment if, for example, the first calculations result in an annual effective dose close to or only slightly above 0.02 mSv/y. This is part of the Initial Source Radiological Assessment illustrated in Figure 1. A detailed source and site assessment would need to follow if there is formal non-compliance with the 0.02 mSv cut-off point for the Initial Radiological Assessment.

Generally, the method is based on cautious assumptions to ensure that doses are not underestimated but without creating unduly unrealistic scenarios.

3.2 Release scenarios

The following release scenarios are specified in discharge authorisations for various sites and therefore need to be included:

- release to air;
- release to estuary/coastal water;
- release to river;
- release to public sewer.

Consequent upon such releases, there are a number of pathways that lead to exposure for members of the public. Some of the pathways can be contributed to by more than one release scenario (e.g. extracting drinking water from a river which receives direct discharges as well as treated sewage effluent).

3.3 Critical group approach

It is the doses received by members of the public and not occupational workers that are compared with dose limits and constraints. In this context 'members of the public' includes workers not employed by the organisation making the radioactive discharges (e.g. farmers, fishermen and sewage workers). Since it is not practical to assess the dose to every individual exposed to the discharges, the concept of 'critical groups' is used. The critical group is intended to be 'representative of those individuals in the population expected to receive the highest dose' [8]. Doses are assessed for four age groups: fetus (or 'offspring'), 1-year-old infants, 10-year-old children and adults.

Recently, the NRPB has recommended that the concept of the critical group is extended to the developing fetus since, for some radionuclides, the fetus may receive the highest dose following the releases of radionuclides to the environment [9]. As some of these radionuclides (notably ^{32}P, ^{33}P and ^{45}Ca) are frequently discharged by small users, the dose to the fetus is included here for those radionuclides for which the fetus receives a higher dose than the mother. The term offspring has been used here to denote collectively the embryo, fetus and newborn child [10].

In order to determine the limiting critical group it is necessary to assess the effective doses to a number of 'exposure groups'. These exposure groups have been selected to ensure full coverage of possible pathways using reasonable habit patterns. The limiting critical group is simply the exposure group that receives the highest dose.

The location and habits of a 'real' critical group might not be known for the site for which an assessment is made and in many situations it might not be practical to carry out a detailed site-specific investigation. This is especially the case for many 'small users' where expected doses are very low. Thus, it might sometimes be unclear as to whether a particular group is exposed or whether particular exposure pathways operate. In such cases, it will be prudent to assume that such exposures do occur. Also, it is important to include any possible changes of habits or locations in the future so that the characteristics of the exposure groups are applicable to the time period over which doses are assessed. In particular, it has been argued that authorised discharges should be controlled such that no reasonable use of environmental media is precluded; that is, pathways and modes of exposure that could reasonably occur over the period between authorisation reviews (typically 5 years) should be treated as if they were certain to occur.

Therefore, for the purpose of this study, hypothetical exposure groups are defined for which, through their assumed location and habits, doses from each of the discharge scenarios will be maximised (but not unrealistically so). In general, it is assumed that no significant cross-over of habits and therefore exposure exists between any of the groups identified. However, if such cross-over did exist, a prudent first approximation would be to sum the estimated doses calculated for the group in question.

3.4 List of radionuclides considered

DPUR factors are required for a substantial number of radionuclides. The list of radionuclides for which DPUR factors are developed needs to be comprehensive in order to allow for quick initial assessments of discharges from a wide range of sources, including ‘small user’ practices (hospitals and research institutes, etc.) and the nuclear industry. The list of radionuclides was agreed with the Environment Agency and is presented in Table 1.

3.5 General method used to calculate environmental concentrations and doses

Numerical dispersion models were applied to calculate concentrations in environmental media, where possible. To calculate the dispersion of radionuclides for most of the discharge scenarios and pathways the 1998 upgrade of the NRPB model PC CREAM [11] was used. It is based on a methodology for assessing the radiological consequences of routine releases to the environment published by the European Commission [12]. The modules PLUME, FARMLAND, DORIS and GRANIS were used to calculate the transfers of the radionuclides through the atmospheric and coastal environments and the foodchain. PC CREAM and its underlying dispersion models are seen to be robust, fit for the purpose and have been verified against environmental data [13,14,15].

For the modelling of the dispersion of atmospheric discharges PC CREAM contains a Gaussian plume model. This approach was chosen because the DPUR factors are required for continuous releases and the assessment of annual doses and Gaussian plume models are considered adequate for this purpose. PC CREAM provides a lot of flexibility as radionuclide concentrations in air and deposition rates can be calculated for a range of receptor point distances, stack heights and a very large number of radionuclides.

For the modelling of marine dispersion, PC CREAM contains a compartment model, which has been configured for coastal discharges of radionuclides from the 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 the discharges of radionuclides to the sea. Discharges occur into a local compartment, which can be configured by the user. From the local compartment exchange of water and sediments take place with the adjacent regional compartment and from there into other European waters. As such the model provides a maximum of flexibility for the set-up of the discharge site as well as allowing the incorporation of almost any radionuclide.

Currently, PC CREAM does not include a model for the assessment of doses as a result of discharges to sewer and the default river model was limited to a set list of radionuclides. As a result, alternative methods were used to calculate radionuclide concentrations in river environments and from sewage sludge disposal (see Appendices F and G). These were based on simple dilution, and the distribution of radionuclides between liquid and sediment phases was governed by sediment partitioning.

All discharges are assumed to be continuous, uniform, routine releases. This is consistent with the requirements of discharge authorisations. To allow for build-up of concentrations of radionuclides in the environment, it was assumed that discharges continue for 50 years and the effective dose in the 50th year was assessed.

Dose assessments were made using the concentrations of radionuclides in the environment predicted by PC CREAM or from alternative approaches, information on exposed population group habits and dose factors. The dose assessment calculations were carried out using spreadsheets.

3.6 Choice of input data

With such a large and comprehensive list of radionuclides, discharge scenarios and exposure paths, finding suitable and robust input data for the calculations has been the greatest challenge of this study. Many gaps exist, even for ‘common’ and well-studied radionuclides, especially where environmental transfer data are concerned. The aim of this study has been to fill the gaps using a range of sources and methods, an overall hierarchy of which can be described as follows:

1. Default data from the databases of the PC CREAM model and underlying documentation, which are directly derived from and referenced to a number of standard compilation sources.
2. Widely applied standard compilations, such as IAEA Technical Series reports for environmental transfer factors and ICRP publications for dose factors. Where these supersede values in 1, the newer data have been used in preference.
3. Other compilations, which demonstrate robust data sources and analyses (e.g. the Balkema series of reviews for environmental transfer factors, US Federal Guidance Reports for external dose factors).
4. The remaining missing data were supplied by techniques such as scaling, use of analogues and one-off analytical calculations.

It was deemed preferable to use the best input data where available, rather than selecting a uniform set of data for all radionuclides. The advantage of this approach is that the calculations are based on the best available data for each radionuclide. In addition, as new and better data are published, they can easily be included by updating the spreadsheets. However, care was taken since this could lead to inconsistencies such as a higher dose from radionuclide A than B, where they should be similar, because the dose from A has been calculated using more conservative data. It is hoped that a uniform set of data for all radionuclides based on detailed reviews of the primary literature will be available from the IAEA EMRAS programme by 2007.

A discussion on input data used in the present study, on an element by element basis, is provided in Appendix C.

3.7 Ingrowth of progeny

The ingrowth of progeny radionuclides can be important for some pathways and some radionuclides. In this study, ingrowth was considered if significant ingrowth is likely to occur in the 50-year discharge period. Ingrowth during transfer through the environment was calculated whenever the PC CREAM code allowed. Where PC CREAM was not used to model environmental transfers, the ingrowth of progeny post-deposition at the location of likely exposure (e.g. radionuclides in river bank sediments) was considered separately. More details are given in Appendices D to G for each of the discharge scenarios.

4 Derivation of dose per unit release factors

4.1 Discharge scenarios and exposure groups

For releases to air an exposure group of ‘local inhabitant family’ was characterised. Members of this group were assumed to be exposed to the discharge plume and to radionuclides that have been deposited to the ground and subsequently incorporated into terrestrial foodstuffs. Releases were assumed to take place at ground level and concentrations in air and deposition rates were derived for a habitation distance of 100 m and a food production distance of 500 m from the release point. More details are given in Appendix D.

For releases to estuary and coastal water an exposure group of ‘fisherman family’ was characterised. Members of this group were assumed to be exposed to activity in coastal discharges by consumption of seafood contaminated by radionuclides in seawater and by spending time on local beaches. Releases were assumed to take place into a local marine compartment characterised by a volumetric water exchange rate of 100 m^3 s^{-1} with the neighbouring regional compartment. More details are given in Appendix E.

For releases to a freshwater river, two exposure groups were considered. Members of the ‘angler family’ group were assumed to consume fish and drinking water from the river and spend some time on its banks. Members of the ‘irrigated food consumer family’ were assumed to consume terrestrial foodstuffs irrigated with water from the river. Releases were assumed to take place into a small river with a water flow rate of 1 m^3 s^{-1}. More details are given in Appendix F.

For releases to sewer three exposure groups were considered. Members of the ‘sewage treatment workers’ were assumed to be exposed in radionuclides in raw sewage and sewage sludge at the sewage treatment works. Members of the ‘farming family’ are exposed to soil conditioned with treated sewage sludge and are assumed to consume terrestrial foodstuffs produced in that soil. Finally, members of the ‘children playing in brook’ exposure group are assumed to be exposed to liquid effluent from the sewage treatment works which have been discharged into a small brook with a flow rate of 0.1 m^3 s^{-1}. For all sewer exposure groups it was assumed that the volumetric flow rate through the sewage treatment works is 60 m^3 d^{-1}. More details are given in Appendix G.

If the liquid effluent from the sewage treatment works is not discharged into a small brook it was assumed that discharge occurs either into a freshwater river or coastal water compartment. As a result, doses to the exposure groups for the river and coastal discharge scenarios were also considered for the sewage discharge scenario.

4.2 Basis for dose per unit release factors

DPURs have been calculated for each release scenario, exposure group, pathway, radionuclide and age group 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^{-1} per unit release of 1 Bq y^{-1})

$CPUR_r$ is the activity concentration per unit release in a relevant material (Bq kg^{-1} or l^{-1} or m^{-3} per unit release of 1 Bq y^{-1})

$H_{p,a}$ is the habit data relevant to the pathway considered, either ingestion rate (kg or l y^{-1}) or inhalation rate (m^3 y^{-1}) or occupancy time (h y^{-1})

$DF_{r,a}$ is the dose per unit intake by ingestion or inhalation factor (μSv Bq^{-1}) or external dose factor (μSv h^{-1} per Bq kg^{-1})

Full details of the approach and formulae used to calculate individual DPURs are given in Appendices D, E, F and G for discharges to atmosphere, coastal water, river and sewer, respectively, together with the relevant habit data. Dose factors per unit intake by ingestion and inhalation are listed in Appendix B.

For each exposure group the DPURs of all relevant pathways were summed. Then, for each radionuclide, the DPURs of the different age groups were compared and the worst age group DPUR selected. These DPURs can then be used to derive the total dose for each discharge scenario and exposure group as follows:

$$D_{tot} = \sum [DPUR_r \times Q_r]$$

where D_{tot} is the total dose for the exposure group under consideration (μSv y^{-1})

Q_r is the discharge rate of the discharge scenario and radionuclide under consideration (Bq y^{-1})

The highest total dose for each exposure group and from each exposure scenario (the critical group dose) should then be compared with 0.02 mSv y^{-1} (see Section 1.1) to determine if further, more site-specific assessments are warranted. The initial assessment can be adapted to reflect more site-specific conditions to a degree. The accompanying report ‘Initial Radiological Assessment Methodology – User Report’ [5] 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.

5 Dose per unit release factors

For discharges to atmosphere the summary total DPURs for the worst age group for the local resident family exposure group are shown in Table 2. Detailed DPURs for each pathway and age group are given in Tables 3–6.

For discharges to estuary and coastal water the summary DPURs for the worst age group for the fisherman family exposure group are shown in Table 7. Detailed DPURs for each pathway and age group are given in Tables 8–11.

For discharges to river the summary DPURs for the worst age group for the angler exposure group are shown in Table 12 and detailed DPURs for each pathway and age group are shown in Tables 13–16. For the irrigated food consumer family exposure group summary DPURs are listed in Table 17 and detailed DPURs in Tables 18–21.

For discharges to sewer the summary DPURs for the sewage treatment worker (adult only) are shown in Table 22. For the farming family exposed to sludge used to condition agricultural soil the summary DPURs are listed in Table 23 and detailed DPURs are shown in Tables 24–27. Finally, for the children playing in brook exposure group the DPURs are presented in Table 28.

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List of abbreviations

Bq	Becquerel
BSS	Basic Safety Standards Directive 1996 (Euratom)
DPUR	dose per unit release
EMRAS	Environmental Modelling for Radiation Safety (IAEA programme)
GDC	Generalised Derived Constraint
GDL	Generalised Derived Limit
GESAMP	Group of Experts on Scientific Aspects of Marine Pollution (IAEA)
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
NRPB	National Radiological Protection Board
RSA 93	Radioactive Substances Act 1993
STW	sewage treatment works
Sv	Sievert

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	12.35 y	✓	✓	✓	✓
H-3 organic	12.35 y	✓	✓	✓	✓
C-11	20.38 m	✓	not considered	not considered	✓
C-14	5,730 y	✓	✓	✓	✓
N-13	9.965 m	✓	gas	gas	gas
O-15	122.24 s	✓	gas	gas	gas
F-18	109.77 m	✓	not considered	not considered	✓
Na-22	2.602 y	✓	✓	✓	✓
Na-24	15 h	✓	✓	✓	✓
P-32	14.29 d	✓	✓	✓	✓
P-33	25.4 d	✓	✓	✓	✓
S-35	87.44 d	✓	✓	✓	✓
Cl-36	301,000 y	✓	✓	✓	✓
Ar-41	1.827 h	✓	gas	gas	gas
Ca-45	163 d	✓	✓	✓	✓
Ca-47	4.53 d	✓	✓	✓	✓
V-48	16.238 d	✓	✓	✓	✓
Cr-51	27.704 d	✓	✓	✓	✓
Mn-52	5.591 d	✓	✓	✓	✓
Mn-54	312.5 d	✓	✓	✓	✓
Mn-56	2.5785 h	✓	not considered	not considered	✓
Fe-55	2.7 y	✓	✓	✓	✓
Fe-59	44.529 d	✓	✓	✓	✓
Co-56	78.76 d	✓	✓	✓	✓
Co-57	270.9 d	✓	✓	✓	✓
Co-58	70.8 d	✓	✓	✓	✓
Co-60	5.271 y	✓	✓	✓	✓
Ni-63	96 y	✓	✓	✓	✓
Zn-65	243.9 d	✓	✓	✓	✓
Ga-67	78.26 h	✓	✓	✓	✓
Se-75	119.8 d	✓	✓	✓	✓
Br-82	35.3 h	✓	✓	✓	✓
Kr-79	35 h	✓	gas	gas	gas
Kr-81m	13 s	✓	gas	gas	gas
Kr-85	10.72 y	✓	gas	gas	gas
Kr-85m	4.48 h	✓	gas	gas	gas
Rb-82	1.3 m	✓	not considered	not considered	✓
Rb-83	86.2 d	✓	✓	✓	✓
Sr-89	50.5 d	✓	✓	✓	✓
Sr-90	29.12 y	✓	✓	✓	✓
Y-90	64 h	✓	✓	✓	✓
Zr-95	63.98 d	✓	✓	✓	✓
Nb-95	35.2 d	✓	✓	✓	✓
Mo-99	66 h	✓	✓	✓	✓
Tc-99	213,000 y	✓	✓	✓	✓
Tc-99m	6.02 h	✓	✓	✓	✓
Ru-103	39.28 d	✓	✓	✓	✓
Ru-106	368.2 d	✓	✓	✓	✓
Ag-110m	249.9 d	✓	✓	✓	✓
In-111	2.83 d	✓	✓	✓	✓

Table 1 continued

Radionuclide	Half-life	Release to air	Release to estuary/coastal water	Release to river	Release to public sewer
In-113m	1.658 h	✓	not considered	not considered	✓
Sb-125	2.77 y	✓	✓	✓	✓
I-123	13.2 h	✓	✓	✓	✓
I-125	60.14 d	✓	✓	✓	✓
I-129	1.57E+07 y	✓	✓	✓	✓
I-131	8.04 d	✓	✓	✓	✓
I-132	2.3 h	✓	not considered	not considered	✓
I-133	20.8 h	✓	✓	✓	✓
I-134	52.6 m	✓	not considered	not considered	✓
I-135	6.61 h	✓	✓	✓	✓
Xe-133	5.245 d	✓	gas	gas	gas
Cs-134	2.062 y	✓	✓	✓	✓
Cs-136	13.1 d	✓	✓	✓	✓
Cs-137	30 y	✓	✓	✓	✓
Ba-140	12.74 d	✓	✓	✓	✓
La-140	40.272 h	✓	✓	✓	✓
Ce-141	32.501 d	✓	✓	✓	✓
Ce-144	284.3 d	✓	✓	✓	✓
Pm-147	2.6234 y	✓	✓	✓	✓
Sm-153	46.7 h	✓	✓	✓	✓
Eu-152	13.33 y	✓	✓	✓	✓
Eu-154	8.8 y	✓	✓	✓	✓
Eu-155	4.96 y	✓	✓	✓	✓
Er-169	9.3 d	✓	✓	✓	✓
Lu-177	6.71 d	✓	✓	✓	✓
Au-198	2.696 d	✓	✓	✓	✓
Tl-201	3.044 d	✓	✓	✓	✓
Pb-210	22.3 y	✓	✓	✓	✓
Po-210	138.38 d	✓	✓	✓	✓
Rn-222	3.8235 d	✓	gas	gas	gas
Ra-223	11.434 d	✓	✓	✓	✓
Ra-226	1,600 y	✓	✓	✓	✓
Th-230	77,000 y	✓	✓	✓	✓
Th-232	1.405E+10 y	✓	✓	✓	✓
Th-234	24.1 d	✓	✓	✓	✓
U-234	244,500 y	✓	✓	✓	✓
U-235	7.038E+08 y	✓	✓	✓	✓
U-238	4.468E+09 y	✓	✓	✓	✓
Np-237	2.14E+06 y	✓	✓	✓	✓
Pu-238	87.74 y	✓	✓	✓	✓
Pu-239	24,065 y	✓	✓	✓	✓
Pu-240	6,537 y	✓	✓	✓	✓
Pu-241	14.4 y	✓	✓	✓	✓
Pu-242	376,300 y	✓	✓	✓	✓
Am-241	432.2 y	✓	✓	✓	✓
Am-242	16.02 h	✓	✓	✓	✓
Am-243	7,380 y	✓	✓	✓	✓
Cm-242	162.8 d	✓	✓	✓	✓
Cm-243	28.5 y	✓	✓	✓	✓
Cm-244	18.11 y	✓	✓	✓	✓

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

Radionuclide	Worst total DPUR ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)	Worst age group
H-3	9.6E-13	Offspring
H-3 organic	1.9E-12	Offspring
C-11	2.8E-12	Adult
C-14	6.8E-11	Infant
N-13	2.4E-12	Adult
O-15	2.1E-12	Adult
F-18	4.0E-12	Adult
Na-22	6.1E-09	Adult
Na-24	2.6E-11	Adult
P-32	1.0E-09	Offspring
P-33	3.5E-11	Child
S-35	8.4E-11	Infant
Cl-36	2.0E-09	Infant
Ar-41	3.2E-12	Adult
Ca-45	6.5E-11	Child
Ca-47	6.5E-11	Adult
V-48	2.5E-10	Adult
Cr-51	4.5E-12	Adult
Mn-52	1.2E-10	Adult
Mn-54	9.7E-10	Adult
Mn-56	7.7E-12	Adult
Fe-55	5.8E-11	Infant
Fe-59	3.0E-10	Adult
Co-56	1.1E-09	Adult
Co-57	1.2E-10	Adult
Co-58	3.1E-10	Adult
Co-60	1.2E-08	Adult
Ni-63	1.2E-11	Infant
Zn-65	1.2E-09	Infant
Ga-67	7.7E-12	Adult
Se-75	1.2E-09	Infant
Br-82	9.1E-11	Infant
Kr-79	5.9E-13	Adult
Kr-81m	8.3E-14	Adult
Kr-85	1.3E-14	Adult
Kr-85m	3.6E-13	Adult
Rb-82	2.2E-12	Adult
Rb-83	2.2E-10	Adult
Sr-89	1.5E-10	Infant
Sr-90	1.4E-09	Child
Y-90	4.8E-11	Infant
Zr-95	4.8E-10	Adult
Nb-95	1.4E-10	Adult
Mo-99	2.6E-11	Infant
Tc-99	7.4E-09	Infant
Tc-99m	8.3E-13	Adult
Ru-103	1.3E-10	Adult
Ru-106	9.0E-10	Adult
Ag-110m	2.9E-09	Adult

Table 2 continued

Radionuclide	Worst total DPUR ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)	Worst age group
In-111	1.0E-11	Adult
In-113m	1.1E-12	Adult
Sb-125	1.4E-09	Adult
I-123	6.8E-12	Infant
I-125	3.1E-09	Infant
I-129	2.9E-08	Infant
I-131	4.5E-09	Infant
I-132	1.5E-11	Adult
I-133	1.8E-10	Infant
I-134	1.1E-11	Adult
I-135	3.0E-11	Infant
Xe-133	7.0E-14	Adult
Cs-134	4.2E-09	Adult
Cs-136	1.6E-10	Adult
Cs-137	7.0E-09	Adult
Ba-140	2.4E-10	Adult
La-140	4.6E-11	Adult
Ce-141	8.2E-11	Adult
Ce-144	9.0E-10	Infant
Pm-147	1.1E-10	Adult
Sm-153	1.6E-11	Child
Eu-152	9.9E-09	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
Au-198	2.6E-11	Infant
Tl-201	2.7E-12	Infant
Pb-210	2.9E-08	Child
Po-210	8.8E-08	Child
Rn-222	2.4E-10	Infant
Ra-223	1.7E-07	Adult
Ra-226	1.1E-07	Adult
Th-230	3.1E-07	Adult
Th-232	6.3E-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	9.4E-07	Adult
Am-242	3.8E-10	Adult
Am-243	9.2E-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 local resident family – atmospheric release scenario

Radionuclide	DPURs for offspring local resident family (μSv y^{-1} per Bq y^{-1})											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External from air	External from deposited	Inhalation	Total
H-3	3.9E-14	5.5E-14	3.2E-14	9.3E-15	3.7E-15	1.7E-14	3.7E-15	1.2E-13	0.0E+00	0.0E+00	6.9E-13	9.6E-13
H-3 organic	7.9E-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	1.9E-12
C-11	<p	<p	<p	<p	<p	<p	<p	<p	2.4E-12	0.0E+00	<p	2.4E-12
C-14	2.4E-12	7.8E-12	4.5E-12	2.3E-12	9.0E-13	4.1E-12	9.0E-13	7.2E-12	1.4E-16	0.0E+00	<p	3.0E-11
N-13	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.4E-12	0.0E+00	0.0E+00	2.4E-12
O-15	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.1E-12	0.0E+00	0.0E+00	2.1E-12
F-18	<p	<p	<p	<p	<p	<p	<p	<p	2.4E-12	3.2E-13	<p	2.7E-12
Na-22	<p	<p	<p	<p	<p	<p	<p	<p	5.4E-12	6.0E-09	<p	6.0E-09
Na-24	<p	<p	<p	<p	<p	<p	<p	<p	1.1E-11	9.1E-12	<p	2.0E-11
P-32	1.8E-11	2.4E-10	1.1E-11	9.4E-11	1.5E-11	6.7E-11	1.5E-11	4.2E-10	2.8E-14	0.0E+00	<p	1.0E-09
P-33	4.8E-12	4.3E-12	2.7E-12	4.4E-12	7.1E-13	3.1E-12	6.9E-13	1.2E-11	7.6E-16	0.0E+00	<p	3.2E-11
S-35	3.1E-13	3.9E-13	1.5E-13	1.2E-11	1.9E-12	8.8E-12	1.9E-12	7.3E-12	1.6E-16	0.0E+00	<p	3.2E-11
Cl-36	<p	<p	<p	<p	<p	<p	<p	<p	8.7E-15	2.3E-12	<p	2.3E-12
Ar-41	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.2E-12	0.0E+00	0.0E+00	3.2E-12
Ca-45	1.3E-11	4.7E-13	1.6E-12	2.8E-13	1.1E-13	3.9E-13	8.7E-14	9.9E-12	8.1E-16	2.5E-19	<p	2.6E-11
Ca-47	2.4E-12	9.4E-15	4.6E-13	1.9E-14	7.6E-15	3.1E-14	7.0E-15	1.3E-12	2.7E-12	1.9E-11	<p	2.5E-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	3.4E-12	<p	3.5E-12
Mn-52	<p	<p	<p	<p	<p	<p	<p	<p	8.5E-12	7.5E-11	<p	8.4E-11
Mn-54	<p	<p	<p	<p	<p	<p	<p	<p	2.0E-12	9.1E-10	<p	9.1E-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	9.1E-12	1.0E-09	<p	1.0E-09
Co-57	<p	<p	<p	<p	<p	<p	<p	<p	2.6E-13	1.0E-10	<p	1.0E-10
Co-58	<p	<p	<p	<p	<p	<p	<p	<p	2.3E-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
Ni-63	<p	<p	<p	<p	<p	<p	<p	<p	0.0E+00	0.0E+00	<p	0.0E+00

Table 3 continued

Radionuclide	DPURs for offspring local resident family (µSv y^{-1} per Bq y^{-1})											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External from air	External from deposited	Inhalation	Total
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
Se-75	4.5E-12	6.1E-12	2.0E-12	4.4E-11	3.5E-10	4.6E-11	2.6E-10	3.0E-11	8.9E-13	1.7E-10	2.5E-11	9.3E-10
Br-82	<p	<p	<p	<p	<p	<p	<p	<p	6.4E-12	1.5E-11	<p	2.2E-11
Kr-79	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.9E-13	0.0E+00	0.0E+00	5.9E-13
Kr-81m	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	8.3E-14	0.0E+00	0.0E+00	8.3E-14
Kr-85	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.3E-14	0.0E+00	0.0E+00	1.3E-14
Kr-85m	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.6E-13	0.0E+00	0.0E+00	3.6E-13
Rb-82	<p	<p	<p	<p	<p	<p	<p	<p	2.1E-12	3.2E-14	<p	2.2E-12
Rb-83	<p	<p	<p	<p	<p	<p	<p	<p	1.2E-12	1.7E-10	<p	1.7E-10
Sr-89	1.3E-11	1.6E-13	2.0E-12	2.5E-13	1.0E-13	3.2E-13	7.1E-14	8.4E-12	2.3E-14	1.6E-14	<p	2.4E-11
Sr-90	3.1E-10	7.2E-11	6.2E-11	3.5E-12	1.4E-12	8.4E-12	1.9E-12	2.1E-10	5.2E-15	1.2E-16	<p	6.7E-10
Y-90	<p	<p	<p	<p	<p	<p	<p	<p	4.2E-14	6.3E-19	<p	4.2E-14
Zr-95	<p	<p	<p	<p	<p	<p	<p	<p	1.8E-12	3.7E-10	<p	3.7E-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	1.6E-12	<p	2.0E-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	3.9E-13
Ru-103	<p	<p	<p	<p	<p	<p	<p	<p	1.1E-12	7.3E-11	<p	7.5E-11
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	2.4E-09	<p	2.4E-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

Table 3 continued

Radionuclide	DPURs for offspring local resident family (µSv y^{-1} per Bq y^{-1})											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External from air	External from deposited	Inhalation	Total
I-123	<p	<p	<p	<p	<p	<p	<p	<p	3.4E-13	2.9E-12	<p	3.3E-12
I-125	<p	<p	<p	<p	<p	<p	<p	<p	2.0E-14	2.1E-11	<p	2.1E-11
I-129	<p	<p	<p	<p	<p	<p	<p	<p	1.5E-14	3.6E-10	<p	3.6E-10
I-131	<p	<p	<p	<p	<p	<p	<p	<p	8.9E-13	1.1E-10	<p	1.1E-10
I-132	<p	<p	<p	<p	<p	<p	<p	<p	5.5E-12	7.8E-12	<p	1.3E-11
I-133	<p	<p	<p	<p	<p	<p	<p	<p	1.5E-12	2.0E-11	<p	2.1E-11
I-134	<p	<p	<p	<p	<p	<p	<p	<p	6.4E-12	3.4E-12	<p	9.8E-12
I-135	<p	<p	<p	<p	<p	<p	<p	<p	4.0E-12	1.7E-11	<p	2.1E-11
Xe-133	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.0E-14	0.0E+00	0.0E+00	7.0E-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	5.2E-12	1.1E-10	<p	1.2E-10
Cs-137	<p	<p	<p	<p	<p	<p	<p	<p	1.3E-12	6.5E-09	<p	6.5E-09
Ba-140	<p	<p	<p	<p	<p	<p	<p	<p	4.3E-13	1.2E-10	<p	1.2E-10
La-140	<p	<p	<p	<p	<p	<p	<p	<p	5.8E-12	1.5E-11	<p	2.1E-11
Ce-141	<p	<p	<p	<p	<p	<p	<p	<p	1.6E-13	8.7E-12	<p	8.9E-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	9.8E-15
Sm-153	<p	<p	<p	<p	<p	<p	<p	<p	1.1E-13	3.5E-13	<p	4.5E-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	8.7E-13	<p	9.5E-13
Au-198	<p	<p	<p	<p	<p	<p	<p	<p	9.5E-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
Po-210	<p	<p	<p	<p	<p	<p	<p	<p	2.0E-17	4.4E-15	<p	4.4E-15
Rn-222	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.5E-16	0.0E+00	0.0E+00	9.5E-16

Table 3 continued

Radionuclide	DPURs for offspring local resident family (µSv y^{-1} per Bq y^{-1})											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External from air	External from deposited	Inhalation	Total
Ra-223	<p	<p	<p	<p	<p	<p	<p	<p	4.2E-13	1.3E-11	<p	1.3E-11
Ra-226	5.1E-10	1.8E-11	1.3E-09	4.8E-11	1.9E-11	4.1E-11	9.2E-12	1.8E-10	1.5E-14	2.7E-08	<p	2.9E-08
Th-230	<p	<p	<p	<p	<p	<p	<p	<p	7.8E-16	2.0E-10	<p	2.0E-10
Th-232	<p	<p	<p	<p	<p	<p	<p	<p	3.8E-16	6.9E-08	<p	6.9E-08
Th-234	<p	<p	<p	<p	<p	<p	<p	<p	7.9E-14	1.7E-12	<p	1.8E-12
U-234	<p	<p	<p	<p	<p	<p	<p	<p	3.2E-16	1.2E-12	<p	1.2E-12
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	1.8E-16	4.4E-13	<p	4.4E-13
Pu-239	<p	<p	<p	<p	<p	<p	<p	<p	1.8E-16	7.0E-13	<p	7.0E-13
Pu-240	<p	<p	<p	<p	<p	<p	<p	<p	1.8E-16	5.6E-13	<p	5.6E-13
Pu-241	<p	<p	<p	<p	<p	<p	<p	<p	3.3E-18	1.6E-12	<p	1.6E-12
Pu-242	<p	<p	<p	<p	<p	<p	<p	<p	1.5E-16	8.7E-12	<p	8.7E-12
Am-241	<p	<p	<p	<p	<p	<p	<p	<p	3.6E-14	1.3E-10	<p	1.3E-10
Am-242	<p	<p	<p	<p	<p	<p	<p	<p	3.2E-14	3.2E-14	<p	6.4E-14
Am-243	<p	<p	<p	<p	<p	<p	<p	<p	9.7E-14	2.4E-09	<p	2.4E-09
Cm-242	<p	<p	<p	<p	<p	<p	<p	<p	2.1E-16	6.7E-14	<p	6.7E-14
Cm-243	<p	<p	<p	<p	<p	<p	<p	<p	2.8E-13	1.1E-09	<p	1.1E-09
Cm-244	<p	<p	<p	<p	<p	<p	<p	<p	1.8E-16	1.9E-12	<p	1.9E-12

<p = not calculated as dose to parent greater than dose to offspring

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

Radionuclide	DPURs for infant local resident family (µSv y^{-1} per Bq y^{-1})											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External from air	External from deposited	Inhalation	Total
H-3	1.1E-14	3.0E-14	2.3E-14	1.8E-15	1.6E-15	5.8E-15	1.6E-15	2.4E-13	0.0E+00	0.0E+00	2.6E-13	5.7E-13
H-3 organic	2.8E-14	7.5E-14	5.8E-14	4.4E-15	4.0E-15	1.5E-14	4.0E-15	6.0E-13	0.0E+00	0.0E+00	5.9E-13	1.4E-12
C-11	nc	nc	nc	nc	nc	nc	nc	nc	1.1E-12	0.0E+00	5.8E-13	1.7E-12
C-14	8.9E-13	5.3E-12	4.2E-12	5.3E-13	4.9E-13	1.8E-12	4.9E-13	1.9E-11	6.4E-17	0.0E+00	3.5E-11	6.8E-11
N-13	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.1E-12	0.0E+00	0.0E+00	1.1E-12
O-15	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.9E-13	0.0E+00	0.0E+00	9.9E-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	4.9E-12	1.3E-11	5.7E-12	1.2E-11	1.1E-11	2.4E-11	6.5E-12	1.5E-10	2.5E-12	2.1E-09	3.9E-11	2.3E-09
Na-24	2.3E-14	3.7E-16	4.7E-14	2.4E-15	2.2E-15	1.4E-15	3.9E-16	1.2E-13	5.1E-12	3.1E-12	9.7E-12	1.8E-11
P-32	2.7E-12	6.5E-11	4.1E-12	8.9E-12	3.2E-12	1.2E-11	3.3E-12	4.5E-10	1.3E-14	0.0E+00	8.1E-11	6.3E-10
P-33	3.4E-13	5.6E-13	4.8E-13	2.0E-13	7.3E-14	2.6E-13	7.1E-14	5.8E-12	3.6E-16	0.0E+00	2.5E-11	3.2E-11
S-35	2.4E-13	5.7E-13	3.0E-13	5.8E-12	2.1E-12	8.2E-12	2.2E-12	4.0E-11	7.6E-17	0.0E+00	2.4E-11	8.4E-11
Cl-36	1.3E-10	3.2E-10	1.6E-11	5.9E-11	5.4E-11	1.7E-10	4.6E-11	1.0E-09	4.1E-15	7.9E-13	1.4E-10	2.0E-09
Ar-41	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.5E-12	0.0E+00	0.0E+00	1.5E-12
Ca-45	1.4E-12	9.4E-14	4.4E-13	1.9E-14	1.8E-14	5.0E-14	1.4E-14	7.6E-12	3.8E-16	8.7E-20	4.7E-11	5.7E-11
Ca-47	5.5E-13	3.9E-15	2.6E-13	2.7E-15	2.5E-15	8.4E-15	2.3E-15	2.0E-12	1.2E-12	6.4E-12	4.1E-11	5.2E-11
V-48	1.4E-12	3.6E-15	6.2E-13	1.9E-16	1.7E-16	4.0E-16	1.1E-16	9.9E-14	3.3E-12	6.3E-11	5.9E-11	1.3E-10
Cr-51	3.6E-14	3.3E-18	7.9E-15	8.7E-15	8.0E-15	1.7E-14	4.7E-15	4.8E-13	3.4E-14	1.2E-12	1.1E-12	2.9E-12
Mn-52	5.9E-13	6.8E-15	2.8E-13	6.5E-14	2.1E-12	1.5E-13	1.5E-12	1.5E-11	4.0E-12	2.6E-11	3.6E-11	8.6E-11
Mn-54	7.9E-13	1.6E-13	3.5E-13	4.6E-13	1.6E-11	8.9E-13	9.6E-12	1.8E-11	9.4E-13	3.1E-10	3.3E-11	4.0E-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	5.9E-13	3.9E-15	2.3E-13	7.3E-15	2.0E-11	2.6E-14	2.9E-11	1.0E-12	0.0E+00	2.7E-15	7.5E-12	5.8E-11
Fe-59	2.4E-12	4.8E-15	9.9E-13	5.3E-15	1.5E-11	1.1E-14	1.2E-11	4.4E-12	1.4E-12	6.9E-11	7.0E-11	1.7E-10
Co-56	3.1E-12	2.8E-14	1.3E-12	8.4E-14	7.7E-12	1.7E-13	4.6E-12	3.7E-11	4.3E-12	3.5E-10	1.1E-10	5.2E-10
Co-57	3.8E-13	8.7E-15	1.5E-13	1.8E-14	1.7E-12	3.9E-14	1.1E-12	4.4E-12	1.2E-13	3.6E-11	1.2E-11	5.6E-11
Co-58	9.0E-13	7.5E-15	3.6E-13	2.3E-14	2.1E-12	4.5E-14	1.2E-12	1.1E-11	1.1E-12	9.2E-11	3.5E-11	1.4E-10
Co-60	6.9E-12	9.3E-13	6.2E-12	5.2E-13	4.8E-11	1.2E-12	3.2E-11	9.1E-11	2.9E-12	3.9E-09	1.8E-10	4.3E-09
Ni-63	2.5E-13	1.4E-13	1.4E-12	2.1E-17	1.9E-16	1.8E-16	5.0E-16	1.8E-14	0.0E+00	0.0E+00	1.0E-11	1.2E-11

Table 4 continued

Radionuclide	DPURs for infant local resident family (µSv y^{-1} per Bq y^{-1})											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External from air	External from deposited	Inhalation	Total
Zn-65	5.9E-12	3.2E-12	3.0E-12	7.8E-13	7.1E-13	2.6E-12	7.2E-13	1.0E-09	6.7E-13	1.7E-10	3.5E-11	1.2E-09
Ga-67	5.3E-14	1.7E-18	2.6E-14	7.7E-17	7.1E-17	1.9E-16	5.3E-17	2.1E-14	1.6E-13	6.6E-13	5.4E-12	6.3E-12
Se-75	4.2E-12	1.1E-11	4.7E-12	2.6E-11	4.8E-10	5.1E-11	3.5E-10	2.0E-10	4.1E-13	5.9E-11	3.2E-11	1.2E-09
Br-82	4.3E-13	2.4E-14	8.5E-13	3.6E-16	3.3E-15	1.0E-15	2.8E-15	6.6E-11	3.0E-12	5.3E-12	1.6E-11	9.1E-11
Kr-79	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.8E-13	0.0E+00	0.0E+00	2.8E-13
Kr-81m	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.9E-14	0.0E+00	0.0E+00	3.9E-14
Kr-85	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.9E-15	0.0E+00	0.0E+00	5.9E-15
Kr-85m	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.7E-13	0.0E+00	0.0E+00	1.7E-13
Rb-82	nc	nc	nc	nc	nc	nc	nc	nc	9.9E-13	1.1E-14	6.5E-14	1.1E-12
Rb-83	2.1E-12	4.9E-12	2.8E-12	1.3E-12	1.2E-12	2.6E-12	7.1E-13	1.2E-10	5.4E-13	5.8E-11	2.0E-11	2.1E-10
Sr-89	3.6E-12	8.5E-14	1.4E-12	4.6E-14	4.2E-14	1.1E-13	2.9E-14	1.7E-11	1.1E-14	5.6E-15	1.3E-10	1.5E-10
Sr-90	1.0E-10	4.3E-11	5.0E-11	7.3E-13	6.7E-13	3.2E-12	8.9E-13	4.8E-10	2.4E-15	4.3E-17	5.9E-10	1.3E-09
Y-90	7.5E-13	6.8E-16	3.7E-13	1.3E-17	1.2E-16	3.4E-17	9.4E-17	1.2E-13	1.9E-14	2.2E-19	4.7E-11	4.8E-11
Zr-95	1.1E-12	2.8E-15	4.6E-13	1.1E-15	9.7E-16	1.9E-15	5.1E-16	6.7E-14	8.3E-13	1.3E-10	8.6E-11	2.2E-10
Nb-95	5.5E-13	2.8E-15	2.3E-13	1.3E-16	1.2E-16	2.6E-16	7.2E-17	3.5E-14	8.6E-13	3.6E-11	2.8E-11	6.6E-11
Mo-99	1.4E-13	1.2E-16	6.7E-14	4.7E-15	8.7E-14	1.2E-14	6.6E-14	1.1E-12	1.7E-13	5.6E-13	2.4E-11	2.6E-11
Tc-99	9.8E-11	2.4E-10	7.6E-10	2.9E-10	8.0E-10	1.5E-10	1.7E-10	4.8E-09	7.1E-16	0.0E+00	7.0E-11	7.4E-09
Tc-99m	6.1E-16	1.8E-16	1.1E-15	3.3E-17	9.2E-17	1.3E-16	1.4E-16	5.1E-14	1.3E-13	4.1E-14	5.3E-13	7.5E-13
Ru-103	8.0E-13	3.1E-15	1.7E-13	1.1E-14	9.7E-15	2.1E-14	5.8E-15	5.1E-15	5.1E-13	2.5E-11	4.5E-11	7.2E-11
Ru-106	1.1E-11	3.0E-13	2.3E-12	5.1E-13	4.7E-13	1.2E-12	3.2E-13	6.9E-14	2.6E-13	9.0E-11	5.9E-10	7.0E-10
Ag-110m	3.7E-12	1.2E-12	1.6E-12	4.1E-13	1.1E-10	8.7E-13	9.6E-11	9.8E-10	3.1E-12	8.4E-10	1.5E-10	2.2E-09
In-111	6.7E-14	1.7E-18	3.3E-14	4.1E-17	3.8E-17	1.0E-16	2.9E-17	1.1E-13	4.1E-13	1.5E-12	6.4E-12	8.5E-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	1.1E-13	8.0E-13	1.8E-13	1.7E-11	2.9E-13	8.0E-12	9.6E-13	4.6E-13	4.3E-10	8.6E-11	5.4E-10

Table 4 continued

Radionuclide	DPURs for infant local resident family ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External from air	External from deposited	Inhalation	Total
I-123	1.2E-13	1.3E-15	2.5E-13	1.4E-15	1.3E-15	8.7E-15	2.4E-15	1.0E-12	1.6E-13	1.0E-12	4.2E-12	6.8E-12
I-125	9.5E-11	2.0E-10	1.3E-10	3.2E-11	2.9E-11	4.6E-11	1.3E-11	2.4E-09	9.2E-15	7.2E-12	1.2E-10	3.1E-09
I-129	6.8E-10	1.9E-09	2.3E-09	3.7E-10	3.4E-10	4.7E-10	1.3E-10	2.2E-08	6.9E-15	1.2E-10	4.6E-10	2.9E-08
I-131	1.2E-10	7.5E-11	2.1E-10	1.8E-11	1.7E-11	4.8E-11	1.3E-11	3.6E-09	4.2E-13	3.8E-11	3.9E-10	4.5E-09
I-132	nc	nc	nc	nc	nc	nc	nc	nc	2.6E-12	2.7E-12	5.2E-12	1.0E-11
I-133	4.4E-12	1.0E-13	8.9E-12	9.6E-14	8.8E-14	5.3E-13	1.4E-13	5.7E-11	6.8E-13	6.9E-12	9.7E-11	1.8E-10
I-134	nc	nc	nc	nc	nc	nc	nc	nc	3.0E-12	1.2E-12	2.0E-12	6.2E-12
I-135	2.9E-13	1.1E-15	6.0E-13	1.1E-15	1.0E-15	7.5E-15	2.1E-15	9.5E-13	1.9E-12	6.0E-12	2.0E-11	3.0E-11
Xe-133	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.3E-14	0.0E+00	0.0E+00	3.3E-14
Cs-134	4.7E-12	1.3E-11	6.0E-12	1.1E-11	1.0E-11	1.9E-11	5.2E-12	1.2E-10	1.7E-12	1.2E-09	3.9E-11	1.5E-09
Cs-136	1.2E-12	1.2E-12	2.0E-12	1.2E-12	1.1E-12	2.0E-12	5.4E-13	2.8E-11	2.4E-12	3.8E-11	2.8E-11	1.1E-10
Cs-137	3.9E-12	1.1E-11	4.7E-12	1.0E-11	9.4E-12	1.6E-11	4.5E-12	1.0E-10	6.3E-13	2.2E-09	2.9E-11	2.4E-09
Ba-140	2.0E-12	2.5E-15	9.2E-13	3.0E-14	2.8E-14	6.4E-14	1.8E-14	7.4E-12	2.0E-13	4.2E-11	1.1E-10	1.6E-10
La-140	3.3E-13	8.1E-17	1.6E-13	6.7E-17	2.4E-15	1.8E-16	1.9E-15	4.9E-14	2.7E-12	5.1E-12	3.4E-11	4.2E-11
Ce-141	8.4E-13	2.9E-16	1.8E-13	7.4E-16	1.3E-13	1.5E-15	8.2E-14	1.1E-13	7.6E-14	3.0E-12	5.9E-11	6.3E-11
Ce-144	8.7E-12	1.8E-14	1.8E-12	3.7E-14	6.7E-12	1.0E-13	5.5E-12	1.0E-12	1.9E-14	1.6E-11	8.6E-10	9.0E-10
Pm-147	4.4E-13	9.4E-15	1.1E-13	1.5E-14	8.4E-14	6.0E-14	1.3E-13	5.5E-14	2.1E-16	3.2E-15	9.7E-11	9.8E-11
Sm-153	1.5E-13	1.3E-17	3.9E-14	7.6E-18	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	1.5E-12	8.3E-14	4.5E-13	4.5E-13	9.8E-13	2.4E-13	1.3E-12	3.1E-09	5.4E-10	3.6E-09
Eu-154	2.9E-12	1.9E-13	1.7E-12	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	1.8E-13	2.1E-14	1.2E-13	9.6E-14	2.1E-13	6.7E-14	5.3E-14	6.4E-11	1.2E-10	1.9E-10
Er-169	2.6E-13	3.9E-17	6.1E-14	7.1E-17	1.3E-14	1.6E-16	8.7E-15	4.0E-14	7.3E-16	2.7E-19	1.9E-11	1.9E-11
Lu-177	3.0E-13	3.7E-17	7.1E-14	5.8E-17	1.1E-14	1.3E-16	7.4E-15	4.7E-14	3.7E-14	3.0E-13	2.2E-11	2.3E-11
Au-198	2.7E-13	8.8E-17	6.8E-14	6.8E-14	6.2E-14	1.7E-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	4.6E-14	9.9E-15	9.0E-15	1.5E-14	4.0E-15	4.7E-13	8.0E-14	3.1E-13	1.8E-12	2.7E-12
Pb-210	1.0E-09	3.8E-10	3.3E-09	7.1E-11	1.3E-10	1.8E-10	1.0E-10	2.1E-09	1.1E-15	2.2E-12	2.0E-08	2.7E-08
Po-210	2.3E-09	5.7E-09	3.1E-09	7.7E-10	8.4E-09	8.2E-10	6.0E-09	1.1E-09	9.6E-18	1.5E-15	5.9E-08	8.7E-08
Rn-222	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.5E-16	0.0E+00	2.4E-10	2.4E-10

Table 4 continued

Radionuclide	DPURs for infant local resident family (µSv y^{-1} per Bq y^{-1})											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External from air	External from deposited	Inhalation	Total
Ra-223	1.2E-10	5.2E-14	5.4E-11	1.9E-12	1.8E-12	4.2E-12	1.1E-12	3.5E-10	2.0E-13	4.4E-12	1.1E-07	1.1E-07
Ra-226	3.0E-10	2.0E-11	1.9E-09	1.8E-11	1.7E-11	2.9E-11	7.9E-12	7.4E-10	7.0E-15	9.2E-09	5.9E-08	7.1E-08
Th-230	9.7E-11	4.0E-12	5.8E-11	3.9E-13	3.6E-12	1.4E-12	3.7E-12	3.2E-12	3.6E-16	6.8E-11	1.9E-07	1.9E-07
Th-232	1.1E-10	4.4E-12	6.4E-11	4.3E-13	4.0E-12	1.5E-12	4.1E-12	3.5E-12	1.8E-16	2.4E-08	2.7E-07	2.9E-07
Th-234	3.7E-12	5.1E-16	8.2E-13	1.2E-15	1.1E-14	2.5E-15	6.8E-15	1.3E-13	3.7E-14	5.8E-13	1.7E-10	1.7E-10
U-234	3.1E-11	2.6E-12	3.1E-11	1.0E-12	9.1E-13	1.5E-12	4.0E-13	1.4E-10	1.5E-16	4.1E-13	5.9E-08	5.9E-08
U-235	3.1E-11	2.6E-12	3.1E-11	1.0E-12	9.1E-13	1.5E-12	4.0E-13	1.4E-10	1.6E-13	7.0E-10	5.4E-08	5.5E-08
U-238	2.9E-11	2.4E-12	2.8E-11	9.2E-13	8.4E-13	1.4E-12	3.7E-13	1.3E-10	6.1E-17	1.1E-10	5.0E-08	5.1E-08
Np-237	5.2E-11	4.1E-12	8.9E-11	4.1E-13	2.7E-11	2.0E-12	6.7E-11	1.1E-12	2.2E-14	1.0E-09	2.1E-07	2.2E-07
Pu-238	9.4E-11	3.3E-13	2.2E-11	6.4E-13	4.2E-11	2.6E-12	8.8E-11	1.5E-12	8.6E-17	1.5E-13	4.0E-07	4.0E-07
Pu-239	9.8E-11	4.1E-13	2.3E-11	6.9E-13	4.5E-11	2.8E-12	9.6E-11	1.6E-12	8.6E-17	2.4E-13	4.1E-07	4.1E-07
Pu-240	9.8E-11	4.1E-13	2.3E-11	6.9E-13	4.5E-11	2.8E-12	9.6E-11	1.6E-12	8.4E-17	1.9E-13	4.1E-07	4.1E-07
Pu-241	1.3E-12	2.3E-15	2.8E-13	8.5E-15	5.5E-13	3.1E-14	1.1E-12	1.8E-14	1.6E-18	5.5E-13	5.2E-09	5.2E-09
Pu-242	9.4E-11	3.9E-13	2.2E-11	6.6E-13	4.3E-11	2.7E-12	9.1E-11	1.6E-12	7.1E-17	3.0E-12	3.9E-07	3.9E-07
Am-241	8.7E-11	5.6E-13	2.5E-11	6.1E-13	4.0E-11	3.0E-12	1.0E-10	1.8E-12	1.7E-14	4.6E-11	3.7E-07	3.7E-07
Am-242	2.3E-14	1.4E-19	6.0E-15	8.9E-19	2.3E-17	1.9E-18	2.6E-17	2.7E-18	1.5E-14	1.1E-14	3.2E-10	3.2E-10
Am-243	8.7E-11	5.8E-13	2.6E-11	6.2E-13	4.0E-11	3.1E-12	1.0E-10	1.8E-12	4.5E-14	8.3E-10	3.6E-07	3.7E-07
Cm-242	1.6E-11	6.0E-16	3.4E-12	3.8E-14	2.4E-12	6.5E-14	2.1E-12	3.8E-14	9.9E-17	2.3E-14	9.7E-08	9.7E-08
Cm-243	7.7E-11	9.6E-14	1.8E-11	5.1E-13	3.3E-11	2.0E-12	6.6E-11	1.1E-12	1.3E-13	3.9E-10	3.3E-07	3.3E-07
Cm-244	6.8E-11	8.0E-14	1.6E-11	4.4E-13	2.9E-11	1.7E-12	5.7E-11	9.8E-13	8.4E-17	6.4E-13	3.1E-07	3.1E-07

nc = not considered due to short half-life

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

Radionuclide	DPURs for child local resident family (µSv y^{-1} per Bq y^{-1})											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External from air	External from deposited	Inhalation	Total
H-3	1.3E-14	3.0E-14	1.6E-14	2.8E-15	1.4E-15	8.4E-15	1.4E-15	8.7E-14	0.0E+00	0.0E+00	3.6E-13	5.2E-13
H-3 organic	3.1E-14	7.5E-14	4.0E-14	6.9E-15	3.5E-15	2.1E-14	3.5E-15	2.2E-13	0.0E+00	0.0E+00	8.6E-13	1.3E-12
C-11	nc	nc	nc	nc	nc	nc	nc	nc	1.4E-12	0.0E+00	4.9E-13	1.9E-12
C-14	1.0E-12	5.6E-12	3.0E-12	8.9E-13	4.5E-13	2.7E-12	4.5E-13	7.1E-12	8.2E-17	0.0E+00	4.4E-11	6.5E-11
N-13	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.4E-12	0.0E+00	0.0E+00	1.4E-12
O-15	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.3E-12	0.0E+00	0.0E+00	1.3E-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	4.2E-12	1.0E-11	3.0E-12	1.5E-11	7.6E-12	2.6E-11	4.3E-12	4.1E-11	3.2E-12	3.1E-09	3.7E-11	3.2E-09
Na-24	1.8E-14	2.6E-16	2.3E-14	2.6E-15	1.3E-15	1.4E-15	2.3E-16	3.1E-14	6.6E-12	4.6E-12	8.9E-12	2.0E-11
P-32	1.7E-12	3.8E-11	1.6E-12	8.3E-12	1.6E-12	9.9E-12	1.7E-12	9.4E-11	1.7E-14	0.0E+00	8.3E-11	2.4E-10
P-33	2.3E-13	3.5E-13	2.0E-13	2.0E-13	3.9E-14	2.3E-13	3.8E-14	1.3E-12	4.6E-16	0.0E+00	3.3E-11	3.5E-11
S-35	1.7E-13	3.7E-13	1.3E-13	6.0E-12	1.2E-12	7.6E-12	1.3E-12	9.4E-12	9.8E-17	0.0E+00	3.1E-11	5.7E-11
Cl-36	9.1E-11	2.0E-10	6.8E-12	5.9E-11	3.0E-11	1.5E-10	2.5E-11	2.3E-10	5.2E-15	1.2E-12	1.6E-10	9.5E-10
Ar-41	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.9E-12	0.0E+00	0.0E+00	1.9E-12
Ca-45	1.2E-12	7.3E-14	2.3E-13	2.4E-14	1.2E-14	5.5E-14	9.2E-15	2.1E-12	4.8E-16	1.3E-19	6.1E-11	6.5E-11
Ca-47	4.1E-13	2.7E-15	1.2E-13	2.9E-15	1.5E-15	8.2E-15	1.4E-15	4.9E-13	1.6E-12	9.4E-12	4.5E-11	5.7E-11
V-48	1.2E-12	2.7E-15	3.2E-13	2.2E-16	1.1E-16	4.2E-16	7.0E-17	2.6E-14	4.3E-12	9.3E-11	6.7E-11	1.7E-10
Cr-51	2.8E-14	2.4E-18	3.8E-15	9.8E-15	4.9E-15	1.7E-14	2.9E-15	1.2E-13	4.4E-14	1.8E-12	1.0E-12	3.0E-12
Mn-52	5.4E-13	5.5E-15	1.6E-13	8.3E-14	1.5E-12	1.8E-13	1.0E-12	4.2E-12	5.1E-12	3.8E-11	3.7E-11	8.9E-11
Mn-54	7.7E-13	1.4E-13	2.1E-13	6.4E-13	1.2E-11	1.1E-12	7.3E-12	5.8E-12	1.2E-12	4.6E-10	3.7E-11	5.3E-10
Mn-56	nc	nc	nc	nc	nc	nc	nc	nc	2.6E-12	3.5E-13	3.7E-12	6.7E-12
Fe-55	6.3E-13	3.8E-15	1.5E-13	1.1E-14	1.7E-11	3.6E-14	2.4E-11	3.5E-13	0.0E+00	4.0E-15	9.7E-12	5.2E-11
Fe-59	2.0E-12	3.7E-15	5.1E-13	6.4E-15	9.5E-12	1.2E-14	7.7E-12	1.2E-12	1.8E-12	1.0E-10	8.6E-11	2.1E-10
Co-56	2.8E-12	2.3E-14	6.9E-13	1.1E-13	5.4E-12	2.0E-13	3.3E-12	1.1E-11	5.5E-12	5.2E-10	1.2E-10	6.6E-10
Co-57	3.2E-13	6.6E-15	7.7E-14	2.2E-14	1.1E-12	4.2E-14	7.0E-13	1.2E-12	1.6E-13	5.3E-11	1.3E-11	7.0E-11
Co-58	8.1E-13	6.1E-15	2.0E-13	2.9E-14	1.5E-12	5.3E-14	8.8E-13	3.1E-12	1.4E-12	1.4E-10	3.7E-11	1.8E-10
Co-60	6.6E-12	8.0E-13	3.6E-12	7.1E-13	3.6E-11	1.4E-12	2.4E-11	2.8E-11	3.8E-12	5.8E-09	2.3E-10	6.1E-09
Ni-63	2.0E-13	9.9E-14	6.5E-13	2.3E-17	1.1E-16	1.8E-16	3.0E-16	4.4E-15	0.0E+00	0.0E+00	1.1E-11	1.2E-11

Table 5 continued

Radionuclide	DPURs for child local resident family (µSv y^{-1} per Bq y^{-1})											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External from air	External from deposited	Inhalation	Total
Zn-65	5.5E-12	2.7E-12	1.7E-12	1.0E-12	5.2E-13	3.1E-12	5.2E-13	3.0E-10	8.6E-13	2.5E-10	3.7E-11	6.1E-10
Ga-67	4.1E-14	1.2E-18	1.2E-14	8.6E-17	4.3E-17	1.9E-16	3.2E-17	5.4E-15	2.1E-13	9.7E-13	5.6E-12	6.9E-12
Se-75	4.5E-12	1.0E-11	3.1E-12	4.0E-11	4.0E-10	7.1E-11	2.9E-10	7.0E-11	5.3E-13	8.7E-11	3.9E-11	1.0E-09
Br-82	3.6E-13	1.8E-14	4.4E-13	4.4E-16	2.2E-15	1.1E-15	1.9E-15	1.8E-11	3.8E-12	7.8E-12	1.7E-11	4.8E-11
Kr-79	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.5E-13	0.0E+00	0.0E+00	3.5E-13
Kr-81m	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.0E-14	0.0E+00	0.0E+00	5.0E-14
Kr-85	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.6E-15	0.0E+00	0.0E+00	7.6E-15
Kr-85m	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.2E-13	0.0E+00	0.0E+00	2.2E-13
Rb-82	nc	nc	nc	nc	nc	nc	nc	nc	1.3E-12	1.7E-14	5.0E-14	1.3E-12
Rb-83	1.9E-12	3.9E-12	1.5E-12	1.7E-12	8.5E-13	3.0E-12	4.9E-13	3.4E-11	7.0E-13	8.5E-11	2.0E-11	1.5E-10
Sr-89	2.7E-12	5.8E-14	6.5E-13	4.9E-14	2.4E-14	1.0E-13	1.7E-14	4.1E-12	1.4E-14	8.2E-15	1.4E-10	1.5E-10
Sr-90	1.9E-10	7.5E-11	5.9E-11	2.0E-12	1.0E-12	8.0E-12	1.3E-12	3.0E-10	3.1E-15	6.3E-17	8.0E-10	1.4E-09
Y-90	5.2E-13	4.2E-16	1.6E-13	1.3E-17	6.6E-17	3.0E-17	5.0E-17	2.7E-14	2.5E-14	3.2E-19	4.2E-11	4.3E-11
Zr-95	8.9E-13	2.0E-15	2.2E-13	1.2E-15	6.0E-16	1.9E-15	3.2E-16	1.7E-14	1.1E-12	1.9E-10	1.1E-10	3.0E-10
Nb-95	4.4E-13	2.0E-15	1.1E-13	1.5E-16	7.6E-17	2.7E-16	4.5E-17	9.0E-15	1.1E-12	5.3E-11	3.4E-11	8.9E-11
Mo-99	1.0E-13	8.2E-17	3.0E-14	5.0E-15	4.9E-14	1.1E-14	3.8E-14	2.6E-13	2.2E-13	8.3E-13	2.3E-11	2.5E-11
Tc-99	6.2E-11	1.4E-10	2.9E-10	2.6E-10	4.0E-10	1.2E-10	8.2E-11	9.8E-10	9.1E-16	0.0E+00	8.9E-11	2.4E-09
Tc-99m	4.7E-16	1.3E-16	5.2E-16	3.7E-17	5.5E-17	1.2E-16	8.3E-17	1.3E-14	1.7E-13	6.0E-14	5.3E-13	7.7E-13
Ru-103	6.1E-13	2.1E-15	8.0E-14	1.1E-14	5.7E-15	2.1E-14	3.4E-15	1.3E-15	6.6E-13	3.7E-11	5.5E-11	9.3E-11
Ru-106	8.0E-12	2.0E-13	9.9E-13	5.2E-13	2.6E-13	1.1E-12	1.8E-13	1.6E-14	3.4E-13	1.3E-10	6.4E-10	7.8E-10
Ag-110m	3.2E-12	9.1E-13	8.5E-13	5.1E-13	7.6E-11	9.7E-13	6.5E-11	2.7E-10	4.0E-12	1.2E-09	1.9E-10	1.8E-09
In-111	5.4E-14	1.3E-18	1.6E-14	4.8E-17	2.4E-17	1.1E-16	1.8E-17	2.8E-14	5.3E-13	2.2E-12	6.4E-12	9.2E-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	8.2E-14	4.0E-13	2.1E-13	1.0E-11	3.0E-13	5.0E-12	2.5E-13	5.9E-13	6.3E-10	1.1E-10	7.5E-10

Table 5 continued

Radionuclide	DPURs for child local resident family ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External from air	External from deposited	Inhalation	Total
I-123	7.4E-14	7.0E-16	9.2E-14	1.2E-15	6.2E-16	6.7E-15	1.1E-15	1.9E-13	2.1E-13	1.5E-12	2.8E-12	4.9E-12
I-125	1.2E-10	2.3E-10	1.0E-10	5.7E-11	2.9E-11	7.5E-11	1.2E-11	9.8E-10	1.2E-14	1.1E-11	1.7E-10	1.8E-09
I-129	1.4E-09	3.5E-09	2.9E-09	1.1E-09	5.3E-10	1.2E-09	2.0E-10	1.4E-08	8.9E-15	1.8E-10	1.0E-09	2.6E-08
I-131	8.1E-11	4.6E-11	8.7E-11	1.8E-11	8.9E-12	4.1E-11	6.9E-12	7.8E-10	5.3E-13	5.6E-11	3.0E-10	1.4E-09
I-132	nc	nc	nc	nc	nc	nc	nc	nc	3.3E-12	4.0E-12	3.4E-12	1.1E-11
I-133	2.3E-12	4.8E-14	2.9E-12	7.3E-14	3.7E-14	3.6E-13	6.0E-14	9.8E-12	8.7E-13	1.0E-11	5.9E-11	8.6E-11
I-134	nc	nc	nc	nc	nc	nc	nc	nc	3.9E-12	1.7E-12	1.5E-12	7.1E-12
I-135	1.7E-13	5.8E-16	2.1E-13	9.0E-16	4.5E-16	5.6E-15	9.3E-16	1.8E-13	2.4E-12	8.8E-12	1.2E-11	2.4E-11
Xe-133	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.2E-14	0.0E+00	0.0E+00	4.2E-14
Cs-134	9.5E-12	2.4E-11	7.5E-12	3.2E-11	1.6E-11	5.0E-11	8.3E-12	7.9E-11	2.2E-12	1.8E-09	8.3E-11	2.1E-09
Cs-136	1.3E-12	1.2E-12	1.3E-12	1.8E-12	9.2E-13	2.7E-12	4.5E-13	9.9E-12	3.1E-12	5.6E-11	3.1E-11	1.1E-10
Cs-137	7.5E-12	1.9E-11	5.6E-12	2.8E-11	1.4E-11	4.1E-11	6.8E-12	6.4E-11	8.1E-13	3.3E-09	5.8E-11	3.6E-09
Ba-140	1.5E-12	1.7E-15	4.2E-13	3.3E-14	1.6E-14	6.2E-14	1.0E-14	1.8E-12	2.6E-13	6.1E-11	1.2E-10	1.8E-10
La-140	2.5E-13	5.5E-17	7.6E-14	7.2E-17	1.4E-15	1.7E-16	1.1E-15	1.2E-14	3.5E-12	7.5E-12	3.1E-11	4.3E-11
Ce-141	5.7E-13	1.8E-16	7.6E-14	7.2E-16	7.2E-14	1.3E-15	4.4E-14	2.4E-14	9.8E-14	4.4E-12	7.2E-11	7.7E-11
Ce-144	5.7E-12	1.1E-14	7.2E-13	3.5E-14	3.5E-12	8.5E-14	2.8E-12	2.2E-13	2.4E-14	2.4E-11	8.6E-10	9.0E-10
Pm-147	3.1E-13	6.0E-15	4.7E-14	1.5E-14	4.6E-14	5.4E-14	7.2E-14	1.2E-14	2.7E-16	4.8E-15	1.1E-10	1.1E-10
Sm-153	1.1E-13	8.0E-18	1.6E-14	7.5E-18	7.5E-16	1.8E-17	5.9E-16	5.3E-15	6.4E-14	1.8E-13	1.6E-11	1.6E-11
Eu-152	1.5E-12	1.2E-13	7.6E-13	9.7E-14	2.9E-13	4.7E-13	6.3E-13	6.3E-14	1.7E-12	4.6E-09	7.7E-10	5.3E-09
Eu-154	2.3E-12	1.4E-13	8.3E-13	1.4E-13	4.3E-13	6.7E-13	8.8E-13	9.6E-14	1.8E-12	4.0E-09	1.0E-09	5.0E-09
Eu-155	3.7E-13	1.3E-14	8.1E-14	2.2E-14	6.5E-14	8.9E-14	1.2E-13	1.5E-14	6.8E-14	9.5E-11	1.4E-10	2.4E-10
Er-169	1.8E-13	2.4E-17	2.6E-14	7.0E-17	7.0E-15	1.4E-16	4.6E-15	8.8E-15	9.4E-16	4.1E-19	2.3E-11	2.4E-11
Lu-177	2.1E-13	2.4E-17	3.1E-14	6.0E-17	6.0E-15	1.2E-16	4.1E-15	1.1E-14	4.7E-14	4.5E-13	2.7E-11	2.7E-11
Au-198	1.9E-13	5.7E-17	3.0E-14	6.9E-14	3.5E-14	1.6E-13	2.7E-14	2.9E-15	5.7E-13	2.2E-12	2.2E-11	2.5E-11
Tl-201	1.8E-14	2.9E-15	2.1E-14	1.1E-14	5.4E-15	1.4E-14	2.4E-15	1.2E-13	1.0E-13	4.5E-13	1.5E-12	2.2E-12
Pb-210	1.2E-09	4.2E-10	2.5E-09	1.2E-10	1.3E-10	2.9E-10	9.7E-11	8.3E-10	1.4E-15	3.2E-12	2.3E-08	2.9E-08
Po-210	1.6E-09	3.6E-09	1.3E-09	7.5E-10	4.5E-09	7.2E-10	3.2E-09	2.5E-10	1.2E-17	2.2E-15	7.2E-08	8.8E-08
Rn-222	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.7E-16	0.0E+00	1.9E-10	1.9E-10

Table 5 continued

Radionuclide	DPURs for child local resident family (μSv y^{-1} per Bq y^{-1})											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External from air	External from deposited	Inhalation	Total
Ra-223	1.1E-10	4.5E-14	3.1E-11	2.6E-12	1.3E-12	5.1E-12	8.5E-13	1.1E-10	2.5E-13	6.4E-12	1.5E-07	1.5E-07
Ra-226	5.8E-10	3.5E-11	2.2E-09	5.0E-11	2.5E-11	7.1E-11	1.2E-11	4.7E-10	9.0E-15	1.4E-08	7.7E-08	9.3E-08
Th-230	1.3E-10	5.0E-12	4.9E-11	7.7E-13	3.8E-12	2.4E-12	4.0E-12	1.4E-12	4.7E-16	1.0E-10	2.5E-07	2.5E-07
Th-232	1.6E-10	6.0E-12	5.9E-11	9.3E-13	4.6E-12	2.9E-12	4.8E-12	1.7E-12	2.3E-16	3.5E-08	4.1E-07	4.4E-07
Th-234	2.6E-12	3.2E-16	3.5E-13	1.2E-15	6.0E-15	2.2E-15	3.7E-15	2.8E-14	4.7E-14	8.6E-13	1.7E-10	1.8E-10
U-234	4.2E-11	3.1E-12	2.5E-11	1.9E-12	9.5E-13	2.5E-12	4.2E-13	6.0E-11	1.9E-16	6.0E-13	7.5E-08	7.5E-08
U-235	4.0E-11	2.9E-12	2.4E-11	1.8E-12	9.1E-13	2.4E-12	4.0E-13	5.8E-11	2.0E-13	1.0E-09	6.7E-08	6.8E-08
U-238	3.8E-11	2.8E-12	2.3E-11	1.7E-12	8.7E-13	2.3E-12	3.8E-13	5.6E-11	7.9E-17	1.6E-10	6.2E-08	6.3E-08
Np-237	6.4E-11	4.6E-12	6.7E-11	7.1E-13	2.5E-11	3.1E-12	6.4E-11	4.5E-13	2.8E-14	1.5E-09	3.4E-07	3.5E-07
Pu-238	1.3E-10	4.2E-13	1.9E-11	1.3E-12	4.6E-11	4.7E-12	9.6E-11	6.8E-13	1.1E-16	2.2E-13	6.9E-07	6.9E-07
Pu-239	1.5E-10	5.6E-13	2.1E-11	1.5E-12	5.3E-11	5.5E-12	1.1E-10	7.9E-13	1.1E-16	3.6E-13	7.5E-07	7.5E-07
Pu-240	1.5E-10	5.6E-13	2.1E-11	1.5E-12	5.3E-11	5.5E-12	1.1E-10	7.9E-13	1.1E-16	2.8E-13	7.5E-07	7.5E-07
Pu-241	2.8E-12	4.3E-15	3.6E-13	2.5E-14	9.0E-13	8.4E-14	1.7E-12	1.2E-14	2.0E-18	8.1E-13	1.3E-08	1.3E-08
Pu-242	1.4E-10	5.4E-13	2.1E-11	1.4E-12	5.1E-11	5.3E-12	1.1E-10	7.6E-13	9.2E-17	4.4E-12	7.0E-07	7.0E-07
Am-241	1.2E-10	7.1E-13	2.1E-11	1.2E-12	4.3E-11	5.4E-12	1.1E-10	7.8E-13	2.1E-14	6.8E-11	6.2E-07	6.2E-07
Am-242	1.6E-14	8.3E-20	2.5E-15	8.7E-19	1.2E-17	1.7E-18	1.4E-17	5.8E-19	1.9E-14	1.6E-14	3.7E-10	3.7E-10
Am-243	1.2E-10	7.3E-13	2.2E-11	1.2E-12	4.4E-11	5.4E-12	1.1E-10	7.9E-13	5.8E-14	1.2E-09	6.2E-07	6.3E-07
Cm-242	1.2E-11	4.0E-16	1.5E-12	4.0E-14	1.4E-12	6.1E-14	1.2E-12	8.9E-15	1.3E-16	3.4E-14	1.1E-07	1.1E-07
Cm-243	8.7E-11	9.9E-14	1.3E-11	8.2E-13	2.9E-11	2.8E-12	5.8E-11	4.1E-13	1.7E-13	5.7E-10	4.8E-07	4.8E-07
Cm-244	7.7E-11	8.2E-14	1.1E-11	7.1E-13	2.6E-11	2.5E-12	5.0E-11	3.6E-13	1.1E-16	9.4E-13	4.2E-07	4.2E-07

nc = not considered due to short half-life

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

Radionuclide	DPURs for adult local resident family (µSv y^{-1} per Bq y^{-1})											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External from air	External from deposited	Inhalation	Total
H-3	2.3E-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	4.0E-13	5.7E-13
H-3 organic	5.3E-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	9.2E-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	1.7E-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	4.5E-11	6.6E-11
N-13	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.4E-12	0.0E+00	0.0E+00	2.4E-12
O-15	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.1E-12	0.0E+00	0.0E+00	2.1E-12
F-18	nc	nc	nc	nc	nc	nc	nc	nc	2.4E-12	3.2E-13	1.3E-12	4.0E-12
Na-22	5.5E-12	8.2E-12	2.6E-12	2.2E-11	8.8E-12	2.3E-11	5.0E-12	2.4E-11	5.4E-12	6.0E-09	2.9E-11	6.1E-09
Na-24	2.3E-14	2.0E-16	1.9E-14	3.7E-15	1.5E-15	1.2E-15	2.6E-16	1.7E-14	1.1E-11	9.1E-12	6.1E-12	2.6E-11
P-32	1.8E-12	2.4E-11	1.1E-12	9.4E-12	1.5E-12	6.7E-12	1.5E-12	4.2E-11	2.8E-14	0.0E+00	7.6E-11	1.6E-10
P-33	2.4E-13	2.2E-13	1.4E-13	2.2E-13	3.6E-14	1.6E-13	3.5E-14	5.8E-13	7.6E-16	0.0E+00	3.4E-11	3.5E-11
S-35	1.9E-13	2.5E-13	9.5E-14	7.3E-12	1.2E-12	5.5E-12	1.2E-12	4.5E-12	1.6E-16	0.0E+00	3.1E-11	5.2E-11
Cl-36	1.0E-10	1.3E-10	5.0E-12	7.3E-11	2.9E-11	1.1E-10	2.4E-11	1.1E-10	8.7E-15	2.3E-12	1.6E-10	7.6E-10
Ar-41	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.2E-12	0.0E+00	0.0E+00	3.2E-12
Ca-45	1.1E-12	4.0E-14	1.4E-13	2.4E-14	9.4E-15	3.3E-14	7.3E-15	8.3E-13	8.1E-16	2.5E-19	6.1E-11	6.3E-11
Ca-47	5.0E-13	2.0E-15	9.5E-14	3.9E-15	1.6E-15	6.5E-15	1.5E-15	2.6E-13	2.7E-12	1.9E-11	4.3E-11	6.5E-11
V-48	1.4E-12	1.9E-15	2.4E-13	2.9E-16	1.2E-16	3.2E-16	7.2E-17	1.3E-14	7.2E-12	1.8E-10	5.4E-11	2.5E-10
Cr-51	3.2E-14	1.6E-18	2.8E-15	1.2E-14	4.8E-15	1.3E-14	2.8E-15	5.9E-14	7.3E-14	3.4E-12	8.3E-13	4.5E-12
Mn-52	6.5E-13	4.0E-15	1.2E-13	1.1E-13	1.6E-12	1.4E-13	1.1E-12	2.2E-12	8.5E-12	7.5E-11	3.1E-11	1.2E-10
Mn-54	9.6E-13	1.1E-13	1.7E-13	8.7E-13	1.4E-11	9.1E-13	8.0E-12	3.2E-12	2.0E-12	9.1E-10	3.4E-11	9.7E-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	4.3E-13	1.6E-15	6.7E-14	8.4E-15	1.0E-11	1.6E-14	1.4E-11	1.1E-13	0.0E+00	7.8E-15	8.5E-12	3.4E-11
Fe-59	1.8E-12	1.9E-15	3.0E-13	6.1E-15	7.3E-12	6.6E-15	5.9E-12	4.6E-13	3.0E-12	2.0E-10	8.3E-11	3.0E-10
Co-56	2.8E-12	1.4E-14	4.5E-13	1.2E-13	4.7E-12	1.3E-13	2.8E-12	4.6E-12	9.1E-12	1.0E-09	1.1E-10	1.1E-09
Co-57	2.6E-13	3.3E-15	4.2E-14	2.0E-14	7.9E-13	2.3E-14	5.1E-13	4.3E-13	2.6E-13	1.0E-10	1.2E-11	1.2E-10
Co-58	8.1E-13	3.7E-15	1.3E-13	3.2E-14	1.3E-12	3.4E-14	7.6E-13	1.4E-12	2.3E-12	2.7E-10	3.6E-11	3.1E-10
Co-60	4.7E-12	3.4E-13	1.7E-12	5.5E-13	2.2E-11	6.6E-13	1.5E-11	8.6E-12	6.3E-12	1.1E-08	2.2E-10	1.2E-08
Ni-63	2.4E-13	7.3E-14	5.2E-13	3.1E-17	1.2E-16	1.5E-16	3.2E-16	2.4E-15	0.0E+00	0.0E+00	1.1E-11	1.2E-11

Table 6 continued

Radionuclide	DPURs for adult local resident family (µSv y^{-1} per Bq y^{-1})											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External from air	External from deposited	Inhalation	Total
Zn-65	7.6E-12	2.3E-12	1.6E-12	1.6E-12	6.3E-13	2.9E-12	6.4E-13	1.8E-10	1.4E-12	5.0E-10	3.6E-11	7.4E-10
Ga-67	4.5E-14	7.6E-19	8.9E-15	1.0E-16	4.1E-17	1.4E-16	3.1E-17	2.6E-15	3.4E-13	1.9E-12	5.4E-12	7.7E-12
Se-75	4.5E-12	6.1E-12	2.0E-12	4.4E-11	3.5E-10	4.6E-11	2.6E-10	3.0E-11	8.9E-13	1.7E-10	2.2E-11	9.3E-10
Br-82	4.7E-13	1.4E-14	3.8E-13	6.3E-16	2.5E-15	9.7E-16	2.1E-15	1.0E-11	6.4E-12	1.5E-11	1.4E-11	4.7E-11
Kr-79	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.9E-13	0.0E+00	0.0E+00	5.9E-13
Kr-81m	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	8.3E-14	0.0E+00	0.0E+00	8.3E-14
Kr-85	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.3E-14	0.0E+00	0.0E+00	1.3E-14
Kr-85m	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.6E-13	0.0E+00	0.0E+00	3.6E-13
Rb-82	nc	nc	nc	nc	nc	nc	nc	nc	2.1E-12	3.2E-14	3.6E-14	2.2E-12
Rb-83	2.5E-12	3.2E-12	1.4E-12	2.5E-12	1.0E-12	2.6E-12	5.8E-13	2.0E-11	1.2E-12	1.7E-10	1.5E-11	2.2E-10
Sr-89	2.8E-12	3.5E-14	4.4E-13	5.5E-14	2.2E-14	7.0E-14	1.5E-14	1.8E-12	2.3E-14	1.6E-14	1.4E-10	1.4E-10
Sr-90	2.1E-10	4.8E-11	4.1E-11	2.3E-12	9.3E-13	5.6E-12	1.2E-12	1.4E-10	5.2E-15	1.2E-16	8.1E-10	1.3E-09
Y-90	5.4E-13	2.7E-16	1.1E-13	1.5E-17	6.0E-17	2.1E-17	4.6E-17	1.2E-14	4.2E-14	6.3E-19	3.4E-11	3.4E-11
Zr-95	1.0E-12	1.4E-15	1.7E-13	1.5E-15	6.0E-16	1.4E-15	3.2E-16	8.5E-15	1.8E-12	3.7E-10	1.1E-10	4.8E-10
Nb-95	5.4E-13	1.5E-15	9.1E-14	2.0E-16	8.0E-17	2.1E-16	4.7E-17	4.7E-15	1.8E-12	1.1E-10	3.4E-11	1.4E-10
Mo-99	1.2E-13	6.1E-17	2.5E-14	6.8E-15	5.4E-14	9.3E-15	4.1E-14	1.4E-13	3.7E-13	1.6E-12	2.0E-11	2.2E-11
Tc-99	7.0E-11	9.3E-11	2.2E-10	3.2E-10	3.9E-10	9.1E-11	8.1E-11	4.8E-10	1.5E-15	0.0E+00	9.0E-11	1.8E-09
Tc-99m	5.5E-16	8.8E-17	4.0E-16	4.7E-17	5.7E-17	9.5E-17	8.5E-17	6.4E-15	2.8E-13	1.2E-13	4.3E-13	8.3E-13
Ru-103	6.7E-13	1.4E-15	5.8E-14	1.4E-14	5.6E-15	1.5E-14	3.3E-15	6.1E-16	1.1E-12	7.3E-11	5.4E-11	1.3E-10
Ru-106	8.5E-12	1.2E-13	7.0E-13	6.1E-13	2.4E-13	7.5E-13	1.7E-13	7.4E-15	5.6E-13	2.6E-10	6.3E-10	9.0E-10
Ag-110m	3.9E-12	6.7E-13	6.8E-13	6.9E-13	8.2E-11	7.8E-13	7.0E-11	1.5E-10	6.7E-12	2.4E-09	1.7E-10	2.9E-09
In-111	6.1E-14	8.4E-19	1.2E-14	5.8E-17	2.3E-17	8.0E-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	1.5E-12	5.9E-14	3.1E-13	2.7E-13	1.1E-11	2.4E-13	5.2E-12	1.3E-13	9.9E-13	1.2E-09	1.1E-10	1.4E-09

Table 6 continued

Radionuclide	DPURs for adult local resident family ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External from air	External from deposited	Inhalation	Total
I-123	7.2E-14	4.1E-16	5.9E-14	1.3E-15	5.3E-16	4.3E-15	9.6E-16	8.3E-14	3.4E-13	2.9E-12	1.7E-12	5.1E-12
I-125	1.3E-10	1.5E-10	7.5E-11	6.9E-11	2.8E-11	5.4E-11	1.2E-11	4.7E-10	2.0E-14	2.1E-11	1.1E-10	1.1E-09
I-129	1.8E-09	2.8E-09	2.5E-09	1.5E-09	6.2E-10	1.1E-09	2.3E-10	8.3E-09	1.5E-14	3.6E-10	8.1E-10	2.0E-08
I-131	7.8E-11	2.7E-11	5.5E-11	1.9E-11	7.5E-12	2.6E-11	5.8E-12	3.3E-10	8.9E-13	1.1E-10	1.7E-10	8.3E-10
I-132	nc	nc	nc	nc	nc	nc	nc	nc	5.5E-12	7.8E-12	2.1E-12	1.5E-11
I-133	2.3E-12	2.8E-14	1.9E-12	7.9E-14	3.1E-14	2.3E-13	5.1E-14	4.2E-12	1.5E-12	2.0E-11	3.4E-11	6.4E-11
I-134	nc	nc	nc	nc	nc	nc	nc	nc	6.4E-12	3.4E-12	1.0E-12	1.1E-11
I-135	1.6E-13	3.3E-16	1.3E-13	9.6E-16	3.8E-16	3.5E-15	7.8E-16	7.4E-14	4.0E-12	1.7E-11	7.2E-12	2.9E-11
Xe-133	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.0E-14	0.0E+00	0.0E+00	7.0E-14
Cs-134	3.0E-11	4.4E-11	1.5E-11	1.1E-10	4.4E-11	1.0E-10	2.2E-11	1.1E-10	3.7E-12	3.6E-09	1.5E-10	4.2E-09
Cs-136	2.0E-12	1.1E-12	1.3E-12	3.1E-12	1.3E-12	2.8E-12	6.2E-13	6.7E-12	5.2E-12	1.1E-10	2.7E-11	1.6E-10
Cs-137	2.2E-11	3.4E-11	1.1E-11	9.2E-11	3.7E-11	8.0E-11	1.8E-11	8.3E-11	1.3E-12	6.5E-09	1.0E-10	7.0E-09
Ba-140	1.6E-12	1.0E-15	2.9E-13	3.6E-14	1.5E-14	4.2E-14	9.3E-15	8.0E-13	4.3E-13	1.2E-10	1.1E-10	2.4E-10
La-140	2.7E-13	3.6E-17	5.4E-14	8.6E-17	1.4E-15	1.2E-16	1.1E-15	5.7E-15	5.8E-12	1.5E-11	2.5E-11	4.6E-11
Ce-141	6.2E-13	1.2E-16	5.4E-14	8.6E-16	6.8E-14	9.3E-16	4.1E-14	1.1E-14	1.6E-13	8.7E-12	7.2E-11	8.2E-11
Ce-144	6.2E-12	7.1E-15	5.1E-13	4.1E-14	3.3E-12	6.0E-14	2.7E-12	1.0E-13	4.0E-14	4.7E-11	8.1E-10	8.7E-10
Pm-147	3.2E-13	3.7E-15	3.2E-14	1.7E-14	4.2E-14	3.7E-14	6.5E-14	5.7E-15	4.6E-16	9.4E-15	1.1E-10	1.1E-10
Sm-153	1.1E-13	5.1E-18	1.1E-14	8.7E-18	6.9E-16	1.2E-17	5.5E-16	2.5E-15	1.1E-13	3.5E-13	1.4E-11	1.5E-11
Eu-152	1.8E-12	9.1E-14	6.2E-13	1.3E-13	3.1E-13	3.8E-13	6.7E-13	3.4E-14	2.8E-12	9.0E-09	9.4E-10	9.9E-09
Eu-154	2.5E-12	9.2E-14	6.0E-13	1.8E-13	4.2E-13	4.9E-13	8.6E-13	4.7E-14	3.0E-12	7.8E-09	1.2E-09	9.0E-09
Eu-155	4.0E-13	8.7E-15	5.7E-14	2.5E-14	6.1E-14	6.3E-14	1.1E-13	7.3E-15	1.1E-13	1.9E-10	1.5E-10	3.4E-10
Er-169	1.8E-13	1.5E-17	1.7E-14	7.8E-17	6.3E-15	9.4E-17	4.2E-15	4.0E-15	1.6E-15	8.0E-19	2.2E-11	2.3E-11
Lu-177	2.2E-13	1.4E-17	2.1E-14	6.6E-17	5.3E-15	8.2E-17	3.6E-15	4.8E-15	7.9E-14	8.7E-13	2.7E-11	2.8E-11
Au-198	2.0E-13	3.5E-17	2.0E-14	7.9E-14	3.2E-14	1.1E-13	2.4E-14	1.3E-15	9.5E-13	4.4E-12	1.9E-11	2.5E-11
Tl-201	2.2E-14	2.1E-15	1.7E-14	1.4E-14	5.7E-15	1.1E-14	2.5E-15	6.1E-14	1.7E-13	8.9E-13	9.9E-13	2.2E-12
Pb-210	1.0E-09	2.1E-10	1.4E-09	1.1E-10	9.1E-11	1.6E-10	7.0E-11	3.0E-10	2.4E-15	6.3E-12	2.5E-08	2.8E-08
Po-210	1.7E-09	2.3E-09	9.1E-10	8.7E-10	4.2E-09	5.0E-10	3.0E-09	1.2E-10	2.0E-17	4.4E-15	7.4E-08	8.8E-08
Rn-222	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.5E-16	0.0E+00	1.3E-10	1.3E-10

Table 6 continued

Radionuclide	DPURs for adult local resident family (μSv y^{-1} per Bq y^{-1})											
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External from air	External from deposited	Inhalation	Total
Ra-223	5.7E-11	1.4E-14	1.0E-11	1.5E-12	5.9E-13	1.7E-12	3.8E-13	2.4E-11	4.2E-13	1.3E-11	1.7E-07	1.7E-07
Ra-226	4.7E-10	1.7E-11	1.2E-09	4.4E-11	1.8E-11	3.7E-11	8.3E-12	1.6E-10	1.5E-14	2.7E-08	7.9E-08	1.1E-07
Th-230	2.6E-10	6.0E-12	6.4E-11	1.7E-12	6.7E-12	3.1E-12	7.0E-12	1.2E-12	7.8E-16	2.0E-10	3.1E-07	3.1E-07
Th-232	2.9E-10	6.5E-12	7.0E-11	1.8E-12	7.4E-12	3.4E-12	7.6E-12	1.4E-12	3.8E-16	6.9E-08	5.6E-07	6.3E-07
Th-234	2.7E-12	2.0E-16	2.4E-13	1.4E-15	5.5E-15	1.5E-15	3.4E-15	1.3E-14	7.9E-14	1.7E-12	1.7E-10	1.8E-10
U-234	6.3E-11	2.8E-12	2.5E-11	3.1E-12	1.3E-12	2.5E-12	5.5E-13	4.0E-11	3.2E-16	1.2E-12	7.9E-08	7.9E-08
U-235	6.0E-11	2.7E-12	2.4E-11	3.0E-12	1.2E-12	2.4E-12	5.3E-13	3.8E-11	3.4E-13	2.0E-09	7.0E-08	7.2E-08
U-238	5.8E-11	2.6E-12	2.3E-11	2.9E-12	1.2E-12	2.3E-12	5.1E-13	3.7E-11	1.3E-16	3.2E-10	6.5E-08	6.6E-08
Np-237	1.5E-10	6.3E-12	1.0E-10	1.8E-12	5.1E-11	4.7E-12	1.3E-10	4.5E-13	4.7E-14	2.9E-09	5.2E-07	5.2E-07
Pu-238	2.9E-10	5.5E-13	2.7E-11	3.1E-12	8.8E-11	6.7E-12	1.8E-10	6.5E-13	1.8E-16	4.4E-13	1.0E-06	1.0E-06
Pu-239	3.1E-10	7.1E-13	3.0E-11	3.4E-12	9.7E-11	7.6E-12	2.1E-10	7.3E-13	1.8E-16	7.0E-13	1.1E-06	1.1E-06
Pu-240	3.1E-10	7.1E-13	3.0E-11	3.4E-12	9.7E-11	7.6E-12	2.1E-10	7.3E-13	1.8E-16	5.6E-13	1.1E-06	1.1E-06
Pu-241	6.0E-12	5.5E-15	5.1E-13	5.9E-14	1.7E-12	1.2E-13	3.2E-12	1.1E-14	3.3E-18	1.6E-12	2.0E-08	2.0E-08
Pu-242	3.0E-10	6.8E-13	2.9E-11	3.3E-12	9.4E-11	7.3E-12	2.0E-10	7.0E-13	1.5E-16	8.7E-12	1.1E-06	1.1E-06
Am-241	2.5E-10	8.8E-13	2.9E-11	2.8E-12	7.9E-11	7.4E-12	2.0E-10	7.1E-13	3.6E-14	1.3E-10	9.4E-07	9.4E-07
Am-242	1.7E-14	5.3E-20	1.8E-15	1.0E-18	1.2E-17	1.2E-18	1.3E-17	2.7E-19	3.2E-14	3.2E-14	3.8E-10	3.8E-10
Am-243	2.5E-10	9.1E-13	3.0E-11	2.8E-12	7.9E-11	7.4E-12	2.0E-10	7.1E-13	9.7E-14	2.4E-09	9.2E-07	9.2E-07
Cm-242	1.4E-11	2.7E-16	1.1E-12	5.0E-14	1.4E-12	4.6E-14	1.2E-12	4.5E-15	2.1E-16	6.7E-14	1.2E-07	1.2E-07
Cm-243	1.9E-10	1.3E-13	1.8E-11	1.9E-12	5.5E-11	4.0E-12	1.1E-10	3.9E-13	2.8E-13	1.1E-09	7.0E-07	7.0E-07
Cm-244	1.5E-10	9.6E-14	1.4E-11	1.5E-12	4.4E-11	3.2E-12	8.6E-11	3.0E-13	1.8E-16	1.9E-12	6.1E-07	6.1E-07

nc = not considered due to short half-life

Table 7 Dose per unit release factors for worst age group fisherman family – coastal release scenario

Radionuclide	Worst total DPUR ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)	Worst age group
H-3	8.9E-16	Offspring
H-3 organic	3.7E-11	Offspring
C-14	4.6E-10	Offspring
Na-22	2.0E-13	Adult
Na-24	8.3E-16	Adult
P-32	6.8E-09	Offspring
P-33	1.6E-09	Offspring
S-35	7.9E-15	Offspring
Cl-36	1.6E-15	Adult
Ca-45	6.7E-13	Offspring
Ca-47	2.5E-13	Offspring
V-48	3.7E-11	Adult
Cr-51	6.0E-13	Adult
Mn-52	2.0E-11	Adult
Mn-54	2.3E-10	Adult
Fe-55	3.0E-13	Adult
Fe-59	4.9E-11	Adult
Co-56	2.8E-10	Adult
Co-57	2.3E-11	Adult
Co-58	6.9E-11	Adult
Co-60	2.8E-09	Adult
Ni-63	3.6E-12	Adult
Zn-65	3.4E-09	Adult
Ga-67	1.1E-12	Adult
Se-75	6.4E-10	Adult
Br-82	1.5E-14	Adult
Rb-83	3.4E-12	Adult
Sr-89	1.5E-12	Offspring
Sr-90	6.1E-12	Offspring
Y-90	6.6E-13	Adult
Zr-95	8.7E-11	Adult
Nb-95	2.2E-11	Adult
Mo-99	2.2E-13	Adult
Tc-99	7.0E-12	Adult
Tc-99m	7.2E-15	Adult
Ru-103	8.8E-12	Adult
Ru-106	4.8E-11	Adult
Ag-110m	4.0E-09	Adult
In-111	6.1E-12	Adult
Sb-125	2.9E-11	Adult
I-123	3.0E-15	Adult
I-125	3.0E-12	Adult
I-129	2.5E-11	Adult
I-131	2.5E-12	Adult
I-133	9.4E-14	Adult
I-135	7.0E-15	Adult

Table 7 continued

Radionuclide	Worst total DPUR ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)	Worst age group
Cs-134	1.2E-10	Adult
Cs-136	5.5E-12	Adult
Cs-137	1.5E-10	Adult
Ba-140	5.0E-12	Adult
La-140	1.5E-12	Adult
Ce-141	1.7E-12	Adult
Ce-144	1.5E-11	Adult
Pm-147	3.9E-13	Adult
Sm-153	2.9E-13	Adult
Eu-152	2.2E-09	Adult
Eu-154	2.0E-09	Adult
Eu-155	3.7E-11	Adult
Er-169	7.0E-14	Adult
Lu-177	2.1E-13	Adult
Au-198	5.4E-13	Adult
Tl-201	2.5E-12	Adult
Pb-210	1.9E-07	Adult
Po-210	5.4E-10	Adult
Ra-223	1.6E-10	Adult
Ra-226	1.1E-09	Offspring
Th-230	1.1E-10	Adult
Th-232	6.7E-09	Adult
Th-234	4.3E-11	Adult
U-234	1.3E-11	Adult
U-235	2.2E-11	Adult
U-238	1.4E-11	Adult
Np-237	3.6E-10	Adult
Pu-238	1.6E-09	Adult
Pu-239	1.7E-09	Adult
Pu-240	1.7E-09	Adult
Pu-241	3.2E-11	Adult
Pu-242	1.6E-09	Adult
Am-241	7.1E-11	Adult
Am-242	1.1E-14	Adult
Am-243	5.8E-10	Adult
Cm-242	2.9E-12	Adult
Cm-243	3.0E-10	Adult
Cm-244	2.7E-11	Adult

Table 8 Dose per unit release factors for offspring fisherman family – coastal release scenario

Radionuclide	DPURs for offspring fisherman family ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)				
	Fish	Crustacea	Molluscs	External	Total
H-3	5.0E-16	2.0E-16	2.0E-16	0.0E+00	8.9E-16
H-3 organic	2.1E-11	8.0E-12	8.0E-12	0.0E+00	3.7E-11
C-14	2.6E-10	1.0E-10	1.0E-10	1.6E-16	4.6E-10
Na-22	<p	<p	<p	1.4E-13	1.4E-13
Na-24	<p	<p	<p	2.7E-16	2.7E-16
P-32	4.9E-09	9.7E-10	9.7E-10	1.3E-17	6.8E-09
P-33	1.2E-09	2.3E-10	2.3E-10	6.8E-20	1.6E-09
S-35	3.1E-15	1.2E-15	3.6E-15	8.4E-20	7.9E-15
Cl-36	<p	<p	<p	3.1E-17	3.1E-17
Ca-45	2.6E-13	2.5E-13	1.5E-13	1.9E-17	6.7E-13
Ca-47	8.7E-14	8.7E-14	5.2E-14	2.3E-14	2.5E-13
V-48	<p	<p	<p	3.6E-11	3.6E-11
Cr-51	<p	<p	<p	3.7E-13	3.7E-13
Mn-52	<p	<p	<p	1.2E-11	1.2E-11
Mn-54	<p	<p	<p	2.2E-10	2.2E-10
Fe-55	<p	<p	<p	0.0E+00	0.0E+00
Fe-59	<p	<p	<p	4.7E-11	4.7E-11
Co-56	<p	<p	<p	2.3E-10	2.3E-10
Co-57	<p	<p	<p	1.9E-11	1.9E-11
Co-58	<p	<p	<p	5.4E-11	5.4E-11
Co-60	<p	<p	<p	2.7E-09	2.7E-09
Ni-63	<p	<p	<p	0.0E+00	0.0E+00
Zn-65	<p	<p	<p	8.0E-11	8.0E-11
Ga-67	<p	<p	<p	5.9E-16	5.9E-16
Se-75	3.6E-10	1.4E-10	1.3E-10	2.6E-12	6.4E-10
Br-82	<p	<p	<p	9.2E-16	9.2E-16
Rb-83	<p	<p	<p	2.3E-13	2.3E-13
Sr-89	4.9E-13	3.3E-13	6.5E-13	4.0E-17	1.5E-12
Sr-90	2.1E-12	1.3E-12	2.7E-12	1.0E-15	6.1E-12
Y-90	<p	<p	<p	8.4E-15	8.4E-15
Zr-95	<p	<p	<p	8.6E-11	8.6E-11
Nb-95	<p	<p	<p	2.2E-11	2.2E-11
Mo-99	<p	<p	<p	3.9E-15	3.9E-15
Tc-99	<p	<p	<p	1.0E-16	1.0E-16
Tc-99m	<p	<p	<p	1.8E-18	1.8E-18
Ru-103	<p	<p	<p	7.6E-12	7.6E-12
Ru-106	<p	<p	<p	3.5E-11	3.5E-11
Ag-110m	<p	<p	<p	1.2E-10	1.2E-10
In-111	<p	<p	<p	1.8E-13	1.8E-13
Sb-125	<p	<p	<p	1.5E-11	1.5E-11
I-123	<p	<p	<p	7.7E-18	7.7E-18
I-125	<p	<p	<p	2.1E-16	2.1E-16
I-129	<p	<p	<p	5.4E-15	5.4E-15
I-131	<p	<p	<p	2.5E-15	2.5E-15
I-133	<p	<p	<p	8.8E-17	8.8E-17
I-135	<p	<p	<p	2.6E-17	2.6E-17

Table 8 continued

Radionuclide	DPURs for offspring fisherman family (µSv y^{-1} per Bq y^{-1})				
	Fish	Crustacea	Molluscs	External	Total
Cs-134	<p	<p	<p	8.4E-11	8.4E-11
Cs-136	<p	<p	<p	1.6E-12	1.6E-12
Cs-137	<p	<p	<p	1.2E-10	1.2E-10
Ba-140	<p	<p	<p	4.6E-12	4.6E-12
La-140	<p	<p	<p	1.3E-12	1.3E-12
Ce-141	<p	<p	<p	1.6E-12	1.6E-12
Ce-144	<p	<p	<p	1.4E-11	1.4E-11
Pm-147	<p	<p	<p	6.0E-15	6.0E-15
Sm-153	<p	<p	<p	1.9E-14	1.9E-14
Eu-152	<p	<p	<p	2.2E-09	2.2E-09
Eu-154	<p	<p	<p	2.0E-09	2.0E-09
Eu-155	<p	<p	<p	3.7E-11	3.7E-11
Er-169	<p	<p	<p	1.5E-16	1.5E-16
Lu-177	<p	<p	<p	1.2E-13	1.2E-13
Au-198	<p	<p	<p	4.6E-13	4.6E-13
Tl-201	<p	<p	<p	1.5E-14	1.5E-14
Pb-210	<p	<p	<p	2.5E-12	2.5E-12
Po-210	<p	<p	<p	9.1E-17	9.1E-17
Ra-223	<p	<p	<p	5.4E-13	5.4E-13
Ra-226	4.8E-10	1.9E-10	1.9E-10	2.6E-10	1.1E-09
Th-230	2.5E-12	1.6E-12	1.6E-12	3.0E-11	3.6E-11
Th-232	<p	<p	<p	5.1E-09	5.1E-09
Th-234	<p	<p	<p	4.2E-11	4.2E-11
U-234	<p	<p	<p	4.9E-15	4.9E-15
U-235	<p	<p	<p	9.6E-12	9.6E-12
U-238	<p	<p	<p	1.8E-12	1.8E-12
Np-237	<p	<p	<p	1.4E-11	1.4E-11
Pu-238	<p	<p	<p	5.0E-14	5.0E-14
Pu-239	<p	<p	<p	1.2E-13	1.2E-13
Pu-240	<p	<p	<p	5.3E-14	5.3E-14
Pu-241	<p	<p	<p	2.4E-13	2.4E-13
Pu-242	<p	<p	<p	4.7E-14	4.7E-14
Am-241	<p	<p	<p	2.5E-11	2.5E-11
Am-242	<p	<p	<p	9.6E-16	9.6E-16
Am-243	<p	<p	<p	5.3E-10	5.3E-10
Cm-242	<p	<p	<p	3.9E-15	3.9E-15
Cm-243	<p	<p	<p	2.6E-10	2.6E-10
Cm-244	<p	<p	<p	4.0E-14	4.0E-14

<p = not calculated as dose to parent greater than dose to offspring

Table 9 Dose per unit release factors for infant fisherman family – coastal release scenario

Radionuclide	DPURs for infant fisherman family (µSv y^{-1} per Bq y^{-1})				
	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	2.0E-12	0.0E+00	0.0E+00	0.0E+00	2.0E-12
C-14	2.6E-11	0.0E+00	0.0E+00	2.3E-18	2.6E-11
Na-22	1.2E-14	0.0E+00	0.0E+00	2.1E-15	1.4E-14
Na-24	1.3E-16	0.0E+00	0.0E+00	4.0E-18	1.4E-16
P-32	1.9E-10	0.0E+00	0.0E+00	2.0E-19	1.9E-10
P-33	2.2E-11	0.0E+00	0.0E+00	1.0E-21	2.2E-11
S-35	6.4E-16	0.0E+00	0.0E+00	1.3E-21	6.4E-16
Cl-36	3.1E-16	0.0E+00	0.0E+00	4.6E-19	3.1E-16
Ca-45	7.4E-15	0.0E+00	0.0E+00	2.8E-19	7.4E-15
Ca-47	5.3E-15	0.0E+00	0.0E+00	3.5E-16	5.6E-15
V-48	1.0E-14	0.0E+00	0.0E+00	5.4E-13	5.5E-13
Cr-51	1.3E-14	0.0E+00	0.0E+00	5.6E-15	1.9E-14
Mn-52	8.5E-14	0.0E+00	0.0E+00	1.7E-13	2.6E-13
Mn-54	4.7E-14	0.0E+00	0.0E+00	3.4E-12	3.4E-12
Fe-55	7.7E-15	0.0E+00	0.0E+00	0.0E+00	7.7E-15
Fe-59	3.8E-14	0.0E+00	0.0E+00	7.1E-13	7.5E-13
Co-56	9.2E-13	0.0E+00	0.0E+00	3.4E-12	4.3E-12
Co-57	1.0E-13	0.0E+00	0.0E+00	2.8E-13	3.8E-13
Co-58	2.7E-13	0.0E+00	0.0E+00	8.2E-13	1.1E-12
Co-60	1.8E-12	0.0E+00	0.0E+00	4.1E-11	4.3E-11
Ni-63	4.6E-13	0.0E+00	0.0E+00	0.0E+00	4.6E-13
Zn-65	4.5E-12	0.0E+00	0.0E+00	1.2E-12	5.7E-12
Ga-67	1.9E-13	0.0E+00	0.0E+00	8.9E-18	1.9E-13
Se-75	9.1E-11	0.0E+00	0.0E+00	3.8E-14	9.1E-11
Br-82	9.6E-16	0.0E+00	0.0E+00	1.4E-17	9.7E-16
Rb-83	6.1E-13	0.0E+00	0.0E+00	3.4E-15	6.2E-13
Sr-89	3.7E-14	0.0E+00	0.0E+00	5.9E-19	3.7E-14
Sr-90	1.8E-13	0.0E+00	0.0E+00	1.5E-17	1.8E-13
Y-90	5.9E-15	0.0E+00	0.0E+00	1.3E-16	6.0E-15
Zr-95	1.8E-15	0.0E+00	0.0E+00	1.3E-12	1.3E-12
Nb-95	3.2E-15	0.0E+00	0.0E+00	3.3E-13	3.4E-13
Mo-99	7.0E-15	0.0E+00	0.0E+00	5.9E-17	7.0E-15
Tc-99	3.1E-13	0.0E+00	0.0E+00	1.5E-18	3.1E-13
Tc-99m	2.5E-16	0.0E+00	0.0E+00	2.8E-20	2.5E-16
Ru-103	3.2E-15	0.0E+00	0.0E+00	1.1E-13	1.2E-13
Ru-106	3.8E-14	0.0E+00	0.0E+00	5.2E-13	5.6E-13
Ag-110m	8.7E-11	0.0E+00	0.0E+00	1.8E-12	8.9E-11
In-111	1.0E-13	0.0E+00	0.0E+00	2.7E-15	1.1E-13
Sb-125	2.9E-12	0.0E+00	0.0E+00	2.2E-13	3.1E-12
I-123	8.7E-16	0.0E+00	0.0E+00	1.2E-19	8.7E-16
I-125	3.6E-13	0.0E+00	0.0E+00	3.1E-18	3.6E-13
I-129	1.6E-12	0.0E+00	0.0E+00	8.1E-17	1.6E-12
I-131	6.4E-13	0.0E+00	0.0E+00	3.8E-17	6.4E-13
I-133	3.1E-14	0.0E+00	0.0E+00	1.3E-18	3.1E-14
I-135	2.1E-15	0.0E+00	0.0E+00	3.8E-19	2.1E-15

Table 9 continued

Radionuclide	DPURs for infant fisherman family (μSv y^{-1} per Bq y^{-1})				
	Fish	Crustacea	Molluscs	External	Total
Cs-134	1.2E-12	0.0E+00	0.0E+00	1.3E-12	2.4E-12
Cs-136	4.3E-13	0.0E+00	0.0E+00	2.4E-14	4.6E-13
Cs-137	8.9E-13	0.0E+00	0.0E+00	1.9E-12	2.7E-12
Ba-140	8.5E-14	0.0E+00	0.0E+00	6.9E-14	1.5E-13
La-140	2.3E-15	0.0E+00	0.0E+00	1.9E-14	2.2E-14
Ce-141	2.4E-15	0.0E+00	0.0E+00	2.3E-14	2.6E-14
Ce-144	2.0E-14	0.0E+00	0.0E+00	2.1E-13	2.3E-13
Pm-147	8.9E-15	0.0E+00	0.0E+00	9.1E-17	9.0E-15
Sm-153	6.2E-15	0.0E+00	0.0E+00	2.9E-16	6.5E-15
Eu-152	3.7E-14	0.0E+00	0.0E+00	3.3E-11	3.4E-11
Eu-154	5.9E-14	0.0E+00	0.0E+00	3.0E-11	3.0E-11
Eu-155	1.1E-14	0.0E+00	0.0E+00	5.5E-13	5.6E-13
Er-169	1.1E-15	0.0E+00	0.0E+00	2.3E-18	1.1E-15
Lu-177	1.3E-15	0.0E+00	0.0E+00	1.8E-15	3.1E-15
Au-198	3.4E-15	0.0E+00	0.0E+00	6.8E-15	1.0E-14
Tl-201	4.7E-13	0.0E+00	0.0E+00	2.3E-16	4.7E-13
Pb-210	1.7E-10	0.0E+00	0.0E+00	3.7E-14	1.7E-10
Po-210	2.2E-11	0.0E+00	0.0E+00	1.4E-18	2.2E-11
Ra-223	4.9E-11	0.0E+00	0.0E+00	8.1E-15	4.9E-11
Ra-226	7.5E-11	0.0E+00	0.0E+00	3.8E-12	7.9E-11
Th-230	3.3E-12	0.0E+00	0.0E+00	4.6E-13	3.8E-12
Th-232	2.9E-10	0.0E+00	0.0E+00	7.6E-11	3.6E-10
Th-234	1.4E-13	0.0E+00	0.0E+00	6.3E-13	7.6E-13
U-234	1.0E-13	0.0E+00	0.0E+00	7.3E-17	1.0E-13
U-235	1.0E-13	0.0E+00	0.0E+00	1.4E-13	2.5E-13
U-238	9.6E-14	0.0E+00	0.0E+00	2.7E-14	1.2E-13
Np-237	1.7E-13	0.0E+00	0.0E+00	2.0E-13	3.7E-13
Pu-238	9.8E-12	0.0E+00	0.0E+00	7.5E-16	9.8E-12
Pu-239	1.0E-11	0.0E+00	0.0E+00	1.8E-15	1.0E-11
Pu-240	1.0E-11	0.0E+00	0.0E+00	8.0E-16	1.0E-11
Pu-241	1.4E-13	0.0E+00	0.0E+00	3.5E-15	1.4E-13
Pu-242	9.9E-12	0.0E+00	0.0E+00	7.0E-16	9.9E-12
Am-241	6.5E-13	0.0E+00	0.0E+00	3.7E-13	1.0E-12
Am-242	5.7E-16	0.0E+00	0.0E+00	1.4E-17	5.9E-16
Am-243	6.5E-13	0.0E+00	0.0E+00	8.0E-12	8.6E-12
Cm-242	1.2E-13	0.0E+00	0.0E+00	5.9E-17	1.2E-13
Cm-243	5.6E-13	0.0E+00	0.0E+00	3.9E-12	4.5E-12
Cm-244	4.9E-13	0.0E+00	0.0E+00	5.9E-16	4.9E-13

Table 10 Dose per unit release factors for child fisherman family – coastal release scenario

Radionuclide	DPURs for child fisherman family (μSv y^{-1} per Bq y^{-1})				
	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	3.7E-12	1.8E-12	1.8E-12	0.0E+00	7.4E-12
C-14	5.1E-11	2.5E-11	2.5E-11	2.3E-17	1.0E-10
Na-22	1.8E-14	6.1E-16	2.6E-15	2.1E-14	4.1E-14
Na-24	1.8E-16	6.2E-18	2.6E-17	4.0E-17	2.5E-16
P-32	2.2E-10	5.4E-11	5.4E-11	2.0E-18	3.2E-10
P-33	2.6E-11	6.3E-12	6.3E-12	1.0E-20	3.8E-11
S-35	7.9E-16	3.9E-16	1.2E-15	1.3E-20	2.4E-15
Cl-36	3.7E-16	1.8E-16	1.5E-16	4.6E-18	7.1E-16
Ca-45	1.1E-14	1.3E-14	8.1E-15	2.8E-18	3.2E-14
Ca-47	6.8E-15	8.5E-15	5.1E-15	3.5E-15	2.4E-14
V-48	1.4E-14	4.8E-14	2.4E-13	5.4E-12	5.7E-12
Cr-51	1.8E-14	4.5E-15	9.0E-14	5.6E-14	1.7E-13
Mn-52	1.3E-13	3.3E-13	3.3E-12	1.7E-12	5.5E-12
Mn-54	7.9E-14	2.0E-13	2.0E-12	3.4E-11	3.6E-11
Fe-55	1.4E-14	1.2E-13	1.2E-13	0.0E+00	2.5E-13
Fe-59	5.4E-14	4.5E-13	4.5E-13	7.1E-12	8.1E-12
Co-56	1.4E-12	7.1E-12	2.0E-11	3.4E-11	6.3E-11
Co-57	1.5E-13	7.4E-13	2.1E-12	2.8E-12	5.8E-12
Co-58	4.1E-13	2.1E-12	5.9E-12	8.2E-12	1.7E-11
Co-60	3.0E-12	1.5E-11	4.2E-11	4.1E-10	4.7E-10
Ni-63	6.2E-13	3.1E-13	6.1E-13	0.0E+00	1.5E-12
Zn-65	7.1E-12	1.1E-09	2.8E-10	1.2E-11	1.4E-09
Ga-67	2.6E-13	1.3E-13	1.3E-13	8.9E-17	5.1E-13
Se-75	1.7E-10	8.3E-11	7.5E-11	3.8E-13	3.3E-10
Br-82	1.4E-15	2.3E-15	2.3E-15	1.4E-16	6.2E-15
Rb-83	9.3E-13	9.2E-14	9.2E-14	3.4E-14	1.2E-12
Sr-89	4.8E-14	3.9E-14	7.9E-14	5.9E-18	1.7E-13
Sr-90	5.9E-13	4.8E-13	9.6E-13	1.5E-16	2.0E-12
Y-90	6.9E-15	1.7E-13	1.7E-13	1.3E-15	3.5E-13
Zr-95	2.5E-15	1.2E-14	3.1E-13	1.3E-11	1.3E-11
Nb-95	4.4E-15	1.5E-14	7.4E-14	3.3E-12	3.4E-12
Mo-99	8.8E-15	4.4E-14	4.4E-14	5.9E-16	9.7E-14
Tc-99	3.4E-13	2.1E-12	1.0E-12	1.5E-17	3.4E-12
Tc-99m	3.3E-16	2.1E-15	1.0E-15	2.8E-19	3.4E-15
Ru-103	4.1E-15	1.0E-13	5.1E-13	1.1E-12	1.8E-12
Ru-106	4.7E-14	1.2E-12	5.8E-12	5.2E-12	1.2E-11
Ag-110m	1.3E-10	1.3E-09	3.8E-10	1.8E-11	1.8E-09
In-111	1.4E-13	1.4E-12	1.4E-12	2.7E-14	3.0E-12
Sb-125	4.0E-12	9.8E-13	9.8E-13	2.2E-12	8.2E-12
I-123	9.0E-16	1.5E-16	5.0E-16	1.2E-18	1.5E-15
I-125	7.9E-13	1.3E-13	4.3E-13	3.1E-17	1.3E-12
I-129	5.6E-12	9.1E-13	3.0E-12	8.1E-16	9.5E-12
I-131	7.4E-13	1.2E-13	4.1E-13	3.8E-16	1.3E-12
I-133	2.8E-14	4.6E-15	1.5E-14	1.3E-17	4.8E-14
I-135	2.1E-15	3.5E-16	1.2E-15	3.8E-18	3.6E-15

Table 10 continued

Radionuclide	DPURs for child fisherman family (μSv y^{-1} per Bq y^{-1})				
	Fish	Crustacea	Molluscs	External	Total
Cs-134	4.1E-12	1.0E-12	1.2E-12	1.3E-11	1.9E-11
Cs-136	8.0E-13	2.0E-13	2.4E-13	2.4E-13	1.5E-12
Cs-137	3.0E-12	7.3E-13	8.7E-13	1.9E-11	2.3E-11
Ba-140	1.1E-13	3.8E-15	5.5E-14	6.9E-13	8.6E-13
La-140	2.9E-15	2.9E-14	5.9E-14	1.9E-13	2.8E-13
Ce-141	2.8E-15	2.8E-14	5.6E-14	2.3E-13	3.2E-13
Ce-144	2.2E-14	2.2E-13	4.5E-13	2.1E-12	2.8E-12
Pm-147	1.1E-14	7.1E-14	1.2E-13	9.1E-16	2.1E-13
Sm-153	7.4E-15	4.9E-14	8.6E-14	2.9E-15	1.5E-13
Eu-152	5.2E-14	3.4E-13	6.0E-13	3.3E-10	3.4E-10
Eu-154	8.0E-14	5.3E-13	9.3E-13	3.0E-10	3.0E-10
Eu-155	1.3E-14	8.7E-14	1.5E-13	5.5E-12	5.7E-12
Er-169	1.2E-15	1.2E-14	2.5E-14	2.3E-17	3.9E-14
Lu-177	1.7E-15	1.7E-14	3.3E-14	1.8E-14	6.9E-14
Au-198	4.1E-15	2.0E-14	2.0E-14	6.8E-14	1.1E-13
Tl-201	6.1E-13	6.1E-14	3.7E-13	2.3E-15	1.0E-12
Pb-210	3.7E-10	8.2E-08	4.6E-08	3.7E-13	1.3E-07
Po-210	2.6E-11	1.3E-10	1.3E-10	1.4E-17	2.9E-10
Ra-223	8.0E-11	4.0E-11	4.0E-11	8.1E-14	1.6E-10
Ra-226	2.5E-10	1.2E-10	1.2E-10	3.8E-11	5.3E-10
Th-230	8.1E-12	6.7E-12	6.7E-12	4.6E-12	2.6E-11
Th-232	7.8E-10	6.3E-10	6.3E-10	7.6E-10	2.8E-09
Th-234	1.6E-13	1.3E-13	1.3E-13	6.3E-12	6.7E-12
U-234	2.4E-13	1.2E-12	3.5E-12	7.3E-16	4.9E-12
U-235	2.3E-13	1.1E-12	3.3E-12	1.4E-12	6.1E-12
U-238	2.2E-13	1.1E-12	3.2E-12	2.7E-13	4.7E-12
Np-237	3.5E-13	1.7E-11	6.9E-11	2.0E-12	8.8E-11
Pu-238	2.4E-11	2.3E-11	3.5E-10	7.5E-15	4.0E-10
Pu-239	2.7E-11	2.7E-11	4.0E-10	1.8E-14	4.5E-10
Pu-240	2.7E-11	2.7E-11	4.0E-10	8.0E-15	4.5E-10
Pu-241	4.9E-13	4.9E-13	7.3E-12	3.5E-14	8.3E-12
Pu-242	2.6E-11	2.6E-11	3.9E-10	7.0E-15	4.4E-10
Am-241	1.5E-12	3.1E-12	7.7E-12	3.7E-12	1.6E-11
Am-242	6.7E-16	1.3E-15	3.3E-15	1.4E-16	5.5E-15
Am-243	1.6E-12	3.1E-12	7.7E-12	8.0E-11	9.2E-11
Cm-242	1.6E-13	3.2E-13	8.0E-13	5.9E-16	1.3E-12
Cm-243	1.1E-12	2.2E-12	5.4E-12	3.9E-11	4.8E-11
Cm-244	9.4E-13	1.9E-12	4.7E-12	5.9E-15	7.5E-12

Table 11 Dose per unit release factors for adult fisherman family – coastal release scenario

Radionuclide	DPURs for adult fisherman family (µSv y^{-1} per Bq y^{-1})				
	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	1.4E-11	5.4E-12	5.4E-12	0.0E+00	2.4E-11
C-14	1.9E-10	7.3E-11	7.3E-11	1.6E-16	3.3E-10
Na-22	5.2E-14	1.4E-15	6.1E-15	1.4E-13	2.0E-13
Na-24	4.9E-16	1.4E-17	5.9E-17	2.7E-16	8.3E-16
P-32	4.9E-10	9.7E-11	9.7E-11	1.3E-17	6.8E-10
P-33	5.8E-11	1.1E-11	1.1E-11	6.8E-20	8.1E-11
S-35	1.9E-15	7.5E-16	2.3E-15	8.4E-20	4.9E-15
Cl-36	9.1E-16	3.6E-16	3.0E-16	3.1E-17	1.6E-15
Ca-45	2.2E-14	2.1E-14	1.3E-14	1.9E-17	5.6E-14
Ca-47	1.8E-14	1.8E-14	1.1E-14	2.3E-14	7.0E-14
V-48	3.7E-14	9.8E-14	4.9E-13	3.6E-11	3.7E-11
Cr-51	4.4E-14	8.8E-15	1.8E-13	3.7E-13	6.0E-13
Mn-52	3.5E-13	6.9E-13	6.9E-12	1.2E-11	2.0E-11
Mn-54	2.2E-13	4.3E-13	4.3E-12	2.2E-10	2.3E-10
Fe-55	2.1E-14	1.4E-13	1.4E-13	0.0E+00	3.0E-13
Fe-59	1.0E-13	6.9E-13	6.9E-13	4.7E-11	4.9E-11
Co-56	3.1E-12	1.2E-11	3.5E-11	2.3E-10	2.8E-10
Co-57	2.7E-13	1.1E-12	3.0E-12	1.9E-11	2.3E-11
Co-58	9.0E-13	3.6E-12	1.0E-11	5.4E-11	6.9E-11
Co-60	4.6E-12	1.8E-11	5.2E-11	2.7E-09	2.8E-09
Ni-63	1.7E-12	6.6E-13	1.3E-12	0.0E+00	3.6E-12
Zn-65	2.2E-11	2.6E-09	6.9E-10	8.0E-11	3.4E-09
Ga-67	6.1E-13	2.4E-13	2.4E-13	5.9E-16	1.1E-12
Se-75	3.6E-10	1.4E-10	1.3E-10	2.6E-12	6.4E-10
Br-82	4.0E-15	5.3E-15	5.3E-15	9.2E-16	1.5E-14
Rb-83	2.8E-12	2.2E-13	2.2E-13	2.3E-13	3.4E-12
Sr-89	1.1E-13	7.1E-14	1.4E-13	4.0E-17	3.2E-13
Sr-90	1.4E-12	8.9E-13	1.8E-12	1.0E-15	4.1E-12
Y-90	1.6E-14	3.2E-13	3.2E-13	8.4E-15	6.6E-13
Zr-95	6.2E-15	2.5E-14	6.2E-13	8.6E-11	8.7E-11
Nb-95	1.2E-14	3.1E-14	1.6E-13	2.2E-11	2.2E-11
Mo-99	2.4E-14	9.5E-14	9.5E-14	3.9E-15	2.2E-13
Tc-99	8.4E-13	4.1E-12	2.0E-12	1.0E-16	7.0E-12
Tc-99m	8.4E-16	4.2E-15	2.1E-15	1.8E-18	7.2E-15
Ru-103	1.0E-14	2.0E-13	1.0E-12	7.6E-12	8.8E-12
Ru-106	1.1E-13	2.2E-12	1.1E-11	3.5E-11	4.8E-11
Ag-110m	3.5E-10	2.7E-09	8.2E-10	1.2E-10	4.0E-09
In-111	3.5E-13	2.8E-12	2.8E-12	1.8E-13	6.1E-12
Sb-125	1.0E-11	2.0E-12	2.0E-12	1.5E-11	2.9E-11
I-123	1.9E-15	2.6E-16	8.5E-16	7.7E-18	3.0E-15
I-125	1.9E-12	2.5E-13	8.4E-13	2.1E-16	3.0E-12
I-129	1.6E-11	2.1E-12	7.0E-12	5.4E-15	2.5E-11
I-131	1.6E-12	2.1E-13	6.9E-13	2.5E-15	2.5E-12
I-133	6.0E-14	7.9E-15	2.6E-14	8.8E-17	9.4E-14
I-135	4.4E-15	5.9E-16	2.0E-15	2.6E-17	7.0E-15

Table 11 continued

Radionuclide	DPURs for adult fisherman family (μSv y^{-1} per Bq y^{-1})				
	Fish	Crustacea	Molluscs	External	Total
Cs-134	2.8E-11	5.4E-12	6.5E-12	8.4E-11	1.2E-10
Cs-136	2.7E-12	5.4E-13	6.5E-13	1.6E-12	5.5E-12
Cs-137	1.9E-11	3.8E-12	4.5E-12	1.2E-10	1.5E-10
Ba-140	2.5E-13	6.9E-15	9.8E-14	4.6E-12	5.0E-12
La-140	7.0E-15	5.6E-14	1.1E-13	1.3E-12	1.5E-12
Ce-141	6.6E-15	5.3E-14	1.1E-13	1.6E-12	1.7E-12
Ce-144	5.3E-14	4.2E-13	8.4E-13	1.4E-11	1.5E-11
Pm-147	2.4E-14	1.3E-13	2.3E-13	6.0E-15	3.9E-13
Sm-153	1.7E-14	9.1E-14	1.6E-13	1.9E-14	2.9E-13
Eu-152	1.4E-13	7.4E-13	1.3E-12	2.2E-09	2.2E-09
Eu-154	2.0E-13	1.0E-12	1.8E-12	2.0E-09	2.0E-09
Eu-155	3.1E-14	1.6E-13	2.9E-13	3.7E-11	3.7E-11
Er-169	2.8E-15	2.2E-14	4.5E-14	1.5E-16	7.0E-14
Lu-177	3.7E-15	2.9E-14	5.9E-14	1.2E-13	2.1E-13
Au-198	9.3E-15	3.7E-14	3.7E-14	4.6E-13	5.4E-13
Tl-201	1.6E-12	1.3E-13	7.7E-13	1.5E-14	2.5E-12
Pb-210	6.7E-10	1.2E-07	6.6E-08	2.5E-12	1.9E-07
Po-210	6.0E-11	2.4E-10	2.4E-10	9.1E-17	5.4E-10
Ra-223	8.9E-11	3.6E-11	3.6E-11	5.4E-13	1.6E-10
Ra-226	4.4E-10	1.7E-10	1.7E-10	2.6E-10	1.0E-09
Th-230	3.2E-11	2.1E-11	2.1E-11	3.0E-11	1.1E-10
Th-232	7.2E-10	4.6E-10	4.6E-10	5.1E-09	6.7E-09
Th-234	3.7E-13	2.4E-13	2.4E-13	4.2E-11	4.3E-11
U-234	7.8E-13	3.1E-12	9.2E-12	4.9E-15	1.3E-11
U-235	7.5E-13	2.9E-12	8.8E-12	9.6E-12	2.2E-11
U-238	7.2E-13	2.8E-12	8.5E-12	1.8E-12	1.4E-11
Np-237	1.8E-12	6.9E-11	2.8E-10	1.4E-11	3.6E-10
Pu-238	1.1E-10	9.0E-11	1.3E-09	5.0E-14	1.6E-09
Pu-239	1.2E-10	9.9E-11	1.5E-09	1.2E-13	1.7E-09
Pu-240	1.2E-10	9.9E-11	1.5E-09	5.3E-14	1.7E-09
Pu-241	2.3E-12	1.8E-12	2.7E-11	2.4E-13	3.2E-11
Pu-242	1.2E-10	9.5E-11	1.4E-09	4.7E-14	1.6E-09
Am-241	7.0E-12	1.1E-11	2.8E-11	2.5E-11	7.1E-11
Am-242	1.6E-15	2.5E-15	6.2E-15	9.6E-16	1.1E-14
Am-243	7.1E-12	1.1E-11	2.8E-11	5.3E-10	5.8E-10
Cm-242	4.4E-13	7.0E-13	1.8E-12	3.9E-15	2.9E-12
Cm-243	5.1E-12	8.2E-12	2.0E-11	2.6E-10	3.0E-10
Cm-244	4.0E-12	6.4E-12	1.6E-11	4.0E-14	2.7E-11

Table 12 Dose per unit release factors for worst age group angler family – river release scenario

Radionuclide	Worst total DPUR ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)	Worst age group
H-3	6.0E-13	Offspring
H-3 organic	8.8E-10	Offspring
C-14	1.0E-08	Offspring
Na-22	1.3E-10	Infant
Na-24	2.1E-11	Infant
P-32	1.5E-07	Offspring
P-33	2.9E-08	Offspring
S-35	2.6E-11	Offspring
Cl-36	6.2E-11	Infant
Ca-45	3.4E-10	Offspring
Ca-47	7.7E-10	Offspring
V-48	3.8E-08	Adult
Cr-51	3.2E-10	Adult
Mn-52	1.1E-08	Adult
Mn-54	1.4E-08	Adult
Fe-55	2.0E-11	Child
Fe-59	9.5E-09	Adult
Co-56	4.4E-08	Adult
Co-57	9.1E-10	Adult
Co-58	1.1E-08	Adult
Co-60	3.0E-08	Adult
Ni-63	6.2E-12	Adult
Zn-65	1.2E-08	Adult
Ga-67	5.8E-11	Adult
Se-75	7.0E-10	Adult
Br-82	1.5E-10	Adult
Rb-83	5.2E-09	Adult
Sr-89	6.3E-10	Offspring
Sr-90	2.2E-09	Offspring
Y-90	1.5E-10	Infant
Zr-95	2.5E-08	Adult
Nb-95	2.1E-10	Adult
Mo-99	6.8E-11	Adult
Tc-99	4.1E-11	Infant
Tc-99m	5.8E-12	Adult
Ru-103	2.6E-09	Adult
Ru-106	1.4E-09	Adult
Ag-110m	6.8E-10	Adult
In-111	1.7E-09	Adult
Sb-125	2.4E-10	Adult
I-123	1.9E-11	Adult
I-125	6.6E-10	Adult
I-129	4.8E-09	Adult
I-131	1.7E-09	Infant
I-133	4.1E-10	Infant
I-135	1.4E-10	Adult

Table 12 continued

Radionuclide	Worst total DPUR ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)	Worst age group
Cs-134	2.5E-08	Adult
Cs-136	4.4E-09	Adult
Cs-137	1.6E-08	Adult
Ba-140	2.2E-09	Adult
La-140	6.0E-09	Adult
Ce-141	6.9E-10	Adult
Ce-144	8.5E-10	Adult
Pm-147	1.4E-11	Infant
Sm-153	1.3E-10	Adult
Eu-152	1.6E-08	Adult
Eu-154	1.7E-08	Adult
Eu-155	3.8E-10	Adult
Er-169	1.0E-11	Infant
Lu-177	9.5E-11	Adult
Au-198	1.1E-09	Adult
Tl-201	4.7E-10	Adult
Pb-210	1.1E-07	Adult
Po-210	6.5E-08	Infant
Ra-223	1.1E-08	Infant
Ra-226	1.6E-08	Offspring
Th-230	1.2E-08	Adult
Th-232	3.3E-08	Adult
Th-234	3.7E-10	Adult
U-234	2.5E-09	Adult
U-235	2.4E-09	Adult
U-238	2.3E-09	Adult
Np-237	4.2E-09	Adult
Pu-238	1.9E-09	Adult
Pu-239	2.1E-09	Adult
Pu-240	2.1E-09	Adult
Pu-241	4.1E-11	Adult
Pu-242	2.0E-09	Adult
Am-241	6.4E-09	Adult
Am-242	6.2E-11	Adult
Am-243	9.2E-09	Adult
Cm-242	3.3E-11	Infant
Cm-243	2.2E-09	Adult
Cm-244	2.0E-10	Adult

Table 13 Dose per unit release factors for offspring angler family – river release scenario

Radionuclide	DPURs for offspring angler family (µSv y^{-1} per Bq y^{-1})			
	Fish	External	Drinking water	Total
H-3	1.7E-14	0.0E+00	5.8E-13	6.0E-13
H-3 organic	8.8E-10	0.0E+00	1.2E-12	8.8E-10
C-14	1.0E-08	3.9E-15	1.4E-11	1.0E-08
Na-22	<p	1.5E-11	<p	1.5E-11
Na-24	<p	5.1E-12	<p	5.1E-12
P-32	1.4E-07	3.8E-12	4.3E-10	1.5E-07
P-33	2.9E-08	9.4E-15	8.7E-11	2.9E-08
S-35	2.3E-11	6.2E-15	3.4E-12	2.6E-11
Cl-36	<p	0.0E+00	<p	0.0E+00
Ca-45	2.0E-10	1.9E-14	1.5E-10	3.4E-10
Ca-47	1.8E-10	4.6E-10	1.3E-10	7.7E-10
V-48	<p	3.4E-10	<p	3.4E-10
Cr-51	<p	3.2E-10	<p	3.2E-10
Mn-52	<p	1.1E-08	<p	1.1E-08
Mn-54	<p	1.4E-08	<p	1.4E-08
Fe-55	<p	0.0E+00	<p	0.0E+00
Fe-59	<p	9.4E-09	<p	9.4E-09
Co-56	<p	4.4E-08	<p	4.4E-08
Co-57	<p	8.9E-10	<p	8.9E-10
Co-58	<p	1.1E-08	<p	1.1E-08
Co-60	<p	3.0E-08	<p	3.0E-08
Ni-63	<p	0.0E+00	<p	0.0E+00
Zn-65	<p	6.5E-10	<p	6.5E-10
Ga-67	<p	6.5E-12	<p	6.5E-12
Se-75	3.1E-10	3.4E-10	4.7E-11	7.0E-10
Br-82	<p	0.0E+00	<p	0.0E+00
Rb-83	<p	3.6E-09	<p	3.6E-09
Sr-89	4.1E-10	5.4E-12	2.1E-10	6.3E-10
Sr-90	1.5E-09	1.4E-11	7.3E-10	2.2E-09
Y-90	<p	1.5E-11	<p	1.5E-11
Zr-95	<p	2.5E-08	<p	2.5E-08
Nb-95	<p	8.6E-11	<p	8.6E-11
Mo-99	<p	5.4E-11	<p	5.4E-11
Tc-99	<p	4.2E-15	<p	4.2E-15
Tc-99m	<p	5.2E-12	<p	5.2E-12
Ru-103	<p	2.6E-09	<p	2.6E-09
Ru-106	<p	1.3E-09	<p	1.3E-09
Ag-110m	<p	6.3E-10	<p	6.3E-10
In-111	<p	1.4E-09	<p	1.4E-09
Sb-125	<p	2.2E-10	<p	2.2E-10
I-123	<p	9.6E-12	<p	9.6E-12
I-125	<p	6.9E-13	<p	6.9E-13
I-129	<p	5.5E-13	<p	5.5E-13
I-131	<p	2.5E-11	<p	2.5E-11
I-133	<p	4.0E-11	<p	4.0E-11
I-135	<p	1.0E-10	<p	1.0E-10

Table 13 continued

Radionuclide	DPURs for offspring angler family (µSv y^{-1} per Bq y^{-1})			
	Fish	External	Drinking water	Total
Cs-134	<p	3.2E-09	<p	3.2E-09
Cs-136	<p	8.6E-10	<p	8.6E-10
Cs-137	<p	1.1E-09	<p	1.1E-09
Ba-140	<p	2.1E-09	<p	2.1E-09
La-140	<p	6.0E-09	<p	6.0E-09
Ce-141	<p	6.8E-10	<p	6.8E-10
Ce-144	<p	7.7E-10	<p	7.7E-10
Pm-147	<p	3.4E-14	<p	3.4E-14
Sm-153	<p	1.2E-10	<p	1.2E-10
Eu-152	<p	1.6E-08	<p	1.6E-08
Eu-154	<p	1.7E-08	<p	1.7E-08
Eu-155	<p	3.8E-10	<p	3.8E-10
Er-169	<p	1.2E-13	<p	1.2E-13
Lu-177	<p	8.7E-11	<p	8.7E-11
Au-198	<p	1.1E-09	<p	1.1E-09
Tl-201	<p	1.7E-10	<p	1.7E-10
Pb-210	<p	7.3E-12	<p	7.3E-12
Po-210	<p	4.8E-14	<p	4.8E-14
Ra-223	<p	1.8E-10	<p	1.8E-10
Ra-226	9.5E-09	1.0E-09	5.7E-09	1.6E-08
Th-230	<p	1.4E-12	<p	1.4E-12
Th-232	<p	2.0E-08	<p	2.0E-08
Th-234	<p	1.8E-10	<p	1.8E-10
U-234	<p	3.4E-15	<p	3.4E-15
U-235	<p	6.7E-12	<p	6.7E-12
U-238	<p	1.4E-12	<p	1.4E-12
Np-237	<p	2.0E-12	<p	2.0E-12
Pu-238	<p	3.8E-13	<p	3.8E-13
Pu-239	<p	8.6E-13	<p	8.6E-13
Pu-240	<p	3.7E-13	<p	3.7E-13
Pu-241	<p	1.7E-14	<p	1.7E-14
Pu-242	<p	3.2E-13	<p	3.2E-13
Am-241	<p	1.4E-10	<p	1.4E-10
Am-242	<p	5.2E-11	<p	5.2E-11
Am-243	<p	3.0E-09	<p	3.0E-09
Cm-242	<p	4.8E-13	<p	4.8E-13
Cm-243	<p	2.0E-09	<p	2.0E-09
Cm-244	<p	3.3E-13	<p	3.3E-13

<p = not calculated as dose to parent greater than dose to offspring

Table 14 Dose per unit release factors for infant angler family – river release scenario

Radionuclide	DPURs for infant angler family (μSv y^{-1} per Bq y^{-1})			
	Fish	External	Drinking water	Total
H-3	1.4E-15	0.0E+00	4.0E-13	4.0E-13
H-3 organic	8.4E-11	0.0E+00	9.9E-13	8.5E-11
C-14	1.0E-09	1.2E-16	1.2E-11	1.0E-09
Na-22	9.5E-12	4.5E-13	1.2E-10	1.3E-10
Na-24	1.5E-12	1.5E-13	1.9E-11	2.1E-11
P-32	5.7E-09	1.1E-13	1.5E-10	5.9E-09
P-33	5.4E-10	2.8E-16	1.4E-11	5.6E-10
S-35	4.8E-12	1.9E-16	6.2E-12	1.1E-11
Cl-36	1.0E-11	0.0E+00	5.2E-11	6.2E-11
Ca-45	5.6E-12	5.7E-16	3.7E-11	4.2E-11
Ca-47	1.1E-11	1.4E-11	7.0E-11	9.4E-11
V-48	1.0E-08	1.0E-11	9.0E-11	1.1E-08
Cr-51	1.5E-13	9.5E-12	9.5E-13	1.1E-11
Mn-52	8.0E-12	3.2E-10	2.1E-11	3.5E-10
Mn-54	2.8E-12	4.1E-10	7.3E-12	4.2E-10
Fe-55	5.1E-12	0.0E+00	1.3E-11	1.8E-11
Fe-59	2.7E-11	2.8E-10	7.1E-11	3.8E-10
Co-56	7.1E-11	1.3E-09	6.2E-11	1.4E-09
Co-57	7.6E-12	2.7E-11	6.6E-12	4.1E-11
Co-58	2.1E-11	3.3E-10	1.8E-11	3.7E-10
Co-60	1.3E-10	9.0E-10	1.1E-10	1.1E-09
Ni-63	1.3E-12	0.0E+00	3.5E-12	4.8E-12
Zn-65	2.4E-09	2.0E-11	1.3E-10	2.6E-09
Ga-67	1.5E-11	1.9E-13	9.8E-12	2.5E-11
Se-75	7.8E-11	1.0E-11	1.0E-10	1.9E-10
Br-82	3.3E-11	0.0E+00	2.1E-11	5.4E-11
Rb-83	3.5E-10	1.1E-10	4.6E-11	5.1E-10
Sr-89	3.1E-11	1.6E-13	1.3E-10	1.7E-10
Sr-90	1.3E-10	4.3E-13	5.5E-10	6.7E-10
Y-90	1.3E-11	4.6E-13	1.4E-10	1.5E-10
Zr-95	1.3E-11	7.6E-10	1.2E-11	7.8E-10
Nb-95	3.0E-11	2.6E-12	2.6E-11	5.9E-11
Mo-99	1.1E-12	1.6E-12	2.7E-11	3.0E-11
Tc-99	2.3E-12	1.3E-16	3.9E-11	4.1E-11
Tc-99m	6.1E-14	1.6E-13	1.1E-12	1.3E-12
Ru-103	1.1E-12	7.8E-11	2.8E-11	1.1E-10
Ru-106	1.2E-11	3.8E-11	3.0E-10	3.5E-10
Ag-110m	1.0E-12	1.9E-11	1.1E-10	1.3E-10
In-111	9.0E-11	4.2E-11	2.3E-12	1.3E-10
Sb-125	1.9E-13	6.5E-12	4.9E-11	5.6E-11
I-123	2.4E-12	2.9E-13	1.5E-11	1.8E-11
I-125	7.1E-11	2.1E-14	4.6E-10	5.3E-10
I-129	2.7E-10	1.7E-14	1.8E-09	2.1E-09
I-131	2.2E-10	7.5E-13	1.5E-09	1.7E-09
I-133	5.5E-11	1.2E-12	3.6E-10	4.1E-10
I-135	1.1E-11	3.0E-12	7.2E-11	8.6E-11

Table 14 continued

Radionuclide	DPURs for infant angler family (µSv y^{-1} per Bq y^{-1})			
	Fish	External	Drinking water	Total
Cs-134	9.2E-10	9.5E-11	1.2E-10	1.1E-09
Cs-136	5.5E-10	2.6E-11	7.1E-11	6.4E-10
Cs-137	6.9E-10	3.4E-11	9.0E-11	8.2E-10
Ba-140	1.8E-12	6.4E-11	1.2E-10	1.8E-10
La-140	6.6E-13	1.8E-10	4.3E-11	2.2E-10
Ce-141	1.9E-12	2.0E-11	1.7E-11	3.9E-11
Ce-144	1.5E-11	2.3E-11	1.3E-10	1.7E-10
Pm-147	1.4E-12	1.0E-15	1.3E-11	1.4E-11
Sm-153	2.1E-12	3.6E-12	1.8E-11	2.3E-11
Eu-152	2.3E-12	4.7E-10	2.4E-11	4.9E-10
Eu-154	3.8E-12	5.1E-10	4.0E-11	5.5E-10
Eu-155	7.0E-13	1.1E-11	7.3E-12	1.9E-11
Er-169	8.9E-13	3.5E-15	9.2E-12	1.0E-11
Lu-177	1.5E-12	2.6E-12	1.3E-11	1.7E-11
Au-198	2.7E-12	3.2E-11	2.4E-11	5.9E-11
Tl-201	8.7E-11	5.0E-12	2.3E-12	9.4E-11
Pb-210	2.6E-08	2.2E-13	2.2E-08	4.8E-08
Po-210	1.0E-08	1.5E-15	5.4E-08	6.5E-08
Ra-223	1.7E-09	5.3E-12	8.8E-09	1.1E-08
Ra-226	1.5E-09	3.0E-11	7.7E-09	9.2E-09
Th-230	8.7E-10	4.2E-14	2.3E-09	3.1E-09
Th-232	9.5E-10	6.0E-10	2.5E-09	4.0E-09
Th-234	5.3E-11	5.5E-12	1.4E-10	2.0E-10
U-234	2.1E-10	1.0E-16	1.1E-09	1.3E-09
U-235	2.1E-10	2.0E-13	1.1E-09	1.3E-09
U-238	1.9E-10	4.1E-14	9.9E-10	1.2E-09
Np-237	2.0E-10	5.9E-14	1.7E-09	1.9E-09
Pu-238	1.1E-10	1.1E-14	5.5E-10	6.5E-10
Pu-239	1.1E-10	2.6E-14	5.8E-10	6.9E-10
Pu-240	1.1E-10	1.1E-14	5.8E-10	6.9E-10
Pu-241	1.5E-12	5.2E-16	7.8E-12	9.3E-12
Pu-242	1.1E-10	9.7E-15	5.5E-10	6.5E-10
Am-241	5.6E-10	4.2E-12	1.5E-10	7.1E-10
Am-242	3.3E-12	1.6E-12	8.6E-13	5.8E-12
Am-243	5.6E-10	9.1E-11	1.5E-10	7.9E-10
Cm-242	2.9E-12	1.4E-14	3.0E-11	3.3E-11
Cm-243	1.2E-11	6.0E-11	1.3E-10	2.0E-10
Cm-244	1.1E-11	1.0E-14	1.1E-10	1.2E-10

Table 15 Dose per unit release factors for child angler family – river release scenario

Radionuclide	DPURs for child angler family (µSv y^{-1} per Bq y^{-1})			
	Fish	External	Drinking water	Total
H-3	3.3E-15	0.0E+00	2.6E-13	2.6E-13
H-3 organic	2.0E-10	0.0E+00	6.3E-13	2.0E-10
C-14	2.5E-09	2.0E-15	8.1E-12	2.5E-09
Na-22	1.7E-11	7.6E-12	6.1E-11	8.6E-11
Na-24	2.4E-12	2.5E-12	8.5E-12	1.4E-11
P-32	8.0E-09	1.9E-12	5.6E-11	8.1E-09
P-33	8.0E-10	4.7E-15	5.6E-12	8.1E-10
S-35	7.4E-12	3.1E-15	2.6E-12	1.0E-11
Cl-36	1.5E-11	0.0E+00	2.1E-11	3.6E-11
Ca-45	1.0E-11	9.5E-15	1.8E-11	2.9E-11
Ca-47	1.7E-11	2.3E-10	3.0E-11	2.8E-10
V-48	1.8E-08	1.7E-10	4.3E-11	1.9E-08
Cr-51	2.5E-13	1.6E-10	4.3E-13	1.6E-10
Mn-52	1.5E-11	5.3E-09	1.1E-11	5.4E-09
Mn-54	5.9E-12	6.8E-09	4.1E-12	6.8E-09
Fe-55	1.2E-11	0.0E+00	8.1E-12	2.0E-11
Fe-59	5.0E-11	4.7E-09	3.5E-11	4.8E-09
Co-56	1.4E-10	2.2E-08	3.2E-11	2.2E-08
Co-57	1.4E-11	4.5E-10	3.2E-12	4.6E-10
Co-58	4.0E-11	5.5E-09	9.4E-12	5.5E-09
Co-60	2.6E-10	1.5E-08	6.1E-11	1.5E-08
Ni-63	2.2E-12	0.0E+00	1.6E-12	3.8E-12
Zn-65	4.8E-09	3.3E-10	6.8E-11	5.2E-09
Ga-67	2.5E-11	3.2E-12	4.4E-12	3.3E-11
Se-75	1.8E-10	1.7E-10	6.3E-11	4.1E-10
Br-82	6.0E-11	0.0E+00	1.1E-11	7.1E-11
Rb-83	6.8E-10	1.8E-09	2.4E-11	2.5E-09
Sr-89	5.0E-11	2.7E-12	5.8E-11	1.1E-10
Sr-90	5.2E-10	7.2E-12	6.0E-10	1.1E-09
Y-90	1.9E-11	7.7E-12	5.5E-11	8.2E-11
Zr-95	2.3E-11	1.3E-08	5.3E-12	1.3E-08
Nb-95	5.2E-11	4.3E-11	1.2E-11	1.1E-10
Mo-99	1.7E-12	2.7E-11	1.2E-11	4.0E-11
Tc-99	3.1E-12	2.1E-15	1.4E-11	1.7E-11
Tc-99m	1.0E-13	2.6E-12	4.7E-13	3.2E-12
Ru-103	1.8E-12	1.3E-09	1.2E-11	1.3E-09
Ru-106	1.8E-11	6.3E-10	1.2E-10	7.7E-10
Ag-110m	1.9E-12	3.1E-10	5.7E-11	3.7E-10
In-111	1.6E-10	7.0E-10	1.1E-12	8.6E-10
Sb-125	3.2E-13	1.1E-10	2.3E-11	1.3E-10
I-123	3.1E-12	4.8E-12	5.4E-12	1.3E-11
I-125	1.9E-10	3.4E-13	3.4E-10	5.3E-10
I-129	1.2E-09	2.8E-13	2.1E-09	3.3E-09
I-131	3.2E-10	1.2E-11	5.7E-10	9.1E-10
I-133	6.2E-11	2.0E-11	1.1E-10	1.9E-10
I-135	1.4E-11	5.0E-11	2.4E-11	8.8E-11

Table 15 continued

Radionuclide	DPURs for child angler family (μSv y^{-1} per Bq y^{-1})			
	Fish	External	Drinking water	Total
Cs-134	4.0E-09	1.6E-09	1.4E-10	5.8E-09
Cs-136	1.3E-09	4.3E-10	4.4E-11	1.7E-09
Cs-137	2.9E-09	5.7E-10	1.0E-10	3.5E-09
Ba-140	2.9E-12	1.1E-09	5.1E-11	1.1E-09
La-140	1.1E-12	3.0E-09	1.9E-11	3.0E-09
Ce-141	2.9E-12	3.4E-10	6.7E-12	3.5E-10
Ce-144	2.1E-11	3.8E-10	4.9E-11	4.5E-10
Pm-147	2.2E-12	1.7E-14	5.1E-12	7.2E-12
Sm-153	3.0E-12	6.1E-11	7.1E-12	7.1E-11
Eu-152	4.1E-12	7.8E-09	1.2E-11	7.8E-09
Eu-154	6.5E-12	8.5E-09	1.8E-11	8.5E-09
Eu-155	1.1E-12	1.9E-10	3.0E-12	1.9E-10
Er-169	1.3E-12	5.8E-14	3.6E-12	5.0E-12
Lu-177	2.3E-12	4.4E-11	5.3E-12	5.1E-11
Au-198	4.2E-12	5.4E-10	9.8E-12	5.5E-10
Tl-201	1.4E-10	8.4E-11	1.0E-12	2.3E-10
Pb-210	6.8E-08	3.7E-12	1.6E-08	8.3E-08
Po-210	1.5E-08	2.4E-14	2.2E-08	3.7E-08
Ra-223	3.5E-09	8.9E-11	4.9E-09	8.4E-09
Ra-226	6.2E-09	5.1E-10	8.7E-09	1.5E-08
Th-230	2.5E-09	7.0E-13	1.8E-09	4.3E-09
Th-232	3.1E-09	1.0E-08	2.1E-09	1.5E-08
Th-234	7.8E-11	9.2E-11	5.5E-11	2.3E-10
U-234	5.8E-10	1.7E-15	8.2E-10	1.4E-09
U-235	5.6E-10	3.4E-12	7.9E-10	1.3E-09
U-238	5.4E-10	6.9E-13	7.5E-10	1.3E-09
Np-237	5.2E-10	9.9E-13	1.2E-09	1.7E-09
Pu-238	3.2E-10	1.9E-13	4.4E-10	7.6E-10
Pu-239	3.6E-10	4.3E-13	5.0E-10	8.6E-10
Pu-240	3.6E-10	1.8E-13	5.0E-10	8.6E-10
Pu-241	6.7E-12	8.6E-15	9.4E-12	1.6E-11
Pu-242	3.4E-10	1.6E-13	4.8E-10	8.2E-10
Am-241	1.7E-09	6.9E-11	1.2E-10	1.8E-09
Am-242	4.8E-12	2.6E-11	3.4E-13	3.1E-11
Am-243	1.7E-09	1.5E-09	1.2E-10	3.3E-09
Cm-242	4.5E-12	2.4E-13	1.3E-11	1.7E-11
Cm-243	3.0E-11	9.9E-10	8.5E-11	1.1E-09
Cm-244	2.6E-11	1.7E-13	7.4E-11	1.0E-10

Table 16 Dose per unit release factors for adult angler family – river release scenario

Radionuclide	DPURs for adult angler family (µSv y^{-1} per Bq y^{-1})			
	Fish	External	Drinking water	Total
H-3	1.0E-14	0.0E+00	3.4E-13	3.5E-13
H-3 organic	5.9E-10	0.0E+00	8.0E-13	5.9E-10
C-14	7.4E-09	3.9E-15	1.0E-11	7.4E-09
Na-22	4.1E-11	1.5E-11	6.1E-11	1.2E-10
Na-24	5.4E-12	5.1E-12	8.2E-12	1.9E-11
P-32	1.4E-08	3.8E-12	4.3E-11	1.5E-08
P-33	1.4E-09	9.4E-15	4.3E-12	1.5E-09
S-35	1.4E-11	6.2E-15	2.1E-12	1.6E-11
Cl-36	2.9E-11	0.0E+00	1.8E-11	4.7E-11
Ca-45	1.6E-11	1.9E-14	1.2E-11	2.9E-11
Ca-47	3.7E-11	4.6E-10	2.8E-11	5.2E-10
V-48	3.8E-08	3.4E-10	3.8E-11	3.8E-08
Cr-51	4.8E-13	3.2E-10	3.6E-13	3.2E-10
Mn-52	3.3E-11	1.1E-08	9.8E-12	1.1E-08
Mn-54	1.3E-11	1.4E-08	3.9E-12	1.4E-08
Fe-55	1.4E-11	0.0E+00	4.2E-12	1.8E-11
Fe-59	7.6E-11	9.4E-09	2.3E-11	9.5E-09
Co-56	2.4E-10	4.4E-08	2.4E-11	4.4E-08
Co-57	2.0E-11	8.9E-10	2.0E-12	9.1E-10
Co-58	7.0E-11	1.1E-08	7.0E-12	1.1E-08
Co-60	3.2E-10	3.0E-08	3.2E-11	3.0E-08
Ni-63	4.8E-12	0.0E+00	1.4E-12	6.2E-12
Zn-65	1.2E-08	6.5E-10	7.1E-11	1.2E-08
Ga-67	4.8E-11	6.5E-12	3.6E-12	5.8E-11
Se-75	3.1E-10	3.4E-10	4.7E-11	7.0E-10
Br-82	1.4E-10	0.0E+00	1.0E-11	1.5E-10
Rb-83	1.6E-09	3.6E-09	2.4E-11	5.2E-09
Sr-89	9.0E-11	5.4E-12	4.5E-11	1.4E-10
Sr-90	9.7E-10	1.4E-11	4.8E-10	1.5E-09
Y-90	3.6E-11	1.5E-11	4.3E-11	9.4E-11
Zr-95	4.5E-11	2.5E-08	4.5E-12	2.5E-08
Nb-95	1.1E-10	8.6E-11	1.1E-11	2.1E-10
Mo-99	3.6E-12	5.4E-11	1.1E-11	6.8E-11
Tc-99	6.0E-12	4.2E-15	1.2E-11	1.8E-11
Tc-99m	2.1E-13	5.2E-12	4.1E-13	5.8E-12
Ru-103	3.4E-12	2.6E-09	1.0E-11	2.6E-09
Ru-106	3.3E-11	1.3E-09	9.9E-11	1.4E-09
Ag-110m	4.0E-12	6.3E-10	5.3E-11	6.8E-10
In-111	3.1E-10	1.4E-09	9.2E-13	1.7E-09
Sb-125	6.8E-13	2.2E-10	2.0E-11	2.4E-10
I-123	5.2E-12	9.6E-12	3.9E-12	1.9E-11
I-125	3.7E-10	6.9E-13	2.8E-10	6.6E-10
I-129	2.7E-09	5.5E-13	2.1E-09	4.8E-09
I-131	5.5E-10	2.5E-11	4.1E-10	9.9E-10
I-133	1.1E-10	4.0E-11	8.1E-11	2.3E-10
I-135	2.3E-11	1.0E-10	1.7E-11	1.4E-10

Table 16 continued

Radionuclide	DPURs for adult angler family (µSv y^{-1} per Bq y^{-1})			
	Fish	External	Drinking water	Total
Cs-134	2.2E-08	3.2E-09	3.3E-10	2.5E-08
Cs-136	3.5E-09	8.6E-10	5.2E-11	4.4E-09
Cs-137	1.5E-08	1.1E-09	2.2E-10	1.6E-08
Ba-140	5.3E-12	2.1E-09	4.0E-11	2.2E-09
La-140	2.0E-12	6.0E-09	1.5E-11	6.0E-09
Ce-141	5.4E-12	6.8E-10	5.4E-12	6.9E-10
Ce-144	4.0E-11	7.7E-10	4.0E-11	8.5E-10
Pm-147	4.0E-12	3.4E-14	4.0E-12	7.9E-12
Sm-153	5.6E-12	1.2E-10	5.6E-12	1.3E-10
Eu-152	8.9E-12	1.6E-08	1.1E-11	1.6E-08
Eu-154	1.3E-11	1.7E-08	1.5E-11	1.7E-08
Eu-155	2.0E-12	3.8E-10	2.4E-12	3.8E-10
Er-169	2.3E-12	1.2E-13	2.8E-12	5.3E-12
Lu-177	4.0E-12	8.7E-11	4.0E-12	9.5E-11
Au-198	7.6E-12	1.1E-09	7.6E-12	1.1E-09
Tl-201	3.0E-10	1.7E-10	9.0E-13	4.7E-10
Pb-210	9.8E-08	7.3E-12	9.8E-09	1.1E-07
Po-210	2.8E-08	4.8E-14	1.7E-08	4.6E-08
Ra-223	3.1E-09	1.8E-10	1.9E-09	5.1E-09
Ra-226	8.7E-09	1.0E-09	5.2E-09	1.5E-08
Th-230	8.9E-09	1.4E-12	2.7E-09	1.2E-08
Th-232	9.7E-09	2.0E-08	2.9E-09	3.3E-08
Th-234	1.4E-10	1.8E-10	4.3E-11	3.7E-10
U-234	1.5E-09	3.4E-15	9.3E-10	2.5E-09
U-235	1.5E-09	6.7E-12	8.9E-10	2.4E-09
U-238	1.4E-09	1.4E-12	8.5E-10	2.3E-09
Np-237	2.1E-09	2.0E-12	2.1E-09	4.2E-09
Pu-238	1.2E-09	3.8E-13	7.3E-10	1.9E-09
Pu-239	1.3E-09	8.6E-13	7.9E-10	2.1E-09
Pu-240	1.3E-09	3.7E-13	7.9E-10	2.1E-09
Pu-241	2.5E-11	1.7E-14	1.5E-11	4.1E-11
Pu-242	1.3E-09	3.2E-13	7.6E-10	2.0E-09
Am-241	6.0E-09	1.4E-10	1.8E-10	6.4E-09
Am-242	9.1E-12	5.2E-11	2.7E-13	6.2E-11
Am-243	6.0E-09	3.0E-09	1.8E-10	9.2E-09
Cm-242	9.1E-12	4.8E-13	1.1E-11	2.0E-11
Cm-243	1.1E-10	2.0E-09	1.4E-10	2.2E-09
Cm-244	9.1E-11	3.3E-13	1.1E-10	2.0E-10

Table 17 Dose per unit release factors for worst age group irrigated food consumer family – river release scenario

Radionuclide	Worst total DPUR ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)	Worst age group
H-3	4.4E-14	Offspring
H-3 organic	2.1E-14	Offspring
C-14	4.8E-11	Offspring
Na-22	1.6E-11	Infant
Na-24	4.8E-14	Infant
P-32	1.8E-10	Offspring
P-33	8.0E-12	Offspring
S-35	7.5E-13	Infant
Cl-36	3.1E-10	Infant
Ca-45	1.0E-11	Offspring
Ca-47	2.0E-12	Offspring
V-48	1.4E-12	Infant
Cr-51	2.9E-14	Infant
Mn-52	6.0E-13	Infant
Mn-54	8.8E-13	Infant
Fe-55	5.5E-13	Infant
Fe-59	2.3E-12	Infant
Co-56	3.0E-12	Infant
Co-57	3.6E-13	Infant
Co-58	8.6E-13	Infant
Co-60	9.5E-12	Infant
Ni-63	1.2E-12	Infant
Zn-65	8.1E-12	Infant
Ga-67	5.4E-14	Infant
Se-75	1.3E-11	Infant
Br-82	1.2E-13	Infant
Rb-83	6.6E-12	Infant
Sr-89	1.0E-11	Offspring
Sr-90	3.0E-10	Offspring
Y-90	7.6E-13	Infant
Zr-95	1.1E-12	Infant
Nb-95	5.3E-13	Infant
Mo-99	1.4E-13	Infant
Tc-99	7.4E-10	Infant
Tc-99m	1.3E-15	Infant
Ru-103	6.5E-13	Infant
Ru-106	9.3E-12	Infant
Ag-110m	4.3E-12	Infant
In-111	6.8E-14	Infant
Sb-125	1.6E-12	Infant
I-123	3.5E-14	Infant
I-125	4.3E-11	Child
I-129	7.2E-10	Child
I-131	3.8E-11	Infant
I-133	1.2E-12	Infant
I-135	8.3E-14	Infant

Table 17 continued

Radionuclide	Worst total DPUR ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)	Worst age group
Cs-134	6.0E-11	Adult
Cs-136	3.0E-12	Adult
Cs-137	4.6E-11	Adult
Ba-140	2.0E-12	Infant
La-140	3.3E-13	Infant
Ce-141	6.9E-13	Infant
Ce-144	7.1E-12	Infant
Pm-147	3.8E-13	Infant
Sm-153	1.3E-13	Infant
Eu-152	2.3E-12	Infant
Eu-154	3.2E-12	Infant
Eu-155	4.9E-13	Infant
Er-169	2.2E-13	Infant
Lu-177	2.5E-13	Infant
Au-198	2.3E-13	Infant
Tl-201	5.0E-14	Infant
Pb-210	3.2E-09	Infant
Po-210	7.5E-09	Infant
Ra-223	1.2E-10	Infant
Ra-226	1.9E-09	Child
Th-230	2.3E-10	Adult
Th-232	2.5E-10	Adult
Th-234	3.1E-12	Infant
U-234	6.1E-11	Adult
U-235	5.9E-11	Adult
U-238	5.6E-11	Adult
Np-237	1.7E-10	Adult
Pu-238	2.1E-10	Adult
Pu-239	2.3E-10	Adult
Pu-240	2.3E-10	Adult
Pu-241	4.4E-12	Adult
Pu-242	2.2E-10	Adult
Am-241	1.9E-10	Adult
Am-242	2.0E-14	Infant
Am-243	1.9E-10	Adult
Cm-242	1.3E-11	Infant
Cm-243	1.4E-10	Adult
Cm-244	1.1E-10	Adult

Table 18 Dose per unit release factors for offspring irrigated food consumer family – river release scenario

Radionuclide	DPURs for offspring irrigated food consumer family (μSv y^{-1} per Bq y^{-1})			
	Green veg	Root veg	Fruit	Total
H-3	1.2E-14	2.0E-14	1.2E-14	4.4E-14
H-3 organic	5.8E-15	9.4E-15	5.4E-15	2.1E-14
C-14	1.5E-11	1.9E-11	1.4E-11	4.8E-11
Na-22	<p	<p	<p	<p
Na-24	<p	<p	<p	<p
P-32	1.2E-11	1.6E-10	7.5E-12	1.8E-10
P-33	3.3E-12	2.9E-12	1.9E-12	8.0E-12
S-35	2.1E-13	2.7E-13	1.0E-13	5.8E-13
Cl-36	<p	<p	<p	<p
Ca-45	8.8E-12	3.2E-13	1.1E-12	1.0E-11
Ca-47	1.6E-12	6.4E-15	3.1E-13	2.0E-12
V-48	<p	<p	<p	<p
Cr-51	<p	<p	<p	<p
Mn-52	<p	<p	<p	<p
Mn-54	<p	<p	<p	<p
Fe-55	<p	<p	<p	<p
Fe-59	<p	<p	<p	<p
Co-56	<p	<p	<p	<p
Co-57	<p	<p	<p	<p
Co-58	<p	<p	<p	<p
Co-60	<p	<p	<p	<p
Ni-63	<p	<p	<p	<p
Zn-65	<p	<p	<p	<p
Ga-67	<p	<p	<p	<p
Se-75	3.0E-12	4.1E-12	1.4E-12	8.5E-12
Br-82	<p	<p	<p	<p
Rb-83	<p	<p	<p	<p
Sr-89	8.6E-12	1.1E-13	1.4E-12	1.0E-11
Sr-90	2.1E-10	4.8E-11	4.2E-11	3.0E-10
Y-90	<p	<p	<p	<p
Zr-95	<p	<p	<p	<p
Nb-95	<p	<p	<p	<p
Mo-99	<p	<p	<p	<p
Tc-99	<p	<p	<p	<p
Tc-99m	<p	<p	<p	<p
Ru-103	<p	<p	<p	<p
Ru-106	<p	<p	<p	<p
Ag-110m	<p	<p	<p	<p
In-111	<p	<p	<p	<p
Sb-125	<p	<p	<p	<p
I-123	<p	<p	<p	<p
I-125	<p	<p	<p	<p
I-129	<p	<p	<p	<p
I-131	<p	<p	<p	<p
I-133	<p	<p	<p	<p
I-135	<p	<p	<p	<p

Table 18 continued

Radionuclide	DPURs for offspring irrigated food consumer family (μSv y^{-1} per Bq y^{-1})			
	Green veg	Root veg	Fruit	Total
Cs-134	<p	<p	<p	<p
Cs-136	<p	<p	<p	<p
Cs-137	<p	<p	<p	<p
Ba-140	<p	<p	<p	<p
La-140	<p	<p	<p	<p
Ce-141	<p	<p	<p	<p
Ce-144	<p	<p	<p	<p
Pm-147	<p	<p	<p	<p
Sm-153	<p	<p	<p	<p
Eu-152	<p	<p	<p	<p
Eu-154	<p	<p	<p	<p
Eu-155	<p	<p	<p	<p
Er-169	<p	<p	<p	<p
Lu-177	<p	<p	<p	<p
Au-198	<p	<p	<p	<p
Tl-201	<p	<p	<p	<p
Pb-210	<p	<p	<p	<p
Po-210	<p	<p	<p	<p
Ra-223	<p	<p	<p	<p
Ra-226	3.5E-10	1.2E-11	8.6E-10	1.2E-09
Th-230	<p	<p	<p	<p
Th-232	<p	<p	<p	<p
Th-234	<p	<p	<p	<p
U-234	<p	<p	<p	<p
U-235	<p	<p	<p	<p
U-238	<p	<p	<p	<p
Np-237	<p	<p	<p	<p
Pu-238	<p	<p	<p	<p
Pu-239	<p	<p	<p	<p
Pu-240	<p	<p	<p	<p
Pu-241	<p	<p	<p	<p
Pu-242	<p	<p	<p	<p
Am-241	<p	<p	<p	<p
Am-242	<p	<p	<p	<p
Am-243	<p	<p	<p	<p
Cm-242	<p	<p	<p	<p
Cm-243	<p	<p	<p	<p
Cm-244	<p	<p	<p	<p

<p = not calculated as dose to parent greater than dose to offspring

Table 19 Dose per unit release factors for infant irrigated food consumer family – river release scenario

Radionuclide	DPURs for infant irrigated food consumer family (µSv y^{-1} per Bq y^{-1})			
	Green veg	Root veg	Fruit	Total
H-3	3.7E-15	1.1E-14	8.6E-15	2.3E-14
H-3 organic	2.1E-15	6.2E-15	4.8E-15	1.3E-14
C-14	5.5E-12	1.3E-11	1.3E-11	3.1E-11
Na-22	3.3E-12	9.0E-12	3.8E-12	1.6E-11
Na-24	1.6E-14	2.5E-16	3.2E-14	4.8E-14
P-32	1.8E-12	4.4E-11	2.8E-12	4.8E-11
P-33	2.3E-13	3.8E-13	3.2E-13	9.3E-13
S-35	1.6E-13	3.8E-13	2.0E-13	7.5E-13
Cl-36	8.7E-11	2.1E-10	1.1E-11	3.1E-10
Ca-45	9.5E-13	6.4E-14	3.0E-13	1.3E-12
Ca-47	3.7E-13	2.7E-15	1.7E-13	5.5E-13
V-48	9.5E-13	2.4E-15	4.2E-13	1.4E-12
Cr-51	2.4E-14	2.2E-18	5.3E-15	2.9E-14
Mn-52	4.0E-13	4.6E-15	1.9E-13	6.0E-13
Mn-54	5.3E-13	1.1E-13	2.4E-13	8.8E-13
Fe-55	4.0E-13	2.6E-15	1.5E-13	5.5E-13
Fe-59	1.6E-12	3.3E-15	6.7E-13	2.3E-12
Co-56	2.1E-12	1.9E-14	8.5E-13	3.0E-12
Co-57	2.6E-13	5.8E-15	1.0E-13	3.6E-13
Co-58	6.1E-13	5.1E-15	2.5E-13	8.6E-13
Co-60	4.7E-12	6.2E-13	4.2E-12	9.5E-12
Ni-63	1.7E-13	9.5E-14	9.2E-13	1.2E-12
Zn-65	4.0E-12	2.2E-12	2.0E-12	8.1E-12
Ga-67	3.6E-14	1.1E-18	1.8E-14	5.4E-14
Se-75	2.8E-12	7.2E-12	3.2E-12	1.3E-11
Br-82	4.0E-14	2.2E-15	7.9E-14	1.2E-13
Rb-83	1.4E-12	3.3E-12	1.9E-12	6.6E-12
Sr-89	2.4E-12	5.7E-14	9.5E-13	3.4E-12
Sr-90	6.8E-11	2.9E-11	3.4E-11	1.3E-10
Y-90	5.1E-13	4.6E-16	2.5E-13	7.6E-13
Zr-95	7.6E-13	1.9E-15	3.1E-13	1.1E-12
Nb-95	3.7E-13	1.9E-15	1.6E-13	5.3E-13
Mo-99	9.2E-14	8.3E-17	4.5E-14	1.4E-13
Tc-99	6.6E-11	1.6E-10	5.1E-10	7.4E-10
Tc-99m	4.1E-16	1.2E-16	7.5E-16	1.3E-15
Ru-103	5.4E-13	2.1E-15	1.2E-13	6.5E-13
Ru-106	7.5E-12	2.0E-13	1.5E-12	9.3E-12
Ag-110m	2.5E-12	7.8E-13	1.1E-12	4.3E-12
In-111	4.5E-14	1.2E-18	2.2E-14	6.8E-14
Sb-125	1.0E-12	7.7E-14	5.4E-13	1.6E-12
I-123	1.1E-14	1.2E-16	2.3E-14	3.5E-14
I-125	8.8E-12	1.9E-11	1.2E-11	4.0E-11
I-129	6.3E-11	1.8E-10	2.2E-10	4.6E-10
I-131	1.1E-11	7.0E-12	2.0E-11	3.8E-11
I-133	4.1E-13	9.3E-15	8.3E-13	1.2E-12
I-135	2.7E-14	1.0E-16	5.6E-14	8.3E-14

Table 19 continued

Radionuclide	DPURs for infant irrigated food consumer family ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)			
	Green veg	Root veg	Fruit	Total
Cs-134	3.2E-12	8.6E-12	4.1E-12	1.6E-11
Cs-136	8.1E-13	8.0E-13	1.3E-12	2.9E-12
Cs-137	2.6E-12	7.4E-12	3.2E-12	1.3E-11
Ba-140	1.4E-12	1.7E-15	6.2E-13	2.0E-12
La-140	2.2E-13	5.5E-17	1.1E-13	3.3E-13
Ce-141	5.6E-13	1.9E-16	1.2E-13	6.9E-13
Ce-144	5.9E-12	1.2E-14	1.2E-12	7.1E-12
Pm-147	3.0E-13	6.4E-15	7.3E-14	3.8E-13
Sm-153	1.0E-13	8.7E-18	2.6E-14	1.3E-13
Eu-152	1.2E-12	1.1E-13	1.0E-12	2.3E-12
Eu-154	1.9E-12	1.3E-13	1.1E-12	3.2E-12
Eu-155	3.5E-13	1.4E-14	1.2E-13	4.9E-13
Er-169	1.8E-13	2.6E-17	4.1E-14	2.2E-13
Lu-177	2.0E-13	2.5E-17	4.8E-14	2.5E-13
Au-198	1.8E-13	5.9E-17	4.6E-14	2.3E-13
Tl-201	1.6E-14	2.8E-15	3.1E-14	5.0E-14
Pb-210	6.8E-10	2.6E-10	2.3E-09	3.2E-09
Po-210	1.6E-09	3.9E-09	2.1E-09	7.5E-09
Ra-223	7.9E-11	3.5E-14	3.6E-11	1.2E-10
Ra-226	2.0E-10	1.3E-11	1.3E-09	1.5E-09
Th-230	6.5E-11	2.7E-12	3.9E-11	1.1E-10
Th-232	7.2E-11	3.0E-12	4.3E-11	1.2E-10
Th-234	2.5E-12	3.5E-16	5.5E-13	3.1E-12
U-234	2.1E-11	1.7E-12	2.1E-11	4.4E-11
U-235	2.1E-11	1.7E-12	2.1E-11	4.4E-11
U-238	2.0E-11	1.6E-12	1.9E-11	4.0E-11
Np-237	3.5E-11	2.8E-12	6.0E-11	9.8E-11
Pu-238	6.3E-11	2.2E-13	1.5E-11	7.8E-11
Pu-239	6.6E-11	2.8E-13	1.6E-11	8.2E-11
Pu-240	6.6E-11	2.8E-13	1.6E-11	8.2E-11
Pu-241	9.0E-13	1.5E-15	1.9E-13	1.1E-12
Pu-242	6.3E-11	2.7E-13	1.5E-11	7.9E-11
Am-241	5.9E-11	3.8E-13	1.7E-11	7.6E-11
Am-242	1.6E-14	9.1E-20	4.1E-15	2.0E-14
Am-243	5.9E-11	3.9E-13	1.7E-11	7.6E-11
Cm-242	1.1E-11	4.1E-16	2.3E-12	1.3E-11
Cm-243	5.2E-11	6.5E-14	1.2E-11	6.5E-11
Cm-244	4.6E-11	5.4E-14	1.1E-11	5.7E-11

Table 20 Dose per unit release factors for child irrigated food consumer family – river release scenario

Radionuclide	DPURs for child irrigated food consumer family ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)			
	Green veg	Root veg	Fruit	Total
H-3	4.1E-15	1.1E-14	5.9E-15	2.1E-14
H-3 organic	2.3E-15	6.2E-15	3.3E-15	1.2E-14
C-14	6.4E-12	1.4E-11	9.1E-12	2.9E-11
Na-22	2.8E-12	7.0E-12	2.0E-12	1.2E-11
Na-24	1.2E-14	1.8E-16	1.5E-14	2.8E-14
P-32	1.2E-12	2.6E-11	1.1E-12	2.8E-11
P-33	1.6E-13	2.4E-13	1.4E-13	5.3E-13
S-35	1.2E-13	2.5E-13	8.9E-14	4.6E-13
Cl-36	6.1E-11	1.4E-10	4.6E-12	2.0E-10
Ca-45	8.2E-13	4.9E-14	1.6E-13	1.0E-12
Ca-47	2.8E-13	1.8E-15	8.1E-14	3.6E-13
V-48	7.9E-13	1.8E-15	2.1E-13	1.0E-12
Cr-51	1.9E-14	1.6E-18	2.6E-15	2.2E-14
Mn-52	3.6E-13	3.7E-15	1.1E-13	4.7E-13
Mn-54	5.2E-13	9.8E-14	1.4E-13	7.6E-13
Fe-55	4.3E-13	2.5E-15	1.0E-13	5.3E-13
Fe-59	1.4E-12	2.5E-15	3.5E-13	1.7E-12
Co-56	1.9E-12	1.6E-14	4.7E-13	2.4E-12
Co-57	2.2E-13	4.5E-15	5.2E-14	2.7E-13
Co-58	5.5E-13	4.2E-15	1.4E-13	6.9E-13
Co-60	4.4E-12	5.4E-13	2.4E-12	7.4E-12
Ni-63	1.3E-13	6.7E-14	4.4E-13	6.4E-13
Zn-65	3.7E-12	1.8E-12	1.2E-12	6.7E-12
Ga-67	2.8E-14	7.9E-19	8.4E-15	3.6E-14
Se-75	3.1E-12	7.0E-12	2.1E-12	1.2E-11
Br-82	3.4E-14	1.7E-15	4.1E-14	7.7E-14
Rb-83	1.3E-12	2.7E-12	1.0E-12	5.0E-12
Sr-89	1.8E-12	3.9E-14	4.4E-13	2.3E-12
Sr-90	1.3E-10	5.1E-11	4.0E-11	2.2E-10
Y-90	3.5E-13	2.9E-16	1.1E-13	4.6E-13
Zr-95	6.0E-13	1.4E-15	1.5E-13	7.5E-13
Nb-95	3.0E-13	1.4E-15	7.7E-14	3.8E-13
Mo-99	6.7E-14	5.5E-17	2.0E-14	8.8E-14
Tc-99	4.2E-11	9.3E-11	2.0E-10	3.3E-10
Tc-99m	3.2E-16	8.4E-17	3.5E-16	7.6E-16
Ru-103	4.1E-13	1.4E-15	5.4E-14	4.6E-13
Ru-106	5.4E-12	1.3E-13	6.7E-13	6.2E-12
Ag-110m	2.1E-12	6.1E-13	5.7E-13	3.3E-12
In-111	3.7E-14	8.4E-19	1.1E-14	4.8E-14
Sb-125	8.3E-13	5.6E-14	2.7E-13	1.1E-12
I-123	6.9E-15	6.5E-17	8.6E-15	1.6E-14
I-125	1.1E-11	2.2E-11	9.6E-12	4.3E-11
I-129	1.3E-10	3.3E-10	2.7E-10	7.2E-10
I-131	7.5E-12	4.3E-12	8.1E-12	2.0E-11
I-133	2.2E-13	4.5E-15	2.7E-13	4.9E-13
I-135	1.6E-14	5.4E-17	2.0E-14	3.6E-14

Table 20 continued

Radionuclide	DPURs for child irrigated food consumer family ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)			
	Green veg	Root veg	Fruit	Total
Cs-134	6.4E-12	1.6E-11	5.1E-12	2.7E-11
Cs-136	8.7E-13	7.8E-13	8.8E-13	2.5E-12
Cs-137	5.1E-12	1.3E-11	3.8E-12	2.2E-11
Ba-140	1.0E-12	1.1E-15	2.9E-13	1.3E-12
La-140	1.7E-13	3.7E-17	5.1E-14	2.2E-13
Ce-141	3.9E-13	1.2E-16	5.2E-14	4.4E-13
Ce-144	3.9E-12	7.4E-15	4.9E-13	4.4E-12
Pm-147	2.1E-13	4.0E-15	3.1E-14	2.4E-13
Sm-153	7.2E-14	5.4E-18	1.1E-14	8.3E-14
Eu-152	9.9E-13	8.3E-14	5.2E-13	1.6E-12
Eu-154	1.5E-12	9.3E-14	5.6E-13	2.2E-12
Eu-155	2.5E-13	9.1E-15	5.5E-14	3.1E-13
Er-169	1.2E-13	1.6E-17	1.7E-14	1.4E-13
Lu-177	1.4E-13	1.6E-17	2.1E-14	1.6E-13
Au-198	1.3E-13	3.8E-17	2.0E-14	1.5E-13
Tl-201	1.2E-14	2.0E-15	1.4E-14	2.9E-14
Pb-210	8.4E-10	2.8E-10	1.7E-09	2.8E-09
Po-210	1.1E-09	2.4E-09	8.9E-10	4.4E-09
Ra-223	7.6E-11	3.0E-14	2.1E-11	9.7E-11
Ra-226	3.9E-10	2.4E-11	1.5E-09	1.9E-09
Th-230	8.9E-11	3.4E-12	3.3E-11	1.3E-10
Th-232	1.1E-10	4.1E-12	4.0E-11	1.5E-10
Th-234	1.7E-12	2.2E-16	2.3E-13	2.0E-12
U-234	2.8E-11	2.1E-12	1.7E-11	4.7E-11
U-235	2.7E-11	2.0E-12	1.6E-11	4.5E-11
U-238	2.6E-11	1.9E-12	1.5E-11	4.3E-11
Np-237	4.3E-11	3.1E-12	4.5E-11	9.1E-11
Pu-238	8.9E-11	2.8E-13	1.3E-11	1.0E-10
Pu-239	1.0E-10	3.8E-13	1.5E-11	1.1E-10
Pu-240	1.0E-10	3.8E-13	1.5E-11	1.1E-10
Pu-241	1.9E-12	2.9E-15	2.5E-13	2.1E-12
Pu-242	9.6E-11	3.6E-13	1.4E-11	1.1E-10
Am-241	8.1E-11	4.8E-13	1.4E-11	9.6E-11
Am-242	1.1E-14	5.6E-20	1.7E-15	1.2E-14
Am-243	8.1E-11	4.9E-13	1.5E-11	9.6E-11
Cm-242	8.1E-12	2.7E-16	1.0E-12	9.2E-12
Cm-243	5.9E-11	6.7E-14	8.6E-12	6.8E-11
Cm-244	5.2E-11	5.5E-14	7.4E-12	5.9E-11

Table 21 Dose per unit release factors for adult irrigated food consumer family – river release scenario

Radionuclide	DPURs for adult irrigated food consumer family ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)			
	Green veg	Root veg	Fruit	Total
H-3	7.3E-15	1.2E-14	6.9E-15	2.6E-14
H-3 organic	3.9E-15	6.3E-15	3.6E-15	1.4E-14
C-14	1.1E-11	1.4E-11	9.9E-12	3.4E-11
Na-22	3.7E-12	5.6E-12	1.8E-12	1.1E-11
Na-24	1.6E-14	1.3E-16	1.3E-14	2.9E-14
P-32	1.2E-12	1.6E-11	7.5E-13	1.8E-11
P-33	1.6E-13	1.5E-13	9.3E-14	4.0E-13
S-35	1.3E-13	1.7E-13	6.4E-14	3.6E-13
Cl-36	6.8E-11	9.1E-11	3.4E-12	1.6E-10
Ca-45	7.4E-13	2.7E-14	9.2E-14	8.5E-13
Ca-47	3.4E-13	1.3E-15	6.4E-14	4.1E-13
V-48	9.2E-13	1.3E-15	1.6E-13	1.1E-12
Cr-51	2.1E-14	1.1E-18	1.9E-15	2.3E-14
Mn-52	4.4E-13	2.7E-15	8.4E-14	5.2E-13
Mn-54	6.5E-13	7.3E-14	1.2E-13	8.4E-13
Fe-55	2.9E-13	1.0E-15	4.5E-14	3.4E-13
Fe-59	1.2E-12	1.3E-15	2.0E-13	1.4E-12
Co-56	1.9E-12	9.2E-15	3.0E-13	2.2E-12
Co-57	1.8E-13	2.2E-15	2.8E-14	2.1E-13
Co-58	5.4E-13	2.5E-15	8.9E-14	6.3E-13
Co-60	3.1E-12	2.3E-13	1.1E-12	4.5E-12
Ni-63	1.6E-13	4.9E-14	3.5E-13	5.7E-13
Zn-65	5.1E-12	1.5E-12	1.1E-12	7.7E-12
Ga-67	3.0E-14	5.2E-19	6.0E-15	3.6E-14
Se-75	3.0E-12	4.1E-12	1.4E-12	8.5E-12
Br-82	4.4E-14	1.3E-15	3.5E-14	8.1E-14
Rb-83	1.7E-12	2.2E-12	9.3E-13	4.8E-12
Sr-89	1.9E-12	2.4E-14	3.0E-13	2.2E-12
Sr-90	1.4E-10	3.2E-11	2.8E-11	2.0E-10
Y-90	3.7E-13	1.8E-16	7.3E-14	4.4E-13
Zr-95	6.8E-13	9.4E-16	1.1E-13	8.0E-13
Nb-95	3.6E-13	9.8E-16	6.1E-14	4.2E-13
Mo-99	8.4E-14	4.1E-17	1.7E-14	1.0E-13
Tc-99	4.7E-11	6.2E-11	1.5E-10	2.6E-10
Tc-99m	3.7E-16	5.9E-17	2.7E-16	7.0E-16
Ru-103	4.5E-13	9.6E-16	3.9E-14	4.9E-13
Ru-106	5.7E-12	8.4E-14	4.7E-13	6.3E-12
Ag-110m	2.6E-12	4.5E-13	4.6E-13	3.5E-12
In-111	4.1E-14	5.7E-19	8.2E-15	4.9E-14
Sb-125	9.9E-13	4.0E-14	2.1E-13	1.2E-12
I-123	6.7E-15	3.8E-17	5.5E-15	1.2E-14
I-125	1.2E-11	1.4E-11	7.0E-12	3.4E-11
I-129	1.7E-10	2.6E-10	2.3E-10	6.6E-10
I-131	7.3E-12	2.5E-12	5.1E-12	1.5E-11
I-133	2.1E-13	2.6E-15	1.7E-13	3.9E-13
I-135	1.5E-14	3.1E-17	1.3E-14	2.8E-14

Table 21 continued

Radionuclide	DPURs for adult irrigated food consumer family ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)			
	Green veg	Root veg	Fruit	Total
Cs-134	2.0E-11	3.0E-11	1.0E-11	6.0E-11
Cs-136	1.4E-12	7.3E-13	9.0E-13	3.0E-12
Cs-137	1.5E-11	2.3E-11	7.4E-12	4.6E-11
Ba-140	1.1E-12	7.0E-16	1.9E-13	1.3E-12
La-140	1.8E-13	2.4E-17	3.7E-14	2.2E-13
Ce-141	4.2E-13	7.8E-17	3.7E-14	4.6E-13
Ce-144	4.2E-12	4.8E-15	3.5E-13	4.5E-12
Pm-147	2.2E-13	2.5E-15	2.2E-14	2.4E-13
Sm-153	7.6E-14	3.4E-18	7.7E-15	8.4E-14
Eu-152	1.2E-12	6.1E-14	4.2E-13	1.7E-12
Eu-154	1.7E-12	6.2E-14	4.1E-13	2.2E-12
Eu-155	2.7E-13	5.8E-15	3.9E-14	3.1E-13
Er-169	1.2E-13	9.9E-18	1.2E-14	1.4E-13
Lu-177	1.5E-13	9.8E-18	1.4E-14	1.6E-13
Au-198	1.4E-13	2.4E-17	1.4E-14	1.5E-13
Tl-201	1.5E-14	1.4E-15	1.1E-14	2.8E-14
Pb-210	7.0E-10	1.4E-10	9.2E-10	1.8E-09
Po-210	1.1E-09	1.5E-09	6.1E-10	3.3E-09
Ra-223	3.8E-11	9.2E-15	7.0E-12	4.6E-11
Ra-226	3.1E-10	1.1E-11	7.9E-10	1.1E-09
Th-230	1.8E-10	4.0E-12	4.3E-11	2.3E-10
Th-232	2.0E-10	4.4E-12	4.7E-11	2.5E-10
Th-234	1.8E-12	1.4E-16	1.6E-13	2.0E-12
U-234	4.3E-11	1.9E-12	1.7E-11	6.1E-11
U-235	4.1E-11	1.8E-12	1.6E-11	5.9E-11
U-238	3.9E-11	1.7E-12	1.5E-11	5.6E-11
Np-237	9.8E-11	4.2E-12	6.7E-11	1.7E-10
Pu-238	1.9E-10	3.7E-13	1.8E-11	2.1E-10
Pu-239	2.1E-10	4.8E-13	2.0E-11	2.3E-10
Pu-240	2.1E-10	4.8E-13	2.0E-11	2.3E-10
Pu-241	4.0E-12	3.7E-15	3.5E-13	4.4E-12
Pu-242	2.0E-10	4.6E-13	1.9E-11	2.2E-10
Am-241	1.7E-10	5.9E-13	2.0E-11	1.9E-10
Am-242	1.1E-14	3.6E-20	1.2E-15	1.3E-14
Am-243	1.7E-10	6.1E-13	2.0E-11	1.9E-10
Cm-242	9.3E-12	1.8E-16	7.8E-13	1.0E-11
Cm-243	1.3E-10	8.5E-14	1.2E-11	1.4E-10
Cm-244	1.0E-10	6.5E-14	9.6E-12	1.1E-10

Table 22 Dose per unit release factors for adult sewage treatment workers – sewage release scenario

Radionuclide	DPURs for adult sewage treatment workers (µSv y^{-1} per Bq y^{-1})			
	External	Inadvertent inhalation	Inadvertent ingestion	Total
H-3	0.0E+00	8.8E-16	3.7E-14	3.8E-14
H-3 organic	0.0E+00	2.0E-15	8.6E-14	8.8E-14
C-11	4.3E-10	5.4E-18	3.0E-16	4.3E-10
C-14	1.4E-13	9.8E-14	1.2E-12	1.4E-12
F-18	2.2E-09	9.1E-17	3.2E-15	2.2E-09
Na-22	1.2E-07	4.6E-14	4.7E-12	1.2E-07
Na-24	4.8E-08	1.8E-15	1.2E-13	4.8E-08
P-32	6.7E-10	4.4E-13	1.3E-11	6.9E-10
P-33	2.1E-12	2.4E-13	1.6E-12	4.0E-12
S-35	1.0E-13	4.6E-14	1.8E-13	3.3E-13
Cl-36	2.3E-11	2.6E-13	1.4E-12	2.4E-11
Ca-45	2.9E-12	5.8E-13	6.3E-12	9.8E-12
Ca-47	1.1E-07	1.1E-13	3.9E-12	1.1E-07
V-48	6.8E-07	3.7E-13	1.3E-11	6.8E-07
Cr-51	7.7E-09	6.9E-15	2.9E-13	7.7E-09
Mn-52	2.5E-07	6.5E-14	3.5E-12	2.5E-07
Mn-54	1.8E-07	2.1E-13	4.2E-12	1.8E-07
Mn-56	7.5E-09	3.3E-16	2.9E-14	7.5E-09
Fe-55	0.0E+00	9.5E-14	3.5E-12	3.6E-12
Fe-59	3.9E-07	7.7E-13	1.6E-11	3.9E-07
Co-56	1.2E-06	9.7E-13	2.1E-11	1.2E-06
Co-57	2.6E-08	1.2E-13	1.9E-12	2.6E-08
Co-58	2.9E-07	3.2E-13	6.2E-12	2.9E-07
Co-60	8.9E-07	2.3E-12	3.2E-11	8.9E-07
Ni-63	0.0E+00	6.9E-14	9.0E-13	9.7E-13
Zn-65	1.3E-07	2.2E-13	2.3E-11	1.3E-07
Ga-67	8.7E-09	1.2E-14	3.9E-13	8.7E-09
Se-75	6.3E-08	1.3E-13	1.5E-11	6.3E-08
Br-82	3.7E-08	5.8E-15	2.1E-13	3.7E-08
Rb-82	4.3E-11	5.5E-20	0.0E+00	4.3E-11
Rb-83	1.4E-07	1.4E-13	1.6E-11	1.4E-07
Sr-89	1.2E-10	1.9E-13	3.3E-12	1.2E-10
Sr-90	3.7E-10	1.3E-12	4.1E-11	4.1E-10
Y-90	1.2E-10	1.7E-14	1.3E-12	1.2E-10
Zr-95	2.4E-07	1.1E-12	8.7E-12	2.4E-07
Nb-95	1.3E-07	1.7E-13	2.7E-12	1.3E-07
Mo-99	3.8E-09	1.0E-14	2.9E-13	3.8E-09
Tc-99	9.9E-13	1.4E-13	9.5E-13	2.1E-12
Tc-99m	5.5E-10	8.1E-17	3.9E-15	5.5E-10
Ru-103	2.0E-08	7.1E-14	9.1E-13	2.0E-08
Ru-106	1.1E-08	9.7E-13	1.0E-11	1.1E-08
Ag-110m	1.0E-06	1.9E-12	2.9E-11	1.0E-06
In-111	2.1E-08	1.0E-14	5.3E-13	2.1E-08
In-113m	7.5E-10	4.4E-17	2.6E-15	7.5E-10
Sb-125	1.3E-07	1.1E-12	1.0E-11	1.3E-07
I-123	1.2E-09	5.4E-16	6.3E-14	1.2E-09
I-125	1.7E-10	2.8E-13	3.4E-11	2.0E-10

Table 22 continued

Radionuclide	DPURs for adult sewage treatment workers ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)			
	External	Inadvertent inhalation	Inadvertent ingestion	Total
I-129	1.5E-10	2.3E-12	2.9E-10	4.4E-10
I-131	1.5E-08	2.1E-13	2.7E-11	1.5E-08
I-132	7.0E-09	1.9E-16	2.5E-14	7.0E-09
I-133	7.8E-09	1.3E-14	1.6E-12	7.8E-09
I-134	3.2E-09	3.6E-17	3.6E-15	3.2E-09
I-135	1.2E-08	1.6E-15	1.9E-13	1.2E-08
Cs-134	2.0E-07	5.9E-13	7.0E-11	2.0E-07
Cs-136	1.7E-07	6.2E-14	6.4E-12	1.7E-07
Cs-137	7.4E-08	4.1E-13	4.9E-11	7.4E-08
Ba-140	8.7E-08	1.1E-13	2.4E-12	8.7E-08
La-140	3.5E-08	1.1E-14	8.0E-13	3.5E-08
Ce-141	8.3E-09	3.6E-13	3.3E-12	8.3E-09
Ce-144	1.2E-08	5.0E-12	3.0E-11	1.2E-08
Pm-147	1.6E-12	7.2E-13	1.6E-12	3.8E-12
Sm-153	7.7E-10	1.3E-14	6.6E-13	7.7E-10
Eu-152	2.5E-07	6.1E-12	8.4E-12	2.5E-07
Eu-154	2.7E-07	7.6E-12	1.2E-11	2.7E-07
Eu-155	6.0E-09	9.9E-13	1.9E-12	6.0E-09
Er-169	2.1E-12	6.6E-14	1.0E-12	3.1E-12
Lu-177	2.0E-09	6.4E-14	1.2E-12	2.0E-09
Au-198	1.5E-08	2.3E-14	1.1E-12	1.5E-08
Tl-201	1.9E-09	1.3E-15	1.2E-13	1.9E-09
Pb-210	4.9E-10	2.8E-10	7.3E-09	8.0E-09
Po-210	3.0E-12	7.8E-10	1.2E-08	1.3E-08
Ra-223	2.0E-07	5.5E-10	3.1E-10	2.0E-07
Ra-226	3.9E-07	5.1E-10	1.7E-09	4.0E-07
Th-230	7.0E-11	3.6E-09	2.2E-09	5.8E-09
Th-232	3.0E-11	6.3E-09	2.4E-09	8.8E-09
Th-234	6.5E-09	1.4E-12	2.5E-11	6.5E-09
U-234	3.1E-12	1.2E-10	7.2E-11	2.0E-10
U-235	6.3E-09	1.1E-10	6.9E-11	6.5E-09
U-238	1.3E-09	1.0E-10	6.6E-11	1.5E-09
Np-237	2.6E-09	3.3E-09	6.6E-10	6.6E-09
Pu-238	4.3E-12	6.6E-09	1.4E-09	8.0E-09
Pu-239	9.8E-12	7.2E-09	1.5E-09	8.7E-09
Pu-240	4.2E-12	7.2E-09	1.5E-09	8.7E-09
Pu-241	2.0E-13	1.3E-10	2.9E-11	1.6E-10
Pu-242	3.7E-12	6.9E-09	1.4E-09	8.4E-09
Am-241	2.4E-09	1.1E-08	2.1E-09	1.5E-08
Am-242	1.7E-10	2.5E-13	1.8E-13	1.7E-10
Am-243	5.3E-08	1.0E-08	2.1E-09	6.6E-08
Cm-242	7.9E-12	1.2E-09	1.2E-10	1.4E-09
Cm-243	3.5E-08	7.9E-09	1.6E-09	4.4E-08
Cm-244	5.8E-12	6.8E-09	1.3E-09	8.1E-09

Table 23 Dose per unit release factors for worst age group farming family – sewage release scenario

Radionuclide	Worst total DPUR ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)	Worst age group
H-3	5.1E-11	Infant
H-3 organic	6.9E-12	Infant
C-14	8.5E-08	Offspring
Na-22	1.1E-06	Adult
P-32	1.0E-07	Offspring
P-33	1.1E-07	Offspring
S-35	1.3E-08	Infant
Cl-36	1.4E-06	Infant
Ca-45	2.6E-08	Offspring
Ca-47	6.6E-10	Offspring
V-48	1.3E-07	Adult
Cr-51	3.4E-09	Adult
Mn-52	3.3E-09	Adult
Mn-54	9.7E-07	Adult
Fe-55	2.4E-08	Infant
Fe-59	3.1E-07	Adult
Co-56	1.8E-06	Adult
Co-57	1.3E-07	Adult
Co-58	3.9E-07	Adult
Co-60	1.4E-05	Adult
Ni-63	7.8E-10	Infant
Zn-65	2.9E-06	Infant
Se-75	2.1E-06	Infant
Rb-83	2.6E-07	Adult
Sr-89	1.2E-09	Infant
Sr-90	3.9E-07	Infant
Zr-95	5.9E-07	Adult
Nb-95	7.5E-08	Adult
Tc-99	5.1E-06	Infant
Ru-103	1.0E-08	Adult
Ru-106	5.5E-08	Adult
Ag-110m	5.5E-06	Adult
Sb-125	1.6E-06	Adult
I-125	9.8E-09	Infant
I-129	1.1E-06	Child
I-131	7.7E-10	Infant
Cs-134	2.1E-06	Adult
Cs-136	2.0E-08	Adult
Cs-137	1.8E-06	Adult
Ba-140	7.4E-09	Adult
Ce-141	4.4E-09	Adult
Ce-144	6.1E-08	Adult
Pm-147	3.0E-10	Infant
Eu-152	4.8E-06	Adult
Eu-154	4.9E-06	Adult
Eu-155	9.1E-08	Adult
Er-169	3.3E-13	Infant
Lu-177	4.9E-11	Adult

Table 23 continued

Radionuclide	Worst total DPUR ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)	Worst age group
Pb-210	9.6E-06	Infant
Po-210	4.0E-06	Infant
Ra-223	2.0E-08	Adult
Ra-226	1.0E-05	Offspring
Th-230	2.3E-07	Adult
Th-232	2.5E-05	Adult
Th-234	2.3E-09	Adult
U-234	2.1E-08	Infant
U-235	1.4E-07	Adult
U-238	3.7E-08	Adult
Np-237	1.3E-06	Adult
Pu-238	3.6E-07	Adult
Pu-239	4.1E-07	Adult
Pu-240	4.1E-07	Adult
Pu-241	6.1E-09	Adult
Pu-242	4.0E-07	Adult
Am-241	7.1E-07	Adult
Am-243	2.0E-06	Adult
Cm-242	4.3E-09	Adult
Cm-243	1.2E-06	Adult
Cm-244	3.2E-07	Adult

Table 24 Dose per unit release factors for offspring farming family – sewage release scenario

Radionuclide	DPURs for offspring farming family (µSv y^{-1} per Bq y^{-1})										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
H-3	0.0E+00	0.0E+00	3.2E-12	1.3E-12	3.7E-12	8.3E-13	2.3E-11	0.0E+00	1.8E-17	3.1E-18	3.2E-11
H-3 organic	0.0E+00	0.0E+00	4.9E-13	2.0E-13	5.8E-13	1.3E-13	2.5E-12	0.0E+00	3.6E-17	6.4E-18	3.9E-12
C-14	2.5E-08	3.3E-08	4.6E-09	1.8E-09	5.2E-09	1.2E-09	1.3E-08	2.7E-13	0.0E+00	9.4E-15	8.5E-08
Na-22	<p	<p	<p	<p	<p	<p	<p	1.1E-06	0.0E+00	0.0E+00	1.1E-06
P-32	nc	nc	1.3E-08	2.0E-09	1.2E-08	2.6E-09	7.4E-08	1.0E-10	9.0E-14	5.7E-14	1.0E-07
P-33	nc	nc	1.5E-08	2.5E-09	1.4E-08	3.1E-09	7.2E-08	8.1E-13	0.0E+00	3.6E-14	1.1E-07
S-35	2.5E-12	3.7E-12	1.9E-09	3.1E-10	2.0E-09	4.4E-10	1.6E-09	1.4E-13	0.0E+00	1.1E-15	6.3E-09
Cl-36	<p	<p	<p	<p	<p	<p	<p	4.4E-10	0.0E+00	0.0E+00	4.4E-10
Ca-45	5.0E-09	7.3E-10	4.2E-10	1.7E-10	7.5E-10	1.7E-10	1.9E-08	9.1E-12	0.0E+00	6.8E-13	2.6E-08
Ca-47	nc	nc	5.7E-15	2.3E-15	9.8E-15	2.2E-15	3.9E-13	6.6E-10	0.0E+00	3.4E-16	6.6E-10
V-48	<p	<p	<p	<p	<p	<p	<p	1.3E-07	0.0E+00	0.0E+00	1.3E-07
Cr-51	<p	<p	<p	<p	<p	<p	<p	3.4E-09	0.0E+00	0.0E+00	3.4E-09
Mn-52	<p	<p	<p	<p	<p	<p	<p	3.3E-09	0.0E+00	0.0E+00	3.3E-09
Mn-54	<p	<p	<p	<p	<p	<p	<p	9.4E-07	0.0E+00	0.0E+00	9.4E-07
Fe-55	<p	<p	<p	<p	<p	<p	<p	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Fe-59	<p	<p	<p	<p	<p	<p	<p	3.1E-07	0.0E+00	0.0E+00	3.1E-07
Co-56	<p	<p	<p	<p	<p	<p	<p	1.8E-06	0.0E+00	0.0E+00	1.8E-06
Co-57	<p	<p	<p	<p	<p	<p	<p	1.2E-07	0.0E+00	0.0E+00	1.2E-07
Co-58	<p	<p	<p	<p	<p	<p	<p	3.9E-07	0.0E+00	0.0E+00	3.9E-07
Co-60	<p	<p	<p	<p	<p	<p	<p	1.4E-05	0.0E+00	0.0E+00	1.4E-05
Ni-63	<p	<p	<p	<p	<p	<p	<p	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Zn-65	<p	<p	<p	<p	<p	<p	<p	5.5E-07	0.0E+00	0.0E+00	5.5E-07
Se-75	6.1E-10	9.5E-10	7.4E-08	5.9E-07	9.4E-08	5.2E-07	6.2E-08	1.4E-07	2.3E-13	9.5E-14	1.5E-06
Rb-83	<p	<p	<p	<p	<p	<p	<p	2.4E-07	0.0E+00	0.0E+00	2.4E-07
Sr-89	8.7E-12	1.4E-12	1.3E-11	5.4E-12	2.2E-11	4.9E-12	5.9E-10	8.2E-11	0.0E+00	3.0E-14	7.3E-10
Sr-90	2.0E-07	5.4E-08	1.8E-09	7.2E-10	4.9E-09	1.1E-09	1.2E-07	3.6E-09	0.0E+00	1.7E-12	3.9E-07
Zr-95	<p	<p	<p	<p	<p	<p	<p	5.9E-07	0.0E+00	0.0E+00	5.9E-07
Nb-95	<p	<p	<p	<p	<p	<p	<p	7.5E-08	0.0E+00	0.0E+00	7.5E-08
Tc-99	<p	<p	<p	<p	<p	<p	<p	1.9E-11	0.0E+00	0.0E+00	1.9E-11

Table 24 continued

Radionuclide	DPURs for offspring farming family (µSv y^{-1} per Bq y^{-1})										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
Ru-103	<p	<p	<p	<p	<p	<p	<p	1.0E-08	0.0E+00	0.0E+00	1.0E-08
Ru-106	<p	<p	<p	<p	<p	<p	<p	5.5E-08	0.0E+00	0.0E+00	5.5E-08
Ag-110m	<p	<p	<p	<p	<p	<p	<p	4.6E-06	0.0E+00	0.0E+00	4.6E-06
Sb-125	<p	<p	<p	<p	<p	<p	<p	1.6E-06	0.0E+00	0.0E+00	1.6E-06
I-125	<p	<p	<p	<p	<p	<p	<p	1.7E-10	0.0E+00	0.0E+00	1.7E-10
I-129	<p	<p	<p	<p	<p	<p	<p	3.4E-09	0.0E+00	0.0E+00	3.4E-09
I-131	<p	<p	<p	<p	<p	<p	<p	5.2E-10	0.0E+00	0.0E+00	5.2E-10
Cs-134	<p	<p	<p	<p	<p	<p	<p	1.9E-06	0.0E+00	0.0E+00	1.9E-06
Cs-136	<p	<p	<p	<p	<p	<p	<p	2.0E-08	0.0E+00	0.0E+00	2.0E-08
Cs-137	<p	<p	<p	<p	<p	<p	<p	1.6E-06	0.0E+00	0.0E+00	1.6E-06
Ba-140	<p	<p	<p	<p	<p	<p	<p	7.4E-09	0.0E+00	0.0E+00	7.4E-09
Ce-141	<p	<p	<p	<p	<p	<p	<p	4.3E-09	0.0E+00	0.0E+00	4.3E-09
Ce-144	<p	<p	<p	<p	<p	<p	<p	5.8E-08	0.0E+00	0.0E+00	5.8E-08
Pm-147	<p	<p	<p	<p	<p	<p	<p	1.8E-11	0.0E+00	0.0E+00	1.8E-11
Eu-152	<p	<p	<p	<p	<p	<p	<p	4.8E-06	0.0E+00	0.0E+00	4.8E-06
Eu-154	<p	<p	<p	<p	<p	<p	<p	4.9E-06	0.0E+00	0.0E+00	4.9E-06
Eu-155	<p	<p	<p	<p	<p	<p	<p	9.0E-08	0.0E+00	0.0E+00	9.0E-08
Er-169	<p	<p	<p	<p	<p	<p	<p	1.2E-13	0.0E+00	0.0E+00	1.2E-13
Lu-177	<p	<p	<p	<p	<p	<p	<p	4.9E-11	0.0E+00	0.0E+00	4.9E-11
Pb-210	<p	<p	<p	<p	<p	<p	<p	1.1E-08	0.0E+00	0.0E+00	1.1E-08
Po-210	<p	<p	<p	<p	<p	<p	<p	8.1E-12	0.0E+00	0.0E+00	8.1E-12
Ra-223	<p	<p	<p	<p	<p	<p	<p	1.9E-08	0.0E+00	0.0E+00	1.9E-08
Ra-226	4.7E-07	6.7E-08	8.3E-08	3.3E-08	7.1E-08	1.6E-08	3.1E-07	9.4E-06	0.0E+00	1.3E-10	1.0E-05
Th-230	<p	<p	<p	<p	<p	<p	<p	1.7E-09	0.0E+00	0.0E+00	1.7E-09
Th-232	<p	<p	<p	<p	<p	<p	<p	2.5E-05	0.0E+00	0.0E+00	2.5E-05
Th-234	<p	<p	<p	<p	<p	<p	<p	2.3E-09	0.0E+00	0.0E+00	2.3E-09
U-234	<p	<p	<p	<p	<p	<p	<p	6.1E-11	0.0E+00	0.0E+00	6.1E-11
U-235	<p	<p	<p	<p	<p	<p	<p	1.2E-07	0.0E+00	0.0E+00	1.2E-07
U-238	<p	<p	<p	<p	<p	<p	<p	2.5E-08	0.0E+00	0.0E+00	2.5E-08

Table 24 continued

Radionuclide	DPURs for offspring farming family ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
Np-237	<p	<p	<p	<p	<p	<p	<p	9.0E-07	0.0E+00	0.0E+00	9.0E-07
Pu-238	<p	<p	<p	<p	<p	<p	<p	1.0E-10	0.0E+00	0.0E+00	1.0E-10
Pu-239	<p	<p	<p	<p	<p	<p	<p	2.3E-10	0.0E+00	0.0E+00	2.3E-10
Pu-240	<p	<p	<p	<p	<p	<p	<p	1.0E-10	0.0E+00	0.0E+00	1.0E-10
Pu-241	<p	<p	<p	<p	<p	<p	<p	3.9E-12	0.0E+00	0.0E+00	3.9E-12
Pu-242	<p	<p	<p	<p	<p	<p	<p	8.8E-11	0.0E+00	0.0E+00	8.8E-11
Am-241	<p	<p	<p	<p	<p	<p	<p	5.9E-08	0.0E+00	0.0E+00	5.9E-08
Am-243	<p	<p	<p	<p	<p	<p	<p	1.3E-06	0.0E+00	0.0E+00	1.3E-06
Cm-242	<p	<p	<p	<p	<p	<p	<p	2.5E-11	0.0E+00	0.0E+00	2.5E-11
Cm-243	<p	<p	<p	<p	<p	<p	<p	7.8E-07	0.0E+00	0.0E+00	7.8E-07
Cm-244	<p	<p	<p	<p	<p	<p	<p	1.2E-10	0.0E+00	0.0E+00	1.2E-10

<p = not calculated as dose to parent greater than dose to offspring
nc = not considered due to short half-life

Table 25 Dose per unit release factors for infant farming family – sewage release scenario

Radionuclide	DPURs for infant farming family (µSv y^{-1} per Bq y^{-1})										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	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	2.4E-13	6.7E-14	6.3E-12	0.0E+00	3.1E-18	1.3E-17	6.9E-12
C-14	9.4E-09	2.3E-08	1.1E-09	1.0E-09	2.3E-09	6.3E-10	3.5E-08	9.5E-14	2.1E-14	2.0E-14	7.3E-08
Na-22	3.9E-10	1.1E-09	3.3E-09	3.1E-09	6.9E-09	1.9E-09	4.4E-08	3.7E-07	7.9E-14	6.2E-13	4.3E-07
P-32	nc	nc	1.2E-09	4.4E-10	2.1E-09	5.7E-10	7.8E-08	3.6E-11	9.9E-15	4.8E-14	8.2E-08
P-33	nc	nc	7.0E-10	2.6E-10	1.2E-09	3.2E-10	3.6E-08	2.8E-13	9.6E-15	1.4E-14	3.9E-08
S-35	1.9E-12	5.3E-12	9.6E-10	3.5E-10	1.8E-09	5.0E-10	9.1E-09	4.7E-14	6.5E-15	4.8E-15	1.3E-08
Cl-36	1.0E-07	2.4E-07	4.3E-08	4.0E-08	1.2E-07	3.4E-08	7.8E-07	1.5E-10	6.0E-13	5.5E-13	1.4E-06
Ca-45	5.4E-10	1.4E-10	2.9E-11	2.6E-11	9.5E-11	2.6E-11	1.4E-08	3.2E-12	2.0E-13	4.1E-13	1.5E-08
Ca-47	nc	nc	8.4E-16	7.7E-16	2.6E-15	7.2E-16	6.3E-13	2.3E-10	9.4E-17	4.3E-16	2.3E-10
V-48	nc	nc	9.1E-15	8.4E-15	1.7E-14	4.6E-15	4.2E-12	4.6E-08	1.1E-14	4.2E-14	4.6E-08
Cr-51	nc	nc	3.0E-13	2.8E-13	1.9E-13	5.3E-14	5.4E-12	1.2E-09	5.7E-16	2.4E-15	1.2E-09
Mn-52	nc	nc	4.1E-14	1.3E-12	9.6E-14	9.3E-13	9.1E-12	1.1E-09	1.4E-16	7.0E-16	1.2E-09
Mn-54	1.5E-10	3.1E-10	4.0E-10	1.6E-08	9.5E-10	1.2E-08	2.3E-08	3.2E-07	1.6E-13	3.0E-13	3.8E-07
Fe-55	1.1E-10	7.2E-12	1.1E-11	3.0E-10	2.0E-11	2.2E-08	7.9E-10	0.0E+00	1.4E-13	9.0E-13	2.4E-08
Fe-59	3.4E-12	1.9E-14	1.1E-12	3.0E-11	1.7E-12	1.8E-09	6.9E-10	1.1E-07	7.2E-14	2.7E-13	1.1E-07
Co-56	3.9E-11	7.3E-12	2.8E-11	2.6E-09	4.5E-11	1.2E-09	9.9E-09	6.1E-07	2.1E-13	5.8E-13	6.2E-07
Co-57	4.0E-11	2.0E-11	1.1E-11	1.0E-09	1.6E-11	4.3E-10	1.8E-09	4.3E-08	7.8E-14	2.2E-13	4.6E-08
Co-58	8.0E-12	1.4E-12	3.6E-12	3.3E-10	4.4E-12	1.2E-10	1.0E-09	1.3E-07	5.8E-14	1.5E-13	1.4E-07
Co-60	2.9E-09	4.9E-09	9.1E-10	8.3E-08	1.6E-09	4.4E-08	1.2E-07	4.9E-06	4.0E-12	1.2E-11	5.1E-06
Ni-63	2.1E-10	5.4E-10	3.4E-14	3.1E-13	2.8E-13	7.6E-13	2.7E-11	0.0E+00	2.1E-13	3.6E-13	7.8E-10
Zn-65	3.5E-09	5.0E-09	1.9E-09	1.7E-09	7.2E-09	2.0E-09	2.7E-06	1.9E-07	1.3E-13	1.2E-12	2.9E-06
Se-75	5.8E-10	1.6E-09	4.5E-08	8.2E-07	1.0E-07	7.2E-07	4.1E-07	5.0E-08	6.1E-14	5.0E-13	2.1E-06
Rb-83	4.9E-11	1.1E-10	8.9E-10	8.2E-10	2.1E-09	5.7E-10	9.6E-08	8.3E-08	4.3E-14	3.6E-13	1.8E-07
Sr-89	2.5E-12	7.4E-13	2.4E-12	2.2E-12	7.4E-12	2.0E-12	1.2E-09	2.8E-11	1.7E-14	4.8E-14	1.2E-09
Sr-90	6.5E-08	3.3E-08	3.7E-10	3.4E-10	1.9E-09	5.2E-10	2.9E-07	1.2E-09	1.3E-12	3.2E-12	3.9E-07
Zr-95	7.5E-12	2.7E-14	3.1E-13	2.8E-13	3.9E-13	1.1E-13	1.4E-11	2.1E-07	1.4E-13	1.9E-13	2.1E-07
Nb-95	1.2E-13	1.4E-14	1.3E-14	1.2E-14	2.1E-14	5.8E-15	2.8E-12	2.6E-08	1.1E-14	2.7E-14	2.6E-08
Tc-99	7.6E-08	1.9E-07	2.2E-07	6.2E-07	1.2E-07	1.3E-07	3.8E-06	6.7E-12	3.0E-13	4.2E-13	5.1E-06

Table 25 continued

Radionuclide	DPURs for infant farming family ($\mu Sv\ y^{-1}$ per $Bq\ y^{-1}$)										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
Ru-103	6.7E-14	8.4E-15	9.2E-14	8.4E-14	1.1E-13	2.9E-14	2.7E-14	3.6E-09	4.3E-15	9.1E-15	3.6E-09
Ru-106	2.0E-10	1.3E-10	4.9E-11	4.5E-11	7.6E-11	2.1E-11	4.6E-12	1.9E-08	6.3E-13	1.1E-12	2.0E-08
Ag-110m	1.4E-09	3.3E-09	9.9E-10	2.7E-07	2.6E-09	2.9E-07	2.9E-06	1.6E-06	1.0E-12	2.0E-12	5.1E-06
Sb-125	4.2E-10	5.3E-10	2.5E-10	2.3E-08	3.0E-08	8.1E-09	9.7E-10	5.4E-07	1.4E-12	2.1E-12	6.0E-07
I-125	1.7E-11	2.9E-11	1.7E-10	1.6E-10	1.8E-10	4.8E-11	9.1E-09	5.8E-11	4.2E-14	4.0E-13	9.8E-09
I-129	4.8E-08	1.4E-07	4.0E-08	3.7E-08	1.6E-08	4.4E-09	7.7E-07	1.2E-09	4.0E-12	3.9E-11	1.1E-06
I-131	nc	nc	3.2E-12	3.0E-12	7.6E-12	2.1E-12	5.7E-10	1.8E-10	2.4E-15	2.3E-14	7.7E-10
Cs-134	3.5E-10	8.0E-10	5.0E-09	4.6E-09	7.7E-09	2.1E-09	4.9E-08	6.7E-07	2.1E-13	1.7E-12	7.4E-07
Cs-136	nc	nc	1.2E-11	1.1E-11	1.9E-11	5.2E-12	2.7E-10	6.8E-09	1.1E-15	7.3E-15	7.1E-09
Cs-137	1.0E-09	2.9E-09	9.0E-09	8.3E-09	1.1E-08	3.0E-09	6.7E-08	5.4E-07	3.4E-13	2.9E-12	6.4E-07
Ba-140	nc	nc	8.9E-14	8.2E-14	1.7E-13	4.6E-14	1.9E-11	2.6E-09	1.3E-15	4.3E-15	2.6E-09
Ce-141	1.0E-13	1.2E-15	5.9E-14	1.1E-11	9.5E-14	5.2E-12	7.0E-12	1.5E-09	2.1E-14	3.8E-14	1.5E-09
Ce-144	5.2E-10	3.3E-11	1.7E-11	3.1E-09	2.7E-11	1.5E-09	2.8E-10	2.0E-08	3.7E-12	3.4E-12	2.6E-08
Pm-147	5.4E-11	2.9E-11	1.3E-11	7.2E-11	3.1E-11	6.8E-11	2.9E-11	6.2E-12	9.8E-13	3.9E-13	3.0E-10
Eu-152	4.2E-10	6.2E-10	1.0E-10	5.7E-10	3.7E-10	8.0E-10	2.0E-10	1.7E-06	9.5E-12	2.7E-12	1.7E-06
Eu-154	5.7E-10	6.9E-10	1.5E-10	8.2E-10	4.9E-10	1.1E-09	2.8E-10	1.7E-06	1.3E-11	4.0E-12	1.7E-06
Eu-155	8.2E-11	7.0E-11	2.2E-11	1.2E-10	6.2E-11	1.4E-10	4.3E-11	3.1E-08	1.7E-12	6.1E-13	3.2E-08
Er-169	nc	nc	3.7E-16	6.8E-14	7.1E-16	3.9E-14	1.8E-13	4.3E-14	4.7E-16	1.4E-15	3.4E-13
Lu-177	nc	nc	7.3E-17	1.3E-14	1.5E-16	8.2E-15	5.2E-14	1.7E-11	1.8E-16	6.5E-16	1.7E-11
Pb-210	1.1E-06	2.5E-06	1.8E-07	3.2E-07	4.1E-07	2.3E-07	4.9E-06	3.7E-09	6.8E-10	2.5E-09	9.6E-06
Po-210	1.0E-07	1.9E-07	2.3E-07	2.5E-06	9.0E-08	6.8E-07	1.2E-07	2.8E-12	2.3E-10	7.1E-10	4.0E-06
Ra-223	nc	nc	2.1E-11	1.9E-11	4.0E-11	1.1E-11	3.3E-09	6.7E-09	5.0E-12	1.0E-12	1.0E-08
Ra-226	2.7E-07	7.3E-08	3.1E-08	2.8E-08	4.9E-08	1.3E-08	1.3E-06	3.3E-06	1.3E-09	4.2E-10	5.0E-06
Th-230	3.2E-08	2.8E-08	9.5E-10	8.7E-09	1.8E-09	5.0E-09	4.3E-09	5.9E-10	7.3E-09	3.2E-10	9.0E-08
Th-232	3.6E-08	3.1E-08	1.0E-09	9.6E-09	2.0E-09	5.5E-09	4.7E-09	8.5E-06	1.0E-08	3.6E-10	8.6E-06
Th-234	nc	nc	1.2E-13	1.1E-12	1.9E-13	5.3E-13	9.8E-12	8.1E-10	6.6E-14	2.0E-13	8.2E-10
U-234	1.5E-09	2.0E-09	2.8E-10	2.6E-10	1.7E-10	4.8E-11	1.7E-08	2.1E-11	2.5E-10	1.1E-11	2.1E-08
U-235	1.5E-09	2.0E-09	2.8E-10	2.6E-10	1.7E-10	4.8E-11	1.7E-08	4.2E-08	2.3E-10	1.1E-11	6.4E-08
U-238	1.4E-09	1.8E-09	2.6E-10	2.4E-10	1.6E-10	4.4E-11	1.5E-08	8.7E-09	2.2E-10	1.1E-11	2.8E-08

Table 25 continued

Radionuclide	DPURs for infant farming family (µSv y^{-1} per Bq y^{-1})										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
Np-237	1.7E-08	1.6E-08	7.0E-10	4.6E-08	3.2E-09	1.1E-07	1.8E-09	3.1E-07	4.6E-09	9.2E-11	5.1E-07
Pu-238	1.2E-08	1.3E-09	7.6E-10	5.0E-08	1.5E-09	4.8E-08	3.3E-09	3.5E-11	8.3E-09	1.7E-10	1.3E-07
Pu-239	1.3E-08	1.6E-09	8.5E-10	5.5E-08	1.6E-09	5.5E-08	3.7E-09	8.1E-11	8.9E-09	1.8E-10	1.4E-07
Pu-240	1.3E-08	1.6E-09	8.5E-10	5.5E-08	1.6E-09	5.2E-08	3.7E-09	3.5E-11	8.9E-09	1.8E-10	1.4E-07
Pu-241	1.7E-10	8.4E-12	9.0E-12	5.9E-10	1.4E-11	5.1E-10	3.3E-11	1.4E-12	9.3E-11	2.1E-12	1.4E-09
Pu-242	1.3E-08	1.5E-09	8.1E-10	5.2E-08	1.5E-09	5.2E-08	3.5E-09	3.0E-11	8.4E-09	1.8E-10	1.3E-07
Am-241	2.2E-08	3.9E-09	1.4E-09	9.0E-08	3.1E-09	1.0E-07	7.4E-09	2.0E-08	1.4E-08	2.9E-10	2.7E-07
Am-243	2.2E-08	4.1E-09	1.4E-09	9.3E-08	3.1E-09	1.1E-07	7.4E-09	4.5E-07	1.4E-08	2.9E-10	7.0E-07
Cm-242	9.4E-10	1.1E-12	1.3E-11	8.9E-10	9.3E-12	3.1E-10	2.1E-11	8.5E-12	4.5E-10	7.2E-12	2.7E-09
Cm-243	1.8E-08	8.0E-10	1.2E-09	7.8E-08	2.7E-09	9.1E-08	1.6E-09	2.7E-07	1.1E-08	2.4E-10	4.7E-07
Cm-244	1.6E-08	5.4E-10	9.1E-10	6.0E-08	1.8E-09	6.0E-08	3.9E-09	4.3E-11	1.0E-08	2.0E-10	1.5E-07

nc = not considered due to short half-life

Table 26 Dose per unit release factors for child farming family – sewage release scenario

Radionuclide	DPURs for child farming family (μSv y^{-1} per Bq y^{-1})										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
H-3	0.0E+00	0.0E+00	9.6E-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	8.9E-14	3.5E-13	5.8E-14	2.3E-12	0.0E+00	9.0E-18	5.0E-18	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	1.4E-13	5.3E-14	8.1E-15	5.5E-08
Na-22	3.4E-10	8.4E-10	4.1E-09	2.0E-09	7.6E-09	1.3E-09	1.2E-08	5.5E-07	1.5E-13	1.8E-13	5.7E-07
P-32	nc	nc	1.1E-09	2.2E-10	1.7E-09	2.9E-10	1.6E-08	5.3E-11	2.0E-14	1.1E-14	2.0E-08
P-33	nc	nc	6.8E-10	1.4E-10	1.0E-09	1.7E-10	8.0E-09	4.1E-13	2.5E-14	3.4E-15	1.0E-08
S-35	1.4E-12	3.5E-12	9.9E-10	2.0E-10	1.7E-09	2.8E-10	2.1E-09	6.9E-14	1.7E-14	1.2E-15	5.3E-09
Cl-36	7.0E-08	1.5E-07	4.3E-08	2.2E-08	1.1E-07	1.9E-08	1.8E-07	2.2E-10	1.3E-12	1.4E-13	6.0E-07
Ca-45	4.6E-10	1.1E-10	3.5E-11	1.8E-11	1.0E-10	1.7E-11	4.0E-09	4.6E-12	5.0E-13	1.2E-13	4.7E-09
Ca-47	nc	nc	9.0E-16	4.5E-16	2.5E-15	4.2E-16	1.5E-13	3.3E-10	2.1E-16	1.1E-16	3.3E-10
V-48	nc	nc	1.1E-14	5.4E-15	1.8E-14	3.0E-15	1.1E-12	6.8E-08	2.5E-14	1.2E-14	6.8E-08
Cr-51	nc	nc	3.4E-13	1.7E-13	1.9E-13	3.2E-14	1.4E-12	1.7E-09	1.0E-15	6.6E-16	1.7E-09
Mn-52	nc	nc	5.3E-14	9.3E-13	1.1E-13	6.5E-13	2.6E-12	1.7E-09	2.9E-16	2.2E-16	1.7E-09
Mn-54	1.4E-10	2.7E-10	5.5E-10	1.2E-08	1.2E-09	9.1E-09	7.2E-09	4.8E-07	3.5E-13	1.0E-13	5.1E-07
Fe-55	1.2E-10	7.0E-12	1.6E-11	2.5E-10	2.8E-11	1.9E-08	2.7E-10	0.0E+00	3.6E-13	3.4E-13	1.9E-08
Fe-59	2.9E-12	1.4E-14	1.3E-12	2.0E-11	1.8E-12	1.2E-09	1.9E-10	1.6E-07	1.8E-13	8.1E-14	1.6E-07
Co-56	3.5E-11	6.0E-12	3.6E-11	1.8E-09	5.3E-11	8.8E-10	2.9E-09	9.0E-07	4.4E-13	1.8E-13	9.0E-07
Co-57	3.4E-11	1.5E-11	1.3E-11	6.6E-10	1.7E-11	2.8E-10	4.9E-10	6.4E-08	1.8E-13	6.4E-14	6.5E-08
Co-58	7.2E-12	1.2E-12	4.7E-12	2.3E-10	5.1E-12	8.5E-11	3.0E-10	2.0E-07	1.3E-13	4.8E-14	2.0E-07
Co-60	2.7E-09	4.3E-09	1.2E-09	6.2E-08	2.0E-09	3.2E-08	3.8E-08	7.2E-06	1.0E-11	4.1E-12	7.3E-06
Ni-63	1.6E-10	3.8E-10	3.8E-14	1.9E-13	2.8E-13	4.6E-13	6.8E-12	0.0E+00	4.6E-13	9.8E-14	5.5E-10
Zn-65	3.3E-09	4.2E-09	2.5E-09	1.3E-09	8.6E-09	1.4E-09	8.2E-07	2.8E-07	2.8E-13	4.0E-13	1.1E-06
Se-75	6.2E-10	1.6E-09	6.9E-08	6.8E-07	1.5E-07	6.0E-07	1.4E-07	7.3E-08	1.5E-13	1.9E-13	1.7E-06
Rb-83	4.4E-11	8.8E-11	1.1E-09	5.7E-10	2.4E-09	3.9E-10	2.7E-08	1.2E-07	8.6E-14	1.1E-13	1.5E-07
Sr-89	1.9E-12	5.0E-13	2.6E-12	1.3E-12	7.2E-12	1.2E-12	2.9E-10	4.2E-11	3.7E-14	1.3E-14	3.4E-10
Sr-90	1.2E-07	5.7E-08	1.0E-09	5.1E-10	4.7E-09	7.8E-10	1.8E-07	1.8E-09	3.4E-12	2.1E-12	3.7E-07
Zr-95	6.0E-12	1.9E-14	3.5E-13	1.7E-13	3.9E-13	6.5E-14	3.5E-12	3.0E-07	3.5E-13	5.3E-14	3.0E-07
Nb-95	9.5E-14	9.8E-15	1.5E-14	7.3E-15	2.2E-14	3.6E-15	7.3E-13	3.8E-08	2.8E-14	7.5E-15	3.8E-08
Tc-99	4.8E-08	1.1E-07	2.0E-07	3.0E-07	9.5E-08	6.3E-08	7.6E-07	9.8E-12	7.7E-13	9.3E-14	1.6E-06

Table 26 continued

Radionuclide	DPURs for child farming family (μSv y^{-1} per Bq y^{-1})										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
Ru-103	5.1E-14	5.8E-15	1.0E-13	5.0E-14	1.0E-13	1.7E-14	6.7E-15	5.2E-09	1.1E-14	2.4E-15	5.2E-09
Ru-106	1.4E-10	8.3E-11	5.0E-11	2.5E-11	7.0E-11	1.2E-11	1.1E-12	2.8E-08	1.4E-12	2.7E-13	2.8E-08
Ag-110m	1.2E-09	2.6E-09	1.2E-09	1.8E-07	2.9E-09	1.9E-07	8.2E-07	2.4E-06	2.6E-12	6.0E-13	3.6E-06
Sb-125	3.4E-10	3.9E-10	2.8E-10	1.4E-08	3.1E-08	5.1E-09	2.5E-10	8.0E-07	3.5E-12	5.8E-13	8.5E-07
I-125	2.2E-11	3.4E-11	3.1E-10	1.5E-10	2.9E-10	4.8E-11	3.7E-09	8.6E-11	1.2E-13	1.8E-13	4.7E-09
I-129	9.7E-08	2.6E-07	1.1E-07	5.7E-08	4.1E-08	6.8E-09	5.0E-07	1.7E-09	1.8E-11	2.7E-11	1.1E-06
I-131	nc	nc	3.1E-12	1.6E-12	6.6E-12	1.1E-12	1.2E-10	2.7E-10	3.7E-15	5.4E-15	4.0E-10
Cs-134	7.1E-10	1.5E-09	1.5E-08	7.3E-09	2.0E-08	3.4E-09	3.2E-08	9.9E-07	8.7E-13	1.2E-12	1.1E-06
Cs-136	nc	nc	1.9E-11	9.6E-12	2.6E-11	4.4E-12	9.5E-11	1.0E-08	2.4E-15	2.8E-15	1.0E-08
Cs-137	2.0E-09	5.1E-09	2.5E-08	1.3E-08	2.7E-08	4.5E-09	4.2E-08	7.9E-07	1.4E-12	2.0E-12	9.1E-07
Ba-140	nc	nc	9.6E-14	4.8E-14	1.6E-13	2.7E-14	4.6E-12	3.8E-09	2.8E-15	1.1E-15	3.8E-09
Ce-141	6.9E-14	7.2E-16	5.8E-14	5.8E-12	8.4E-14	2.8E-12	1.6E-12	2.2E-09	5.2E-14	9.1E-15	2.2E-09
Ce-144	3.4E-10	1.9E-11	1.6E-11	1.6E-09	2.3E-11	7.6E-10	5.9E-11	3.0E-08	7.4E-12	7.9E-13	3.3E-08
Pm-147	3.8E-11	1.8E-11	1.3E-11	3.9E-11	2.8E-11	3.7E-11	6.5E-12	9.1E-12	2.2E-12	9.6E-14	1.9E-10
Eu-152	3.4E-10	4.6E-10	1.2E-10	3.6E-10	3.9E-10	5.1E-10	5.1E-11	2.5E-06	2.7E-11	7.7E-13	2.5E-06
Eu-154	4.5E-10	5.0E-10	1.7E-10	5.1E-10	5.0E-10	6.7E-10	7.3E-11	2.5E-06	3.3E-11	1.1E-12	2.5E-06
Eu-155	5.9E-11	4.6E-11	2.2E-11	6.7E-11	5.8E-11	7.7E-11	1.0E-11	4.6E-08	3.9E-12	1.5E-13	4.6E-08
Er-169	nc	nc	3.6E-16	3.6E-14	6.3E-16	2.1E-14	4.0E-14	6.3E-14	1.2E-15	3.4E-16	1.7E-13
Lu-177	nc	nc	7.5E-17	7.5E-15	1.4E-16	4.6E-15	1.2E-14	2.5E-11	4.3E-16	1.6E-16	2.5E-11
Pb-210	1.3E-06	2.8E-06	3.2E-07	3.1E-07	6.5E-07	2.2E-07	1.9E-06	5.4E-09	1.6E-09	1.1E-09	7.6E-06
Po-210	7.2E-08	1.2E-07	2.3E-07	1.4E-06	8.0E-08	3.7E-07	2.7E-08	4.1E-12	5.7E-10	1.7E-10	2.3E-06
Ra-223	nc	nc	2.9E-11	1.4E-11	4.9E-11	8.1E-12	1.0E-09	9.8E-09	1.4E-11	3.3E-13	1.1E-08
Ra-226	5.3E-07	1.3E-07	8.6E-08	4.3E-08	1.2E-07	2.0E-08	8.0E-07	4.8E-06	3.3E-09	2.9E-10	6.5E-06
Th-230	4.4E-08	3.5E-08	1.9E-09	9.3E-09	3.2E-09	5.3E-09	1.9E-09	8.7E-10	1.9E-08	1.6E-10	1.3E-07
Th-232	5.3E-08	4.2E-08	2.2E-09	1.1E-08	3.8E-09	6.4E-09	2.3E-09	1.2E-05	3.1E-08	1.9E-10	1.3E-05
Th-234	nc	nc	1.1E-13	5.7E-13	1.7E-13	2.8E-13	2.2E-12	1.2E-09	1.4E-13	4.9E-14	1.2E-09
U-234	2.0E-09	2.4E-09	5.4E-10	2.7E-10	3.0E-10	5.0E-11	7.1E-09	3.1E-11	6.4E-10	5.3E-12	1.3E-08
U-235	1.9E-09	2.3E-09	5.2E-10	2.6E-10	2.9E-10	4.8E-11	6.8E-09	6.3E-08	5.8E-10	5.1E-12	7.5E-08
U-238	1.8E-09	2.2E-09	4.9E-10	2.5E-10	2.7E-10	4.6E-11	6.5E-09	1.3E-08	5.4E-10	4.9E-12	2.5E-08

Table 26 continued

Radionuclide	DPURs for child farming family (µSv y^{-1} per Bq y^{-1})										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
Np-237	2.1E-08	1.8E-08	1.2E-09	4.3E-08	5.0E-09	1.0E-07	7.2E-10	4.6E-07	1.5E-08	3.9E-11	6.6E-07
Pu-238	1.7E-08	1.6E-09	1.5E-09	5.4E-08	2.6E-09	5.2E-08	1.5E-09	5.1E-11	2.9E-08	8.3E-11	1.6E-07
Pu-239	2.0E-08	2.2E-09	1.8E-09	6.4E-08	3.1E-09	6.4E-08	1.8E-09	1.2E-10	3.2E-08	9.7E-11	1.9E-07
Pu-240	2.0E-08	2.2E-09	1.8E-09	6.4E-08	3.1E-09	6.1E-08	1.8E-09	5.1E-11	3.2E-08	9.7E-11	1.9E-07
Pu-241	3.5E-10	1.6E-11	2.7E-11	9.7E-10	3.9E-11	8.3E-10	2.2E-11	2.0E-12	4.6E-10	1.5E-12	2.8E-09
Pu-242	1.9E-08	2.1E-09	1.7E-09	6.1E-08	3.0E-09	6.1E-08	1.7E-09	4.5E-11	3.0E-08	9.3E-11	1.8E-07
Am-241	3.0E-08	4.9E-09	2.7E-09	9.7E-08	5.6E-09	1.1E-07	3.3E-09	3.0E-08	4.8E-08	1.4E-10	3.4E-07
Am-243	3.0E-08	5.1E-09	2.7E-09	1.0E-07	5.6E-09	1.2E-07	3.3E-09	6.6E-07	4.8E-08	1.4E-10	9.8E-07
Cm-242	7.0E-10	7.2E-13	1.4E-11	5.1E-10	8.8E-12	1.8E-10	5.1E-12	1.3E-11	1.1E-09	1.9E-12	2.5E-09
Cm-243	2.1E-08	8.1E-10	1.9E-09	6.9E-08	3.9E-09	8.0E-08	5.7E-10	4.0E-07	3.4E-08	9.4E-11	6.1E-07
Cm-244	1.8E-08	5.5E-10	1.5E-09	5.2E-08	2.6E-09	5.2E-08	1.4E-09	6.3E-11	2.8E-08	7.8E-11	1.6E-07

nc = not considered due to short half-life

Table 27 Dose per unit release factors for adult farming family – sewage release scenario

Radionuclide	DPURs for adult farming family (µSv y^{-1} per Bq y^{-1})										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	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	3.8E-13	8.5E-14	1.7E-12	0.0E+00	2.4E-17	4.3E-18	2.6E-12
C-14	1.8E-08	2.4E-08	3.3E-09	1.3E-09	3.7E-09	8.3E-10	9.6E-09	2.7E-13	1.4E-13	6.7E-15	6.1E-08
Na-22	4.5E-10	6.7E-10	5.9E-09	2.4E-09	6.6E-09	1.5E-09	7.1E-09	1.1E-06	2.9E-13	1.2E-13	1.1E-06
P-32	nc	nc	1.3E-09	2.0E-10	1.2E-09	2.6E-10	7.4E-09	1.0E-10	4.7E-14	5.7E-15	1.0E-08
P-33	nc	nc	7.7E-10	1.2E-10	7.1E-10	1.6E-10	3.6E-09	8.1E-13	6.5E-14	1.8E-15	5.4E-09
S-35	1.5E-12	2.3E-12	1.2E-09	1.9E-10	1.2E-09	2.7E-10	1.0E-09	1.4E-13	4.2E-14	6.7E-16	3.9E-09
Cl-36	7.9E-08	1.0E-07	5.3E-08	2.1E-08	8.3E-08	1.8E-08	8.6E-08	4.4E-10	3.5E-12	7.7E-14	4.4E-07
Ca-45	4.2E-10	6.0E-11	3.5E-11	1.4E-11	6.2E-11	1.4E-11	1.6E-09	9.1E-12	1.3E-12	5.7E-14	2.2E-09
Ca-47	nc	nc	1.2E-15	4.8E-16	2.0E-15	4.5E-16	8.1E-14	6.6E-10	4.8E-16	7.0E-17	6.6E-10
V-48	nc	nc	1.4E-14	5.6E-15	1.4E-14	3.0E-15	5.7E-13	1.3E-07	5.0E-14	7.1E-15	1.3E-07
Cr-51	nc	nc	4.2E-13	1.7E-13	1.4E-13	3.2E-14	6.7E-13	3.4E-09	2.1E-15	3.7E-16	3.4E-09
Mn-52	nc	nc	7.0E-14	9.9E-13	8.8E-14	6.9E-13	1.4E-12	3.3E-09	6.1E-16	1.3E-16	3.3E-09
Mn-54	1.8E-10	2.0E-10	7.6E-10	1.4E-08	9.8E-10	1.0E-08	4.0E-09	9.4E-07	7.9E-13	6.4E-14	9.7E-07
Fe-55	8.1E-11	2.9E-12	1.2E-11	1.5E-10	1.3E-11	1.1E-08	8.2E-11	0.0E+00	7.9E-13	1.2E-13	1.1E-08
Fe-59	2.5E-12	7.5E-15	1.3E-12	1.5E-11	1.0E-12	9.2E-10	7.2E-11	3.1E-07	4.3E-13	3.6E-14	3.1E-07
Co-56	3.4E-11	3.5E-12	3.9E-11	1.6E-09	3.4E-11	7.5E-10	1.2E-09	1.8E-06	1.0E-12	9.1E-14	1.8E-06
Co-57	2.8E-11	7.5E-12	1.2E-11	4.8E-10	9.3E-12	2.1E-10	1.8E-10	1.2E-07	4.1E-13	2.7E-14	1.3E-07
Co-58	7.2E-12	6.9E-13	5.1E-12	2.0E-10	3.3E-12	7.4E-11	1.3E-10	3.9E-07	3.0E-13	2.4E-14	3.9E-07
Co-60	1.9E-09	1.8E-09	9.5E-10	3.8E-08	9.1E-10	2.0E-08	1.2E-08	1.4E-05	2.5E-11	1.4E-12	1.4E-05
Ni-63	2.0E-10	2.8E-10	5.1E-14	2.0E-13	2.2E-13	4.9E-13	3.7E-12	0.0E+00	1.1E-12	6.0E-14	4.9E-10
Zn-65	4.6E-09	3.5E-09	3.8E-09	1.5E-09	7.9E-09	1.8E-09	5.0E-07	5.5E-07	6.8E-13	2.8E-13	1.1E-06
Se-75	6.1E-10	9.5E-10	7.4E-08	5.9E-07	9.4E-08	5.2E-07	6.2E-08	1.4E-07	2.1E-13	9.5E-14	1.5E-06
Rb-83	6.0E-11	7.2E-11	1.7E-09	6.8E-10	2.1E-09	4.7E-10	1.6E-08	2.4E-07	1.6E-13	7.7E-14	2.6E-07
Sr-89	1.9E-12	3.1E-13	2.9E-12	1.2E-12	4.8E-12	1.1E-12	1.3E-10	8.2E-11	9.0E-14	6.6E-15	2.2E-10
Sr-90	1.3E-07	3.6E-08	1.2E-09	4.8E-10	3.3E-09	7.3E-10	8.3E-08	3.6E-09	8.6E-12	1.2E-12	2.6E-07
Zr-95	6.8E-12	1.3E-14	4.3E-13	1.7E-13	2.9E-13	6.5E-14	1.8E-12	5.9E-07	9.0E-13	3.0E-14	5.9E-07
Nb-95	1.1E-13	7.1E-15	1.9E-14	7.7E-15	1.7E-14	3.8E-15	3.8E-13	7.5E-08	6.9E-14	4.6E-15	7.5E-08
Tc-99	5.4E-08	7.1E-08	2.5E-07	3.0E-07	7.0E-08	6.2E-08	3.8E-07	1.9E-11	1.9E-12	5.3E-14	1.2E-06

Table 27 continued

Radionuclide	DPURs for adult farming family (µSv y^{-1} per Bq y^{-1})										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
Ru-103	5.6E-14	3.8E-15	1.2E-13	4.9E-14	7.6E-14	1.7E-14	3.3E-15	1.0E-08	2.6E-14	1.4E-15	1.0E-08
Ru-106	1.5E-10	5.3E-11	5.8E-11	2.3E-11	4.9E-11	1.1E-11	4.9E-13	5.5E-08	3.4E-12	1.4E-13	5.5E-08
Ag-110m	1.5E-09	1.9E-09	1.6E-09	2.0E-07	2.4E-09	2.1E-07	4.4E-07	4.6E-06	5.9E-12	3.7E-13	5.5E-06
Sb-125	4.1E-10	2.8E-10	3.7E-10	1.5E-08	2.4E-08	5.3E-09	1.3E-10	1.6E-06	9.0E-12	3.5E-13	1.6E-06
I-125	2.4E-11	2.2E-11	3.7E-10	1.5E-10	2.1E-10	4.6E-11	1.8E-09	1.7E-10	2.0E-13	9.9E-14	2.8E-09
I-129	1.3E-07	2.0E-07	1.7E-07	6.6E-08	3.6E-08	7.9E-09	2.9E-07	3.4E-09	3.5E-11	1.8E-11	9.0E-07
I-131	nc	nc	3.3E-12	1.3E-12	4.2E-12	9.3E-13	5.2E-11	5.2E-10	5.2E-15	2.6E-15	5.8E-10
Cs-134	2.2E-09	2.7E-09	5.0E-08	2.0E-08	4.1E-08	9.1E-09	4.4E-08	1.9E-06	3.9E-12	1.9E-12	2.1E-06
Cs-136	nc	nc	3.3E-11	1.3E-11	2.7E-11	5.9E-12	6.5E-11	2.0E-08	5.1E-15	2.2E-15	2.0E-08
Cs-137	6.0E-09	9.2E-09	8.1E-08	3.3E-08	5.3E-08	1.2E-08	5.4E-08	1.6E-06	6.1E-12	2.9E-12	1.8E-06
Ba-140	nc	nc	1.1E-13	4.3E-14	1.1E-13	2.4E-14	2.1E-12	7.4E-09	6.7E-15	5.9E-16	7.4E-09
Ce-141	7.5E-14	4.7E-16	6.9E-14	5.5E-12	6.0E-14	2.7E-12	7.4E-13	4.3E-09	1.3E-13	5.0E-15	4.4E-09
Ce-144	3.7E-10	1.3E-11	1.9E-11	1.5E-09	1.6E-11	7.2E-10	2.8E-11	5.8E-08	1.7E-11	4.3E-13	6.1E-08
Pm-147	4.0E-11	1.1E-11	1.5E-11	3.6E-11	1.9E-11	3.4E-11	2.9E-12	1.8E-11	5.7E-12	5.1E-14	1.9E-10
Eu-152	4.2E-10	3.4E-10	1.6E-10	3.9E-10	3.1E-10	5.5E-10	2.8E-11	4.8E-06	8.3E-11	4.8E-13	4.8E-06
Eu-154	5.1E-10	3.3E-10	2.1E-10	5.0E-10	3.7E-10	6.5E-10	3.6E-11	4.9E-06	9.6E-11	6.2E-13	4.9E-06
Eu-155	6.4E-11	3.0E-11	2.6E-11	6.3E-11	4.1E-11	7.2E-11	4.7E-12	9.0E-08	1.0E-11	8.3E-14	9.1E-08
Er-169	nc	nc	4.1E-16	3.2E-14	4.2E-16	1.9E-14	1.8E-14	1.2E-13	2.8E-15	1.8E-16	2.1E-13
Lu-177	nc	nc	8.3E-17	6.7E-15	9.1E-17	4.0E-15	5.3E-15	4.9E-11	1.1E-15	8.3E-17	4.9E-11
Pb-210	1.1E-06	1.4E-06	2.9E-07	2.2E-07	3.5E-07	1.6E-07	7.0E-07	1.1E-08	4.2E-09	4.5E-10	4.3E-06
Po-210	7.6E-08	7.7E-08	2.6E-07	1.3E-06	5.5E-08	3.4E-07	1.3E-08	8.1E-12	1.5E-09	9.1E-11	2.1E-06
Ra-223	nc	nc	1.6E-11	6.3E-12	1.6E-11	3.6E-12	2.2E-10	1.9E-08	3.7E-11	8.6E-14	2.0E-08
Ra-226	4.2E-07	6.1E-08	7.5E-08	3.0E-08	6.4E-08	1.4E-08	2.8E-07	9.4E-06	8.4E-09	1.2E-10	1.0E-05
Th-230	8.9E-08	4.2E-08	4.1E-09	1.6E-08	4.2E-09	9.3E-09	1.7E-09	1.7E-09	6.1E-08	1.6E-10	2.4E-07
Th-232	9.7E-08	4.6E-08	4.4E-09	1.8E-08	4.6E-09	1.0E-08	1.8E-09	2.5E-05	1.1E-07	1.7E-10	2.5E-05
Th-234	nc	nc	1.3E-13	5.2E-13	1.2E-13	2.6E-13	1.0E-12	2.3E-09	3.4E-13	2.6E-14	2.3E-09
U-234	3.0E-09	2.2E-09	8.9E-10	3.6E-10	3.0E-10	6.6E-11	4.7E-09	6.1E-11	1.7E-09	4.1E-12	1.4E-08
U-235	2.8E-09	2.1E-09	8.5E-10	3.4E-10	2.8E-10	6.3E-11	4.5E-09	1.2E-07	1.5E-09	3.9E-12	1.4E-07
U-238	2.7E-09	2.0E-09	8.2E-10	3.3E-10	2.7E-10	6.1E-11	4.3E-09	2.5E-08	1.4E-09	3.7E-12	3.7E-08

Table 27 continued

Radionuclide	DPURs for adult farming family (μSv y^{-1} per Bq y^{-1})										
	Green veg	Root veg	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk	External	Inadvert. inhalation	Inadvert. ingestion	Total
Np-237	4.8E-08	2.4E-08	3.0E-09	8.7E-08	7.5E-09	2.0E-07	7.2E-10	9.0E-07	5.5E-08	4.6E-11	1.3E-06
Pu-238	3.8E-08	2.1E-09	3.7E-09	1.0E-07	3.8E-09	1.0E-07	1.4E-09	1.0E-10	1.1E-07	9.2E-11	3.7E-07
Pu-239	4.2E-08	2.8E-09	4.2E-09	1.2E-07	4.3E-09	1.2E-07	1.6E-09	2.3E-10	1.2E-07	1.0E-10	4.2E-07
Pu-240	4.2E-08	2.8E-09	4.2E-09	1.2E-07	4.3E-09	1.1E-07	1.6E-09	1.0E-10	1.2E-07	1.0E-10	4.2E-07
Pu-241	7.5E-10	2.0E-11	6.3E-11	1.8E-09	5.5E-11	1.6E-09	2.1E-11	3.9E-12	1.8E-09	1.7E-12	6.2E-09
Pu-242	4.0E-08	2.6E-09	4.0E-09	1.1E-07	4.1E-09	1.1E-07	1.6E-09	8.8E-11	1.2E-07	9.9E-11	4.0E-07
Am-241	6.2E-08	6.1E-09	6.2E-09	1.8E-07	7.7E-09	2.0E-07	3.0E-09	5.9E-08	1.8E-07	1.5E-10	7.2E-07
Am-243	6.2E-08	6.3E-09	6.2E-09	1.8E-07	7.7E-09	2.1E-07	3.0E-09	1.3E-06	1.8E-07	1.5E-10	2.0E-06
Cm-242	8.0E-10	4.9E-13	1.8E-11	5.1E-10	6.6E-12	1.8E-10	2.5E-12	2.5E-11	2.7E-09	1.1E-12	4.3E-09
Cm-243	4.4E-08	1.0E-09	4.5E-09	1.3E-07	5.5E-09	1.5E-07	5.3E-10	7.8E-07	1.2E-07	1.0E-10	1.2E-06
Cm-244	3.5E-08	6.5E-10	3.1E-09	9.0E-08	3.3E-09	9.0E-08	1.2E-09	1.2E-10	1.0E-07	7.7E-11	3.3E-07

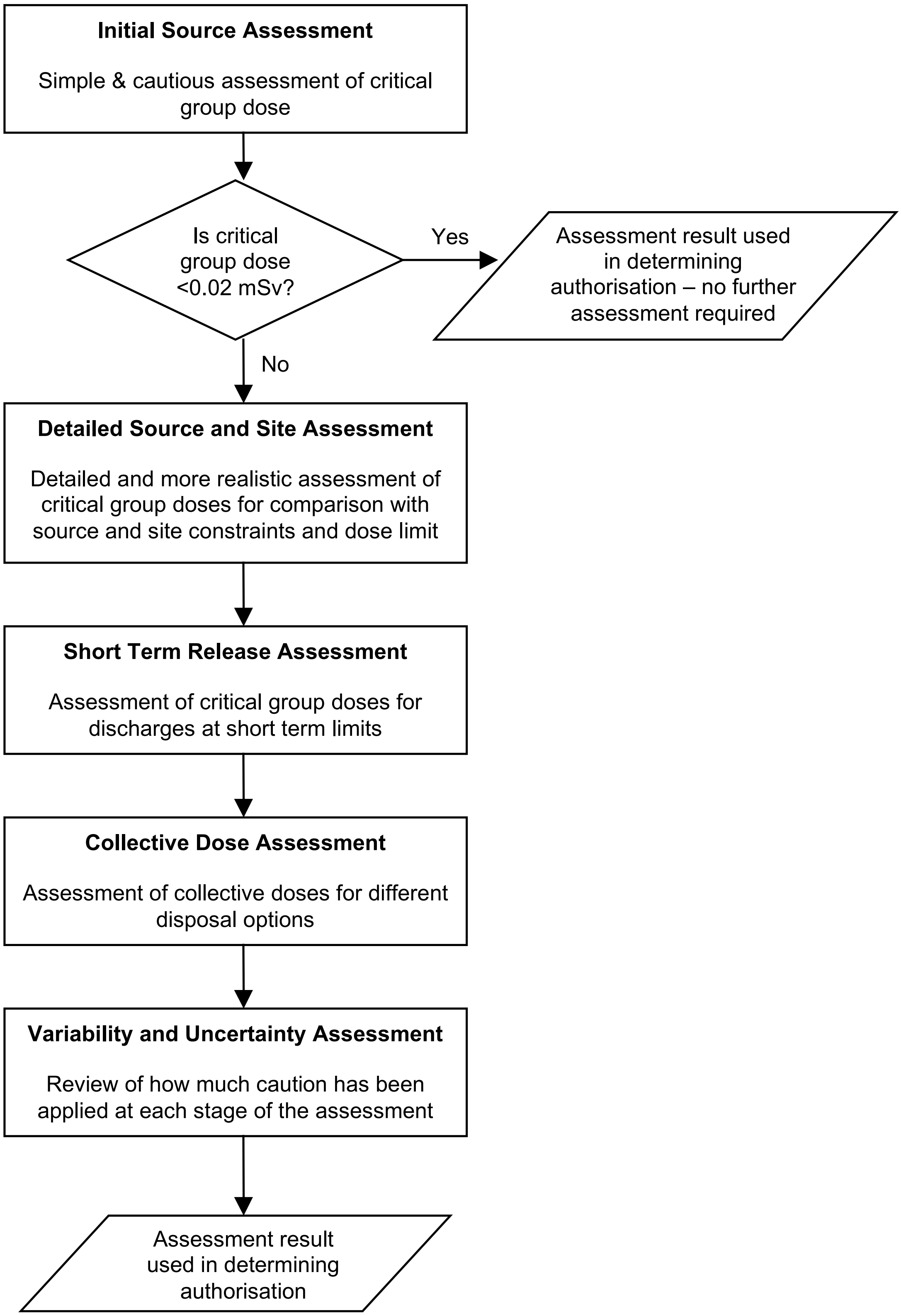
nc = not considered due to short half-life

Table 28 Dose per unit release factors for children playing in brook – sewage release scenario

Radionuclide	DPURs for child playing in brook (μSv y^{-1} per Bq y^{-1})			
	External	Inadvertent inhalation	Inadvertent ingestion	Total
H-3	0.0E+00	3.1E-14	9.3E-19	3.1E-14
H-3 organic	0.0E+00	7.6E-14	2.3E-18	7.6E-14
C-11	0.0E+00	0.0E+00	0.0E+00	0.0E+00
C-14	1.7E-14	1.1E-12	2.0E-12	1.1E-12
F-18	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Na-22	6.8E-11	7.8E-12	4.7E-14	7.6E-11
Na-24	1.1E-11	5.5E-13	3.3E-15	1.2E-11
P-32	3.7E-12	1.6E-12	1.5E-12	5.3E-12
P-33	9.2E-15	1.6E-13	1.6E-13	1.7E-13
S-35	2.8E-14	3.8E-13	1.0E-12	4.1E-13
Cl-36	0.0E+00	2.7E-12	0.0E+00	2.7E-12
Ca-45	1.9E-14	5.7E-13	1.0E-12	5.9E-13
Ca-47	4.2E-10	8.6E-13	1.6E-12	4.2E-10
V-48	1.6E-10	6.0E-13	6.0E-14	1.6E-10
Cr-51	1.6E-10	1.2E-14	1.2E-13	1.6E-10
Mn-52	2.5E-08	2.5E-12	3.5E-11	2.5E-08
Mn-54	3.4E-08	1.0E-12	1.5E-11	3.4E-08
Mn-56	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Fe-55	0.0E+00	1.7E-13	1.2E-12	1.7E-13
Fe-59	4.7E-09	7.3E-13	4.9E-12	4.7E-09
Co-56	4.3E-08	1.8E-12	1.8E-11	4.3E-08
Co-57	8.9E-10	1.8E-13	1.8E-12	8.9E-10
Co-58	1.1E-08	5.3E-13	5.3E-12	1.1E-08
Co-60	3.0E-08	3.5E-12	3.5E-11	3.0E-08
Ni-63	0.0E+00	2.2E-13	2.2E-12	2.2E-13
Zn-65	1.6E-09	5.0E-12	4.8E-12	1.6E-09
Ga-67	2.8E-12	5.5E-14	1.1E-14	2.9E-12
Se-75	8.5E-10	4.7E-12	4.5E-12	8.5E-10
Br-82	0.0E+00	1.0E-12	0.0E+00	1.0E-12
Rb-82	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Rb-83	3.5E-09	1.0E-12	6.7E-12	3.5E-09
Sr-89	2.4E-11	8.2E-12	1.5E-11	3.2E-11
Sr-90	6.5E-11	8.5E-11	1.5E-10	1.5E-10
Y-90	5.8E-11	7.1E-12	2.4E-11	6.6E-11
Zr-95	1.3E-08	3.0E-13	4.5E-12	1.3E-08
Nb-95	2.1E-10	8.6E-13	8.5E-14	2.1E-10
Mo-99	2.1E-10	1.3E-12	1.3E-12	2.1E-10
Tc-99	1.9E-14	1.8E-12	3.7E-13	1.9E-12
Tc-99m	4.2E-12	1.1E-14	2.2E-15	4.2E-12
Ru-103	1.2E-08	2.1E-12	1.1E-11	1.2E-08
Ru-106	5.7E-09	2.1E-11	1.1E-10	5.7E-09
Ag-110m	3.1E-10	8.2E-13	1.6E-13	3.1E-10
In-111	6.0E-10	8.0E-14	1.3E-12	6.0E-10
In-113m	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Sb-125	2.2E-10	6.6E-13	3.2E-13	2.2E-10
I-123	1.7E-11	2.8E-13	8.3E-14	1.8E-11
I-125	2.7E-12	3.9E-11	1.1E-11	4.2E-11

Table 28 continued

Radionuclide	DPURs for child playing in brook (µSv y^{-1} per Bq y^{-1})			
	External	Inadvertent inhalation	Inadvertent ingestion	Total
I-129	2.2E-12	2.4E-10	7.1E-11	2.4E-10
I-131	9.4E-11	6.2E-11	1.8E-11	1.6E-10
I-132	0.0E+00	0.0E+00	0.0E+00	0.0E+00
I-133	9.6E-11	7.7E-12	2.3E-12	1.0E-10
I-134	0.0E+00	0.0E+00	0.0E+00	0.0E+00
I-135	8.3E-11	5.8E-13	1.7E-13	8.3E-11
Cs-134	1.1E-08	1.5E-11	2.8E-11	1.1E-08
Cs-136	2.9E-09	4.7E-12	8.6E-12	2.9E-09
Cs-137	4.0E-09	1.1E-11	2.0E-11	4.0E-09
Ba-140	9.3E-09	8.0E-12	3.2E-11	9.3E-09
La-140	2.1E-08	4.6E-12	5.5E-11	2.1E-08
Ce-141	1.7E-09	1.2E-12	1.4E-11	1.7E-09
Ce-144	1.9E-09	8.7E-12	1.0E-10	1.9E-09
Pm-147	8.4E-14	4.5E-13	1.8E-12	5.4E-13
Sm-153	2.4E-10	1.0E-12	1.2E-11	2.4E-10
Eu-152	3.9E-08	2.1E-12	2.5E-11	3.9E-08
Eu-154	4.2E-08	3.2E-12	3.9E-11	4.2E-08
Eu-155	9.4E-10	5.4E-13	6.4E-12	9.5E-10
Er-169	2.8E-13	6.2E-13	7.4E-12	9.0E-13
Lu-177	2.0E-10	8.9E-13	1.1E-11	2.0E-10
Au-198	2.3E-09	1.5E-12	1.8E-11	2.3E-09
Tl-201	3.6E-10	1.2E-13	1.2E-12	3.6E-10
Pb-210	3.7E-12	3.0E-10	1.5E-09	3.1E-10
Po-210	2.4E-14	4.1E-10	2.1E-09	4.1E-10
Ra-223	4.3E-10	3.4E-10	1.7E-10	7.7E-10
Ra-226	2.5E-09	6.3E-10	3.1E-10	3.2E-09
Th-230	6.9E-13	3.8E-11	2.5E-10	3.9E-11
Th-232	9.9E-09	4.6E-11	3.1E-10	1.0E-08
Th-234	9.0E-11	1.1E-12	7.6E-12	9.1E-11
U-234	1.5E-14	1.1E-10	5.2E-12	1.1E-10
U-235	3.0E-11	1.0E-10	5.0E-12	1.3E-10
U-238	6.2E-12	9.7E-11	4.8E-12	1.0E-10
Np-237	4.9E-12	8.7E-11	8.7E-13	9.2E-11
Pu-238	9.5E-13	1.9E-10	3.2E-09	1.9E-10
Pu-239	2.1E-12	2.1E-10	3.6E-09	2.2E-10
Pu-240	9.1E-13	2.1E-10	3.6E-09	2.2E-10
Pu-241	4.3E-14	4.0E-12	6.7E-11	4.1E-12
Pu-242	8.0E-13	2.1E-10	3.4E-09	2.1E-10
Am-241	6.9E-11	3.5E-11	6.6E-10	1.0E-10
Am-242	1.4E-11	5.3E-14	1.0E-12	1.4E-11
Am-243	1.5E-09	3.5E-11	6.6E-10	1.5E-09
Cm-242	2.4E-13	3.8E-12	7.2E-11	4.1E-12
Cm-243	9.9E-10	2.5E-11	4.8E-10	1.0E-09
Cm-244	1.7E-13	2.2E-11	4.2E-10	2.3E-11



(diagram reproduced from [3])

Figure 1 Stages of dose assessment process for discharge authorisations

Appendix A Review of available methodologies

A.1 Overview

In assessing the radiological impact of discharges of radionuclides, any methodology must give consideration to the scenarios for release, the pathways for transport through the environment and the modes of exposure of the receptor (humans). Thus, a source–pathway–receptor analysis is appropriate. For the current application, the sources are atmospheric and liquid discharges, with the liquid discharges being routed to streams and rivers, sewage treatment works, or estuarine and coastal environments. All these routes of discharge have been extensively studied over many years (though discharges via sewage treatment works have been given rather less attention than the other routes). Thus, the dominant pathways of radionuclide transport through the environment for each of these sources have been well characterised.

Not only have the dominant pathways of transport been identified by research and monitoring activities over the last several decades, so also have the modes of exposure of humans. In broad terms, these modes are external exposure, ingestion and inhalation. Each mode may be further broken down into constituents. Thus, external exposure can be disaggregated into components arising from soils and sediments, water bodies, a dispersing atmospheric plume, building materials and human artefacts (such as fishing nets). Inhalation can be disaggregated into that from an atmospheric plume, resuspension from soils and sediments, and spume and seaspray. Ingestion can be disaggregated into contributions from water, soil and sediment, plant products and animal products. Further distinctions can be made, for example between freshwater, estuarine and coastal fauna, or between different plant types, as appropriate to the context.

The main distinctions between methodologies do not arise at the level of selecting pathways for inclusion. Rather, they arise at the level of defining how those pathways should be represented mathematically in models and in associating parameter values with those mathematical representations. In a research context and in radiological assessments of short-term releases, kinetic approaches are sometimes used. However, for chronic releases, equilibrium approaches are almost invariably employed. Therefore, for example, partitioning of radionuclides between solid and liquid phases uses a distribution coefficient approach, uptake by plants from soil and by aquatic organisms from sediments and water uses a concentration ratio approach, and uptake by terrestrial animals uses a transfer factor approach in which the radionuclide concentration in a particular food product is taken to be directly proportional to the rate of intake of that radionuclide by the animal. Thus, for an initial radiological assessment model, the approach adopted reduces to the definition of simple dispersion models coupled with the selection of radionuclide-specific equilibrium factors.

In defining simple dispersion models, the key issue is the volumetric flow rate (of either air or water) into which dispersion occurs. Although atmospheric dispersion models of great complexity have been developed, they do not help to quantify the dispersion of chronic uniform releases significantly better than sectorised Gaussian plume models. For aquatic systems, flow rates are very variable. Generic values appropriate to different environmental contexts are generally available.

In defining radionuclide-specific equilibrium factors, a considerable amount of effort could easily be expended in reviewing the many thousands of relevant articles in the primary literature in order to achieve consistency between factors for one radionuclide and between radionuclides. Such a review was outside the scope of this study, but is being conducted within the scope of the IAEA Environmental Modelling for Radiation Safety (EMRAS) programme. However, comprehensive datasets have been developed in the past for use with various biosphere models. In this study, these datasets were reviewed and a coherent set of data were selected for use. It is emphasised that these data undoubtedly have limitations and may include some biases, but that these limitations and biases can only properly be addressed in the type of international review and evaluation exercise that is currently being undertaken under the auspices of the IAEA.

A.2 Atmospheric dispersion and calculation of air concentrations

Radionuclides released to atmosphere are diluted and dispersed downwind. Due to turbulence in the atmosphere and variations in the wind direction, the released radionuclides form a plume that widens in both the horizontal and vertical directions with increasing distance downwind from the source. For short-term releases, both horizontal and vertical dispersion can be treated as random-walk processes, so the corresponding activity concentration profiles are Gaussian. For long-term releases, the vertical profile can again be taken as Gaussian, but the horizontal wind direction can be taken to be distributed according to the observed windrose. In a sectorised model, the probability of the wind blowing into each 30° or 45° sector is specified and the plume is treated as uniformly distributed in angle within each sector.

The dispersion of an atmospheric plume of radioactive contamination can be estimated in various ways. For releases from complex building geometries, the preferred approach is to scale up from experimental results obtained in wind tunnels, in which realistic models of both the spatial pattern of release and the overall geometry of the release context are represented. However, this approach is not appropriate for generic studies in which a wide range of circumstances have to be investigated. It is also over-elaborate when other uncertainties in the calculations are substantial.

For generic and prospective studies, dispersion is normally estimated using mathematical models. These are often, but not always, implemented in computer codes. The simplest types of models are Gaussian plume models. Such models have been described by the UK Working Group on Atmospheric Dispersion (e.g. [A.1]) and are implemented in a wide variety of computer codes, including those for accident consequence assessment, such as PC COSYMA [A.2] and CONDOR [A.3], as well as routine release consequence assessment codes, such as PC CREAM [A.4]. Although details of such models differ, the general principles can be summarised as follows:

- the plume exhibits a Gaussian profile, both in the horizontal and vertical directions for short-term releases, or in the vertical only for long-term releases;
- the variance in the Gaussian component or components of the plume increases with downwind distance, with the rate of increase determined by atmospheric stability characteristics and the nature of the ground surface ('ground roughness');
- reflections of the plume at the ground surface and at the atmospheric inversion height are included, with the inversion height being a function of the atmospheric stability category.

Such models can incorporate additional factors such as building wake effects (effectively making the horizontal and vertical dispersion non-zero at the point of release), plume rise (due to buoyancy or momentum at the location of discharge), and sea-breeze effects (through spatial and temporal variations in boundary layer thickness). These factors are of limited relevance in the current context for various reasons. In particular, as the location of the release and the topographical context cannot be specified in detail, it is appropriate to adopt the cautious assumption of a near-surface point release. As the amount of energy and momentum associated with the releases of interest are likely to be limited, it is also appropriate to adopt the cautious position of assuming no buoyancy or momentum-driven plume rise.

Although Gaussian plume models are conventionally used to estimate atmospheric dispersion in accident consequence assessments and sectorised Gaussian plume models are conventionally used for routine (chronic) releases, it should be recognised that more physically based models, such as the Atmospheric Dispersion Modelling System (ADMS) model [A.5], are available. Although such models are likely to yield very similar results to Gaussian plume models when applied in a generic context, it may be desirable to compare the results from such a model with results from a simpler, Gaussian plume model to demonstrate consistency in the context of a site-specific assessment.

It is emphasised that atmospheric transport models are based on a simplified and idealised view of the dispersive characteristics of the atmosphere and that the dispersion factors obtained from such models should be regarded as order-of-magnitude estimates rather than definitive point values.

Having defined a source term and dispersion factor, radionuclide concentrations in air can be defined at the point (or points) of interest. These air concentrations form the starting point for estimates of radiological consequences.

A.3 Transfers 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 chronic releases of radionuclides to terrestrial systems. Radionuclides released to and dispersed in the atmosphere enter the terrestrial environment because of dry and wet deposition on soils and vegetation. A comprehensive account of such deposition and of the subsequent behaviour of radionuclides in the terrestrial environment is given by Thorne [A.6]. Dry deposition is typically quantified by use of a deposition velocity, an empirically derived quantity that depends on a number of factors such as particle size. In modelling studies, the dry deposition velocity is often taken as constant. However, in practice, it typically decreases with increasing distance from the source, due to depletion of the plume by the deposition of larger particles. Gaseous radionuclides can be classified by their incorporation into reactive or non-reactive gases. Noble gases, such as krypton or xenon, exhibit negligible deposition, whereas reactive gases (e.g. I_2, CO_2 and SO_2) are characterised by rapid and effective interactions with plants.

Wet deposition is typically represented through the use of a washout coefficient (dimensions $[T]^{-1}$) that multiplies the vertically integrated concentration of a radionuclide in the plume to generate a deposition rate.

With both dry and wet deposition, the initial deposit is partitioned into that deposited on plants and that deposited directly to soil. Generally, a simple model is used for dry deposition that depends, through a saturating exponential, on standing biomass density [A.7]. For wet deposition, empirical values of fractional deposition per unit biomass are used [A.6,A.8]. These values depend on leaf area index, rate of rainfall and chemical form, with the absorption of cations to the leaf surface much more effective than that of anions [A.6].

Once deposited on vegetation, radionuclides are lost from plants due to removal by wind and rain, either through leaching or by cuticular abrasion. Plant growth can also lead to a reduction in radionuclide concentrations, a reduction termed ‘growth dilution’. Weathering losses and growth dilution effects are often estimated in models using a weathering half-life, typically in the range 5 to 30 days.

Translocation from foliage to edible parts of plants is generally represented using an empirical scaling factor. The units of this quantity vary depending on the particular modelling approach adopted, but the various forms can be readily related. However, quantification of translocation as a function of the element, plant and stage of development remains a problem because of limitations in the available data [A.6].

In the case of soils, most models treat the soil as one, or at most a few, well-mixed compartments. However, more sophisticated, physically based models have been developed for research purposes. These have been compared with assessment models and experimental data in validation studies (e.g. [A.9]). Although binding of radionuclides to soil solids and uptake by plants have been treated kinetically in some models for more than 20 years (e.g. [A.10]), it is usual to treat sorption using an equilibrium isotherm (K_d value) and plant uptake using a plant–soil concentration ratio. These approaches reflect the availability of data and have been adopted in various reviews (see [A.8,A.11]).

Similarly, although transfers to animals can be treated kinetically, most assessment models utilise transfer factors that relate concentrations of radionuclides in meat, offal and milk to daily rates of intake in diet. Relationships between transfer factor and kinetic approaches have recently been discussed in detail by Thorne [A.12].

Resuspension may also be included in terrestrial models. This term refers to the removal of deposited material from the ground to the atmosphere as a result of wind, traffic, soil cultivation and other activities. Various approaches to deriving resuspension factors have been applied. A recent review is provided by the US NCRP [A.13]. The NCRP has also produced a useful report on screening models for releases of radionuclides to atmosphere, surface waters and ground [A.14].

A.4 Dispersion in estuarine and coastal water

The key issue in modelling estuarine and coastal environments is the, generally large, degree of dispersion that occurs. Approaches to modelling have been discussed by Thorne [A.6]. In the context of marine modelling, it is useful to note the distinction made by the IAEA Group of Experts on Scientific Aspects of Marine Pollution (GESAMP) between water circulation and transport models, sediment transport models and biological transport models [A.15]. The main solution methods available for transport modelling involve the use of single and multiple uniformly mixed compartments, or numerical or semi-analytical solutions to the transport equations. The differences between models that use multiple compartments and those that employ numerical solutions to advection–dispersion equations may, in reality, be small. In particular, the multi-compartment and numerical solutions should converge as the number of compartments is increased in the multi-compartment case.

Estuaries represent a particularly complex aquatic environment. They are of particular interest, as discharges of radionuclides are more likely to occur to them than directly to the coastal environment, and the initial degree of dilution will often be less. Estuaries can be defined as semi-enclosed coastal bodies of water that have a free connection with the open sea and within which seawater is measurably diluted with freshwater. Estuaries are usually classified according to their physical oceanographic characteristics, particularly the magnitude of vertical mixing [A.6]. 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 generally difficult to apply generic methods. Where detailed studies into the dispersion of radionuclides in estuaries are required, estuary-specific proprietary models are usually developed [A.16].

Radionuclide uptake by organisms in estuarine and coastal environments is almost universally modelled using a concentration ratio approach. Comprehensive compilations of such ratios are available (e.g. [A.17]).

A.5 Modelling of freshwater rivers and streams

Rivers are complex and dynamic systems and it is common to make simplifying assumptions in modelling river geometry and processes. In the UK, freshwater streams 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.

Radionuclide interactions with sediments in particular are complicated, as the chemical properties of any suspended particles can vary as a function of time depending on a variety of physical, chemical and biological processes. In the simplest mathematical models radionuclides are assumed to remain in solution and their concentration will decrease as a consequence of advection and dispersion. More complex models require the parameterisation of terms to describe dispersion, advection and bed-load sediment resuspension under a variety of water flow conditions. The complexity of aquatic models will depend ultimately on the required accuracy and timescale of predictions. River models can also be embedded in physically based models for water flow and sediment transport in surface water catchments (e.g. [A.18]). However, such models are primarily of relevance for use in a site-specific context. Difficulties in application of such models will be compounded by parameterisation difficulties and lack of relevant data. An overview of the requirements of models of varying complexity is given in Simmonds *et al.* [A.16]. Further reviews of river models are given in Hilton *et al.* [A.19] and alternative approaches to modelling radionuclide transport in rivers are discussed by Thorne [A.6].

The highest radiological impact can be expected immediately downstream of the disposal point, where the activity concentrations of the radionuclides are highest, if consistent habit data are applied. At such short distances downstream, it is unlikely that much can be gained from a detailed dispersion model. In addition, some of the precision will be lost (e.g. in radionuclide concentrations across the river) when selecting a representative (in some sense average) concentration for subsequent pathways modelling.

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 dilution in the volumetric flow rate and allowing for depletion by radioactive decay and deposition to bottom sediments. Partitioning between solution and suspended sediments in such models almost always uses a K_d-based approach.

As with coastal environments, radionuclide uptake by organisms in freshwater environments is almost always based on a concentration ratio approach (e.g. [A.8]).

A.6 Sewage treatment works

A.6.1 Partitioning of radionuclides in sewage treatment works

Comprehensive information is available on the full range of processes that are used in wastewater treatment and in the subsequent processing of the various types of sludge that may arise. This information includes characterisation of the types of plant used, normal ranges of operating parameters, details of physical, chemical and biological conditions within the system, and descriptions of how conditions can be altered during start-up and abnormal operations. Therefore, the availability of information does not place any substantial constraints on the development of full biogeochemical models of different types of wastewater treatment [A.20].

However, information on the behaviour of radionuclides and other substances (such as potentially toxic elements) on passing through sewage treatment works is very limited. For a limited number of radionuclides and metals, removal efficiencies have been measured [A.21,A.22]. However, these empirical measurements have not been complemented by detailed studies of the processes involved. This means that detailed biogeochemical models of sewage treatment would not be likely to provide substantial guidance on the degree to which different radionuclides would be incorporated in sludges. Similarly, such models would be of only limited utility in determining the chemical form in which the radionuclides would be present in those sludges.

In view of these observations, it seems more appropriate to use a simple model, such as that adopted by Titley *et al*. [A.21] for assessment purposes. This model is characterised in terms of the time taken for each operation and radionuclide-specific or element-specific removal coefficients. In several cases, the removal coefficients can be defined from empirical observations. However, in order to achieve a comprehensive set of values for all the radionuclides and treatment processes of interest in this study, it would be necessary to derive removal coefficients from collateral data. A possible approach is to use K_d values. A preliminary analysis, shows that this approach can yield plausible removal coefficients, in circumstances where comparisons can be made with empirical observations [A.20]. However, it must be recognised that the use of K_d values is subject to some drawbacks. First, the nature of the sewage sludge, whether suspended or settled, is substantially different from the types of materials for which K_d values have typically been measured. Second, even for more standard materials, such as soils, K_d values show substantial variations depending on the type of sample and the conditions under which it was determined. Third, radionuclides may be structurally incorporated in the organic component of sewage sludge as it is produced by microbial growth. Such structural incorporation cannot be represented using the K_d concept. Fourth, transit times in some stages of sewage treatment can be short (as little as a few hours), so kinetic factors may be of importance.

Notwithstanding these remarks, these uncertainties have less severe implications for model development than might appear at first sight. First, particle-reactive elements such as the transition metals, lanthanides and actinides will be strongly associated with the settled sludges, so that uncertainties in their routing to those sludges will be limited. Similarly, elements such as carbon, sulphur and phosphorus that are in substantial demand for biomass growth will tend to be associated with the sludges. The main difficulties will arise with elements such as chlorine that are generally conserved in the liquid phase, but may have some affinity to the organic matter content of sludges. Even in this case, uncertainties in partitioning are limited because of the amount of water present in the settled sludge, or even after mechanical removal.

Particular issues arise with ^{3}H and ^{14}C 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.

A.6.2 Application of sewage sludge to agricultural land

Once sludge has been produced in a suitable form, there is no reason why there should be any delay in its application to agricultural land. However, constraints of supply and demand may result in some delay at this stage. The degree of delay is mainly a matter for consideration in developing scenarios to simulate using the model. It is not a parameter for which values or distributions can readily be established by literature review. In this, it contrasts with delay times during sewage treatment. These delay times are set by the nature of the processes involved and are strongly constrained.

An agreement between the main sludge producers and the main food retailers was reached in 1998. This agreement has led to the adoption of a 'Safe Sludge Matrix' by the UK Water Industry and the British Retailer Consortium. This Safe Sludge Matrix provides advice on restrictions over and above those imposed in law on the use of sewage sludge on agricultural land, including categories of crops on which sludge may not be used. One of the main elements of this agreement is a ban on the use of untreated sludge, except on non-food industrial crops on which untreated sludge was allowed to be applied until the end of 2001.

The most recent version of the Safe Sludge Matrix identified has been developed by ADAS (Agricultural Development and Advisory Service) [A.23]. The provisions of this agreement were incorporated into legislation and amended versions of the Sludge (Use in Agriculture) Regulations were produced. It comprises a table of crop types together with guidance on the minimum acceptable level of treatment for any sludge-based product that may be applied to land used to produce that crop. Conventional and advanced treatments are distinguished. Conventionally treated sludge may not be used for fruit or horticulture. For salads it can be used with a 30-month delay and for vegetables it can be used with a 12-month delay. There are no restrictions on use for combinable and animal-feed crops. For grazed grass and forage, the sludge must be deep injected or ploughed down, and there must be at least a 3-week delay before harvesting or grazing. For harvested grass and forage, there must be no grazing in the season of application, if the sludge is applied to the surface. There must also be at least a 3-week delay before harvesting. For sludge subject to advanced treatment, a 10-month delay applies to fruit, salads, vegetables and horticulture. There are no restrictions on combinable and animal feed crops. For grass or forage, whether grazed or harvested, a delay of at least 3 weeks is required before grazing or harvesting. Advanced treated sludge can be surface applied to grazed pasture or harvested pasture. For some radionuclides, surface spreading of sludge to pasture is likely to lead to the highest doses.

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. Application schemes for sewage sludge are well documented and historical data exist on rates of application.

In principle, radionuclide transfers from soils to plants could differ between sludge-amended and unamended soils. However, in practice, the information that is available suggests only very limited distinctions [A.20]. 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.

A.7 Generalised derived constraints

The NRPB has published Generalised Derived Constraints (GDCs), based on a dose constraint of 0.3 mSv y^{-1} [A.24, A.25]. Each GDC represent the annual discharge of a particular radionuclide by a single mode of discharge that is assessed to give an effective dose rate of 0.3 mSv y^{-1} to the critical group, to allow for direct comparison with proposed controlled discharges from a facility. GDCs have been developed for a number of radionuclides and the following discharge scenarios: discharges to atmosphere, river and sewer.

A.7.1 Assumptions underlying GDCs

The GDCs for each discharge scenario have been derived using defined models with generic assumptions made on the discharge locations, receiving environments and habits of exposed groups.

The GDCs are for continuous uniform annual discharges of radionuclides, which are assumed to take place over 50 years and are such as to ensure that the constraint is just complied with in the last year of discharge. The ingrowth of progeny has been determined for this 50 year period. The age groups considered are infants (1 year old), children (10 years old) and adults, taking into account variations in dose coefficients, physiological characteristics and habits with age. In addition, GDCs for infants on an all-milk diet have been calculated, based on the dose coefficient for a 3-month old. The overall GDC for each discharge scenario and radionuclide is based on the most restrictive age group.

For discharges to atmosphere, dispersion was modelled using a Gaussian plume model, assuming cautious values for stack height and critical group locations. The transfer of activity through the foodchain and activity concentration in the soil profile were modelled using the dynamic foodchain model FARMLAND [A.26]. The following pathways were included: inhalation of radionuclides in the effluent plume and resuspended after deposition, external irradiation from the plume and deposited radionuclides, ingestion of terrestrial foodstuffs and inadvertent ingestion of soil.

For discharges to river, it was assumed that the radionuclides are discharged in solution and activity concentrations in the river water were modelled using a simple compartment model [A.16] with a sedimentation model from BIOS [A.27]. A single compartment was defined and downstream transport of river water and bed sediments as well as sedimentation to the riverbed were modelled. Transfer through the foodchain was modelled using FARMLAND and assuming a representative irrigation rate. The following pathways were included: ingestion of drinking water, freshwater fish and terrestrial foodstuffs grown on irrigated land, inhalation of radionuclides resuspended into the air from sediments and external irradiation from sediments.

For discharges to sewer, it was assumed that the radionuclides are present in solution and that discharges occur to a relatively small sewage treatment works. In deriving sewage GDCs, two separate scenarios were considered: that all the radioactivity is transferred to the sewage sludge or that all the activity remains in the liquid effluent. Radionuclide partitioning between the solution and solid phases was not modelled. For the latter scenario, doses were calculated as for discharges to river. For activity transferred to the sludge, first doses to workers at the sewage treatment works were calculated, including the following pathways: external irradiation from radionuclides in sewage sludge stored in tanks, inhalation of activity resuspended from the sludge and inadvertent ingestion of sludge. Second, doses to a critical group consuming food produced on land treated with sewage sludge were calculated, including the following pathways: external irradiation from radionuclides in soil, inadvertent ingestion of soil, inhalation of resuspended soil and ingestion of animal products from animals raised on the treated land.

For the disposal of sewage sludge to land only animal pathways were considered. It was assumed that application was directly onto permanent pasture where the grass growth occurred after the application, thus there would be no direct contamination of the grass by the sludge. The applied sludge was assumed to effectively become part of the top 2 cm of soil. Of all realistic sewage sludge disposal routes this type of sludge-to-land application was chosen as it was expected to lead to the worst doses. The limited area of land which could be treated was assumed to only support one type of animal product (sheep meat and offal, beef meat and offal or cow's milk). The three exposure routes were assumed to be mutually exclusive and the most restrictive dose taken to be the GDC.

A.7.2 The application of GDCs

Due to the conservative assumptions underlying the GDCs, compliance with the GDC should ensure virtual certainty of compliance with the dose constraint.

GDCs are intended to be reference quantities, especially for small (non-nuclear industry) users of radioactive materials, discharging low levels of radionuclides into the environment. The NRPB has suggested that a further investigation should be undertaken when discharges exceed about 30% of the GDC, that is, an implied effective dose rate of 0.1 mSv y^{-1} [A.28]. However, the effective dose rate actually incurred by a critical group for discharge at 30% of the GDC will often be considerably less than 0.1 mSv y^{-1}, because of the cautious assumptions made in the derivation of the GDCs.

A.8 Conclusions of review and implications for initial assessment methodology

Although numerous biosphere models are available, none of them fulfil the requirements of this study. In particular, the set of radionuclides to be addressed is beyond the scope of existing models. However, for the purposes of generic analyses, the biosphere calculations required can be expressed through simple analytic equations. Therefore, rather than using existing models as they stand, either the datasets underpinning those models can be extracted or the models can be used to compute input data for use in simple analytical calculations. Although the extracted or computed datasets will be incomplete, it is relatively straightforward to use a variety of techniques to generate the missing data. In addition, where comprehensive up-to-date datasets exist independently of the existing models, those can be used in preference to earlier or incomplete datasets within the models. External dose factors and intake-to-dose factors are good examples of such independently available datasets.

This approach of abstracting information from existing models or data compilations and using that information in transparent analytical calculations forms the basis of the method adopted in this study and is described in detail in the following sections.

The method adopted is considered to have advantages over the application of GDCs. Currently, GDCs are available only for a restricted range of radionuclides and have not been developed for discharges to a coastal environment. Also, the degree of caution used in the computation of GDCs makes them of limited utility as a screening tool, as they may be too restrictive to exclude many small discharges of radionuclides from a requirement for detailed assessment. Furthermore, the methods used in computation of the GDCs mean that it is difficult to modify the values to reflect site-specific considerations. In contrast, the analytical techniques applied in this study lead themselves to scaling calculations. Thus, if initial screening calculations indicate that annual effective doses could be significantly in excess of 0.02 mSv y^{-1}, it is straightforward to undertake a simple site-specific assessment without having to enter into a substantial site-specific data collection and analysis exercise. Specifically, a few key site-specific quantities (e.g. local river flow rates or atmospheric dispersion factors) can be inserted into the generic analysis and revised annual effective dose estimates can be produced.

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Appendix B Dose factors

B.1 Introduction

Radionuclides taken into the body, either by ingestion or inhalation, cause exposure both to the organs and tissues of accumulation and to other organs and tissues by cross-fire effects. For the purposes of assessing dose to a member of the critical group, it is the weighted sum of doses to individual organs and tissues, expressed as effective dose, which is of prime concern. The actual exposure depends on many factors, including the solubility of the radionuclide and its characteristic retention in the body. The values of the effective dose coefficients for intakes by inhalation and ingestion applied here reflect the most recent advice of 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.

In determining the effective dose arising from ingestion of material containing radionuclides, it is necessary to consider the fractions of those radionuclides that are absorbed across the wall of the gastrointestinal tract. Such absorption is referred to as the gut uptake factor (f_1) and varies with the physical and chemical form of the radionuclide and with the metabolism and physiology of the individual.

The dose following intake of a radionuclide by inhalation depends upon a number of factors in addition to the radioactive properties of the nuclide involved – in particular, the particle size of the inhaled material and the rate at which deposited material can be absorbed into body fluids from the respiratory tract. A significant proportion of particulate material deposited in the respiratory tract is cleared directly via the gastrointestinal tract in swallowed mucus, which also influences the effective dose. 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, and these have been applied here. Where no default is specified, the absorption type producing the highest value of dose per unit intake has generally been taken.

B.2 Dose factors for *in utero* exposure of offspring

Dose coefficients for assessing effective dose to the embryo and fetus following intake of radionuclides by the mother were issued by the ICRP 2001 [B.2]. The NRPB has published guidance on the application of these dose factors for the control of exposures of members of the public in the UK and ratios of fetal to adult doses for those radionuclides where the fetus receives a higher dose than the mother dose, following intake by the mother. This approach takes account of the 9 months of pregnancy and implicitly allows for intakes by the infant through breastfeeding for 3 months [B.3]. The term offspring has been applied here to collectively denote the embryo, fetus and newborn child. For the radionuclides considered here offspring exposure is taken into account for ^{3}H, organically bound ^{3}H, ^{14}C, ^{32}P, ^{33}P, ^{35}S, ^{45}Ca, ^{47}Ca, ^{89}Sr, ^{90}Sr, ^{75}Se and ^{226}Ra.

B.3 Dose factor for ^{82}Rb

ICRP [B.4] does not list dose factors for ^{82}Rb. Because of its very short half-life of 1.3 minutes, ingestion pathways do not need to be considered for this radionuclide. Dose factors for inhalation of ^{82}Rb 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 and cross-fire effects are of limited importance.

Because of its very short half-life, there is virtually no opportunity for ingestion, so the effective dose per unit intake by ingestion can be set to zero with no risk of underestimating the radiological impact of this radionuclide. However, ^{82}Rb released to atmosphere may be inhaled almost immediately from the dispersing plume, so it is useful to estimate an effective dose per unit intake value by inhalation.

Because of its very short half-life, there is little opportunity for inhaled and deposited ^{82}Rb to be translocated from the respiratory system. Therefore, the effective dose per unit intake can be based on the absorbed dose to the respiratory system, neglecting cross-fire from the respiratory system to other tissues and organs as a second-order effect. 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 ^{82}Rb 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 ^{82}Rb as 0.00886 s^{-1}, this results in a total of 67.72 transformations. From ICRP Publication 38 [B.4], each transformation of ^{82}Rb results in the emission of 1.09 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.

Because the radiation is low Linear Energy Transfer(LET) and, in adult man, the respiratory system has a mass of 1 kg [B.5], 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.6] (i.e. 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 taken. 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.5]).

B.4 Dose factor for ^{222}Rn

For the purposes of this study, ^{222}Rn dose factors for the infant and child age groups were derived, based on epidemiological data and using simplifying assumptions to allow for age group scaling.

The dosimetry of ^{222}Rn has recently been summarised by Thorne [B.7]. The radiation dose is delivered primarily not by the noble gas itself, but by its short-lived radioactive progeny. These short-lived progeny are formed as small positive ions or neutral atoms approximately 0.5 nm in diameter. They increase rapidly to 0.5 to 5 nm, as a result of clustering on water or other molecules in the air. This ultrafine aerosol is called the unattached fraction. However, many of these particles become attached to the ambient aerosol, hence becoming the attached fraction. The radiation dose delivered depends on the degree of attachment. In addition, short-lived progeny may be removed from the ambient air by physico-chemical attachment to surfaces, so that concentrations of the progeny are less than those of the ancestor radionuclide.

Detailed dosimetric studies have been undertaken to estimate that the absorbed dose to basal cells of the bronchial epithelium per unit exposure is in the range 5 to 25 nGy per Bq h m^{-3}. A central case, for average indoor conditions gives 9 nGy per Bq h m^{-3}. For an apportioned tissue weighting factor of 0.08 for the bronchial and bronchiolar regions and a radiation weighting factor of 20 for alpha particles, the effective dose per unit EEC is 15 nSv per Bq h m^{-3}. The dose to the pulmonary region of the lungs is considered to be of much less radiological significance [B.8].

In an alternative approach, the ICRP [B.9] derived a conversion coefficient for ^{222}Rn based directly on epidemiological data. The nominal mortality probability coefficient for ^{222}Rn was estimated as 8E-05 per mJ h m^{-3}. As the health detriment per unit effective dose is 5.6E-05 per mSv for workers and 7.3E-05 per mSv for members of the public [B.6], the conversion coefficients were estimated as 1.4 and 1.1 mSv per mJ h m^{-3} at work and at home, respectively. These values correspond to 7.8 and 6.1 nSv per Bq h m^{-3} [B.9], a factor of 2 to 2.5 lower than the value derived from the dosimetric approach. In view of the uncertainties in dosimetry, and the assignment of both radiation and tissue weighting factors, the epidemiologically based estimate is preferred. Based on an adult breathing rate of 1.2 m^3 h^{-1} under conditions of light exercise [B.10], these epidemiological estimates correspond to 6.8E-09 or 5.1E-09 Sv per Bq intake, respectively. Here, a rounded value of 6.0E-09 Sv per Bq is adopted. The dose from ^{222}Rn 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. Thus, values of 6.0E-09, 1.2E-08 and 4.5E-08 Sv per Bq are adopted for adults, children and infants, respectively.

It should be noted that the approaches to estimate inhalation dose factors for ^{222}Rn and ^{82}Rb taken here are not comprehensive but are deemed appropriate for use in this study.

B.5 Dose factor tables

Table B.1 lists the dose per unit intake factor, lung class and gut uptake factor for each radionuclide and age group for intake by ingestion and Table B.2 for inhalation. For the fetus the ratio of fetal to adult dose is given, as well as resulting dose factors.

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Table B.1 Dose factors for intake by inhalation

Radionuclide	Absor. type*	f_1	Ratio of fetal to adult dose coefficient	Dose per unit intake by inhalation (Sv Bq^{-1})			
				Offspring$	Infant	Child	Adult
H-3+	V	1	1.7	3.1E-11	4.8E-11	2.3E-11	1.8E-11
H-3 organic	V	1	1.5	6.2E-11	1.1E-10	5.5E-11	4.1E-11
C-11	M	0.1			1.1E-10	3.2E-11	1.8E-11
C-14	M	0.1			6.6E-09	2.8E-09	2.0E-09
F-18	S	1			3.1E-10	1.0E-10	5.9E-11
Na-22	F	1			7.3E-09	2.4E-09	1.3E-09
Na-24	F	1			1.8E-09	5.7E-10	2.7E-10
P-32	M	0.8	1.9	6.5E-09	1.5E-08	5.3E-09	3.4E-09
P-33	M	0.8			4.6E-09	2.1E-09	1.5E-09
S-35	M	0.1			4.5E-09	2.0E-09	1.4E-09
Cl-36	M	1			2.6E-08	1.0E-08	7.3E-09
Ca-45	M	0.1			8.8E-09	3.9E-09	2.7E-09
Ca-47	M	0.1			7.7E-09	2.9E-09	1.9E-09
V-48	M	0.01			1.1E-08	4.3E-09	2.4E-09
Cr-51	S	0.1			2.1E-10	6.6E-11	3.7E-11
Mn-52	M	0.1			6.8E-09	2.4E-09	1.4E-09
Mn-54	M	0.1			6.2E-09	2.4E-09	1.5E-09
Mn-56	M	0.1			7.8E-10	2.4E-10	1.2E-10
Fe-55	M	0.1			1.4E-09	6.2E-10	3.8E-10
Fe-59	M	0.1			1.3E-08	5.5E-09	3.7E-09
Co-56	M	0.1			2.1E-08	7.4E-09	4.8E-09
Co-57	M	0.1			2.2E-09	8.5E-10	5.5E-10
Co-58	M	0.1			6.5E-09	2.4E-09	1.6E-09
Co-60	M	0.1			3.4E-08	1.5E-08	1.0E-08
Ni-63	M	0.05			1.9E-09	7.0E-10	4.8E-10
Zn-65	M	0.1			6.5E-09	2.4E-09	1.6E-09
Ga-67	M	0.001			1.0E-09	3.6E-10	2.4E-10
Se-75	F	0.8	1.1	1.1E-09	6.0E-09	2.5E-09	1.0E-09
Br-82	M	1			3.0E-09	1.1E-09	6.3E-10
Rb-82	F	1			1.5E-11	4.0E-12	2.0E-12
Rb-83	F	1			3.8E-09	1.3E-09	6.9E-10
Sr-89	M	0.1			2.4E-08	9.1E-09	6.1E-09
Sr-90	M	0.1			1.1E-07	5.1E-08	3.6E-08
Y-90	S	0.0001			8.8E-09	2.7E-09	1.5E-09
Zr-95	M	0.002			1.6E-08	6.8E-09	4.8E-09
Nb-95	M	0.01			5.2E-09	2.2E-09	1.5E-09
Mo-99	M	0.1			4.4E-09	1.5E-09	8.9E-10
Tc-99	M	0.1			1.3E-08	5.7E-09	4.0E-09
Tc-99m	M	0.1			9.9E-11	3.4E-11	1.9E-11
Ru-103	M	0.05			8.4E-09	3.5E-09	2.4E-09
Ru-106	M	0.05			1.1E-07	4.1E-08	2.8E-08
Ag-110m	M	0.05			2.8E-08	1.2E-08	7.6E-09
In-111	M	0.02			1.2E-09	4.1E-10	2.3E-10
In-113m	M	0.02			1.1E-10	3.6E-11	2.0E-11
Sb-125	M	0.01			1.6E-08	6.8E-09	4.8E-09
I-123	F	1			7.9E-10	1.8E-10	7.4E-11
I-125	F	1			2.3E-08	1.1E-08	5.1E-09
I-129	F	1			8.6E-08	6.7E-08	3.6E-08
I-131	F	1			7.2E-08	1.9E-08	7.4E-09

Table B.1 continued

Radionuclide	Absor. type*	f_1	Ratio of fetal to adult dose coefficient	Dose per unit intake by inhalation (Sv Bq^{-1})			
				Offspring$	Infant	Child	Adult
I-132	F	1			9.6E-10	2.2E-10	9.4E-11
I-133	F	1			1.8E-08	3.8E-09	1.5E-09
I-134	F	1			3.7E-10	9.7E-11	4.5E-11
I-135	F	1			3.7E-09	7.9E-10	3.2E-10
Cs-134	F	1			7.3E-09	5.3E-09	6.6E-09
Cs-136	F	1			5.2E-09	2.0E-09	1.2E-09
Cs-137	F	1			5.4E-09	3.7E-09	4.6E-09
Ba-140	M	0.1			2.0E-08	7.6E-09	5.1E-09
La-140	M	0.0005			6.3E-09	2.0E-09	1.1E-09
Ce-141	M	0.0005			1.1E-08	4.6E-09	3.2E-09
Ce-144	M	0.0005			1.6E-07	5.5E-08	3.6E-08
Pm-147	M	0.0005			1.8E-08	7.0E-09	5.0E-09
Sm-153	M	0.0005			2.9E-09	1.0E-09	6.3E-10
Eu-152	M	0.0005			1.0E-07	4.9E-08	4.2E-08
Eu-154	M	0.0005			1.5E-07	6.5E-08	5.3E-08
Eu-155	M	0.0005			2.3E-08	9.2E-09	6.9E-09
Er-169	M	0.0005			3.5E-09	1.5E-09	1.0E-09
Lu-177	S	0.0005			4.1E-09	1.7E-09	1.2E-09
Au-198	S	0.1			4.4E-09	1.4E-09	8.6E-10
Tl-201	F	1			3.3E-10	9.4E-11	4.4E-11
Pb-210	M	0.1			3.7E-06	1.5E-06	1.1E-06
Po-210	M	0.1			1.1E-05	4.6E-06	3.3E-06
Rn-222	G	-			4.5E-08	1.2E-08	6.0E-09
Ra-223	M	0.1			2.1E-05	9.9E-06	7.4E-06
Ra-226	M	0.1			1.1E-05	4.9E-06	3.5E-06
Th-230	S	0.0005			3.5E-05	1.6E-05	1.4E-05
Th-232	S	0.0005			5.0E-05	2.6E-05	2.5E-05
Th-234	S	0.0005			3.1E-08	1.1E-08	7.7E-09
U-234	M	0.02			1.1E-05	4.8E-06	3.5E-06
U-235	M	0.02			1.0E-05	4.3E-06	3.1E-06
U-238	M	0.02			9.4E-06	4.0E-06	2.9E-06
Np-237	M	0.0005			4.0E-05	2.2E-05	2.3E-05
Pu-238	M	0.0005			7.4E-05	4.4E-05	4.6E-05
Pu-239	M	0.0005			7.7E-05	4.8E-05	5.0E-05
Pu-240	M	0.0005			7.7E-05	4.8E-05	5.0E-05
Pu-241	M	0.0005			9.7E-07	8.3E-07	9.0E-07
Pu-242	M	0.0005			7.3E-05	4.5E-05	4.8E-05
Am-241	M	0.0005			6.9E-05	4.0E-05	4.2E-05
Am-242	M	0.0005			5.9E-08	2.4E-08	1.7E-08
Am-243	M	0.0005			6.8E-05	4.0E-05	4.1E-05
Cm-242	M	0.0005			1.8E-05	7.3E-06	5.2E-06
Cm-243	M	0.0005			6.1E-05	3.1E-05	3.1E-05
Cm-244	M	0.0005			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. To relate it to the annual dose to the mother it was further assumed that breastfeeding occurs for 3 months after birth

Table B.2 Dose factors for intake by ingestion

Radionuclide	f_1	Ratio of fetal to adult dose coefficient	Dose per unit intake by ingestion (Sv Bq^{-1})			
			Offspring$	Infant	Child	Adult
H-3+	1	1.7	3.1E-11	4.8E-11	2.3E-11	1.8E-11
H-3 organic	1	1.5	6.3E-11	1.2E-10	5.7E-11	4.2E-11
C-11	1			1.5E-10	4.3E-11	2.4E-11
C-14	1	1.4	8.1E-10	1.6E-09	8.0E-10	5.8E-10
F-18	1			3.0E-10	9.1E-11	4.9E-11
Na-22	1			1.5E-08	5.5E-09	3.2E-09
Na-24	1			2.3E-09	7.7E-10	4.3E-10
P-32	0.8	10	2.4E-08	1.9E-08	5.3E-09	2.4E-09
P-33	0.8	20	4.8E-09	1.8E-09	5.3E-10	2.4E-10
S-35	1	1.6	2.1E-10	8.7E-10	2.7E-10	1.3E-10
Cl-36	1			6.3E-09	1.9E-09	9.3E-10
Ca-45	0.3	12	8.5E-09	4.9E-09	1.8E-09	7.1E-10
Ca-47	0.3	4.8	7.7E-09	9.3E-09	3.0E-09	1.6E-09
V-48	0.01			1.1E-08	3.9E-09	2.0E-09
Cr-51	0.1			2.3E-10	7.8E-11	3.8E-11
Mn-52	0.1			8.8E-09	3.4E-09	1.8E-09
Mn-54	0.1			3.1E-09	1.3E-09	7.1E-10
Mn-56	0.1			1.7E-09	5.1E-10	2.5E-10
Fe-55	0.1			2.4E-09	1.1E-09	3.3E-10
Fe-59	0.1			1.3E-08	4.7E-09	1.8E-09
Co-56	0.1			1.5E-08	5.8E-09	2.5E-09
Co-57	0.1			1.6E-09	5.8E-10	2.1E-10
Co-58	0.1			4.4E-09	1.7E-09	7.4E-10
Co-60	0.1			2.7E-08	1.1E-08	3.4E-09
Ni-63	0.05			8.4E-10	2.8E-10	1.5E-10
Zn-65	0.5			1.6E-08	6.4E-09	3.9E-09
Ga-67	0.001			1.2E-09	4.0E-10	1.9E-10
Se-75	0.8	1	2.6E-09	1.3E-08	6.0E-09	2.6E-09
Br-82	1			2.6E-09	9.5E-10	5.4E-10
Rb-82	-			-	-	-
Rb-83	1			8.4E-09	3.2E-09	1.9E-09
Sr-89	0.3	4.6	1.2E-08	1.8E-08	5.8E-09	2.6E-09
Sr-90	0.3	1.5	4.2E-08	7.3E-08	6.0E-08	2.8E-08
Y-90	0.0001			2.0E-08	5.9E-09	2.7E-09
Zr-95	0.01			5.6E-09	1.9E-09	9.5E-10
Nb-95	0.01			3.2E-09	1.1E-09	5.8E-10
Mo-99	1			3.5E-09	1.1E-09	6.0E-10
Tc-99	0.5			4.8E-09	1.3E-09	6.4E-10
Tc-99m	0.5			1.3E-10	4.3E-11	2.2E-11
Ru-103	0.05			4.6E-09	1.5E-09	7.3E-10
Ru-106	0.05			4.9E-08	1.5E-08	7.0E-09
Ag-110m	0.05			1.4E-08	5.2E-09	2.8E-09
In-111	0.02			1.7E-09	5.9E-10	2.9E-10
In-113m	0.02			1.8E-10	6.2E-11	2.8E-11
Sb-125	0.1			6.1E-09	2.1E-09	1.1E-09
I-123	1			1.9E-09	4.9E-10	2.1E-10
I-125	1			5.7E-08	3.1E-08	1.5E-08
I-129	1			2.2E-07	1.9E-07	1.1E-07
I-131	1			1.8E-07	5.2E-08	2.2E-08

Table B.2 continued

Radionuclide	f_1	Ratio of fetal to adult dose coefficient	Dose per unit intake by ingestion (Sv Bq^{-1})			
			Offspring$	Infant	Child	Adult
I-132	1			2.4E-09	6.2E-10	2.9E-10
I-133	1			4.4E-08	1.0E-08	4.3E-09
I-134	1			7.5E-10	2.1E-10	1.1E-10
I-135	1			8.9E-09	2.2E-09	9.3E-10
Cs-134	1			1.6E-08	1.4E-08	1.9E-08
Cs-136	1			9.5E-09	4.4E-09	3.0E-09
Cs-137	1			1.2E-08	1.0E-08	1.3E-08
Ba-140	0.2			1.8E-08	5.8E-09	2.6E-09
La-140	0.0005			1.3E-08	4.2E-09	2.0E-09
Ce-141	0.0005			5.1E-09	1.5E-09	7.1E-10
Ce-144	0.0005			3.9E-08	1.1E-08	5.2E-09
Pm-147	0.0005			1.9E-09	5.7E-10	2.6E-10
Sm-153	0.0005			5.4E-09	1.6E-09	7.4E-10
Eu-152	0.0005			7.4E-09	2.6E-09	1.4E-09
Eu-154	0.0005			1.2E-08	4.1E-09	2.0E-09
Eu-155	0.0005			2.2E-09	6.8E-10	3.2E-10
Er-169	0.0005			2.8E-09	8.2E-10	3.7E-10
Lu-177	0.0005			3.9E-09	1.2E-09	5.3E-10
Au-198	0.1			7.2E-09	2.2E-09	1.0E-09
Tl-201	1			5.5E-10	1.8E-10	9.5E-11
Pb-210	0.2			3.6E-06	1.9E-06	6.9E-07
Po-210	0.5			8.8E-06	2.6E-06	1.2E-06
Rn-222	-			-	-	-
Ra-223	0.2			1.1E-06	4.5E-07	1.0E-07
Ra-226	0.2	1.1	3.1E-07	9.6E-07	8.0E-07	2.8E-07
Th-230	0.0005			4.1E-07	2.4E-07	2.1E-07
Th-232	0.0005			4.5E-07	2.9E-07	2.3E-07
Th-234	0.0005			2.5E-08	7.4E-09	3.4E-09
U-234	0.02			1.3E-07	7.4E-08	4.9E-08
U-235	0.02			1.3E-07	7.1E-08	4.7E-08
U-238	0.02			1.2E-07	6.8E-08	4.5E-08
Np-237	0.0005			2.1E-07	1.1E-07	1.1E-07
Pu-238	0.0005			4.0E-07	2.4E-07	2.3E-07
Pu-239	0.0005			4.2E-07	2.7E-07	2.5E-07
Pu-240	0.0005			4.2E-07	2.7E-07	2.5E-07
Pu-241	0.0005			5.7E-09	5.1E-09	4.8E-09
Pu-242	0.0005			4.0E-07	2.6E-07	2.4E-07
Am-241	0.0005			3.7E-07	2.2E-07	2.0E-07
Am-242	0.0005			2.2E-09	6.4E-10	3.0E-10
Am-243	0.0005			3.7E-07	2.2E-07	2.0E-07
Cm-242	0.0005			7.6E-08	2.4E-08	1.2E-08
Cm-243	0.0005			3.3E-07	1.6E-07	1.5E-07
Cm-244	0.0005			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. To relate it to the annual dose to the mother it was further assumed that breastfeeding occurs for 3 months after birth

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 factor data used in this study were taken from a small number of standard compilations. However, those compilations did not cover all the radionuclides of interest and did not necessarily always provide all the parameter values of interest for those radionuclides that were included. This appendix describes how the missing data were supplied by techniques such as scaling, use of analogues and one-off analytical calculations.

C.2 Environmental distribution and transfer factors

Where data were not available in standard compilations, various approaches were used to derive the values required. These included:

- Analogies between media, e.g. saltwater K_d values could be used for freshwaters and vice versa, where the chemistry of the element was not considered to be strongly affected by salinity.
- 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.
- Analogies between elements, e.g. rubidium has similar biogeochemical characteristics to caesium and potassium, and the properties of the alkaline earth elements (calcium, strontium, barium and radium) are similar.

It is noted that:

- Environmental transfer factors were not required for very short-lived radionuclides (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 direct pathways of exposure were considered.
- In FARMLAND, the animal models for caesium and strontium are hard-wired into the code – where these elements were used as analogues, the procedure used was to run the caesium or strontium animal model, substituting the half-life of the radionuclide of interest.

The elements for which one or more items of data were missing from the standard compilations used were Na, Cl, Ca, V, Ni, Ga, Se, Br, Rb, Y, Mo, In, Ba, La, Pm, Sm, Eu, Er, Lu, Pb, Po, Au and Tl. Details on how these deficiencies in the available data were remedied are given in Table C.1. Note that scaling relations between different animal types are not mentioned in this table for conciseness, but were generally applied, as required.

It is noted that the overall environmental behaviour of a wide variety of radionuclides of interest has recently been summarised in qualitative terms for the Environmental Agency in a Radionuclides Handbook [C.3].

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 Kelly, M and Thorne, M C (2003). Radionuclides Handbook, Environment Agency R&D Technical Report P3-101/SP1b.

C.4 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.5 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.6 Coughtrey, P J and Thorne, M C (1983). Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems, Volume 1, A A Balkema, Rotterdam.

C.7 Coughtrey, P J, Jackson, D and Thorne, M C (1985). Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems, Volume 6, A A Balkema, Rotterdam.

C.8 IPCS (1977). International Programme on Chemical Safety Environmental Health Criteria No. 3 – Lead, UNEP and WHO, Geneva.

C.9 ATSDR (1992). Agency for Toxic Substances and Disease Registry, US Public Health Service, Toxicological Profile for Vanadium and Compounds.

Table C.1 Remediation of deficiencies in the available data

Biological half-lives in meat and liver		
Element	**Basis**	**Comment**
Sodium	Caesium taken as analogue	Sodium is retained mainly in soft tissues and a single half-life applies to the majority of the material. The half-life is somewhat shorter than that for caesium [C.4].
Chlorine	Caesium taken as analogue	Chloride is uniformly distributed throughout the body and retained with a single half-life that is somewhat shorter than that for caesium [C.4].
Calcium	Strontium taken as analogue	Environmental discrimination between strontium and calcium is very limited.
Vanadium	Niobium taken as analogue	Based on a comparison of biokinetic models from ICRP Publication 30 [C.5].
Gallium	Niobium taken as analogue	Based on a comparison of biokinetic models from ICRP Publication 30 [C.5].
Indium	Cerium taken as analogue	From ICRP Publication 30 [C.5], indium is only poorly taken up from the gastrointestinal tract but is tenaciously retained in the body and is accumulated in the liver. These properties are analogous to those of cerium.
Samarium	Cerium taken as analogue	Lanthanide elements with similar biokinetic characteristics [C.6].
Erbium	Cerium taken as analogue	Lanthanide elements with similar biokinetic characteristics [C.6].
Lutetium	Cerium taken as analogue	Lanthanide elements with similar biokinetic characteristics [C.6].
Gold	Technetium taken as analogue	Both gold and technetium are rapidly excreted from the body [C.5].
Thallium	Caesium taken as analogue	Similar biochemical properties to potassium, which is itself closely analogous to caesium.
Animal product transfer factors		
Element	**Basis**	**Comment**
Vanadium	Niobium taken as analogue	Based on a comparison of biokinetic models from ICRP Publication 30 [C.5].
Samarium	Cerium taken as analogue	Lanthanide elements with similar biokinetic characteristics [C.6].
Erbium	Cerium taken as analogue	Lanthanide elements with similar biokinetic characteristics [C.6].
Lutetium	Cerium taken as analogue	Lanthanide elements with similar biokinetic characteristics [C.6].
Translocation in plants		
Element	**Basis**	**Comment**
Sodium	Assigned mobile (m)	Sodium is a major nutritional element in plants and is highly mobile. Coughtrey *et al.* [C.4] commented 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	Assigned semi-mobile (s)	Analogous to strontium. The environmental behaviour of these two elements is very similar.
Vanadium	Assigned semi-mobile (s)	Based on niobium, as for plant:soil concentration ratio.
Gallium	Assigned semi-mobile (s)	Based on niobium. Both are elements that are not considered to be essential for plants, but for which general metal transport processes could operate.
Indium	Assigned semi-mobile (s)	Based on niobium. Both are elements that are not considered to be essential for plants, but for which general metal transport processes could operate.
Lutetium	Cerium taken as analogue	Similar properties to lanthanide elements [C.6]

Table C.1 continued

Element	Basis	Comment
Plant:soil concentration ratios for pasture		
Element	**Basis**	**Comment**
Calcium	Strontium taken as analogue	Environmental discrimination between strontium and calcium is very limited.
Vanadium	Niobium taken as analogue	Both elements are moderately to highly particle reactive and are not accumulated by most plants.
Samarium	Cerium taken as analogue	Plant uptake of lanthanide elements is very similar [C.6].
Erbium	Cerium taken as analogue	Plant uptake of lanthanide elements is very similar [C.6].
Lutetium	Cerium taken as analogue	Plant uptake of lanthanide elements is very similar [C.6].
Plant:soil concentration ratios for green vegetables and root vegetables		
Element	**Basis**	**Comment**
Vanadium	Niobium taken as analogue	Both elements are moderately to highly particle reactive and are not accumulated by most plants.
Samarium	Cerium taken as analogue	Plant uptake of lanthanide elements is very similar [C.6].
Erbium	Cerium taken as analogue	Plant uptake of lanthanide elements is very similar [C.6].
Lutetium	Cerium taken as analogue	Plant uptake of lanthanide elements is very similar [C.6].
Thallium	Indium used as analogue	Although relatively mobile, ^{201}Tl has only a short half-life, so uptake by plants will be limited. This was achieved by selecting indium as an analogue.
Plant:soil concentration ratios for fruit		
Element	**Basis**	**Comment**
Vanadium	Niobium taken as analogue	Both elements are moderately to highly particle reactive and are not accumulated by most plants.
Gallium	Indium used as analogue	Its short half-life and chemical analogy with indium make ^{67}Ga of only limited availability to plants.
Samarium	Cerium taken as analogue	Plant uptake of lanthanide elements is very similar [C.6].
Erbium	Cerium taken as analogue	Plant uptake of lanthanide elements is very similar [C.6].
Lutetium	Cerium taken as analogue	Plant uptake of lanthanide elements is very similar [C.6].
Partitioning coefficient between effluent and sewage sludge		
Element	**Basis**	**Comment**
Yttrium	Same value used for ^{90}Y as ^{90}Sr	Based on secular equilibrium.
Indium	Gallium taken as analogue	Both elements are thought to be similarly particle reactive.
Barium	Strontium taken as analogue	Both are alkaline earths with similar chemical characteristics.
Lanthanum	Same value used for ^{140}La as for ^{140}Ba	Based on secular equilibrium.
Promethium	Cerium and samarium taken as analogues	Particle interactions of lanthanides are very similar [C.6].
Erbium	Cerium and samarium taken as analogues	Particle interactions of lanthanides are very similar [C.6].
Lutetium	Cerium taken as analogue	Particle interactions of lanthanides are very similar [C.6].
Thallium	Cerium and samarium taken as analogues	The short half-life of ^{201}Tl makes the analogue selected of little significance.

Table C.1 continued

K_d ***values for saltwater sediments***		
Element	**Basis**	**Comment**
Chlorine	Taken as zero	Chloride is conservative in waters.
Gallium	Based on data for silicon in soils	Based on chemical similarities. Of limited importance because of the short half-life of ^{67}Ga.
Bromine	Taken as zero	Bromide is analogous to chloride and is widely used as a non-sorbing tracer for groundwater flow.
Molybdenum	Freshwater value used	No good reason to make a distinction, but only limited data are readily available.
Lanthanum	Cerium taken as analogue	Particle interactions of lanthanides are very similar [C.6].
Erbium	Cerium taken as analogue	Particle interactions of lanthanides are very similar [C.6].
Lutetium	Cerium taken as analogue	Particle interactions of lanthanides are very similar [C.6].
Gold	Cerium taken 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. The short half-life of ^{198}Au makes this factor of limited significance.
K_d ***values for freshwater sediments***		
Element	**Basis**	**Comment**
Chlorine	Taken as zero	Chloride is conservative in waters.
Calcium	Strontium taken as analogue	Environmental discrimination between strontium and calcium is very limited.
Vanadium	Niobium taken as analogue	Both elements are moderately to highly particle reactive.
Nickel	Cobalt taken as analogue	Similar transition metals.
Selenium	Saltwater value used	No good reason to make a distinction (see discussion in Coughtrey *et al.* [C.4].
Bromine	Taken as zero	Bromide is conservative in waters.
Rubidium	Taken as 10,000 $m^3\ te^{-1}$	Value from Coughtrey *et al.* [C.7], based on data for the stable element.
Indium	Saltwater value used	No good reason to make a distinction, but only limited data are readily available.
Barium	Saltwater value used	No large distinction between freshwater and saltwater values for the analogous element strontium [C.7].
Lanthanum	Cerium taken as analogue	Particle interactions of lanthanides are very similar [C.6].
Samarium	Cerium taken as analogue	Particle interactions of lanthanides are very similar [C.6].
Erbium	Cerium taken as analogue	Particle interactions of lanthanides are very similar [C.6].
Lutetium	Cerium taken as analogue	Particle interactions of lanthanides are very similar [C.6].
Gold	Cerium taken 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. The short half-life of ^{198}Au makes this factor of limited significance.
Thallium	Saltwater value used	No good reason to make a distinction, but only limited data are readily available. The short half-life of ^{201}Tl makes this of limited significance.
Lead	Value of 6,700 $m^3\ te^{-1}$ compared with 200,000 $m^3\ te^{-1}$ for coastal waters	Based on stable lead concentrations in sediments being similar in the two environments, but water concentrations being a factor of thirty higher in freshwater environments [C.8].
Polonium	Value of 6,700 $m^3\ te^{-1}$	Secular equilibrium with ^{210}Pb.

Table C.1 continued

Concentration ratios for saltwater fish, molluscs and crustaceans		
Element	**Basis**	**Comment**
Organically bound tritium	C-14 taken as analogue	Whereas, H-3 as tritiated water will exhibit a concentration ratio in fish of approximately unity, as relatively little of the hydrogen in water is converted to organic forms within fish by metabolic processes, a much higher concentration ratio could be applicable to some organic forms of H-3 present in the environment. 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 C-14 also for organic H-3. This is likely to be cautious, as metabolism of such compound is likely to result in some of the H-3 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 taken as analogue	Based on chemical analogy and environmental observations for vanadium [C.9].
Lanthanum	Cerium taken as analogue	Biochemical and biokinetic behaviour of all the lanthanides is very similar [C.6].
Erbium	Cerium taken as analogue	Biochemical and biokinetic behaviour of all the lanthanides is very similar [C.6].
Lutetium	Cerium taken as analogue	Biochemical and biokinetic behaviour of all the lanthanides is very similar [C.6].
Concentration ratios for freshwater fish		
Element	**Basis**	**Comment**
Organically bound tritium	C-14 taken as analogue	Whereas, H-3 as tritiated water will exhibit a concentration ratio in fish of approximately unity, as relatively little of the hydrogen in water is converted to organic forms within fish by metabolic processes, a much higher concentration ratio could be applicable to some organic forms of H-3 present in the environment. 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 C-14 also for organic H-3. This is likely to be cautious, as metabolism of such compound is likely to result in some of the H-3 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.
Lutetium	Cerium taken as analogue	Biochemical and biokinetic behaviour of all the lanthanides is very similar [C.6].
Vanadium	Niobium taken as analogue.	Based on chemical analogy and environmental observations for vanadium [C.9].

Appendix D Input data and calculation of DPUR values 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 indicated in Table 1.

Releases to atmosphere can be from single stacks, multiple stacks, vents on building roofs or sides or area sources (e.g. materials containing radionuclides stored at ground level). For the purpose of this study, a single release point is assumed. Plume rise and building effects are ignored but can be incorporated, to a degree, into the stack height. A ground-level release was 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, as are of relevance here. With increasing stack height and increasing distances from the stack, ground-level air concentrations generally decrease.

D.2 Exposed population groups

The following exposed population group is considered. This is taken to be representative of exposure groups from atmospheric releases across the UK:

Local resident family

Relevant pathways are:

- internal irradiation 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 irradiation 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 resulting matrix of pathways that needs to be evaluated.

Inhalation of resuspended deposited activity was 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 were assumed. 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, as described in NRPB R-91 [D.2] and implemented in PC CREAM's atmospheric module, PLUME [D.3,D.4]. In its simplest form the model can be expressed using the formula:

$$X(x,y,z) = \frac{Q}{2\pi\ \sigma_y \sigma_z\ u} \exp - \left[\frac{y^2}{2\sigma_y^2} + \frac{(z-h_e)^2}{2\sigma_z^2} \right]$$

where	*X(x,y,z)*	is activity concentration in air at the point (x,y,z) in Bq m^{-3}, referenced to a coordinate system with its origin at ground level below the release point
	x	is downwind distance (m)
	y	is cross wind distance from the plume centreline (m)
	z	is height above ground for which concentrations are calculated (m)
	σ_y, σ_z	is standard deviation of the Gaussian distribution describing the horizontal (y) and vertical (z) distribution of activity in the plume (m)
	Q	is release rate (Bq s^{-1})
	u	is mean wind speed (m s^{-1})
	h_e	is effective release height (m)

This model excludes reflections at the inversion layer and the ground.

For a continuous release the horizontal dispersion of the plume is determined by the fluctuations in the wind direction. As a result, for a continuous release into a uniform windrose the preceding equation can be re-written as:

$$X(x,z) = \frac{Q}{2\pi\ x\sqrt{2\pi}\ \sigma_z u_s} \exp - \left[\frac{(z-h_e)^2}{2\sigma_z^2} \right]$$

where	*X(x,z)*	is mean activity concentration in air at the point (x,z) in Bq m^{-3}
	u_s	is wind speed at the effective release height (m s^{-1})

In the application of the model the following underlying assumptions were made:

- Building effects such as re-entrainment in the building wake can be ignored, or, if this is not the case then the effect can be adequately modelled by considering a virtual point source located at ground level directly below the actual discharge point.
- Plume rise and similar factors can be ignored.

- The discharge rate is uniform and constant and takes place into a uniform windrose under atmospheric conditions that are a weighted mean of the actual conditions experienced at the site in question. Under these conditions, a constant air concentration is established at each point around the discharge point. The assumption of a uniform release rate and average weather conditions is clearly unlikely to represent the actual physical situation. However, it greatly simplifies calculations and should not lead to underestimation of doses in the case of releases taking place frequently (e.g. once a week or more) provided that it is assumed that there is continuous occupancy at the receptor points.

Dry deposition is calculated using the formula:

$$D_{dry} = v_g C$$

where D_{dry} is dry deposition rate (Bq m^{-2} s^{-1})
v_g is dry deposition velocity (m s^{-1})
C is air concentration at ground level (Bq m^{-3})

A suitable default value for v_g is 0.001 m s^{-1}. A value of 0.01 m s^{-1} has been used for inorganic forms of isotopes of iodine [D.4]. v_g is zero for noble gases, while the deposition of tritium and ^{14}C is calculated using the method described in Section D.5.3. The above formulae neglect source depletion, i.e. they ignore the reduction in the airborne concentration at any given distance due to previous deposition closer to the release point. This effect will be negligible over the short distances considered here.

Wet deposition for a continuous release into a uniform windrose 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^{-1})
Λ is washout coefficient (s^{-1})
Q is release rate (Bq s^{-1})
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^{-1})

A suitable value for Λ in the UK is 0.0001 s^{-1}, except for noble gases where Λ is 0. Assuming that it rains for 10% of the time, the combined deposition rate is given by:

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

The meteorological conditions were characterised by a uniform windrose and a defined distribution of atmospheric stability conditions. The atmospheric stability conditions assumed are based on average UK meteorological conditions. Stability categories were chosen emphasising those in which dispersion is more limited at the distances of interest, leading to cautious estimates of air concentrations and deposition rates. The stability category distribution is shown in Table D.2. A roughness length at the receptor locations of 0.3 m, corresponding to a rural environment, was applied.

PLUME was used to derive air concentration and deposition rates for a unit discharge of 1 Bq y^{-1} at a distance of 500 m for all radionuclides, allowing for decay of short-lived radionuclides. Air concentrations and deposition rates at 100 m were taken from Titley *et al.* [D.5]. The air concentrations and deposition rates at 100 m were corrected to allow for decay of radionuclides with half-lives of less than 5 minutes, by assuming an average wind speed of 4.2 m s^{-1}.

To run PLUME for non-default radionuclides entailed manipulating some of the PLUME input databases, which are not designed to be changed by the user. A number of extra radionuclides were added, together with data on their decay and deposition rates.

The resulting activity concentrations in air (Bq m^{-3}) and deposition rates (Bq m^{-2} s^{-1}) 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.6,D.7], 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 daughters with half-lives of less than a few minutes were included with their parents for the following parent/daughter(s): ^{106}Ru/^{106}Rh, ^{137}Cs/^{137m}Ba, ^{223}Ra/^{219}Rn/^{215}Po and ^{234}Th/^{234m}Pa. The dose rates for air immersion per unit air concentration are listed in Table D.4.

PLUME contains an integrated finite cloud gamma dose model. The external dose rates calculated using Eckerman and Leggett dose coefficients were compared with the PLUME gamma dose model output for a unit release rate of 1 Bq s^{-1} from a 1-m high stack at a distance of 300 m. External dose rates from PLUME were significantly lower, by an average of 4 orders of magnitude, for 97% of the radionuclides. For radionuclides for which external dose is the main pathway, including the noble gases and short-lived gamma and beta emitters, the PLUME dose rates were all lower by an average of a factor of 6 (see Table D.5).

D.4.2 External exposure from deposited radionuclides

The PC CREAM 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 'wet generic 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.4]. GRANIS includes full decay chains when calculating transfer between soil compartments and the contributions of daughters 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.

To run GRANIS for non-default radionuclides entailed a degree of manipulation of input data in an Access database. Output is effective dose rate per unit deposition rate (Bq m^{-2} s^{-1}) and is listed in Table D.6.

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^{-1} per Bq y^{-1})

$DR_{ext\_cloud(u)}$ is external dose rate per unit air concentration (µSv h^{-1} per Bq m^{-3})

A_{air} is activity concentration in air at 100 m per unit release (Bq m^{-3} per Bq y^{-1})

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^{-1} per Bq y^{-1})

$DR_{ext\_depos(u)}$ is external dose rate per unit deposition rate (µSv h^{-1} per Bq m^{-2} s^{-1})

R_{depos} is deposition rate at 100 m per unit release (Bq m^{-2} s^{-1} per Bq y^{-1})

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

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. 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, 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].

D.5.2 FARMLAND modelling approach

Running FARMLAND for non-default radionuclides is not straightforward. FARMLAND was run initially for the radionuclides present in the default database. The following describes the approach taken to run the model for non-default radionuclides:

- Radionuclides with one isotope of the same element already present in the default database could be run relatively easily, by amending only radionuclide-specific data (i.e. the radioactive decay constant) while leaving element-specific data at the default values.
- For radionuclides for which there was no other isotope of the same element present in the default database, element-specific transfer factors were substituted. The radionuclide-specific parameters entered were: translocation, radioactive decay constant, biological half-life (meat and liver), transfer factors (soil–pasture, pasture–cow meat, pasture–cow liver, pasture–cow milk, pasture–sheep meat, pasture–sheep liver, soil–green vegetables, soil–root vegetables, soil–fruit).
- To ensure that the most appropriate animal module was run for radionuclides analogous to caesium and strontium, 'dummy' caesium and strontium runs were set up. This was the case for ^{22}Na, ^{24}Na, ^{36}Cl, ^{201}Tl (analogues to caesium) and ^{45}Ca, ^{47}Ca (analogues to strontium). Transfer factors and radionuclide half-life data specific to the radionuclides were substituted.

FARMLAND input data are listed in the following tables, together with relevant data sources: equilibrium fractions transferred to cow meat, cow liver, milk, sheep meat and sheep liver are listed in Table D.8 and Table D.9 and equilibrium concentration ratios between soil and pasture, root vegetables, green vegetables and fruit are listed in Table D.10 and Table D.11. Where data had to be converted between wet and dry weight plant material a 20% dry matter content was assumed.

Activity concentrations in terrestrial foodstuffs integrated over a 50-year time interval were calculated per unit deposition rate (Bq kg^{-1} per Bq m^{-2} s^{-1}). They are listed in Table D.12.

D.5.3 Equilibrium modelling for ^{3}H and ^{14}C

Tritium and ^{14}C are not included in FARMLAND. The transfer of tritium and ^{14}C 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 PC CREAM to calculate the activity concentrations of tritium and ^{14}C in foodstuffs [D.4]. It is assumed that all foodstuffs come into rapid equilibrium with atmospheric ^{14}C, 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 tritium: the specific activity of ^{3}H 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 tritium and ^{14}C are calculated using the formula:

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

F^* (Bq kg^{-1} per Bq m^{-3}) is a factor relating the airborne concentration of tritium or ^{14}C 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.13.

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^{-1} per Bq y^{-1})

$A_{food(u)}$ is activity concentration in foodstuffs per unit deposition rate (Bq kg^{-1} per Bq m^{-2} s^{-1})

R_{depos} is deposition rate at 500 m (Bq m^{-3} per Bq m^{-2} s^{-1})

Note that for ^{3}H and ^{14}C 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.14.

D.6 Method to calculate DPUR factors

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^{-1} per Bq y^{-1})

A_{air} is activity concentration in air at 100 m (Bq m^{-3} per Bq y^{-1})

$H_{occ,a}$ is total occupancy for the age group considered (h y^{-1})

B_a is inhalation rate for the age group considered (m^3 h^{-1})

$DF_{inh,a}$ is inhalation dose coefficient for the age group considered (μSv Bq^{-1})

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:

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

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^{-1} per Bq y^{-1})

DR_{ext} is external dose rate from either activity in air or deposited activity (μSv h^{-1} per Bq y^{-1})

$H_{occ,a}$ is total occupancy for the age group considered (h y^{-1})

$F_{ind,a}$ is fraction spent indoors for the age group considered

$T_{ind,a}$ is indoor shielding factor for either cloud shine or ground shine

$F_{out,a}$ is fraction spent outdoors for age group considered = 1– $F_{ind,a}$

$T_{out,a}$ is outdoor shielding factor for either cloud shine or 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^{-1} per Bq y^{-1})

A_{food} is activity concentration in the foodstuff considered (Bq kg^{-1} per Bq y^{-1})

$I_{food,a}$ is ingestion rate of the foodstuff for the age group considered (kg y^{-1})

$DF_{ing,a}$ is ingestion dose coefficient for age group (μSv Bq^{-1})

The resulting inhalation DPUR factors are listed in Tables 3–6 in the main report.

D.7 References

D.1 Jones, K A, Walsh C, Bexon A, Simmonds, J R, Jones A L, Harvey M, Artmann, A and Martens, R (2002). Guidance on the Assessment of Radiation Doses to Members of the Public due to the Operation of Nuclear Installations under Normal Conditions. Report produced for DG Environment of the European Commission. Contract B4-0304/99/136234/MAR/C1.

D.2 Clarke R H (1979). The First Report of a Working Group on Atmospheric Dispersion: A Model for Short and Medium Range Dispersion of Radionuclides Released to the Atmosphere. NRPB-R91.

D.3 Mayall, A, Cabianca, T, Attwood, C, Fayers, C A, Smith, J G, Penfold, J, Steadman, D, Martin, G, Morris, T P and Simmonds, J R (1997). PC-CREAM Installing and Using the PC System for Assessing the Radiological Impact of Routine Releases. EUR 17791 EN, NRPB-SR296.

D.4 Simmonds, J R, Lawson, G and Mayall, A (1995). Methodology for Assessing the Radiological Consequences of Routine Releases of Radionuclides to the Environment. European Commission, Luxembourg, EUR 15760 EN, Radiation Protection 72.

D.5 Titley, J G, Attwood, C A and Simmonds, J R (2000). Generalised Derived Constraints for Radioisotopes of Strontium, Ruthenium, Iodine, Caesium, Plutonium, Americium and Curium. Doc NRPB, 11(2), 1–41.

D.6 Eckerman, K F and Leggett, R W (2002). DCFPAK: Dose Coefficient File Package for Sandia National Laboratory. Dosimetry Research Group, Oak Ridge National Laboratory.

D.7 Eckerman, K F and Ryman, J C (1993). External Exposure to Radionuclides in Air, Water and Soil. Federal Guidance Report 12. EPA Report 402-R-93-081. Washington, DC.

D.8 Brown, J and Simmonds, J R (1995). FARMLAND: A Dynamic Model for the Transfer of Radionuclides Through Terrestrial Foodchains. NRPB R273.

D.9 Smith, K R and Jones, A L (2003). Generalised Habit Data for Radiological Assessments. NRPB-W41.

D.10 Staven L H, Rhoads, K, Napier, B A and Strenge, D L (2003). A Compendium of Transfer Factors for Agricultural and Animal Products. A report prepared for the US Department of Energy. PNNL-13421.

D.11 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 D.1 Habit data of local resident family exposure group

	Infant	Child	Adult	Comment
Food consumption rates (kg y^{-1})				[D.9]
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	
Milk	320	240	240	
Breathing rates (m^3 h^{-1})	0.22	0.64	0.92	[D.9]
Occupancy at habitation (h y^{-1})	8,760	8,760	8,760	100%
Fraction of time spent indoors	0.9	0.8	0.5	[D.9]
Cloud shielding factor	0.2	0.2	0.2	[D.4]
Shielding factor for deposited radionuclides	0.1	0.1	0.1	[D.4]

Table D.2 Atmospheric conditions

Pasquill stability category	Frequency of occurrence (%)	Wind speed at 10 m height (m s^{-1})
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 concentrations in air (Bq m^{-3} per Bq y^{-1})*		Deposition rate (Bq m^{-2} s^{-1} per Bq y^{-1})*	
	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	-	-
O-15	2.4E-12	5.4E-14	-	-
F-18	2.8E-12	1.3E-13	2.8E-15	1.5E-16
Na-22	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Na-24	2.8E-12	1.4E-13	2.8E-15	1.5E-16
P-32	2.8E-12	1.4E-13	2.8E-15	1.5E-16
P-33	2.8E-12	1.4E-13	2.8E-15	1.5E-16
S-35	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Cl-36	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Ar-41	2.8E-12	1.4E-13	-	-
Ca-45	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Ca-47	2.8E-12	1.4E-13	2.8E-15	1.5E-16
V-48	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Cr-51	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Mn-52	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Mn-54	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Mn-56	2.8E-12	1.3E-13	2.8E-15	1.5E-16
Fe-55	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Fe-59	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Co-56	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Co-57	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Co-58	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Co-60	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Ni-63	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Zn-65	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Ga-67	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Se-75	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Br-82	2.8E-12	1.1E-13	2.8E-15	1.1E-15
Kr-79	2.8E-12	1.4E-13	-	-
Kr-81m	7.9E-13	2.7E-16	-	-
Kr-85	2.8E-12	1.4E-13	-	-
Kr-85m	2.8E-12	1.4E-13	-	-
Rb-82	2.2E-12	3.5E-14	2.3E-14	3.8E-17
Rb-83	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Sr-89	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Sr-90	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Y-90	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Zr-95	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Nb-95	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Mo-99	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Tc-99	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Tc-99m	2.8E-12	1.4E-13	2.8E-15	1.5E-16

Table D.3 continued

Radionuclide	Activity concentrations in air (Bq m^{-3} per Bq y^{-1})*		Deposition rate (Bq m^{-2} s^{-1} per Bq y^{-1})*	
	100 m	500 m	100 m	500 m
Ru-103	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Ru-106	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Ag-110m	2.8E-12	1.4E-13	2.8E-15	1.5E-16
In-111	2.8E-12	1.4E-13	2.8E-15	1.5E-16
In-113m	2.8E-12	1.3E-13	2.8E-15	1.5E-16
Sb-125	2.8E-12	1.4E-13	2.8E-15	1.5E-16
I-123	2.8E-12	1.0E-13	2.6E-14	1.1E-15
I-125	2.8E-12	1.1E-13	2.6E-14	1.1E-15
I-129	2.8E-12	1.1E-13	2.6E-14	1.1E-15
I-131	2.8E-12	1.1E-13	2.6E-14	1.1E-15
I-132	2.8E-12	1.0E-13	2.6E-14	1.0E-15
I-133	2.8E-12	1.1E-13	2.6E-14	1.1E-15
I-134	2.8E-12	1.0E-13	2.6E-14	1.0E-15
I-135	2.8E-12	1.0E-13	2.6E-14	1.1E-15
Xe-133	2.8E-12	1.4E-13	-	-
Cs-134	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Cs-136	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Cs-137	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Ba-140	2.8E-12	1.4E-13	2.8E-15	1.5E-16
La-140	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Ce-141	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Ce-144	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Pm-147	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Sm-153	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Eu-152	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Eu-154	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Eu-155	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Er-169	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Lu-177	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Au-198	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Tl-201	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Pb-210	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Po-210	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Rn-222	2.8E-12	1.4E-13	-	-
Ra-223	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Ra-226	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Th-230	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Th-232	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Th-234	2.8E-12	1.4E-13	2.8E-15	1.5E-16
U-234	2.8E-12	1.4E-13	2.8E-15	1.5E-16
U-235	2.8E-12	1.4E-13	2.8E-15	1.5E-16
U-238	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Np-237	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Pu-238	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Pu-239	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Pu-240	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Pu-241	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Pu-242	2.8E-12	1.4E-13	2.8E-15	1.5E-16

Table D.3 continued

Radionuclide	Activity concentrations in air (Bq m^{-3} per Bq y^{-1})*		Deposition rate (Bq m^{-2} s^{-1} per Bq y^{-1})*	
	100 m	500 m	100 m	500 m
Am-241	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Am-242	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Am-243	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Cm-242	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Cm-243	2.8E-12	1.4E-13	2.8E-15	1.5E-16
Cm-244	2.8E-12	1.4E-13	2.8E-15	1.5E-16

*for a release at ground level

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

Radionuclide	External dose rate (µSv h^{-1} per Bq m^{-3})		
	Parent	Parent and all daughters	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	
Zn-65	9.8E-05	9.8E-05	
Ga-67	2.3E-05	2.3E-05	
Se-75	6.0E-05	6.0E-05	
Br-82	4.4E-04	4.4E-04	

Table D.4 continued

Radionuclide	External dose rate (µSv h^{-1} per Bq m^{-3})		
	Parent	Parent and all daughters	Comments
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-82	1.8E-04	1.8E-04	
Rb-83	8.0E-05	8.0E-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-95	1.2E-04	1.2E-04	
Nb-95	1.3E-04	1.3E-04	
Mo-99	2.5E-05	2.5E-05	
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-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	
Au-198	6.5E-05	6.5E-05	
Tl-201	1.2E-05	1.2E-05	
Pb-210	1.6E-07	1.6E-07	
Po-210	1.4E-09	1.4E-09	
Rn-222	6.4E-08	6.5E-08	Po-218 included

Table D.4 continued

Radionuclide	External dose rate (µSv h^{-1} per Bq m^{-3})		
	Parent	Parent and all daughters	Comments
Ra-223	2.0E-05	2.9E-05	Rn-219 and Po-215 included
Ra-226	1.0E-06	1.0E-06	
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 Comparison of external dose from air immersion based on semi-infinite versus finite cloud source model

Radionuclide	External dose rate from air immersion (Sv h^{-1})		Ratio of semi-infinite to finite source model dose rates
	Semi-infinite source model	Finite source model	
C-11	1.6E-15	3.1E-16	5.3
N-13	1.6E-15	3.0E-16	5.3
O-15	9.9E-16	1.9E-16	5.1
F-18	1.6E-15	3.2E-16	5.1
Ar-41	2.4E-15	3.7E-16	6.7
Mn-56	2.9E-15	4.7E-16	6.3
Kr-79	4.4E-16	8.1E-17	5.5
Kr-81m	3.6E-18	9.6E-19	3.7*
Kr-85	9.5E-18	7.1E-19	13*
Kr-85m	2.7E-16	5.7E-17	4.8*
Rb-82	7.8E-16	1.5E-16	5.2*
I-123	2.0E-16	4.8E-17	4.2
I-131	5.3E-16	1.1E-16	5.0
I-132	3.3E-15	5.8E-16	5.6
I-133	8.6E-16	1.6E-16	5.4
I-134	3.7E-15	6.5E-16	5.7
I-135	2.3E-15	3.8E-16	6.2
Xe-133	5.3E-17	1.6E-17	3.3*

*note that for these radionuclides beta radiation contributes in part to the dose rate calculated using the semi-infinite source model

Table D.6 External dose rates from deposited radionuclides per unit deposition rate

Radionuclide	External dose rate (for a 50 y integration time) (μSv h^{-1} per Bq m^{-2} s^{-1})
H-3	0.0E+00
H-3 organic	0.0E+00
C-11	4.3E-03
C-14	0.0E+00
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	1.3E+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	5.7E-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
Zn-65	3.6E+01
Ga-67	1.4E-01
Se-75	1.2E+01
Br-82	1.1E+00
Rb-82	2.9E-04
Rb-83	1.2E+01
Sr-89	1.2E-03
Sr-90	9.0E-06
Y-90	4.6E-08
Zr-95	2.7E+01
Nb-95	7.7E+00
Mo-99	1.2E-01
Tc-99	0.0E+00
Tc-99m	8.6E-03
Ru-103	5.4E+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	2.4E-02
I-125	1.7E-01
I-129	2.9E+00

Table D.6 continued

Radionuclide	External dose rate (for a 50 y integration time) (µSv h^{-1} per Bq m^{-2} s^{-1})
I-131	8.9E-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	8.8E+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
Au-198	3.2E-01
Tl-201	6.5E-02
Pb-210	4.6E-01
Po-210	3.2E-04
Ra-223	9.2E-01
Ra-226	1.9E+03
Th-230	1.4E+01
Th-232	5.0E+03
Th-234	1.2E-01
U-234	8.6E-02
U-235	1.5E+02
U-238	2.3E+01
Np-237	2.1E+02
Pu-238	3.2E-02
Pu-239	5.1E-02
Pu-240	4.1E-02
Pu-241	1.2E-01
Pu-242	6.4E-01
Am-241	9.8E+00
Am-242	2.3E-03
Am-243	1.8E+02
Cm-242	4.9E-03
Cm-243	8.2E+01
Cm-244	1.4E-01

Table D.7 External dose rates per unit release rate

Radionuclide	External dose rates (μSv h^{-1} per Bq y^{-1})*	
	Air immersion	Deposited radionuclides
H-3	0.0E+00	0.0E+00
H-3 organic	0.0E+00	0.0E+00
C-11	4.5E-16	0.0E+00
C-14	2.6E-20	0.0E+00
N-13	4.5E-16	0.0E+00
O-15	4.0E-16	0.0E+00
F-18	4.6E-16	6.6E-17
Na-22	1.0E-15	1.2E-12
Na-24	2.1E-15	1.9E-15
P-32	5.4E-18	0.0E+00
P-33	1.5E-19	0.0E+00
S-35	3.1E-20	0.0E+00
Cl-36	1.7E-18	4.8E-16
Ar-41	6.2E-16	0.0E+00
Ca-45	1.5E-19	5.2E-23
Ca-47	5.1E-16	3.8E-15
V-48	1.4E-15	3.8E-14
Cr-51	1.4E-17	7.2E-16
Mn-52	1.6E-15	1.6E-14
Mn-54	3.8E-16	1.9E-13
Mn-56	8.2E-16	1.4E-16
Fe-55	0.0E+00	1.6E-18
Fe-59	5.6E-16	4.2E-14
Co-56	1.7E-15	2.1E-13
Co-57	5.0E-17	2.2E-14
Co-58	4.5E-16	5.5E-14
Co-60	1.2E-15	2.4E-12
Ni-63	0.0E+00	0.0E+00
Zn-65	2.7E-16	1.0E-13
Ga-67	6.5E-17	4.0E-16
Se-75	1.7E-16	3.6E-14
Br-82	1.2E-15	3.2E-15
Kr-79	1.1E-16	0.0E+00
Kr-81m	1.6E-17	0.0E+00
Kr-85	2.4E-18	0.0E+00
Kr-85m	6.9E-17	0.0E+00
Rb-82	4.1E-16	6.7E-18
Rb-83	2.2E-16	3.5E-14
Sr-89	4.4E-18	3.3E-18
Sr-90	9.9E-19	2.6E-20
Y-90	7.9E-18	1.3E-22
Zr-95	3.4E-16	7.6E-14
Nb-95	3.5E-16	2.2E-14
Mo-99	7.0E-17	3.4E-16
Tc-99	2.9E-19	0.0E+00
Tc-99m	5.3E-17	2.4E-17
Ru-103	2.1E-16	1.5E-14
Ru-106	1.1E-16	5.4E-14
Ag-110m	1.3E-15	5.0E-13
In-111	1.7E-16	8.9E-16

Table D.7 continued

Radionuclide	External dose rates ($\mu Sv\ h^{-1}$ per $Bq\ y^{-1}$)*	
	Air immersion	Deposited radionuclides
In-113m	1.1E-16	1.5E-17
Sb-125	1.9E-16	2.6E-13
I-123	6.5E-17	6.1E-16
I-125	3.7E-18	4.3E-15
I-129	2.8E-18	7.5E-14
I-131	1.7E-16	2.3E-14
I-132	1.1E-15	1.6E-15
I-133	2.8E-16	4.1E-15
I-134	1.2E-15	7.0E-16
I-135	7.6E-16	3.6E-15
Xe-133	1.3E-17	0.0E+00
Cs-134	7.1E-16	7.4E-13
Cs-136	1.0E-15	2.3E-14
Cs-137	2.6E-16	1.4E-12
Ba-140	8.1E-17	2.5E-14
La-140	1.1E-15	3.1E-15
Ce-141	3.1E-17	1.8E-15
Ce-144	7.6E-18	9.7E-15
Pm-147	8.7E-20	1.9E-18
Sm-153	2.0E-17	7.2E-17
Eu-152	5.3E-16	1.9E-12
Eu-154	5.8E-16	1.6E-12
Eu-155	2.1E-17	3.9E-14
Er-169	3.0E-19	1.7E-22
Lu-177	1.5E-17	1.8E-16
Au-198	1.8E-16	9.1E-16
Tl-201	3.3E-17	1.8E-16
Pb-210	4.5E-19	1.3E-15
Po-210	3.9E-21	9.1E-19
Rn-222	1.8E-19	0.0E+00
Ra-223	8.0E-17	2.6E-15
Ra-226	2.8E-18	5.5E-12
Th-230	1.5E-19	4.1E-14
Th-232	7.3E-20	1.4E-11
Th-234	1.5E-17	3.5E-16
U-234	6.1E-20	2.5E-16
U-235	6.5E-17	4.2E-13
U-238	2.5E-20	6.7E-14
Np-237	8.9E-18	6.0E-13
Pu-238	3.5E-20	9.1E-17
Pu-239	3.5E-20	1.4E-16
Pu-240	3.4E-20	1.2E-16
Pu-241	6.3E-22	3.3E-16
Pu-242	2.9E-20	1.8E-15
Am-241	6.8E-18	2.8E-14
Am-242	6.1E-18	6.6E-18
Am-243	1.9E-17	5.0E-13
Cm-242	4.0E-20	1.4E-17
Cm-243	5.3E-17	2.3E-13
Cm-244	3.4E-20	3.8E-16

*for a release at ground level

Table D.8 Environmental transfer factors for animal products – cow meat, liver and milk

Radionuclide	Transfer factors (TF) pasture to animal product (Bq kg^{-1} wet muscle or liver or Bq l^{-1} milk per Bq d^{-1} intake)					
	TF pasture to cow meat	Comment#	TF pasture to cow liver	Comment#	TF pasture to cow milk	Comment#
Na-22	0.08	[D.10]	0.08	[D.10]	0.016	[D.10]
Na-24	0.08	[D.10]	0.08	[D.10]	0.016	[D.10]
P-32	0.003		0.003		0.002	
P-33	0.003		0.003		0.002	
S-35	0.3		0.3		0.02	
Cl-36	0.02	[D.10]	0.02	[D.10]	0.017	[D.10]
Ca-45	0.002	[D.10]	0.002	[D.10]	0.003	[D.10]
Ca-47	0.002	[D.10]	0.002	[D.10]	0.003	[D.10]
V-48	0.00001	as Nb+	0.00001	as Nb+	0.00001	as Nb+
Cr-51	0.005		0.005		0.002	
Mn-52	0.005		0.2		0.003	
Mn-54	0.005		0.2		0.003	
Fe-55	0.001		4		0.0003	
Fe-59	0.001		4		0.0003	
Co-56	0.001		0.1		0.002	
Co-57	0.001		0.1		0.002	
Co-58	0.001		0.1		0.002	
Co-60	0.001		0.1		0.002	
Ni-63	0.001		0.01		0.00001	
Zn-65	0.002		0.002		0.01	
Ga-67	0.0005	[D.10]	0.0005	[D.10]	0.00005	[D.10]
Se-75	0.04		1		0.004	
Br-82	0.025		0.25		0.02	
Rb-83	0.01		0.01		0.01	
Sr-89	0.0003		0.0003		0.002	
Sr-90	0.0003		0.0003		0.002	
Y-90	0.001		0.01		0.00002	
Zr-95	0.00001		0.00001		0.00001	
Nb-95	0.00001		0.00001		0.00001	
Mo-99	0.005		0.1		0.003	
Tc-99	0.01		0.04		0.01	
Tc-99m	0.01		0.04		0.01	
Ru-103	0.001		0.001		0.000001	
Ru-106	0.001		0.001		0.000001	
Ag-110m	0.001		0.4		0.03	
In-111	0.008	[D.10]	0.008	[D.10]	0.0002	[D.10]
Sb-125	0.001		0.1		0.0001	
I-123	0.002		0.002		0.005	
I-125	0.002		0.002		0.005	
I-129	0.002		0.002		0.005	
I-131	0.002		0.002		0.005	
I-133	0.002		0.002		0.005	
I-135	0.002		0.002		0.005	
Cs-134	0.03		0.03		0.005	
Cs-136	0.03		0.03		0.005	
Cs-137	0.03		0.03		0.005	

Table D.8 continued

Radionuclide	Transfer factors (TF) pasture to animal product (Bq kg^{-1} wet muscle or liver or Bq l^{-1} milk per Bq d^{-1} intake)					
	TF pasture to cow meat	Comment#	TF pasture to cow liver	Comment#	TF pasture to cow milk	Comment#
Ba-140	0.0005		0.0005		0.0005	
La-140	0.005		0.2		0.00002	
Ce-141	0.001		0.2		0.00002	
Ce-144	0.001		0.2		0.00002	
Pm-147	0.005		0.04		0.00002	
Sm-153	0.001	as Ce+	0.2	as Ce+	0.00002	as Ce+
Eu-152	0.005		0.04		0.00002	
Eu-154	0.005		0.04		0.00002	
Eu-155	0.005		0.04		0.00002	
Er-169	0.001	as Ce+	0.2	as Ce+	0.00002	as Ce+
Lu-177	0.001	as Ce+	0.2	as Ce+	0.00002	as Ce+
Au-198	0.005	[D.10]	0.005	[D.10]	5.50E-06	[D.10]
Tl-201	0.04	[D.10]	0.04	[D.10]	0.002	[D.10]
Pb-210	0.001		0.002		0.0003	
Po-210	0.003		0.08		0.0001	
Ra-223	0.0005		0.0005		0.0004	
Ra-226	0.0005		0.0005		0.0004	
Th-230	0.0001		0.001		0.000005	
Th-232	0.0001		0.001		0.000005	
Th-234	0.0001		0.001		0.000005	
U-234	0.0002		0.0002		0.0006	
U-235	0.0002		0.0002		0.0006	
U-238	0.0002		0.0002		0.0006	
Np-237	0.0001		0.02		0.000001	
Pu-238	0.0001		0.02		0.000001	
Pu-239	0.0001		0.02		0.000001	
Pu-240	0.0001		0.02		0.000001	
Pu-241	0.0001		0.02		0.000001	
Pu-242	0.0001		0.02		0.000001	
Am-241	0.0001		0.02		0.000001	
Am-242	0.0001		0.02		0.000001	
Am-243	0.0001		0.02		0.000001	
Cm-242	0.0001		0.02		0.000001	
Cm-243	0.0001		0.02		0.000001	
Cm-244	0.0001		0.02		0.000001	

where no comment made, value taken from FARMLAND database in PC-CREAM [D.3]
+ see Table C.1 for details

Table D.9 Environmental transfer factors for animal products – sheep meat and liver and biological half-lives

Radio-nuclide	Transfer factors (TF) pasture to animal product (Bq kg^{-1} wet muscle or liver per Bq d^{-1} 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#
Na-22	0.8		0.8		n/a	n/a	Cs analogue+$
Na-24	0.8		0.8		n/a	n/a	Cs analogue+$
P-32	0.05		0.02		0.003	0.003	
P-33	0.05		0.02		0.003	0.003	
S-35	5		2		0.3	0.3	
Cl-36	0.2		0.2		n/a	n/a	Cs analogue+$
Ca-45	0.02		0.02		n/a	n/a	Sr analogue+$
Ca-47	0.02		0.02		n/a	n/a	Sr analogue+$
V-48	0.0001	as Nb+	0.0001	as Nb+	0.3	0.3	as Nb+
Cr-51	0.05		0.05		0.09	0.09	
Mn-52	0.05		2		0.06	0.07	
Mn-54	0.05		2		0.06	0.07	
Fe-55	0.01		0.3		5	5	
Fe-59	0.01		0.3		5	5	
Co-56	0.01		1		0.5	0.5	
Co-57	0.01		1		0.5	0.5	
Co-58	0.01		1		0.5	0.5	
Co-60	0.01		1		0.5	0.5	
Ni-63	0.01		0.1		1,200	1,200	
Zn-65	0.02		0.02		0.8	0.8	
Ga-67	0.005		0.005		0.3	0.3	as Nb+
Se-75	0.5		10		0.07	0.07	
Br-82	0.25		2.5		10	10	
Rb-83	0.1		0.1		0.1	0.1	
Sr-89	0.003		0.003		n/a	n/a	Sr module$
Sr-90	0.003		0.003		n/a	n/a	Sr module$
Y-90	0.01		0.1		40	40	
Zr-95	0.0001		0.0001		0.02	0.02	
Nb-95	0.0001		0.0001		0.3	0.3	
Mo-99	0.05		1		0.1	0.1	
Tc-99	0.1		0.3		0.008	0.008	
Tc-99m	0.1		0.3		0.008	0.008	
Ru-103	0.01		0.01		0.7	0.7	
Ru-106	0.01		0.01		0.7	0.7	
Ag-110m	0.01		3		0.1	0.1	
In-111	0.08		0.08		10	10	as Ce+
Sb-125	0.01		1		0.05	0.05	
I-123	0.05		0.05		n/a	n/a	I module$
I-125	0.05		0.05		n/a	n/a	I module$
I-129	0.05		0.05		n/a	n/a	I module$
I-131	0.05		0.05		n/a	n/a	I module$
I-133	0.05		0.05		n/a	n/a	I module$
I-135	0.05		0.05		n/a	n/a	I module$
Cs-134	0.5		0.5		n/a	n/a	Cs module$
Cs-136	0.5		0.5		n/a	n/a	Cs module$

Table D.9 continued

Radio-nuclide	Transfer factors (TF) pasture to animal product (Bq kg^{-1} wet muscle or liver per Bq d^{-1} 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#
Cs-137	0.5		0.5		n/a	n/a	Cs module$
Ba-140	0.005		0.005		0.09	0.09	
La-140	0.05		2		10	10	
Ce-141	0.01		2		10	10	
Ce-144	0.01		2		10	10	
Pm-147	0.05		0.3		10	10	
Sm-153	0.01	as Ce+	2	as Ce+	10	10	as Ce+
Eu-152	0.05		0.3		10	10	
Eu-154	0.05		0.3		10	10	
Eu-155	0.05		0.3		10	10	
Er-169	0.01	as Ce+	2	as Ce+	10	10	as Ce+
Lu-177	0.01	as Ce+	2	as Ce+	10	10	as Ce+
Au-198	0.05		0.05		0.008	0.008	as Tc+
Tl-201	0.4		0.4		n/a	n/a	Cs analogue+$
Pb-210	0.01		0.02		0.7	0.7	
Po-210	0.05		0.6		0.1	0.1	
Ra-223	0.005		0.005		0.07	0.07	
Ra-226	0.005		0.005		0.07	0.07	
Th-230	0.001		0.01		2	2	
Th-232	0.001		0.01		2	2	
Th-234	0.001		0.01		2	2	
U-234	0.002		0.002		0.03	0.03	
U-235	0.002		0.002		0.03	0.03	
U-238	0.002		0.002		0.03	0.03	
Np-237	0.0004		0.03		n/a	n/a	transuranics module$
Pu-238	0.0004		0.03		n/a	n/a	transuranics module$
Pu-239	0.0004		0.03		n/a	n/a	transuranics module$
Pu-240	0.0004		0.03		n/a	n/a	transuranics module$
Pu-241	0.0004		0.03		n/a	n/a	transuranics module$
Pu-242	0.0004		0.03		n/a	n/a	transuranics module$

Table D.9 continued

Radio-nuclide	Transfer factors (TF) pasture to animal product (Bq kg^{-1} wet muscle or liver per Bq d^{-1} 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#
Am-241	0.0004		0.03		n/a	n/a	transuranics module$
Am-242	0.0004		0.03		n/a	n/a	transuranics module$
Am-243	0.0004		0.03		n/a	n/a	transuranics module$
Cm-242	0.0004		0.03		n/a	n/a	transuranics module$
Cm-243	0.0004		0.03		n/a	n/a	transuranics module$
Cm-244	0.0004		0.03		n/a	n/a	transuranics module$

where no comment made, value taken from FARMLAND database in PC-CREAM [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.10 Environmental transfer factors for plant products – translocation and concentration ratios for pasture

Radionuclide	Translocation$	Comment#	Plant:soil concentration ratio (Bq kg^{-1} plant wet weight per Bq kg^{-1} soil dry weight)	
			CR pasture:soil	Comment#
Na-22	m	+	0.12	[D.11]
Na-24	m	+	0.12	[D.11]
P-32	m		1	
P-33	m		1	
S-35	m		0.6	
Cl-36	m		5	
Ca-45	s	as Sr+	0.05	as Sr+
Ca-47	s	as Sr+	0.05	as Sr+
V-48	s	as Nb+	0.01	as Nb+
Cr-51	i		0.0003	
Mn-52	s		0.1	
Mn-54	s		0.1	
Fe-55	s		0.0004	
Fe-59	s		0.0004	
Co-56	s		0.01	
Co-57	s		0.01	
Co-58	s		0.01	
Co-60	s		0.01	
Ni-63	s		0.01	
Zn-65	s		1	
Ga-67	s	as Nb+	0.02	[D.11]
Se-75	m		1	
Br-82	m		0.02	
Rb-83	m		0.1	
Sr-89	s		0.05	
Sr-90	s		0.05	
Y-90	s		0.01	
Zr-95	s		0.0001	
Nb-95	s		0.01	
Mo-99	s		0.1	
Tc-99	m		5	
Tc-99m	m		5	
Ru-103	i		0.01	
Ru-106	i		0.01	
Ag-110m	s		0.2	
In-111	s	as Nb+	0.02	[D.11]
Sb-125	s		0.01	
I-123	m		0.02	
I-125	m		0.02	
I-129	m		0.02	
I-131	m		0.02	
I-133	m		0.02	
I-135	m		0.02	
Cs-134	m		0.03	
Cs-136	m		0.03	
Cs-137	m		0.03	
Ba-140	s		0.01	

Table D.10 continued

Radionuclide	Translocation$	Comment#	Plant:soil concentration ratio (Bq kg^{-1} plant wet weight per Bq kg^{-1} soil dry weight)	
			CR pasture:soil	Comment#
La-140	s		0.003	
Ce-141	i		0.001	
Ce-144	i		0.001	
Pm-147	i		0.003	
Sm-153	i	as Ce+	0.001	as Ce+
Eu-152	i		0.003	
Eu-154	i		0.003	
Eu-155	i		0.003	
Er-169	i	as Ce+	0.001	as Ce+
Lu-177	i	as Ce+	0.001	as Ce+
Au-198	i	as Ce+	0.08	[D.11]
Tl-201	m	as Ce+	0.4	[D.11]
Pb-210	s		0.01	
Po-210	m		0.0002	
Ra-223	s		0.01	
Ra-226	s		0.01	
Th-230	i		0.0005	
Th-232	i		0.0005	
Th-234	i		0.0005	
U-234	i		0.001	
U-235	i		0.001	
U-238	i		0.001	
Np-237	i		0.01	
Pu-238	i		0.0001	
Pu-239	i		0.0001	
Pu-240	i		0.0001	
Pu-241	i		0.0001	
Pu-242	i		0.0001	
Am-241	i		0.001	
Am-242	i		0.001	
Am-243	i		0.001	
Cm-242	i		0.001	
Cm-243	i		0.001	
Cm-244	i		0.001	

$ m-mobile, s-semi-mobile, I-immobile
# where no comment made, value taken from FARMLAND database in PC-CREAM [D.3]
+ see Table C.1 for details

Table D.11 Environmental transfer factors for plant products – concentration ratios for green and root vegetables and fruit

Radionuclide	Plant:soil concentration ratio (Bq kg^{-1} plant wet weight per Bq kg^{-1} soil dry weight)					
	CR green vegetables:soil	Comment#	CR root vegetables:soil	Comment#	CR fruit:soil	Comment#
Na-22	0.06	[D.10]	0.06	[D.10]	0.06	[D.10]
Na-24	0.06	[D.10]	0.06	[D.10]	0.06	[D.10]
P-32	1		1		1	
P-33	1		1		1	
S-35	0.6		0.6		0.6	
Cl-36	5		5		5	
Ca-45	0.7	[D.10]	0.07	[D.10]	0.07	[D.10]
Ca-47	0.7	[D.10]	0.07	[D.10]	0.07	[D.10]
V-48	0.01	as Nb+	0.01	as Nb+	0.01	as Nb+
Cr-51	0.0003		0.0003		0.0003	
Mn-52	0.1		0.1		0.1	
Mn-54	0.1		0.1		0.1	
Fe-55	0.0002		0.0003		0.0002	
Fe-59	0.0002		0.0003		0.0002	
Co-56	0.01		0.01		0.01	
Co-57	0.01		0.01		0.01	
Co-58	0.01		0.01		0.01	
Co-60	0.01		0.01		0.01	
Ni-63	0.01		0.01		0.01	
Zn-65	1		0.5		1	
Ga-67	0.0008	[D.10]	0.00008	[D.10]	0.00008	based on In+
Se-75	1		1		1	
Br-82	0.02		0.02		0.02	
Rb-83	0.1		0.1		0.1	
Sr-89	0.3		0.05		0.04	
Sr-90	0.3		0.05		0.04	
Y-90	0.01		0.01		0.01	
Zr-95	0.0001		0.0001		0.0001	
Nb-95	0.01		0.01		0.01	
Mo-99	0.1		0.01		0.1	
Tc-99	5		5		5	
Tc-99m	5		5		5	
Ru-103	0.01		0.01		0.002	
Ru-106	0.01		0.01		0.002	
Ag-110m	0.2		0.2		0.2	
In-111	0.0008	[D.10]	0.00008	[D.10]	0.00008	[D.10]
Sb-125	0.01		0.01		0.01	
I-123	0.02		0.02		0.04	
I-125	0.02		0.02		0.04	
I-129	0.02		0.02		0.04	
I-131	0.02		0.02		0.04	
I-133	0.02		0.02		0.04	
I-135	0.02		0.02		0.04	
Cs-134	0.007		0.007		0.024	
Cs-136	0.007		0.007		0.024	
Cs-137	0.007		0.007		0.024	

Table D.11 continued

Radionuclide	Plant:soil concentration ratio (Bq kg^{-1} plant wet weight per Bq kg^{-1} soil dry weight)					
	CR green vegetables:soil	Comment#	CR root vegetables:soil	Comment#	CR fruit:soil	Comment#
Ba-140	0.01		0.005		0.01	
La-140	0.003		0.003		0.003	
Ce-141	0.001		0.001		0.0008	
Ce-144	0.001		0.001		0.0008	
Pm-147	0.003		0.003		0.003	
Sm-153	0.001	as Ce+	0.001	as Ce+	0.0008	as Ce+
Eu-152	0.003		0.003		0.003	
Eu-154	0.003		0.003		0.003	
Eu-155	0.003		0.003		0.003	
Er-169	0.001	as Ce+	0.001	as Ce+	0.0008	as Ce+
Lu-117	0.001	as Ce+	0.001	as Ce+	0.0008	as Ce+
Au-198	0.002	[D.10]	0.0036	[D.10]	0.0028	[D.10]
Tl-201	0.0008	based on In+	0.00008	based on In+	0.00008	[D.10]
Pb-210	0.01		0.01		0.01	
Po-210	0.0002		0.0002		0.0002	
Ra-223	0.01		0.001		0.01	
Ra-226	0.01		0.001		0.01	
Th-230	0.0005		0.0005		0.0005	
Th-232	0.0005		0.0005		0.0005	
Th-234	0.0005		0.0005		0.0005	
U-234	0.001		0.001		0.001	
U-235	0.001		0.001		0.001	
U-238	0.001		0.001		0.001	
Np-237	0.002		0.001		0.002	
Pu-238	0.00001		0.00005		0.0003	
Pu-239	0.00001		0.00005		0.0003	
Pu-240	0.00001		0.00005		0.0003	
Pu-241	0.00001		0.00005		0.0003	
Pu-242	0.00001		0.00005		0.0003	
Am-241	0.00005		0.00008		0.0008	
Am-242	0.00005		0.00008		0.0008	
Am-243	0.00005		0.00008		0.0008	
Cm-242	0.00005		0.00003		0.0008	
Cm-243	0.00005		0.00003		0.0008	
Cm-244	0.00005		0.00003		0.0008	

where no comment made, value taken from FARMLAND database in PC-CREAM [D.3]
+ see Table C.1 for details

Table D.12 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^{-1} or Bq l^{-1} per Bq m^{-2} s^{-1})							
	Green vegetables	Root vegetables	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	Fruit
H-3*	1.1E+02	1.0E+02	8.8E+01	8.8E+01	8.8E+01	8.8E+01	1.1E+02	1.0E+02
H-3 organic*	1.1E+02	1.0E+02	8.8E+01	8.8E+01	8.8E+01	8.8E+01	1.1E+02	1.0E+02
C-14*	2.7E+02	5.3E+02	8.0E+02	8.0E+02	8.0E+02	8.0E+02	2.7E+02	5.3E+02
Na-22	1.5E+05	1.3E+05	1.9E+06	1.9E+06	1.1E+06	1.1E+06	2.1E+05	7.3E+04
Na-24	4.5E+03	2.4E+01	2.3E+03	2.3E+03	4.1E+02	4.1E+02	1.1E+03	3.9E+03
P-32	6.3E+04	5.1E+05	1.1E+06	4.2E+05	4.2E+05	4.2E+05	5.0E+05	4.1E+04
P-33	8.5E+04	4.7E+04	2.5E+05	1.0E+05	9.7E+04	9.7E+04	6.7E+04	5.1E+04
S-35	1.2E+05	9.8E+04	1.5E+07	6.0E+06	6.3E+06	6.3E+06	9.8E+05	6.6E+04
Cl-36	9.2E+06	7.5E+06	2.1E+07	2.1E+07	1.8E+07	1.8E+07	3.5E+06	4.8E+05
Ca-45	1.3E+05	2.9E+03	8.9E+03	8.9E+03	6.9E+03	6.9E+03	3.3E+04	1.7E+04
Ca-47	2.7E+04	6.3E+01	6.6E+02	6.6E+02	6.1E+02	6.1E+02	4.6E+03	5.4E+03
V-48	5.8E+04	4.9E+01	3.9E+01	3.9E+01	2.4E+01	2.4E+01	1.9E+02	1.1E+04
Cr-51	7.0E+04	2.1E+00	8.5E+04	8.5E+04	5.0E+04	5.0E+04	4.4E+04	6.6E+03
Mn-52	3.0E+04	1.2E+02	1.7E+04	5.8E+05	1.2E+04	4.1E+05	3.5E+04	6.2E+03
Mn-54	1.1E+05	7.9E+03	3.3E+05	1.3E+07	1.9E+05	7.6E+06	1.3E+05	2.2E+04
Fe-55	1.1E+05	2.4E+02	6.8E+03	2.1E+07	7.4E+03	2.9E+07	8.9E+03	1.8E+04
Fe-59	8.3E+04	5.6E+01	9.1E+02	2.7E+06	5.5E+02	2.2E+06	7.2E+03	1.5E+04
Co-56	9.3E+04	2.8E+02	1.3E+04	1.3E+06	7.6E+03	7.6E+05	5.2E+04	1.6E+04
Co-57	1.1E+05	8.1E+02	2.5E+04	2.5E+06	1.6E+04	1.6E+06	5.8E+04	1.8E+04
Co-58	9.2E+04	2.6E+02	1.2E+04	1.2E+06	6.9E+03	6.9E+05	5.1E+04	1.6E+04
Co-60	1.2E+05	5.1E+03	4.3E+04	4.4E+06	2.9E+04	2.9E+06	7.1E+04	4.4E+04
Ni-63	1.4E+05	2.5E+04	5.5E+01	5.5E+02	1.5E+02	1.5E+03	4.4E+02	3.1E+05
Zn-65	1.6E+05	3.0E+04	1.1E+05	1.1E+05	1.1E+05	1.1E+05	1.3E+06	3.6E+04
Ga-67	2.0E+04	2.1E-01	1.4E+02	1.4E+02	1.1E+02	1.1E+02	3.8E+02	4.2E+03
Se-75	1.5E+05	1.2E+05	4.5E+06	9.0E+07	2.6E+06	6.6E+07	3.3E+05	7.0E+04
Br-82	1.0E+04	1.9E+02	4.3E+01	4.3E+02	3.7E+01	3.7E+02	7.4E+04	8.7E+03
Rb-83	1.1E+05	8.7E+04	3.6E+05	3.6E+05	2.1E+05	2.1E+05	3.0E+05	6.5E+04
Sr-89	8.9E+04	7.0E+02	5.7E+03	5.7E+03	4.0E+03	4.0E+03	2.0E+04	1.5E+04
Sr-90	6.2E+05	8.8E+04	2.2E+04	2.2E+04	3.0E+04	3.0E+04	1.4E+05	1.3E+05
Y-90	1.7E+04	5.1E+00	1.5E+00	1.5E+01	1.2E+00	1.2E+01	1.3E+02	3.6E+03
Zr-95	9.0E+04	7.6E+01	4.3E+02	4.3E+02	2.2E+02	2.2E+02	2.5E+02	1.6E+04
Nb-95	7.8E+04	1.3E+02	9.2E+01	9.3E+01	5.5E+01	5.5E+01	2.3E+02	1.4E+04
Mo-99	1.7E+04	5.3E+00	3.0E+03	6.1E+04	2.3E+03	4.6E+04	6.6E+03	3.7E+03
Tc-99	9.2E+06	7.5E+06	1.4E+08	4.1E+08	2.1E+07	8.5E+07	2.1E+07	3.0E+07
Tc-99m	2.1E+03	2.1E+02	5.8E+02	1.7E+03	6.5E+02	2.6E+03	8.2E+03	1.6E+03
Ru-103	7.8E+04	1.0E+02	5.1E+03	5.1E+03	3.1E+03	3.1E+03	2.4E+01	7.2E+03
Ru-106	1.0E+05	9.2E+02	2.3E+04	2.3E+04	1.6E+04	1.6E+04	3.0E+01	8.9E+03
Ag-110m	1.2E+05	1.2E+04	6.6E+04	2.0E+07	4.2E+04	1.7E+07	1.5E+06	2.2E+04
In-111	1.8E+04	1.5E-01	5.4E+01	5.4E+01	4.1E+01	4.1E+01	1.3E+03	3.8E+03
Sb-125	1.1E+05	2.8E+03	6.7E+04	6.7E+06	3.2E+04	3.2E+06	3.3E+03	2.5E+04
I-123	4.0E+03	1.4E+01	2.3E+02	2.3E+02	4.3E+02	4.3E+02	1.5E+03	3.5E+03
I-125	1.0E+05	7.4E+04	1.7E+05	1.7E+05	7.5E+04	7.5E+04	1.2E+05	6.2E+04
I-129	1.9E+05	1.8E+05	5.2E+05	5.2E+05	2.0E+05	2.0E+05	2.9E+05	2.8E+05
I-131	4.1E+04	8.6E+03	3.2E+04	3.2E+04	2.5E+04	2.5E+04	5.8E+04	3.1E+04
I-133	6.2E+03	4.7E+01	6.8E+02	6.8E+02	1.1E+03	1.1E+03	3.8E+03	5.4E+03
I-135	2.0E+03	2.6E+00	3.8E+01	3.8E+01	7.8E+01	7.8E+01	3.1E+02	1.8E+03

Table D.12 continued

Radio-nuclide	50th year activity concentrations in foods per unit deposition rate (Bq kg^{-1} or Bq l^{-1} per Bq m^{-2} s^{-1})							
	Green vegetables	Root vegetables	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	Fruit
Cs-134	1.3E+05	1.2E+05	1.5E+06	1.5E+06	7.9E+05	7.9E+05	1.6E+05	7.2E+04
Cs-136	5.6E+04	1.9E+04	2.8E+05	2.8E+05	1.4E+05	1.4E+05	6.3E+04	4.0E+04
Cs-137	1.5E+05	1.4E+05	1.9E+06	1.9E+06	9.1E+05	9.1E+05	1.8E+05	7.5E+04
Ba-140	5.1E+04	2.1E+01	3.8E+03	3.8E+03	2.4E+03	2.4E+03	8.6E+03	9.8E+03
La-140	1.1E+04	9.3E-01	1.2E+01	4.6E+02	9.2E+00	3.7E+02	8.0E+01	2.4E+03
Ce-141	7.3E+04	8.4E+00	3.2E+02	6.5E+04	2.0E+02	3.9E+04	4.5E+02	6.9E+03
Ce-144	1.0E+05	7.0E+01	2.1E+03	4.2E+05	1.7E+03	3.5E+05	5.6E+02	8.8E+03
Pm-147	1.0E+05	7.4E+02	1.8E+04	1.1E+05	2.1E+04	1.7E+05	6.1E+02	1.1E+04
Sm-153	1.3E+04	3.6E-01	3.2E+00	6.3E+02	2.5E+00	5.0E+02	9.3E+01	1.4E+03
Eu-152	1.1E+05	3.4E+03	2.5E+04	1.5E+05	4.1E+04	3.2E+05	6.7E+02	4.0E+04
Eu-154	1.1E+05	2.4E+03	2.4E+04	1.4E+05	3.6E+04	2.9E+05	6.6E+02	2.7E+04
Eu-155	1.1E+05	1.4E+03	2.1E+04	1.3E+05	2.9E+04	2.4E+05	6.4E+02	1.6E+04
Er-169	4.2E+04	2.1E+00	5.7E+01	1.1E+04	3.8E+01	7.6E+03	3.0E+02	4.2E+03
Lu-177	3.4E+04	1.4E+00	3.3E+01	6.7E+03	2.3E+01	4.6E+03	2.5E+02	3.5E+03
Au-198	1.7E+04	1.8E+00	2.1E+04	2.1E+04	1.6E+04	1.6E+04	3.7E+01	1.8E+03
Tl-201	1.9E+04	1.1E+03	4.0E+04	4.0E+04	1.8E+04	1.8E+04	1.8E+04	1.6E+04
Pb-210	1.3E+05	1.6E+04	4.4E+04	8.9E+04	3.4E+04	6.8E+04	1.2E+04	1.8E+05
Po-210	1.2E+05	9.7E+04	2.0E+05	2.3E+06	6.2E+04	1.7E+06	2.7E+03	6.8E+04
Ra-223	4.8E+04	7.0E+00	4.0E+03	4.0E+03	2.5E+03	2.5E+03	6.6E+03	9.4E+03
Ra-226	1.4E+05	3.1E+03	4.2E+04	4.2E+04	2.0E+04	2.0E+04	1.6E+04	3.7E+05
Th-230	1.1E+05	1.5E+03	2.2E+03	2.2E+04	2.2E+03	2.2E+04	1.7E+02	2.7E+04
Th-232	1.1E+05	1.5E+03	2.2E+03	2.2E+04	2.2E+03	2.2E+04	1.7E+02	2.7E+04
Th-234	6.6E+04	3.1E+00	1.1E+02	1.1E+03	6.6E+01	6.6E+02	1.1E+02	6.3E+03
U-234	1.1E+05	2.9E+03	1.7E+04	1.7E+04	7.6E+03	7.6E+03	2.3E+04	4.5E+04
U-235	1.1E+05	2.9E+03	1.7E+04	1.7E+04	7.6E+03	7.6E+03	2.3E+04	4.5E+04
U-238	1.1E+05	2.9E+03	1.7E+04	1.7E+04	7.6E+03	7.6E+03	2.3E+04	4.5E+04
Np-237	1.1E+05	2.9E+03	4.3E+03	3.1E+05	6.4E+03	7.8E+05	1.2E+02	8.2E+04
Pu-238	1.1E+05	1.2E+02	3.6E+03	2.6E+05	4.4E+03	5.4E+05	7.9E+01	1.0E+04
Pu-239	1.1E+05	1.5E+02	3.7E+03	2.6E+05	4.5E+03	5.6E+05	8.2E+01	1.1E+04
Pu-240	1.1E+05	1.5E+02	3.7E+03	2.6E+05	4.5E+03	5.6E+05	8.2E+01	1.1E+04
Pu-241	1.1E+05	5.9E+01	3.3E+03	2.4E+05	3.7E+03	4.5E+05	6.7E+01	9.6E+03
Pu-242	1.1E+05	1.5E+02	3.7E+03	2.6E+05	4.5E+03	5.6E+05	8.2E+01	1.1E+04
Am-241	1.1E+05	2.3E+02	3.7E+03	2.7E+05	5.5E+03	6.7E+05	1.0E+02	1.3E+04
Am-242	4.8E+03	9.2E-03	9.1E-01	2.6E+01	5.9E-01	2.9E+01	2.5E-02	5.2E+02
Am-243	1.1E+05	2.4E+02	3.7E+03	2.7E+05	5.6E+03	6.8E+05	1.0E+02	1.3E+04
Cm-242	9.7E+04	1.2E+00	1.1E+03	7.8E+04	5.7E+02	6.9E+04	1.0E+01	8.6E+03
Cm-243	1.1E+05	4.4E+01	3.5E+03	2.5E+05	4.0E+03	4.9E+05	7.2E+01	1.1E+04
Cm-244	1.1E+05	4.1E+01	3.4E+03	2.5E+05	3.9E+03	4.8E+05	7.1E+01	1.1E+04

*Bq kg^{-1} per Bq m^{-3} in air – from the Specific Activity Model (see Section D.5.3)

Table D.13 Factors relating concentrations of tritium and ^{14}C in foodstuffs to concentrations in air

Foodstuff	Water content (fraction)	Carbon of dry matter (fraction)	Total carbon (fraction)	Conversion factor (Bq kg^{-1} per Bq m^{-3})	
				H-3	C-14
Green vegetables	0.9	0.4	0.04	112.5	267
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

Table D.14 Activity concentration in terrestrial foodstuffs per unit release rate

Radio-nuclide	Activity concentration ($Bq\ kg^{-1}$ per $Bq\ y^{-1}$)*							
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk
H-3	1.6E-11	1.4E-11	1.4E-11	1.2E-11	1.2E-11	1.2E-11	1.2E-11	1.6E-11
H-3 organic	1.6E-11	1.4E-11	1.4E-11	1.2E-11	1.2E-11	1.2E-11	1.2E-11	1.6E-11
C-14	3.7E-11	7.4E-11	7.4E-11	1.1E-10	1.1E-10	1.1E-10	1.1E-10	3.7E-11
Na-22	2.2E-11	2.0E-11	1.1E-11	2.8E-10	2.8E-10	1.6E-10	1.6E-10	3.1E-11
Na-24	6.7E-13	3.6E-15	5.9E-13	3.4E-13	3.4E-13	6.1E-14	6.1E-14	1.7E-13
P-32	9.3E-12	7.6E-11	6.2E-12	1.6E-10	6.2E-11	6.2E-11	6.2E-11	7.4E-11
P-33	1.3E-11	6.9E-12	7.6E-12	3.7E-11	1.5E-11	1.4E-11	1.4E-11	1.0E-11
S-35	1.8E-11	1.5E-11	9.8E-12	2.2E-09	8.9E-10	9.4E-10	9.4E-10	1.5E-10
Cl-36	1.4E-09	1.1E-09	7.1E-11	3.1E-09	3.1E-09	2.6E-09	2.6E-09	5.1E-10
Ca-45	1.9E-11	4.3E-13	2.6E-12	1.3E-12	1.3E-12	1.0E-12	1.0E-12	4.8E-12
Ca-47	3.9E-12	9.4E-15	8.0E-13	9.8E-14	9.8E-14	9.1E-14	9.1E-14	6.8E-13
V-48	8.6E-12	7.3E-15	1.6E-12	5.8E-15	5.8E-15	3.6E-15	3.6E-15	2.8E-14
Cr-51	1.0E-11	3.2E-16	9.8E-13	1.3E-11	1.3E-11	7.4E-12	7.4E-12	6.5E-12
Mn-52	4.5E-12	1.7E-14	9.2E-13	2.5E-12	8.7E-11	1.7E-12	6.2E-11	5.2E-12
Mn-54	1.7E-11	1.2E-12	3.2E-12	4.9E-11	1.9E-09	2.9E-11	1.1E-09	1.9E-11
Fe-55	1.6E-11	3.6E-14	2.7E-12	1.0E-12	3.0E-09	1.1E-12	4.4E-09	1.3E-12
Fe-59	1.2E-11	8.3E-15	2.2E-12	1.4E-13	4.1E-10	8.2E-14	3.3E-10	1.1E-12
Co-56	1.4E-11	4.2E-14	2.4E-12	1.9E-12	1.9E-10	1.1E-12	1.1E-10	7.7E-12
Co-57	1.6E-11	1.2E-13	2.7E-12	3.8E-12	3.8E-10	2.4E-12	2.4E-10	8.6E-12
Co-58	1.4E-11	3.8E-14	2.4E-12	1.7E-12	1.7E-10	1.0E-12	1.0E-10	7.6E-12
Co-60	1.7E-11	7.6E-13	6.6E-12	6.5E-12	6.5E-10	4.3E-12	4.3E-10	1.1E-11
Ni-63	2.0E-11	3.7E-12	4.6E-11	8.2E-15	8.2E-14	2.2E-14	2.2E-13	6.6E-14
Zn-65	2.4E-11	4.4E-12	5.4E-12	1.6E-11	1.6E-11	1.6E-11	1.6E-11	1.9E-10
Ga-67	3.0E-12	3.1E-17	6.2E-13	2.1E-14	2.1E-14	1.6E-14	1.6E-14	5.6E-14
Se-75	2.2E-11	1.8E-11	1.0E-11	6.7E-10	1.3E-08	3.9E-10	9.8E-09	4.8E-11
Br-82	1.1E-11	2.0E-13	9.3E-12	4.7E-14	4.7E-13	4.0E-14	4.0E-13	7.9E-11
Rb-83	1.7E-11	1.3E-11	9.7E-12	5.3E-11	5.3E-11	3.1E-11	3.1E-11	4.5E-11
Sr-89	1.3E-11	1.0E-13	2.2E-12	8.4E-13	8.4E-13	5.9E-13	5.9E-13	2.9E-12
Sr-90	9.3E-11	1.3E-11	2.0E-11	3.3E-12	3.3E-12	4.4E-12	4.4E-12	2.1E-11
Y-90	2.5E-12	7.6E-16	5.3E-13	2.2E-16	2.2E-15	1.7E-16	1.7E-15	1.9E-14
Zr-95	1.3E-11	1.1E-14	2.3E-12	6.3E-14	6.3E-14	3.3E-14	3.3E-14	3.7E-14
Nb-95	1.2E-11	1.9E-14	2.1E-12	1.4E-14	1.4E-14	8.2E-15	8.1E-15	3.4E-14
Mo-99	2.6E-12	7.8E-16	5.5E-13	4.5E-13	9.0E-12	3.4E-13	6.9E-12	9.9E-13
Tc-99	1.4E-09	1.1E-09	4.5E-09	2.0E-08	6.1E-08	3.2E-09	1.3E-08	3.2E-09
Tc-99m	3.1E-13	3.1E-14	2.4E-13	8.6E-14	2.6E-13	9.6E-14	3.9E-13	1.2E-12
Ru-103	1.2E-11	1.5E-14	1.1E-12	7.6E-13	7.6E-13	4.6E-13	4.6E-13	3.5E-15
Ru-106	1.5E-11	1.4E-13	1.3E-12	3.5E-12	3.5E-12	2.4E-12	2.4E-12	4.4E-15
Ag-110m	1.7E-11	1.8E-12	3.3E-12	9.8E-12	2.9E-09	6.2E-12	2.5E-09	2.2E-10
In-111	2.6E-12	2.2E-17	5.6E-13	8.1E-15	8.1E-15	6.1E-15	6.1E-15	2.0E-13
Sb-125	1.7E-11	4.1E-13	3.8E-12	9.9E-12	9.9E-10	4.8E-12	4.8E-10	4.9E-13
I-123	4.3E-12	1.5E-14	3.8E-12	2.5E-13	2.5E-13	4.6E-13	4.6E-13	1.6E-12
I-125	1.1E-10	7.9E-11	6.7E-11	1.9E-10	1.9E-10	8.0E-11	8.0E-11	1.3E-10
I-129	2.1E-10	1.9E-10	3.0E-10	5.6E-10	5.6E-10	2.1E-10	2.1E-10	3.2E-10
I-131	4.4E-11	9.3E-12	3.3E-11	3.4E-11	3.4E-11	2.7E-11	2.7E-11	6.3E-11
I-133	6.7E-12	5.0E-14	5.8E-12	7.3E-13	7.3E-13	1.2E-12	1.2E-12	4.1E-12
I-135	2.2E-12	2.8E-15	1.9E-12	4.1E-14	4.1E-14	8.4E-14	8.4E-14	3.3E-13

Table D.14 continued

Radio-nuclide	Activity concentration (Bq kg^{-1} per Bq y^{-1})*							
	Green veg	Root veg	Fruit	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk
Cs-134	1.9E-11	1.8E-11	1.1E-11	2.3E-10	2.3E-10	1.2E-10	1.2E-10	2.4E-11
Cs-136	8.4E-12	2.8E-12	5.9E-12	4.2E-11	4.2E-11	2.1E-11	2.1E-11	9.4E-12
Cs-137	2.2E-11	2.0E-11	1.1E-11	2.8E-10	2.8E-10	1.4E-10	1.4E-10	2.7E-11
Ba-140	7.6E-12	3.1E-15	1.5E-12	5.6E-13	5.6E-13	3.6E-13	3.6E-13	1.3E-12
La-140	1.7E-12	1.4E-16	3.6E-13	1.7E-15	6.8E-14	1.4E-15	5.4E-14	1.2E-14
Ce-141	1.1E-11	1.2E-15	1.0E-12	4.8E-14	9.6E-12	2.9E-14	5.8E-12	6.7E-14
Ce-144	1.5E-11	1.0E-14	1.3E-12	3.2E-13	6.3E-11	2.6E-13	5.1E-11	8.3E-14
Pm-147	1.5E-11	1.1E-13	1.6E-12	2.7E-12	1.6E-11	3.2E-12	2.5E-11	9.1E-14
Sm-153	1.9E-12	5.3E-17	2.1E-13	4.7E-16	9.4E-14	3.7E-16	7.4E-14	1.4E-14
Eu-152	1.6E-11	5.0E-13	5.9E-12	3.7E-12	2.2E-11	6.0E-12	4.8E-11	1.0E-13
Eu-154	1.6E-11	3.6E-13	4.0E-12	3.5E-12	2.1E-11	5.4E-12	4.3E-11	9.8E-14
Eu-155	1.6E-11	2.1E-13	2.4E-12	3.2E-12	1.9E-11	4.4E-12	3.5E-11	9.5E-14
Er-169	6.2E-12	3.1E-16	6.2E-13	8.5E-15	1.7E-12	5.6E-15	1.1E-12	4.5E-14
Lu-177	5.1E-12	2.1E-16	5.2E-13	5.0E-15	9.9E-13	3.4E-15	6.9E-13	3.7E-14
Au-198	2.5E-12	2.7E-16	2.7E-13	3.2E-12	3.2E-12	2.4E-12	2.4E-12	5.6E-15
Tl-201	2.9E-12	1.7E-13	2.4E-12	6.0E-12	6.0E-12	2.7E-12	2.7E-12	2.7E-12
Pb-210	1.9E-11	2.3E-12	2.6E-11	6.6E-12	1.3E-11	5.1E-12	1.0E-11	1.8E-12
Po-210	1.8E-11	1.4E-11	1.0E-11	2.9E-11	3.5E-10	9.3E-12	2.5E-10	4.0E-13
Ra-223	7.1E-12	1.0E-15	1.4E-12	5.9E-13	5.9E-13	3.8E-13	3.8E-13	9.8E-13
Ra-226	2.1E-11	4.6E-13	5.5E-11	6.2E-12	6.3E-12	3.0E-12	3.0E-12	2.4E-12
Th-230	1.6E-11	2.2E-13	4.1E-12	3.2E-13	3.2E-12	3.3E-13	3.3E-12	2.5E-14
Th-232	1.6E-11	2.2E-13	4.1E-12	3.2E-13	3.2E-12	3.3E-13	3.3E-12	2.5E-14
Th-234	9.9E-12	4.6E-16	9.4E-13	1.6E-14	1.6E-13	9.9E-15	9.9E-14	1.6E-14
U-234	1.6E-11	4.4E-13	6.8E-12	2.6E-12	2.6E-12	1.1E-12	1.1E-12	3.4E-12
U-235	1.6E-11	4.4E-13	6.8E-12	2.6E-12	2.6E-12	1.1E-12	1.1E-12	3.4E-12
U-238	1.6E-11	4.4E-13	6.8E-12	2.6E-12	2.6E-12	1.1E-12	1.1E-12	3.4E-12
Np-237	1.7E-11	4.4E-13	1.2E-11	6.4E-13	4.6E-11	9.5E-13	1.2E-10	1.7E-14
Pu-238	1.6E-11	1.8E-14	1.5E-12	5.4E-13	3.8E-11	6.5E-13	8.0E-11	1.2E-14
Pu-239	1.6E-11	2.2E-14	1.6E-12	5.5E-13	3.9E-11	6.8E-13	8.3E-11	1.2E-14
Pu-240	1.6E-11	2.2E-14	1.6E-12	5.5E-13	3.9E-11	6.8E-13	8.3E-11	1.2E-14
Pu-241	1.6E-11	8.8E-15	1.4E-12	5.0E-13	3.5E-11	5.5E-13	6.7E-11	9.9E-15
Pu-242	1.6E-11	2.2E-14	1.6E-12	5.5E-13	3.9E-11	6.8E-13	8.3E-11	1.2E-14
Am-241	1.6E-11	3.4E-14	1.9E-12	5.5E-13	3.9E-11	8.2E-13	1.0E-10	1.5E-14
Am-242	7.1E-13	1.4E-18	7.8E-14	1.4E-16	3.9E-15	8.8E-17	4.3E-15	3.8E-18
Am-243	1.6E-11	3.5E-14	2.0E-12	5.5E-13	4.0E-11	8.3E-13	1.0E-10	1.5E-14
Cm-242	1.4E-11	1.8E-16	1.3E-12	1.7E-13	1.2E-11	8.5E-14	1.0E-11	1.5E-15
Cm-243	1.6E-11	6.5E-15	1.6E-12	5.1E-13	3.7E-11	5.9E-13	7.3E-11	1.1E-14
Cm-244	1.6E-11	6.1E-15	1.6E-12	5.1E-13	3.6E-11	5.9E-13	7.2E-11	1.1E-14

*for a release at ground level

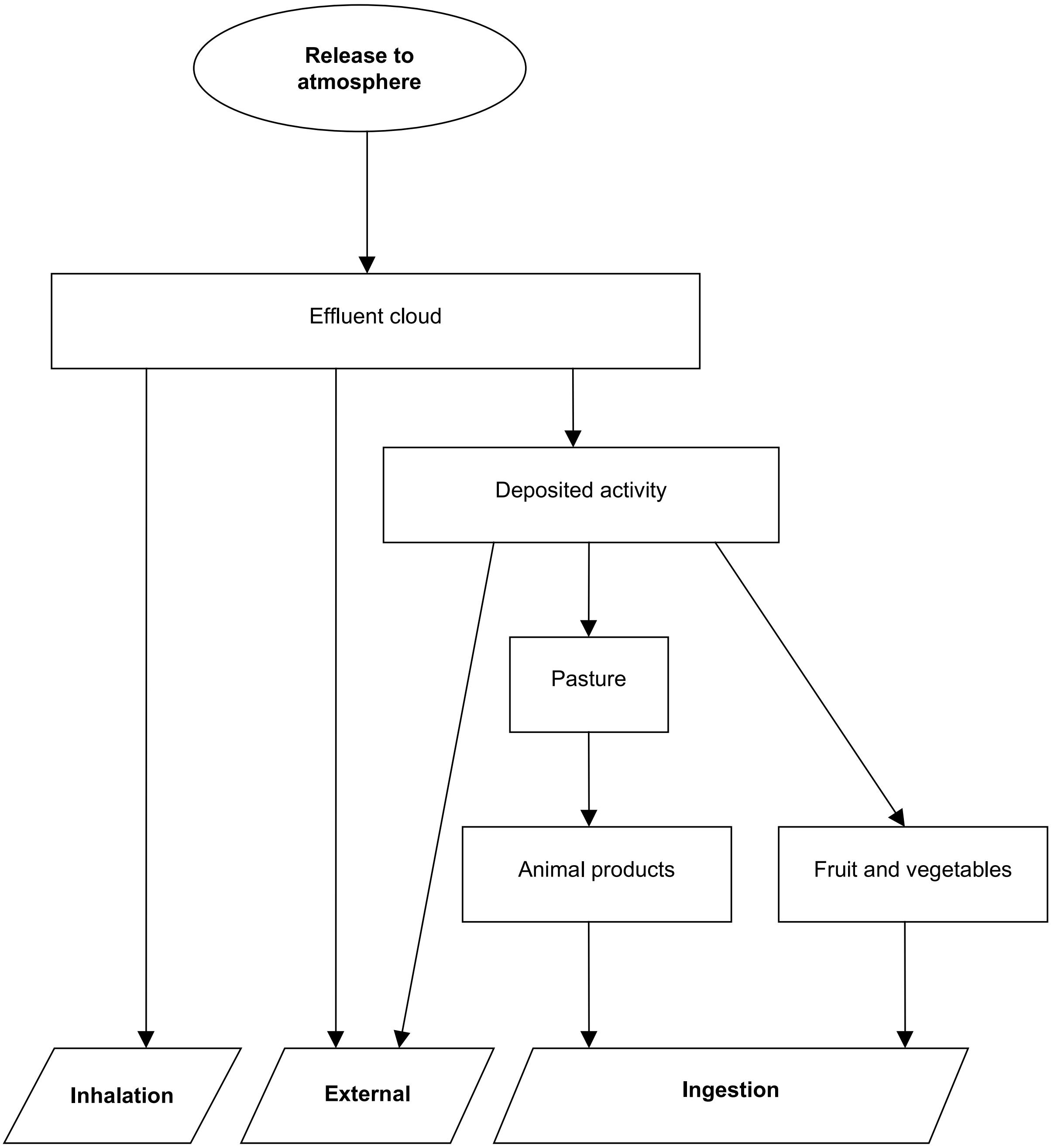

Figure D.1 Flow diagram of aerial pathways

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

E.1 Source term

The source term for releases to the estuarine or coastal environment is made up from direct discharges to an estuary or into coastal water 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. The radionuclides considered for releases to the estuarine or coastal environment are indicated in Table 1.

E.2 Exposed population groups

The following exposed population group was considered. This was taken to be representative of exposure groups from liquid discharges into the sea around the UK:

Fisherman family
Relevant pathways are:

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

Figure E.1 shows the resulting matrix of pathways that were evaluated. Inhalation of seaspray, inhalation of resuspended sediment, inadvertent ingestion of seawater and external irradiation 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 fisherman 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.

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 point(s) at which exposure occurs was determined by the marine dispersion model DORIS, which is part of the PC CREAM suite of models [E.2]. DORIS is a compartment model designed to model the dispersion of radionuclides in the North European coastal water. The model consists of a water dispersion model and a sedimentation model, which are described in detail elsewhere [E.3]. A brief summary of the model's main characteristics is given below.

Dispersion is modelled using the concept of a local marine compartment, which is connected with 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^{-1})
C_{unf} is concentration in unfiltered seawater (Bq l^{-1})
K_d is seawater sediment partition coefficient (Bq kg^{-1} per Bq l^{-1})
SSL is suspended sediment load (kg l^{-1})

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).

For the purpose of this study, 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.3]. The water sediment partition coefficients are listed in Table E.2.

E.3.2 Characterisation of coastal compartment

DORIS is set up to run for a number of specified sites around the UK's coastlines. 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.

A limited sensitivity analysis of DORIS was carried out to determine the effect of varying some of the model parameters on the resulting doses. Both DORIS and PC CREAM's main dose calculating module, ASSESSOR, were run with a discharge list and pathway and habit data representative for this study. The results are summarised below:

- Site selection: when running the model for all UK coastal sites using the same source term for a representative list of radionuclides, the highest overall dose occurred for discharges to the local compartment for Heysham, which is adjacent to the regional compartment 'Liverpool and Morecambe Bays'.
- Local compartment volume and suspended sediment load: the volume of the local compartment and suspended sediment load were varied independently by 2 orders of magnitude. This had little effect on overall dose.
- Volumetric exchange rate of local compartment: model runs were carried out for volumetric exchange rates between 8.0E+06 and 8.0E+10 $m^3 y^{-1}$ (corresponding to 0.25 and 2,500 $m^3 s^{-1}$, respectively). This had by far the biggest effect on dose, with doses increasing with decreasing volumetric exchange rates, as shown in Figure E.2. For sufficiently large flushing rates, approximately inverse proportionality applies, as expected. At low flushing rates or short half-lives, the curves level off because sedimentation and decay dominate over flushing.
- Effect of local compartment versus regional compartment: the runs varying the volumetric exchange rate were carried out assuming first that all occupancy and seafood catches occur in the local compartment and, second, that 50% of the occupancy and fish catches occur in the regional compartment. This had an overall effect on the magnitude of the resulting doses but not on the relationship between dose and volumetric exchange rate.

For the purposes of this study it is important not to underestimate exposure, implying choosing a low volumetric exchange rate. On the other hand scalability of dose by influential environmental characteristics is desirable. As a consequence a volumetric exchange rate of 100 $m^3 s^{-1}$ (about 3.2E+09 $m^3 y^{-1}$) was chosen to represent the local compartment, as this is the lowest volumetric exchange rate at which the dose and volumetric exchange rate is essentially linear. As a result the DPUR data can be scaled by larger volumetric exchanges. If scaling for lower exchange rates below 100 $m^3 s^{-1}$ to about 30 $m^3 s^{-1}$ then the dose will be cautious by a factor of about 2. 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 decay of up to one descendant by modelling the distribution of parent and daughter separately at each step. The following parent/daughter pairs were therefore considered explicitly in this part of the study: $^{95}Zr/^{95}Nb$, $^{99m}Tc/^{99}Tc$, $^{125}Sb/^{125m}Te$, $^{140}Ba/^{140}La$, $^{210}Pb/^{210}Po$, $^{226}Ra/^{210}Pb$, $^{230}Th/^{226}Ra$, $^{232}Th/^{228}Ra$, $^{234}Th/^{234}Pa$, $^{234}U/^{230}Th$, $^{235}U/^{231}Pa$, $^{238}U/^{234}U$, $^{237}Np/^{233}U$, $^{238}Pu/^{234}U$, $^{239}Pu/^{235}U$, $^{240}Pu/^{236}U$, $^{241}Pu/^{241}Am$, $^{241}Am/^{237}Np$, $^{243}Am/^{239}Pu$, $^{242}Cm/^{238}Pu$, $^{243}Cm/^{239}Pu$ and $^{244}Cm/^{240}Pu$.

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^{-1} for all radionuclides. To run DORIS for non-default radionuclides entailed manipulating several of the DORIS input databases, which are not designed to be changed by the user. A number of extra radionuclides were added to the databases, together with data on their decay and sediment partitioning characteristics. The resulting activity concentrations in seawater and beach sediment (Bq l^{-1} for seawater or Bq kg^{-1} for sediment) per unit release 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.4].

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.5]. 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.6,E.7] were applied and converted from a volume source (Bq m^{-3}) to a source per unit mass basis (Bq kg^{-1}), applying a soil density of 1,600 kg m^{-3} [E.7]. It was assumed that the spatial extent of tidally exposed sediments is large enough to assume an infinite source term.

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 daughter radionuclides for which sediment concentrations have been calculated. In addition, for the purpose of calculating external dose, dose coefficients for daughters 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. This has been carried out for the following parent/daughter(s): ^{47}Ca/^{47}Sc, ^{90}Sr/^{90}Y, ^{99}Mo/^{99m}Tc, ^{106}Ru/^{106}Rh, ^{137}Cs/^{137m}Ba, ^{144}Ce/^{144}Pr, ^{210}Pb/^{210}Bi, ^{223}Ra through to ^{208}Tl, ^{226}Ra/^{222}Rn through to ^{214}Po, ^{234Th}/^{234m}Pa, ^{235}U/^{231}Th, ^{238}U/^{234}Th/^{234m}Pa/^{234}Pa, ^{237}Np/^{233}Pa, ^{242}Am/^{242}Cm and ^{234}Am/^{239}Np. 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:

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

where DR_{ext_beach} is external dose rate from radionuclides in beach sediments (μSv h^{-1} per Bq y^{-1})
$DR_{ext\_beach(u)}$ is external dose rate per unit activity concentration in beach sediments (μSv h^{-1} per Bq kg^{-1})
A_{sed} is activity concentration in sediments (Bq kg^{-1} per Bq y^{-1})

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^{-1} per Bq y^{-1})
$A_{seawater}$ is activity concentration in filtered seawater per unit release rate (Bq l^{-1} per Bq y^{-1})
$CF_{seafood}$ is the concentration factor for the seafood under consideration (Bq kg^{-1} per Bq l^{-1})

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

E.6 Method to calculate DPUR factors

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

$$DPUR_{ext,a} = H_{occ,a} \, (DR_{ext\_loc} F_{loc} + DR_{ext\_reg} F_{reg})$$

where $DPUR_{ext,a}$ is dose per unit release factor from external exposure to activity in beach sediments for the age group considered (μSv y^{-1} per Bq y^{-1})
DR_{ext_loc} is external dose rate from activity in beach sediments adjacent to the local compartment (μSv h^{-1} per Bq y^{-1})
DR_{ext_reg} is external dose rate from activity in beach sediments adjacent to the regional compartment (μSv h^{-1} per Bq y^{-1})
$H_{occ,a}$ is total occupancy for the age group considered (h y^{-1})
F_{loc} is fraction spent on beaches adjacent to the local compartment
F_{reg} is fraction spent on beaches adjacent to the regional compartment

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 for the age group considered (μSv y^{-1} per Bq y^{-1})
	A_{food_loc}	is activity concentration in the seafood considered in the local compartment (Bq kg^{-1} per Bq y^{-1})
	A_{food_reg}	is activity concentration in the seafood considered in the regional compartment (Bq kg^{-1} per Bq y^{-1})
	f_{food_loc}	is the fraction of the seafood considered from the local compartment
	f_{food_reg}	is fraction of the seafood considered from the regional compartment
	$I_{food,a}$	is ingestion rate of the seafood for the age group considered (kg y^{-1})
	$DF_{ing,a}$	is ingestion dose coefficient for the age group considered (μSv Bq^{-1})

The resulting DPUR factors are listed in Tables 7–11 in the main report.

E.7 References

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E.8 Smith, K R and Jones, A L (2003). Generalised Habit Data for Radiological Assessments. NRPB-W41.

E.9 Coughtrey, P J, Jackson, D and Thorne, M C (1985). Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems, Volume 6, A A Balkema, Rotterdam.

E.10 IAEA (2004). Sediment Distribution Coefficients and Concentration Factors for Biota in the Marine Environment. IAEA Technical Report Series No 422, International Atomic Energy Agency, Vienna.

E.11 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 fisherman family exposure group

	Infant	Child	Adult	Comment	Fraction in compartment	
					Local	Regional
Food consumption rates (kg y^{-1})				[E.8]		
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^{-1})	30	300	2,000	[E.8]	1	0

Table E.2 Coastal water/sediment K_d

Radionuclide	Sediment K_d (l kg^{-1})	
	Coastal K_d	Comment#
H-3	1	
H-3 org.	1	same as H-3
C-14	1,000	
Na-22	0.1	
Na-24	0.1	
P-32	10	[E.2]
P-33	10	[E.2]
S-35	0.5	
Cl-36	0.03	
Ca-45	500	
Ca-47	500	
V-48	800,000	as Nb+
Cr-51	50,000	
Mn-52	2,000,000	
Mn-54	2,000,000	
Fe-55	300,000,000	
Fe-59	300,000,000	
Co-56	300,000	
Co-57	300,000	
Co-58	300,000	
Co-60	300,000	
Ni-63	20,000	
Zn-65	70,000	
Ga-67	200	based on Si in soils+
Se-75	3,000	
Br-82	0	non-sorbing+
Rb-83	250	[E.9]
Sr-89	8	
Sr-90	8	
Y-90	900,000	
Zr-95	2,000,000	
Nb-95	800,000	
Mo-99	1,000	freshwater+
Tc-99	100	
Tc-99m	100	
Ru-103	40,000	
Ru-106	40,000	

Table E.2 continued

Radionuclide	Sediment K_d (l kg^{-1})	
	Coastal K_d	Comment#
Ag-110m	10,000	
In-111	50,000	
Sb-125	2,000	
I-123	70	
I-125	70	
I-129	70	
I-131	70	
I-133	70	
I-135	70	
Cs-134	4,000	
Cs-136	4,000	
Cs-137	4,000	
Ba-140	2,000	
La-140	3,000,000	as Ce+
Ce-141	3,000,000	
Ce-144	3,000,000	
Pm-147	2,000,000	
Sm-153	3,000,000	
Eu-152	2,000,000	
Eu-154	2,000,000	
Eu-155	2,000,000	
Er-169	3,000,000	as Ce+
Lu-177	3,000,000	as Ce+
Au-198	3,000,000	as Ce+
Tl-201	20,000	
Pb-210	100,000	
Po-210	20,000,000	
Ra-223	2,000	
Ra-226	2,000	
Th-230	3,000,000	
Th-232	3,000,000	
Th-234	3,000,000	
U-234	1,000	
U-235	1,000	
U-238	1,000	
Np-237	1,000	
Pu-238	100,000	
Pu-239	100,000	
Pu-240	100,000	
Pu-241	100,000	
Pu-242	100,000	
Am-241	2,000,000	
Am-242	2,000,000	
Am-243	2,000,000	
Cm-242	2,000,000	
Cm-243	2,000,000	
Cm-244	2,000,000	

where no comment made, value taken from IAEA [E.10]
+ see Table C.1 for details

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^{-1})	3.2E+09	see Section E.3.2
Suspended sediment load (te m^{-3})	1.0E-05	[E.2]
Sedimentation rate (te m^{-2} y^{-1})	4.9E-03	[E.2]
Density of dry sediment particles (te m^{-3})	2.6	[E.2]
Bioturbation rate (coastal water) (m^2 y^{-1})	3.6E-05	[E.2]
Diffusion rate (sediment diffusion coefficient) (m^2 y^{-1})	3.15E-02	[E.2]

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

Radionuclide		Filtered seawater concentration ($Bq\ l^{-1}$ per $Bq\ y^{-1}$)*				Seabed sediment concentration ($Bq\ kg^{-1}$ per $Bq\ y^{-1}$)*+			
		Local compartment		Regional compart.		Local compartment		Regional compart.	
Parent	Daughter	Parent	Daughter	Parent	Daughter	Parent	Daughter	Parent	Daughter
H-3		3.2E-13		7.2E-15		2.1E-13		6.1E-15	
H-3 org.		3.2E-13		7.2E-15		2.1E-13		6.1E-15	
C-14		3.1E-13		6.7E-15		2.3E-10		5.0E-12	
Na-22		3.2E-13		6.7E-15		2.0E-13		5.5E-15	
Na-24		2.3E-14		5.6E-18		2.0E-16		6.4E-20	
P-32		2.0E-13		8.9E-16		1.1E-14		5.2E-17	
P-33		2.4E-13		1.6E-15		2.2E-14		1.6E-16	
S-35		2.9E-13		3.8E-15		1.1E-13		1.9E-15	
Cl-36		3.2E-13		7.3E-15		2.1E-13		6.3E-15	
Ca-45		3.0E-13		4.7E-15		5.7E-12		9.2E-14	
Ca-47		1.1E-13		1.9E-16		6.3E-14		1.1E-16	
V-48		1.2E-14		2.9E-17		3.9E-11		9.5E-14	
Cr-51		1.2E-13		4.9E-16		4.0E-11		1.7E-13	
Mn-52		3.8E-15		7.2E-18		1.1E-11		2.0E-14	
Mn-54		6.1E-15		1.6E-17		8.6E-10		2.3E-12	
Fe-55		4.3E-17		1.1E-19		2.4E-09		6.4E-12	
Fe-59		3.9E-17		9.3E-20		1.3E-10		3.1E-13	
Co-56		3.5E-14		1.1E-16		2.0E-10		6.3E-13	
Co-57		3.6E-14		1.2E-16		6.8E-10		2.2E-12	
Co-58		3.5E-14		1.1E-16		1.8E-10		5.6E-13	
Co-60		3.8E-14		1.3E-16		3.4E-09		1.2E-11	
Ni-63		2.2E-13		2.4E-15		3.2E-09		3.4E-11	
Zn-65		1.1E-13		5.6E-16		4.4E-10		2.3E-12	
Ga-67		9.1E-14		1.1E-16		1.5E-14		1.8E-17	
Se-75		2.8E-13		3.6E-15		2.4E-11		3.1E-13	
Br-82		4.9E-14		2.8E-17		1.1E-15		8.2E-19	
Rb-83		2.9E-13		3.7E-15		1.5E-12		2.0E-14	
Sr-89		2.7E-13		2.8E-15		4.4E-14		5.1E-16	
Sr-90		3.2E-13		7.3E-15		4.1E-13		1.1E-14	
Y-90		5.9E-15		8.2E-18		3.5E-12		5.0E-15	
Zr-95	Nb-95	5.8E-15	1.2E-15	1.5E-17	5.4E-18	1.8E-10	1.9E-10	4.6E-13	5.0E-13
Nb-95		1.3E-14		3.5E-17		9.3E-11		2.4E-13	
Mo-99		8.0E-14		8.2E-17		5.4E-14		5.7E-17	
Tc-99		3.2E-13		7.3E-15		1.5E-11		3.5E-13	
Tc-99m	Tc-99	9.6E-15	1.0E-21	9.5E-19	2.4E-23	6.0E-17	4.9E-20	6.1E-21	1.1E-21
Ru-103		1.4E-13		6.8E-16		5.3E-11		2.7E-13	
Ru-106		1.6E-13		1.0E-15		5.1E-10		3.4E-12	
Ag-110m		2.5E-13		2.8E-15		1.4E-10		1.6E-12	
In-111		4.8E-14		5.7E-17		1.7E-12		2.0E-15	
Sb-125	Te-125m	3.0E-13	1.1E-14	5.6E-15	1.3E-15	1.1E-10	1.1E-10	2.2E-12	2.1E-12
I-123		2.0E-14		4.4E-18		2.0E-16		4.4E-20	
I-125		2.8E-13		3.1E-15		2.9E-13		3.2E-15	
I-129		3.2E-13		7.3E-15		9.2E-12		2.1E-13	
I-131		1.6E-13		4.3E-16		2.2E-14		6.2E-17	
I-133		3.1E-14		1.0E-17		4.7E-16		1.6E-19	
I-135		1.1E-14		1.1E-18		5.1E-17		5.6E-21	

Table E.4 continued

Radionuclide		Filtered seawater concentration (Bq l^{-1} per Bq y^{-1})*				Seabed sediment concentration (Bq kg^{-1} per Bq y^{-1})*+			
		Local compartment		Regional compart.		Local compartment		Regional compart.	
Parent	Daughter	Parent	Daughter	Parent	Daughter	Parent	Daughter	Parent	Daughter
Cs-134		2.9E-13		4.7E-15		1.7E-10		2.9E-12	
Cs-136		1.8E-13		7.2E-16		2.4E-12		9.5E-15	
Cs-137		2.9E-13		5.2E-15		7.1E-10		1.3E-11	
Ba-140	La-140	1.9E-13	4.0E-15	7.3E-16	4.6E-17	1.2E-12	6.2E-12	4.7E-15	6.3E-14
La-140		1.4E-15		1.6E-18		1.8E-12		2.0E-15	
Ce-141		3.7E-15		9.0E-18		8.9E-11		2.2E-13	
Ce-144		4.1E-15		1.1E-17		7.9E-10		2.1E-12	
Pm-147		6.2E-15		1.7E-17		2.3E-09		6.4E-12	
Sm-153		1.5E-15		1.9E-18		2.2E-12		2.8E-15	
Eu-152		6.6E-15		2.0E-17		6.4E-09		1.9E-11	
Eu-154		6.5E-15		1.9E-17		5.2E-09		1.6E-11	
Eu-155		6.4E-15		1.8E-17		3.7E-09		1.1E-11	
Er-169		3.0E-15		6.4E-18		2.1E-11		4.5E-14	
Lu-177		2.8E-15		5.4E-18		1.4E-11		2.8E-14	
Au-198		1.9E-15		2.7E-18		3.7E-12		5.5E-15	
Tl-201		6.8E-14		8.0E-17		1.0E-12		1.2E-15	
Pb-210	Po-210	9.6E-14	2.2E-16	5.0E-16	2.1E-18	5.5E-09	5.5E-09	2.9E-11	2.9E-11
Po-210		5.0E-16		1.1E-18		3.4E-11		7.7E-14	
Ra-223		1.8E-13		6.5E-16		1.0E-12		3.7E-15	
Ra-226	Pb-210	3.1E-13	2.8E-16	6.2E-15	1.4E-17	4.6E-10	1.4E-10	9.4E-12	3.3E-12
Th-230	Ra-226	4.7E-15	2.6E-16	1.6E-17	9.4E-18	1.1E-08	5.4E-11	3.6E-11	1.8E-13
Th-232	Ra-228	4.7E-15	3.2E-14	1.6E-17	1.1E-15	1.1E-08	6.5E-09	3.6E-11	2.1E-11
Th-234	Pa-234	3.6E-15	8.1E-17	8.5E-18	3.4E-19	6.4E-11	7.1E-11	1.6E-13	1.9E-13
U-234	Th-230	3.1E-13	3.0E-21	6.7E-15	1.4E-22	2.3E-10	3.1E-14	5.0E-12	8.1E-16
U-235	Pa-231	3.1E-13	4.3E-21	6.7E-15	1.9E-22	2.3E-10	7.3E-14	5.0E-12	1.9E-15
U-238	U-234	3.1E-13	7.6E-20	6.7E-15	1.2E-20	2.3E-10	7.3E-15	5.0E-12	1.6E-16
Np-237	U-233	3.1E-13	1.2E-19	6.7E-15	1.8E-20	2.3E-10	1.1E-14	5.0E-12	2.5E-16
Pu-238	U-234	9.8E-14	1.2E-18	5.3E-16	5.9E-20	7.0E-09	2.2E-13	3.8E-11	1.2E-15
Pu-239	U-235	9.9E-14	4.6E-22	5.5E-16	2.2E-23	7.7E-09	8.3E-17	4.2E-11	4.5E-19
Pu-240	U-236	9.9E-14	1.4E-20	5.5E-16	6.7E-22	7.7E-09	2.5E-15	4.2E-11	1.4E-17
Pu-241	Am-241	9.5E-14	9.3E-18	4.8E-16	1.1E-19	4.7E-09	1.0E-10	2.4E-11	5.9E-13
Pu-242		9.9E-14		5.5E-16		7.7E-09		4.2E-11	
Am-241	Np-237	7.0E-15	2.1E-19	2.3E-17	7.8E-21	1.1E-08	3.8E-14	3.5E-11	1.3E-16
Am-242		1.0E-15		6.3E-19		3.5E-13		2.1E-16	
Am-243	Pu-239	7.0E-15	5.2E-18	2.3E-17	6.3E-20	1.1E-08	4.0E-12	3.6E-11	1.5E-14
Cm-242	Pu-238	6.0E-15	7.0E-17	1.6E-17	7.3E-19	4.6E-10	4.6E-11	1.2E-12	1.6E-13
Cm-243	Pu-239	6.8E-15	4.1E-18	2.1E-17	4.8E-20	8.2E-09	3.1E-12	2.6E-11	1.2E-14
Cm-244	Pu-240	6.7E-15	1.3E-17	2.1E-17	1.6E-19	7.2E-09	1.0E-11	2.2E-11	3.8E-14

*for a water exchange rate of 100 m^3 s^{-1}
+activity concentrations in sediments contain fraction of activity in pore water

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

Radionuclide	Dose rate above sediment ($\mu Sv\ h^{-1}$ per $Bq\ kg^{-1}$)			Daughter considered explicitly in assessment	Dose rate above sediment ($\mu Sv\ h^{-1}$ per $Bq\ kg^{-1}$)		
	Dose rate parent	Dose rate including all daughters	Comments		Dose rate	Dose rate including all daughters	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	1.8E-04	Sc-47 included, since all will decay in 1 year				
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					
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-82	4.1E-04	4.1E-04					
Rb-83	7.7E-05	7.7E-05					

Table E.5 continued

Radionuclide	Dose rate above sediment (µSv h^{-1} per Bq kg^{-1})			Daughter considered explicitly in assessment	Dose rate above sediment (µSv h^{-1} per Bq kg^{-1})		
	Dose rate parent	Dose rate including all daughters	Comments		Dose rate	Dose rate including all daughters	Comments
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-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	3.6E-05	Tc-99m included				
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					
I-125	3.7E-07	3.7E-07					
I-129	2.9E-07	2.9E-07					
I-131	5.7E-05	5.7E-05					
I-133	9.4E-05	9.4E-05					
I-135	2.5E-04	2.5E-04					
Cs-134	2.4E-04	2.4E-04					
Cs-136	3.4E-04	3.4E-04					
Cs-137	2.5E-08	8.8E-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-153	4.3E-06	4.3E-06					

Table E.5 continued

Radionuclide	Dose rate above sediment (µSv h^{-1} per Bq kg^{-1})			Daughter considered explicitly in assessment	Dose rate above sediment (µSv h^{-1} per Bq kg^{-1})		
	Dose rate parent	Dose rate including all daughters	Comments		Dose rate	Dose rate including all daughters	Comments
Eu-152	1.8E-04	1.8E-04					
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					
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, since Po-210 treated explicitly	Po-210	1.3E-09	1.3E-09	
Po-210	1.3E-09	1.3E-09					
Ra-223	1.6E-05	2.7E-04	Rn-219 through to Tl-208 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
Th-230	3.3E-08	3.3E-08		Ra-226	8.7E-07	2.8E-04	Rn-222 through to Po-214 included
Th-232	1.4E-08	1.4E-08		Ra-228	0.0E+00	3.9E-04	Ac-228 through to Tl-208 are included
Th-234	6.6E-07	3.4E-06	Pa-234m only included	Pa-234	2.9E-04	2.9E-04	
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	4.0E-06	Th-234, etc. 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					

Table E.5 continued

Radionuclide	Dose rate above sediment (µSv h^{-1} per Bq kg^{-1})			Daughter considered explicitly in assessment	Dose rate above sediment (µSv h^{-1} per Bq kg^{-1})		
	Dose rate parent	Dose rate including all daughters	Comments		Dose rate	Dose rate including all daughters	Comments
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 included since significant decay in 1 year. Pu-242 not included.				
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	
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 ($\mu Sv\ h^{-1}$ per $Bq\ y^{-1}$)*			
		Local compartment		Regional compartment	
Parent	Daughter	Parent	Daughter	Parent	Daughter
H-3		0.0E+00		0.0E+00	
H-3 organic		0.0E+00		0.0E+00	
C-14		7.8E-20		1.7E-21	
Na-22		6.8E-17		1.9E-18	
Na-24		1.3E-19		4.2E-23	
P-32		6.5E-21		3.2E-23	
P-33		3.4E-23		2.5E-25	
S-35		4.2E-23		7.1E-25	
Cl-36		1.5E-20		4.6E-22	
Ca-45		9.4E-21		1.5E-22	
Ca-47		1.2E-17		1.9E-20	
V-48		1.8E-14		4.4E-17	
Cr-51		1.9E-16		8.0E-19	
Mn-52		5.8E-15		1.1E-17	
Mn-54		1.1E-13		3.0E-16	
Fe-55		0.0E+00		0.0E+00	
Fe-59		2.4E-14		5.8E-17	
Co-56		1.1E-13		3.5E-16	
Co-57		9.4E-15		3.1E-17	
Co-58		2.7E-14		8.5E-17	
Co-60		1.4E-12		4.8E-15	
Ni-63		0.0E+00		0.0E+00	
Zn-65		4.0E-14		2.1E-16	
Ga-67		3.0E-19		3.7E-22	
Se-75		1.3E-15		1.7E-17	
Br-82		4.6E-19		3.4E-22	
Rb-83		1.1E-16		1.5E-18	
Sr-89		2.0E-20		2.3E-22	
Sr-90		5.0E-19		1.3E-20	
Y-90		4.2E-18		6.0E-21	
Zr-95	Nb-95	2.1E-14	2.2E-14	5.4E-17	6.0E-17
Nb-95		1.1E-14		2.9E-17	
Mo-99		2.0E-18		2.1E-21	
Tc-99		5.1E-20		1.2E-21	
Tc-99m	Tc-99	9.2E-22	1.6E-28	9.3E-26	3.8E-30
Ru-103		3.8E-15		1.9E-17	
Ru-106		1.7E-14		1.2E-16	
Ag-110m		6.1E-14		7.1E-16	
In-111		9.1E-17		1.1E-19	
Sb-125	Te-125m	7.3E-15	3.6E-17	1.4E-16	7.1E-19
I-123		3.8E-21		8.5E-25	
I-125		1.0E-19		1.2E-21	
I-129		2.7E-18		6.3E-20	
I-131		1.3E-18		3.5E-21	
I-133		4.4E-20		1.5E-23	
I-135		1.3E-20		1.4E-24	
Cs-134		4.2E-14		6.9E-16	
Cs-136		7.9E-16		3.2E-18	
Cs-137		6.2E-14		1.1E-15	

Table E.6 continued

Radionuclide		Dose rate per unit release (µSv h^{-1} per Bq y^{-1})*			
		Local compartment		Regional compartment	
Parent	Daughter	Parent	Daughter	Parent	Daughter
Ba-140	La-140	3.2E-17	2.3E-15	1.3E-19	2.3E-17
La-140		6.4E-16		7.5E-19	
Ce-141		7.8E-16		1.9E-18	
Ce-144		7.0E-15		1.9E-17	
Pm-147		3.0E-18		8.4E-21	
Sm-153		9.5E-18		1.2E-20	
Eu-152		1.1E-12		3.4E-15	
Eu-154		1.0E-12		3.0E-15	
Eu-155		1.8E-14		5.3E-17	
Er-169		7.7E-20		1.7E-22	
Lu-177		6.0E-17		1.2E-19	
Au-198		2.3E-16		3.4E-19	
Tl-201		7.6E-18		9.2E-21	
Pb-210	Po-210	1.2E-15	7.3E-18	6.5E-18	3.8E-20
Po-210		4.6E-20		1.0E-22	
Ra-223		2.7E-16		9.9E-19	
Ra-226	Pb-210	1.3E-13	3.2E-17	2.6E-15	7.5E-19
Th-230	Ra-226	3.6E-16	1.5E-14	1.2E-18	4.9E-17
Th-232	Ra-228	1.5E-16	2.5E-12	5.0E-19	8.4E-15
Th-234	Pa-234	2.2E-16	2.1E-14	5.2E-19	5.4E-17
U-234	Th-230	2.4E-18	1.0E-21	5.3E-20	2.7E-23
U-235	Pa-231	4.8E-15	3.7E-19	1.0E-16	9.8E-21
U-238	U-234	9.1E-16	7.8E-23	2.0E-17	1.7E-24
Np-237	U-233	6.8E-15	4.3E-22	1.5E-16	9.5E-24
Pu-238	U-234	2.5E-17	2.3E-21	1.3E-19	1.3E-23
Pu-239	U-235	6.0E-17	1.7E-21	3.3E-19	9.4E-24
Pu-240	U-236	2.7E-17	1.4E-23	1.5E-19	7.4E-26
Pu-241	Am-241	7.6E-19	1.2E-16	3.9E-21	6.8E-19
Pu-242		2.3E-17		1.3E-19	
Am-241	Np-237	1.2E-14	1.1E-18	4.0E-17	3.7E-21
Am-242		4.8E-19		3.0E-22	
Am-243	Pu-239	2.7E-13	3.1E-20	8.7E-16	1.2E-22
Cm-242	Pu-238	1.8E-18	1.7E-19	4.8E-21	5.6E-22
Cm-243	Pu-239	1.3E-13	2.4E-20	4.1E-16	9.1E-23
Cm-244	Pu-240	2.0E-17	3.5E-20	6.1E-20	1.3E-22

*for a water exchange rate of 100 m^3 s^{-1}

Table E.7 Concentration factors for seafoods

Radionuclide	Seafood/water concentration factor (Bq kg^{-1} per Bq l^{-1})					
	Fish	Comment#	Mollusc	Comment#	Crustaceans	Comment#
H-3	1		1		1	
H-3 organic	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	20,000	[E.2]	10,000	[E.2]	10,000	[E.2]
P-33	20,000	[E.2]	10,000	[E.2]	10,000	[E.2]
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	
Zn-65	1,000		80,000		300,000	
Ga-67	700	[E.11]	700	[E.11]	700	[E.11]
Se-75	10,000		9,000		10,000	
Br-82	3	[E.11]	10	[E.11]	10	[E.11]
Rb-83	100	[E.11]	20	[E.11]	20	[E.11]
Sr-89	3		10		5	
Sr-90	3		10		5	
Y-90	20		1,000		1,000	
Zr-95	20		5,000		200	
Nb-95	30		1,000		200	
Mo-99	10	[E.11]	100	[E.11]	100	[E.11]
Tc-99	80		500		1,000	
Tc-99m	80		500		1,000	
Ru-103	2		500		100	
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-125	9		10		3	
I-129	9		10		3	
I-131	9		10		3	
I-133	9		10		3	
I-135	9		10		3	

Table E.7 continued

Radionuclide	Seafood/water concentration factor (Bq kg^{-1} per Bq l^{-1})					
	Fish	Comment#	Molluscs	Comment#	Crustaceans	Comment#
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+
Au-198	100	[E.11]	1,000	[E.11]	1,000	[E.11]
Tl-201	5,000		6,000		1,000	
Pb-210	200		50,000		90,000	
Po-210	2,000		20,000		20,000	
Ra-223	100		100		100	
Ra-226	100		100		100	
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	
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.1 for details

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

Radionuclide		Activity concentration in fish (Bq kg^{-1} per Bq y^{-1})*		Activity concentration in crustaceans (Bq kg^{-1} per Bq y^{-1})*		Activity concentration in molluscs (Bq kg^{-1} per Bq y^{-1})*	
Parent	Daughter	Parent	Daughter	Parent	Daughter	Parent	Daughter
H-3		1.6E-13		3.2E-13		3.2E-13	
H-3 organic		3.3E-09		6.4E-09		6.4E-09	
C-14		3.2E-09		6.3E-09		6.3E-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		2.0E-09		2.0E-09		2.0E-09	
P-33		2.4E-09		2.4E-09		2.4E-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		9.0E-13	
Ca-47		1.1E-13		5.7E-13		3.4E-13	
V-48		1.8E-13		2.4E-12		1.2E-11	
Cr-51		1.2E-11		1.2E-11		2.3E-10	
Mn-52		1.9E-12		1.9E-11		1.9E-10	
Mn-54		3.0E-12		3.0E-11		3.0E-10	
Fe-55		6.4E-13		2.1E-11		2.1E-11	
Fe-59		5.8E-13		1.9E-11		1.9E-11	
Co-56		1.2E-11		2.4E-10		7.0E-10	
Co-57		1.3E-11		2.5E-10		7.3E-10	
Co-58		1.2E-11		2.4E-10		6.9E-10	
Co-60		1.3E-11		2.7E-10		7.6E-10	
Ni-63		1.1E-10		2.2E-10		4.4E-10	
Zn-65		5.6E-11		3.3E-08		8.9E-09	
Ga-67		3.2E-11		6.4E-11		6.4E-11	
Se-75		1.4E-09		2.8E-09		2.5E-09	
Br-82		7.4E-14		4.9E-13		4.9E-13	
Rb-83		1.5E-11		5.8E-12		5.8E-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		5.9E-14		5.9E-12		5.9E-12	
Zr-95	Nb-95	5.8E-14	1.2E-14	1.2E-12	2.4E-13	2.9E-11	6.0E-12
Nb-95		2.0E-13		2.7E-12		1.3E-11	
Mo-99		4.0E-13		8.0E-12		8.0E-12	
Tc-99		1.3E-11		3.2E-10		1.6E-10	
Tc-99m	Tc-99	3.8E-13	4.1E-20	9.6E-12	1.0E-18	4.8E-12	5.0E-19
Ru-103		1.4E-13		1.4E-11		6.9E-11	
Ru-106		1.6E-13		1.6E-11		7.8E-11	
Ag-110m		1.2E-09		4.9E-08		1.5E-08	
In-111		1.2E-11		4.8E-10		4.8E-10	
Sb-125	Te-125m	9.2E-11	3.6E-12	9.0E-11	3.2E-12	9.0E-11	3.2E-12
I-123		9.1E-14		6.1E-14		2.0E-13	
I-125		1.3E-12		8.4E-13		2.8E-12	
I-129		1.5E-12		9.6E-13		3.2E-12	
I-131		7.1E-13		4.7E-13		1.6E-12	
I-133		1.4E-13		9.2E-14		3.1E-13	
I-135		4.7E-14		3.2E-14		1.1E-13	

Table E.8 continued

Radionuclide		Activity concentration in fish (Bq kg^{-1} per Bq y^{-1})*		Activity concentration in crustaceans (Bq kg^{-1} per Bq y^{-1})*		Activity concentration in molluscs (Bq kg^{-1} per Bq y^{-1})*	
Parent	**Daughter**	**Parent**	**Daughter**	**Parent**	**Daughter**	**Parent**	**Daughter**
Cs-134		1.5E-11		1.4E-11		1.7E-11	
Cs-136		9.1E-12		9.1E-12		1.1E-11	
Cs-137		1.5E-11		1.5E-11		1.7E-11	
Ba-140	La-140	9.3E-13	2.0E-14	1.3E-13	2.8E-15	1.9E-12	4.0E-14
La-140		3.5E-14		1.4E-12		2.8E-12	
Ce-141		9.3E-14		3.7E-12		7.4E-12	
Ce-144		1.0E-13		4.1E-12		8.1E-12	
Pm-147		9.4E-13		2.5E-11		4.4E-11	
Sm-153		2.3E-13		6.2E-12		1.1E-11	
Eu-152		1.0E-12		2.6E-11		4.6E-11	
Eu-154		9.8E-13		2.6E-11		4.6E-11	
Eu-155		9.6E-13		2.5E-11		4.5E-11	
Er-169		7.6E-14		3.0E-12		6.1E-12	
Lu-177		6.9E-14		2.8E-12		5.5E-12	
Au-198		9.3E-14		1.9E-12		1.9E-12	
Tl-201		1.7E-10		6.8E-11		4.1E-10	
Pb-210	Po-210	9.6E-12	2.2E-14	8.6E-09	2.0E-11	4.8E-09	1.1E-11
Po-210		5.0E-13		1.0E-11		1.0E-11	
Ra-223		8.9E-12		1.8E-11		1.8E-11	
Ra-226	Pb-210	1.6E-11	1.4E-14	3.1E-11	2.8E-14	3.1E-11	2.8E-14
Th-230	Ra-226	1.4E-12	8.2E-14	4.7E-12	2.6E-13	4.7E-12	2.6E-13
Th-232	Ra-228	1.4E-12	9.9E-12	4.7E-12	3.2E-11	4.7E-12	3.2E-11
Th-234	Pa-234	1.1E-12	2.4E-14	3.6E-12	8.1E-14	3.6E-12	8.1E-14
U-234	Th-230	1.6E-13	1.6E-21	3.1E-12	3.0E-20	9.4E-12	9.1E-20
U-235	Pa-231	1.6E-13	2.2E-21	3.1E-12	4.3E-20	9.4E-12	1.3E-19
U-238	U-234	1.6E-13	4.4E-20	3.1E-12	7.6E-19	9.4E-12	2.3E-18
Np-237	U-233	1.6E-13	6.8E-20	3.1E-11	1.2E-17	1.3E-10	4.7E-17
Pu-238	U-234	4.9E-12	6.3E-17	2.0E-11	2.4E-16	2.9E-10	3.6E-15
Pu-239	U-235	5.0E-12	2.4E-20	2.0E-11	9.2E-20	3.0E-10	1.4E-18
Pu-240	U-236	5.0E-12	7.2E-19	2.0E-11	2.8E-18	3.0E-10	4.1E-17
Pu-241	Am-241	4.8E-12	4.7E-16	1.9E-11	1.9E-15	2.8E-10	2.8E-14
Pu-242		5.0E-12		2.0E-11		3.0E-10	
Am-241	Np-237	3.5E-13	1.1E-17	2.8E-12	8.2E-17	7.0E-12	2.1E-16
Am-242		5.2E-14		4.2E-13		1.0E-12	
Am-243	Pu-239	3.5E-13	2.7E-16	2.8E-12	2.1E-15	7.0E-12	5.2E-15
Cm-242	Pu-238	3.0E-13	3.5E-15	2.4E-12	2.8E-14	6.0E-12	7.0E-14
Cm-243	Pu-239	3.4E-13	2.1E-16	2.7E-12	1.6E-15	6.8E-12	4.1E-15
Cm-244	Pu-240	3.4E-13	6.7E-16	2.7E-12	5.3E-15	6.7E-12	1.3E-14

*for a water exchange rate of 100 m^3 s^{-1}

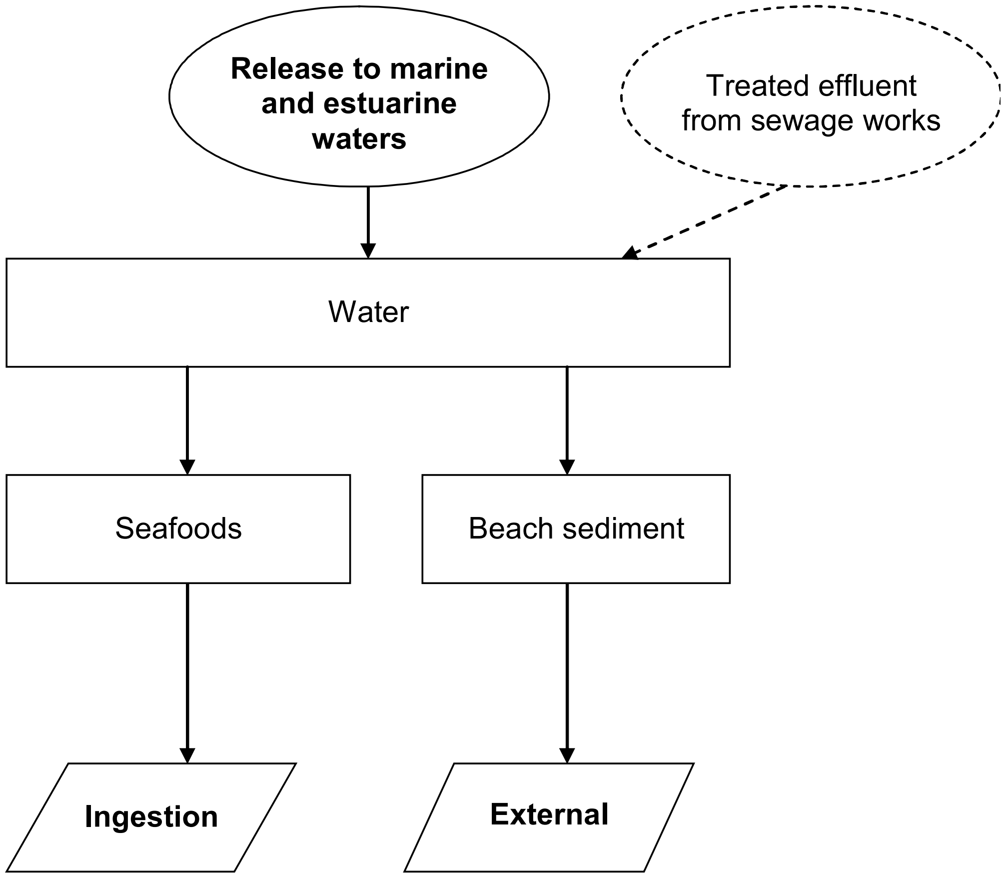

Figure E.1 Flow diagram of coastal pathways

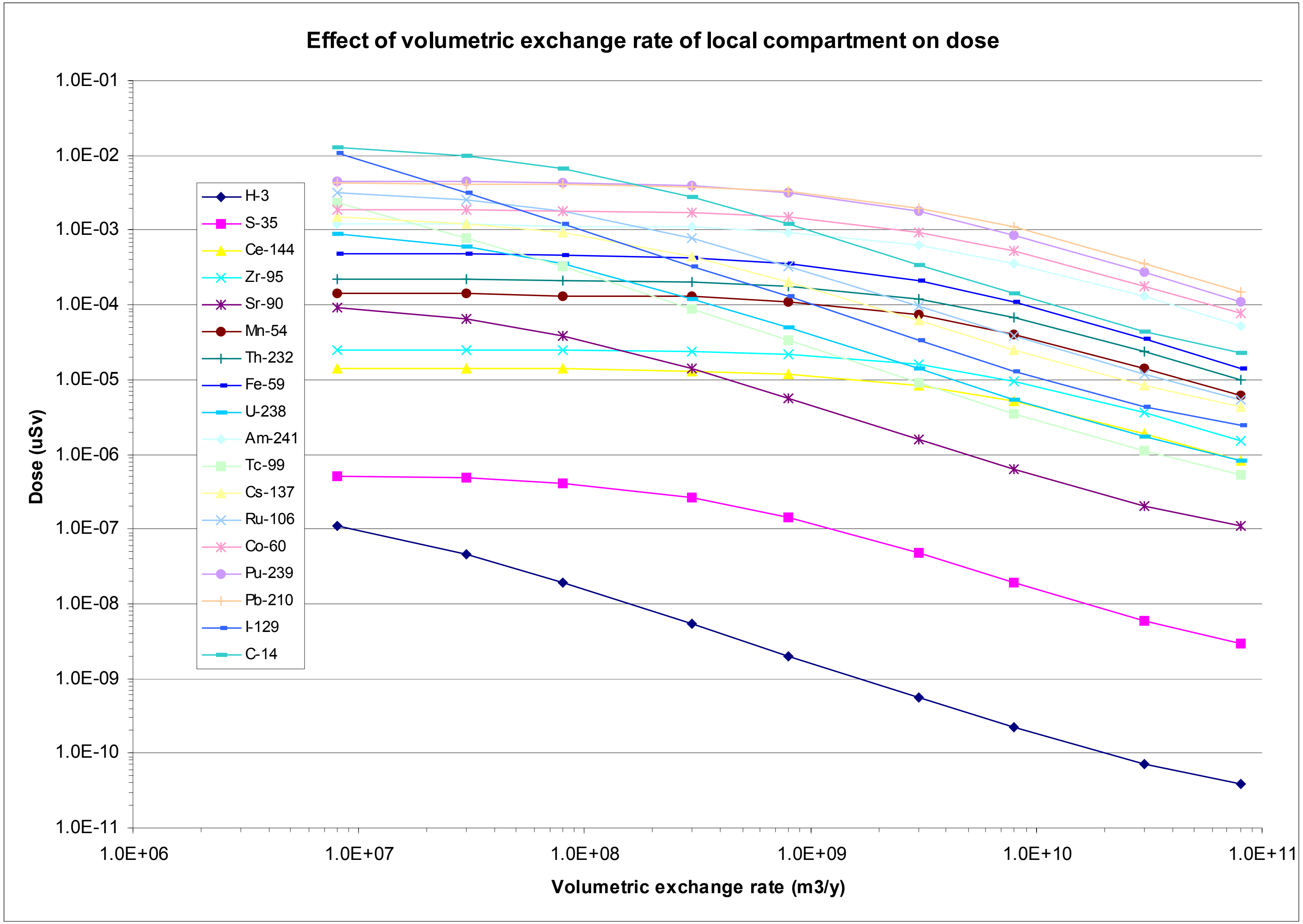

Figure E.2 Effect of volumetric exchange rate of local compartment on dose

Appendix F Input data and calculation of DPUR values 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 population groups

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

Angler family

Relevant pathways are:

- internal irradiation from the consumption of drinking water, assuming commercial abstraction from the river or a well on the bank;
- internal irradiation 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^{-1} was taken for adults, from generalised data published by the NRPB [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.

Irrigated food consumer family

Relevant pathway:

- internal irradiation from the consumption of appropriate terrestrial food types incorporating radionuclides from irrigation water.

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 0.1 m^3

per m^2 y^{-1} was used [F.2] and irrigation carried out with unfiltered river water. Habit data for the irrigated food consumer family exposure group are shown in Table F.2.

Figure F.1 shows the resulting matrix of pathways that were evaluated. Inadvertent ingestion of 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 and bank sediments

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^{-1} was adopted, which was taken to be 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^{-1};
- all flow rates remain constant;
- instantaneous and complete dilution of the radionuclides at the discharge point with the river flow takes place;
- no downstream transport takes place and, as a consequence, no radioactive decay;
- 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; 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^{-1})
	Q	is discharge rate (Bq s^{-1})
	V	is river volumetric flow rate (l s^{-1})

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

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

where C_{Sed} is activity concentration in sediments (Bq kg^{-1})
C_{filt} is activity concentration in *filtered* river water (Bq l^{-1})
K_d is freshwater sediment distribution coefficient (Bq kg^{-1} per Bq l^{-1})

and where 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^{-1})

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. 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 listed in Table F.4, together with relevant data sources.

The resulting activity concentrations in river water and bank sediment 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] were applied. A well-mixed profile to infinite depth was assumed, except for radionuclides with half-lives of less than 2 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^{-1}), 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 shorelines, was applied [F.6].

For the purpose of calculating external dose, dose coefficients for daughters 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. This has been carried out for the following parent/daughter(s): $^{47}Ca/^{47}Sc$, $^{90}Sr/^{90}Y$, $^{95}Zr/^{95}Nb$, $^{99}Mo/^{99m}Tc$, $^{106}Ru/^{106}Rh$, $^{137}Cs/^{137m}Ba$, $^{140}Ba/^{140}La$, $^{144}Ce/^{144}Pr$, $^{210}Pb/^{210}Bi/^{210}Po$, ^{223}Ra through to ^{208}Tl, $^{226}Ra/^{222}Rn$ through to ^{210}Pb, $^{232}Th/^{228}Ra$ through to ^{208}Tl, $^{234}Th/^{234m}Pa/^{234}Pa$, $^{235}U/^{231}Th$, $^{238}U/^{234}Th/^{234m}Pa/^{234}Pa$, $^{237}Np/^{233}Pa$,

$^{242}Am/^{242}Cm$ and $^{234}Am/^{239}Np$. The resulting dose rates for external exposure above contaminated bank sediments per unit activity concentration in sediments are shown in Table F.6.

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 (μSv h^{-1} per Bq kg^{-1})

$DR_{ext\_river(u)}$ is external dose rate per unit activity concentration in river bank sediments (μSv h^{-1} per Bq kg^{-1})

A_{sed} is activity concentration in river bank sediments (Bq kg^{-1} per Bq y^{-1})

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

F.5 Activity concentrations in fish

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^{-1} per Bq y^{-1})

A_{water} is activity concentration in filtered river water per unit release rate (Bq l^{-1} per Bq y^{-1})

CF_{fish} is the concentration factor for freshwater fish (Bq kg^{-1} per Bq l^{-1})

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

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 0.1 m^3 y^{-1} per m^2 (or 3.2E-06 l s^{-1} per m^2) of irrigated land. This irrigation rate is appropriate for UK climate and soil conditions and is sustainable regarding a volumetric flow rate of the river of 1 m^3 s^{-1} [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^{-1} per

Bq m^{-2} s^{-1}) grown on irrigated soil have been calculated using the PC CREAM 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 ^{3}H and ^{14}C

For ^{3}H and ^{14}C 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 (HTO) 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 ^{14}C, the interception by plants of ^{14}C in water, translocation through the leaves, root uptake and direct uptake of ^{14}C in air were included [F.8]. In the absence of more specific data the activity concentrations of ^{3}H and ^{14}C 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^{-1} per Bq y^{-1})

$A_{food(u)}$ is activity concentration in food products per unit deposition rate (Bq kg^{-1} per Bq m^{-2} s^{-1})

I_{app} is irrigation water application rate (l s^{-1} per m^{2})

C_{unf} is activity concentration in unfiltered river water per unit discharge into the river (Bq l^{-1} per Bq y^{-1})

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

F.7 Method to calculate DPUR factors

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 for the age group considered (μSv y^{-1} per Bq y^{-1})

DR_{ext} is external dose rate from river bank sediments (μSv h^{-1} per Bq y^{-1})

$H_{occc,a}$ is total occupancy on the river banks for the age group considered (h y^{-1})

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^{-1} per Bq y^{-1})

A_{food} is activity concentration in the foodstuff or water considered (Bq kg^{-1} or Bq l^{-1} per Bq y^{-1})

$I_{food,a}$ is ingestion rate of the foodstuff or water for the age group considered (kg y^{-1})

$DF_{ing,a}$ is ingestion dose coefficient for the age group considered (µSv Bq^{-1})

The resulting DPUR factors are listed in Tables 13–16 in the main report for the angler family exposure group and Tables 18–21 for the irrigated food consumer family exposure group.

F.8 References

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

F.2 Harvey, M P and Simmonds, J R (2002). Generalised Derived Constraints for Radioisotopes of Polonium, Lead, Radium and Uranium. Doc NRPB, 13(2), 1–38.

F.3 Jones, K A, Walsh C, Bexon A, Simmonds, J R, Jones A L, Harvey M, Artmann, A and Martens, R (2002). Guidance on the Assessment of Radiation Doses to Members of the Public due to the Operation of Nuclear Installations under Normal Conditions. Report produced for DG Environment of the European Commission. Contract B4-0304/99/136234/MAR/C1.

F.4 McDonnell, C E (1996). Assessment of the Radiological Consequences of Accumulation and Disposal of Radioactive Wastes by Small Users of Radioactive Materials. NRPB M-744.

F.5 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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F.7 Simmonds, J R, Lawson, G and Mayall, A (1995). Methodology for Assessing the Radiological Consequences of Routine Releases of Radionuclides to the Environment. European Commission, Luxembourg, EUR 15760 EN, Radiation Protection 72.

F.8 Jones, A L, Harvey, M P and Simmonds, J R (2005). Generalised Derived Limits for Radioisotopes of Hydrogen, Carbon, Phosphorus, Sulphur, Chromium, Manganese, Cobalt, Zinc, Selenium, Technetium, Antimony, Thorium and Neptunium. Doc NRPB, 16(3), 1–45.

F.9 Smith, J T, Bowes, M and Denison, F H (2002). Modelling the Dispersion of Radionuclides Following Short Duration Releases to Rivers. Environment Agency R&D Technical Report P3-074/TR.

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F.11 IAEA (1994). Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments. IAEA Technical Report Series No 364.

F.12 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.

F.13 Coughtrey, P J, Jackson, D and Thorne, M C (1985). Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems, Volume 6, A A Balkema, Rotterdam.

F.14 Staven, L H, Rhoads, K, Napier, B A and Strenge, D L (2003). A Compendium of Transfer Factors for Agricultural and Animal Products. A report prepared for the US Department of Energy. PNNL-13421.

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

	Infant	Child	Adult	Comment
Consumption rates				
Freshwater fish (kg y^{-1})	1	5	20	[F.1]
Water (l y^{-1})	260	350	600	[F.1]
Occupancy on bank sediments (h y^{-1})	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^{-1})				[F.1]
Green vegetables	15	35	80	
Root vegetables	45	95	130	
Fruit	35	50	75	

Table F.3 Parameters characterising the river

	Value	Comment
River flow rate (m^3 s^{-1})	1	[F.2]
Suspended sediment load (kg l^{-1})	4.0E-05	[F.2]
Irrigation rate (m^3 per m^2 y^{-1})	0.1	[F.2]

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

Radionuclide	Sediment/freshwater K_d (Bq kg^{-1} per Bq l^{-1})		Fish/freshwater concentration factor (Bq kg^{-1} per Bq l^{-1})	
	K_d	Comment#	Concentration factor	Comment#
H-3	0.03		0.9	
H-3 organic	0.03		22,000	as C-14+
C-14	2,000		22,000	[F.9]
Na-22	6	[F.4,F.10]	20	[F.11]
Na-24	6	[F.4,F.10]	20	[F.11]
P-32	1,000		10,000	[F.9]
P-33	1,000		10,000	[F.9]
S-35	3,000		200	
Cl-36	0	is non-sorbing+	50	[F.4,F.10]
Ca-45	2,000	as Sr+	40	[F.4,F.10]
Ca-47	2,000	as Sr+	40	[F.4,F.10]
V-48	100	as Nb+	30,000	as Nb+
Cr-51	20,000		40	
Mn-52	50,000		100	
Mn-54	50,000		100	
Fe-55	10,000		100	
Fe-59	10,000		100	
Co-56	20,000		300	
Co-57	20,000		300	
Co-58	20,000		300	
Co-60	20,000		300	
Ni-63	20,000	as Co+	100	[F.11]
Zn-65	1,000		5,000	[F.9]
Ga-67	200	based on Si in soils+	400	[F.12]
Se-75	1,000	based on seawater+	200	[F.12]
Br-82	0	is non-sorbing+	400	[F.11]
Rb-83	10,000	[F.13]	2,000	[F.11]
Sr-89	2,000		60	
Sr-90	2,000		60	
Y-90	4,000		25	
Zr-95	60,000		300	[F.11]
Nb-95	100		300	[F.11]
Mo-99	1,000	[F.4]	10	[F.11]
Tc-99	200		15	
Tc-99m	200		15	
Ru-103	7,000		10	
Ru-106	7,000		10	
Ag-110m	200		2.3	
In-111	100,000	based on seawater+	10,000	[F.12]
Sb-125	500		1	

Table F.4 continued

Radionuclide	Sediment/freshwater K_d (Bq kg^{-1} per Bq l^{-1})		Fish/freshwater concentration factor (Bq kg^{-1} per Bq l^{-1})	
	K_d	Comment#	Concentration factor	Comment#
I-123	300		40	[F.9]
I-125	300		40	[F.9]
I-129	300		40	[F.9]
I-131	300		40	[F.9]
I-133	300		40	[F.9]
I-135	300		40	[F.9]
Cs-134	2,000		2,000	
Cs-136	2,000		2,000	
Cs-137	2,000		2,000	
Ba-140	5,000	based on seawater+	4	[F.12]
La-140	30,000	as Ce+	4	[F.12]
Ce-141	30,000		30	
Ce-144	30,000		30	
Pm-147	5,000	[F.11]	30	[F.11]
Sm-153	30,000	as Ce+	30	[F.14]
Eu-152	30,000		25	
Eu-154	30,000		25	
Eu-155	30,000		25	
Er-169	30,000	as Ce+	25	[F.4]
Lu-177	30,000	as Ce+	30	as Ce+
Au-198	30,000	as Ce+	30	[F.4]
Tl-201	20,000	based on seawater+	10,000	[F.4]
Pb-210	6,700	+	300	[F.11]
Po-210	6,700	+	50	[F.11]
Ra-223	500		50	
Ra-226	500		50	
Th-230	10,000	[F.11]	100	[F.11]
Th-232	10,000	[F.11]	100	[F.11]
Th-234	10,000	[F.11]	100	[F.11]
U-234	50		50	[F.9]
U-235	50		50	[F.9]
U-238	50		50	[F.9]
Np-237	10	[F.11]	30	[F.11]
Pu-238	100,000		50	[F.9]
Pu-239	100,000		50	[F.9]
Pu-240	100,000		50	[F.9]
Pu-241	100,000		50	[F.9]
Pu-242	100,000		50	[F.9]
Am-241	400,000		1,000	[F.9]
Am-242	400,000		1,000	[F.9]
Am-243	400,000		1,000	[F.9]
Cm-242	400,000		25	
Cm-243	400,000		25	
Cm-244	400,000		25	

where no comment made, value taken from PC CREAM databases
+ see Table C.1 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^{-1} per Bq y^{-1})	Filtered water (Bq l^{-1} per Bq y^{-1})	Bank sediment (Bq kg^{-1} per Bq y^{-1})	Freshwater fish (Bq kg^{-1} per Bq y^{-1})
H-3	3.2E-11	3.2E-11	9.5E-13	2.9E-11
H-3 organic	3.2E-11	3.2E-11	9.5E-13	7.0E-07
C-14	3.2E-11	2.9E-11	5.8E-08	6.3E-07
Na-22	3.2E-11	3.2E-11	1.9E-10	6.3E-10
Na-24	3.2E-11	3.2E-11	1.9E-10	6.3E-10
P-32	3.2E-11	3.0E-11	3.0E-08	3.0E-07
P-33	3.2E-11	3.0E-11	3.0E-08	3.0E-07
S-35	3.2E-11	2.8E-11	8.3E-08	5.5E-09
Cl-36	3.2E-11	3.2E-11	0.0E+00	1.6E-09
Ca-45	3.2E-11	2.9E-11	5.8E-08	1.2E-09
Ca-47	3.2E-11	2.9E-11	5.8E-08	1.2E-09
V-48	3.2E-11	3.2E-11	3.2E-09	9.5E-07
Cr-51	3.2E-11	1.6E-11	3.2E-07	6.3E-10
Mn-52	3.2E-11	9.1E-12	4.5E-07	9.1E-10
Mn-54	3.2E-11	9.1E-12	4.5E-07	9.1E-10
Fe-55	3.2E-11	2.1E-11	2.1E-07	2.1E-09
Fe-59	3.2E-11	2.1E-11	2.1E-07	2.1E-09
Co-56	3.2E-11	1.6E-11	3.2E-07	4.8E-09
Co-57	3.2E-11	1.6E-11	3.2E-07	4.8E-09
Co-58	3.2E-11	1.6E-11	3.2E-07	4.8E-09
Co-60	3.2E-11	1.6E-11	3.2E-07	4.8E-09
Ni-63	3.2E-11	1.6E-11	3.2E-07	1.6E-09
Zn-65	3.2E-11	3.0E-11	3.0E-08	1.5E-07
Ga-67	3.2E-11	3.1E-11	6.3E-09	1.3E-08
Se-75	3.2E-11	3.0E-11	3.0E-08	6.0E-09
Br-82	3.2E-11	3.2E-11	0.0E+00	1.3E-08
Rb-83	3.2E-11	2.1E-11	2.1E-07	4.2E-08
Sr-89	3.2E-11	2.9E-11	5.8E-08	1.7E-09
Sr-90	3.2E-11	2.9E-11	5.8E-08	1.7E-09
Y-90	3.2E-11	2.6E-11	1.1E-07	6.6E-10
Zr-95	3.2E-11	7.9E-12	4.8E-07	2.4E-09
Nb-95	3.2E-11	3.2E-11	3.2E-09	9.5E-09
Mo-99	3.2E-11	3.0E-11	3.0E-08	3.0E-10
Tc-99	3.2E-11	3.1E-11	6.3E-09	4.7E-10
Tc-99m	3.2E-11	3.1E-11	6.3E-09	4.7E-10
Ru-103	3.2E-11	2.3E-11	1.6E-07	2.3E-10
Ru-106	3.2E-11	2.3E-11	1.6E-07	2.3E-10
Ag-110m	3.2E-11	3.1E-11	6.3E-09	7.2E-11
In-111	3.2E-11	5.3E-12	5.3E-07	5.3E-08
Sb-125	3.2E-11	3.1E-11	1.5E-08	3.1E-11
I-123	3.2E-11	3.1E-11	9.4E-09	1.2E-09
I-125	3.2E-11	3.1E-11	9.4E-09	1.2E-09
I-129	3.2E-11	3.1E-11	9.4E-09	1.2E-09
I-131	3.2E-11	3.1E-11	9.4E-09	1.2E-09
I-133	3.2E-11	3.1E-11	9.4E-09	1.2E-09
I-135	3.2E-11	3.1E-11	9.4E-09	1.2E-09

Table F.5 continued

Radionuclide	Activity concentration*			
	Unfiltered water ($Bq\ l^{-1}$ per $Bq\ y^{-1}$)	Filtered water ($Bq\ l^{-1}$ per $Bq\ y^{-1}$)	Bank sediment ($Bq\ kg^{-1}$ per $Bq\ y^{-1}$)	Freshwater fish ($Bq\ kg^{-1}$ per $Bq\ y^{-1}$)
Cs-134	3.2E-11	2.9E-11	5.8E-08	5.8E-08
Cs-136	3.2E-11	2.9E-11	5.8E-08	5.8E-08
Cs-137	3.2E-11	2.9E-11	5.8E-08	5.8E-08
Ba-140	3.2E-11	2.5E-11	1.3E-07	1.0E-10
La-140	3.2E-11	1.3E-11	3.8E-07	5.1E-11
Ce-141	3.2E-11	1.3E-11	3.8E-07	3.8E-10
Ce-144	3.2E-11	1.3E-11	3.8E-07	3.8E-10
Pm-147	3.2E-11	2.5E-11	1.3E-07	7.6E-10
Sm-153	3.2E-11	1.3E-11	3.8E-07	3.8E-10
Eu-152	3.2E-11	1.3E-11	3.8E-07	3.2E-10
Eu-154	3.2E-11	1.3E-11	3.8E-07	3.2E-10
Eu-155	3.2E-11	1.3E-11	3.8E-07	3.2E-10
Er-169	3.2E-11	1.3E-11	3.8E-07	3.2E-10
Lu-177	3.2E-11	1.3E-11	3.8E-07	3.8E-10
Au-198	3.2E-11	1.3E-11	3.8E-07	3.8E-10
Tl-201	3.2E-11	1.6E-11	3.2E-07	1.6E-07
Pb-210	3.2E-11	2.4E-11	1.6E-07	7.1E-09
Po-210	3.2E-11	2.4E-11	1.6E-07	1.2E-09
Ra-223	3.2E-11	3.1E-11	1.5E-08	1.5E-09
Ra-226	3.2E-11	3.1E-11	1.5E-08	1.5E-09
Th-230	3.2E-11	2.1E-11	2.1E-07	2.1E-09
Th-232	3.2E-11	2.1E-11	2.1E-07	2.1E-09
Th-234	3.2E-11	2.1E-11	2.1E-07	2.1E-09
U-234	3.2E-11	3.2E-11	1.6E-09	1.6E-09
U-235	3.2E-11	3.2E-11	1.6E-09	1.6E-09
U-238	3.2E-11	3.2E-11	1.6E-09	1.6E-09
Np-237	3.2E-11	3.2E-11	3.2E-10	9.5E-10
Pu-238	3.2E-11	5.3E-12	5.3E-07	2.6E-10
Pu-239	3.2E-11	5.3E-12	5.3E-07	2.6E-10
Pu-240	3.2E-11	5.3E-12	5.3E-07	2.6E-10
Pu-241	3.2E-11	5.3E-12	5.3E-07	2.6E-10
Pu-242	3.2E-11	5.3E-12	5.3E-07	2.6E-10
Am-241	3.2E-11	1.5E-12	6.0E-07	1.5E-09
Am-242	3.2E-11	1.5E-12	6.0E-07	1.5E-09
Am-243	3.2E-11	1.5E-12	6.0E-07	1.5E-09
Cm-242	3.2E-11	1.5E-12	6.0E-07	3.8E-11
Cm-243	3.2E-11	1.5E-12	6.0E-07	3.8E-11
Cm-244	3.2E-11	1.5E-12	6.0E-07	3.8E-11

*for a river flow rate of 1 $m^3\ s^{-1}$

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

Radionuclide	Dose rate above sediment ($\mu Sv\ h^{-1}$ per $Bq\ kg^{-1}$)			
	Dose rate parent	Dose rate including all daughters	Comments	Dose rate after application of river bank scaling factor
H-3	0.0E+00	0.0E+00		0.0E+00
H-3 organic	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	6.3E-07	6.3E-07		1.3E-07
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	5.4E-04	5.4E-04		1.1E-04
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
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-82	9.1E-05	9.1E-05		1.8E-05
Rb-83	8.5E-05	8.5E-05		1.7E-05
Sr-89	4.7E-07	4.7E-07		9.3E-08
Sr-90	2.0E-08	1.5E-07	Y-90 included	2.9E-08
Y-90	7.3E-07	7.3E-07		1.5E-07
Zr-95	1.3E-04	1.6E-04	Nb-95 included since significant decay in 1 year	3.1E-05
Nb-95	1.4E-04	1.4E-04		2.7E-05
Mo-99	5.3E-06	6.2E-06	Tc-99m included. Tc-99 not included since much longer half-life	1.2E-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-06	Rh-106 included	7.7E-07
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	5.1E-06	5.1E-06		1.0E-06
I-125	3.7E-07	3.7E-07		7.3E-08
I-129	2.9E-07	2.9E-07		5.9E-08

Table F.6 continued

Radionuclide	Dose rate above sediment (µSv h^{-1} per Bq kg^{-1})			
	Dose rate parent	Dose rate including all daughters	Comments	Dose rate after application of river bank scaling factor
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-06	Ba-137m included	2.0E-06
Ba-140	6.3E-06	1.5E-05	La-140 included	2.9E-06
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	3.0E-06	Pr-144 included	6.0E-07
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	1.1E-06	1.1E-06		2.3E-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	8.4E-08	Bi-210 and Po-210 included	1.7E-08
Po-210	1.5E-09	1.5E-09		3.0E-10
Ra-223	4.3E-06	1.0E-05	Rn-219 through to Tl-208 included	2.0E-06
Ra-226	9.0E-07	3.4E-05	Rn-222 through to Pb-210 included	6.7E-06
Th-230	3.3E-08	3.3E-08		6.6E-09
Th-232	1.4E-08	4.7E-05	Ra-228 through to Tl-208 included	9.5E-06
Th-234	6.6E-07	1.1E-06	Pa-234m and Pa-234 included, half-life of rest of chain too long	2.2E-07
U-234	1.1E-08	1.1E-08		2.1E-09
U-235	2.0E-05	2.2E-05	Th-231 only included	4.5E-06
U-238	2.5E-09	4.4E-07	Th-234, etc. included	8.8E-08
Np-237	2.1E-06	5.3E-06	Pa-233 only included	1.1E-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	4.7E-07	Cm-242 included since significant decay in 1 year. Pu-242 not included half-life too long	9.5E-08
Am-243	3.8E-06	6.3E-06	Np-239 only included	1.3E-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 ($\mu Sv\ h^{-1}$ per $Bq\ y^{-1}$)*
H-3	0.0E+00
H-3 organic	0.0E+00
C-14	3.9E-18
Na-22	1.5E-14
Na-24	5.1E-15
P-32	3.8E-15
P-33	9.4E-18
S-35	6.2E-18
Cl-36	0.0E+00
Ca-45	1.9E-17
Ca-47	4.6E-13
V-48	3.4E-13
Cr-51	3.2E-13
Mn-52	1.1E-11
Mn-54	1.4E-11
Fe-55	0.0E+00
Fe-59	9.4E-12
Co-56	4.4E-11
Co-57	8.9E-13
Co-58	1.1E-11
Co-60	3.0E-11
Ni-63	0.0E+00
Zn-65	6.5E-13
Ga-67	6.5E-15
Se-75	3.4E-13
Br-82	0.0E+00
Rb-83	3.6E-12
Sr-89	5.4E-15
Sr-90	1.4E-14
Y-90	1.5E-14
Zr-95	2.5E-11
Nb-95	8.6E-14
Mo-99	5.4E-14
Tc-99	4.2E-18
Tc-99m	5.2E-15
Ru-103	2.6E-12
Ru-106	1.3E-12
Ag-110m	6.3E-13
In-111	1.4E-12
Sb-125	2.2E-13
I-123	9.6E-15
I-125	6.9E-16
I-129	5.5E-16
I-131	2.5E-14
I-133	4.0E-14
I-135	1.0E-13
Cs-134	3.2E-12
Cs-136	8.6E-13
Cs-137	1.1E-12

Table F.7 continued

Radionuclide	Dose rate per unit release ($\mu Sv\ h^{-1}$ per $Bq\ y^{-1}$)*
Ba-140	2.1E-12
La-140	6.0E-12
Ce-141	6.8E-13
Ce-144	7.7E-13
Pm-147	3.4E-17
Sm-153	1.2E-13
Eu-152	1.6E-11
Eu-154	1.7E-11
Eu-155	3.8E-13
Er-169	1.2E-16
Lu-177	8.7E-14
Au-198	1.1E-12
Tl-201	1.7E-13
Pb-210	7.3E-15
Po-210	4.8E-17
Ra-223	1.8E-13
Ra-226	1.0E-12
Th-230	1.4E-15
Th-232	2.0E-11
Th-234	1.8E-13
U-234	3.4E-18
U-235	6.7E-15
U-238	1.4E-15
Np-237	2.0E-15
Pu-238	3.8E-16
Pu-239	8.6E-16
Pu-240	3.7E-16
Pu-241	1.7E-17
Pu-242	3.2E-16
Am-241	1.4E-13
Am-242	5.2E-14
Am-243	3.0E-12
Cm-242	4.8E-16
Cm-243	2.0E-12
Cm-244	3.3E-16

*for a river flow rate of 1 $m^3\ s^{-1}$

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 ($Bq\ kg^{-1}$ per $Bq\ m^{-2}\ s^{-1}$)		
	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	1.5E+05	1.3E+05	7.3E+04
Na-24	4.5E+03	2.4E+01	3.9E+03
P-32	6.3E+04	5.1E+05	4.1E+04
P-33	8.5E+04	4.7E+04	5.1E+04
S-35	1.2E+05	9.8E+04	6.6E+04
Cl-36	9.2E+06	7.5E+06	4.8E+05
Ca-45	1.3E+05	2.9E+03	1.7E+04
Ca-47	2.7E+04	6.3E+01	5.4E+03
V-48	5.8E+04	4.9E+01	1.1E+04
Cr-51	7.0E+04	2.1E+00	6.6E+03
Mn-52	3.0E+04	1.2E+02	6.2E+03
Mn-54	1.1E+05	7.9E+03	2.2E+04
Fe-55	1.1E+05	2.4E+02	1.8E+04
Fe-59	8.3E+04	5.6E+01	1.5E+04
Co-56	9.3E+04	2.8E+02	1.6E+04
Co-57	1.1E+05	8.1E+02	1.8E+04
Co-58	9.2E+04	2.6E+02	1.6E+04
Co-60	1.2E+05	5.1E+03	4.4E+04
Ni-63	1.4E+05	2.5E+04	3.1E+05
Zn-65	1.6E+05	3.0E+04	3.6E+04
Ga-67	2.0E+04	2.1E-01	4.2E+03
Se-75	1.5E+05	1.2E+05	7.0E+04
Br-82	1.0E+04	1.9E+02	8.7E+03
Rb-83	1.1E+05	8.7E+04	6.5E+04
Sr-89	8.9E+04	7.0E+02	1.5E+04
Sr-90	6.2E+05	8.8E+04	1.3E+05
Y-90	1.7E+04	5.1E+00	3.6E+03
Zr-95	9.0E+04	7.6E+01	1.6E+04
Nb-95	7.8E+04	1.3E+02	1.4E+04
Mo-99	1.7E+04	5.3E+00	3.7E+03
Tc-99	9.2E+06	7.5E+06	3.0E+07
Tc-99m	2.1E+03	2.1E+02	1.6E+03
Ru-103	7.8E+04	1.0E+02	7.2E+03
Ru-106	1.0E+05	9.2E+02	8.9E+03
Ag-110m	1.2E+05	1.2E+04	2.2E+04
In-111	1.8E+04	1.5E-01	3.8E+03
Sb-125	1.1E+05	2.8E+03	2.5E+04
I-123	4.0E+03	1.4E+01	3.5E+03
I-125	1.0E+05	7.4E+04	6.2E+04
I-129	1.9E+05	1.8E+05	2.8E+05
I-131	4.1E+04	8.6E+03	3.1E+04
I-133	6.2E+03	4.7E+01	5.4E+03
I-135	2.0E+03	2.6E+00	1.8E+03

Table F.8 continued

Radionuclide	50th year activity concentrations in foods per unit deposition rate (Bq kg^{-1} per Bq m^{-2} s^{-1})		
	Green vegetables	Root vegetables	Fruit
Cs-134	1.3E+05	1.2E+05	7.2E+04
Cs-136	5.6E+04	1.9E+04	4.0E+04
Cs-137	1.5E+05	1.4E+05	7.5E+04
Ba-140	5.1E+04	2.1E+01	9.8E+03
La-140	1.1E+04	9.3E-01	2.4E+03
Ce-141	7.3E+04	8.4E+00	6.9E+03
Ce-144	1.0E+05	7.0E+01	8.8E+03
Pm-147	1.0E+05	7.4E+02	1.1E+04
Sm-153	1.3E+04	3.6E-01	1.4E+03
Eu-152	1.1E+05	3.4E+03	4.0E+04
Eu-154	1.1E+05	2.4E+03	2.7E+04
Eu-155	1.1E+05	1.4E+03	1.6E+04
Er-169	4.2E+04	2.1E+00	4.2E+03
Lu-177	3.4E+04	1.4E+00	3.5E+03
Au-198	1.7E+04	1.8E+00	1.8E+03
Tl-201	1.9E+04	1.1E+03	1.6E+04
Pb-210	1.3E+05	1.6E+04	1.8E+05
Po-210	1.2E+05	9.7E+04	6.8E+04
Ra-223	4.8E+04	7.0E+00	9.4E+03
Ra-226	1.4E+05	3.1E+03	3.7E+05
Th-230	1.1E+05	1.5E+03	2.7E+04
Th-232	1.1E+05	1.5E+03	2.7E+04
Th-234	6.6E+04	3.1E+00	6.3E+03
U-234	1.1E+05	2.9E+03	4.5E+04
U-235	1.1E+05	2.9E+03	4.5E+04
U-238	1.1E+05	2.9E+03	4.5E+04
Np-237	1.1E+05	2.9E+03	8.2E+04
Pu-238	1.1E+05	1.2E+02	1.0E+04
Pu-239	1.1E+05	1.5E+02	1.1E+04
Pu-240	1.1E+05	1.5E+02	1.1E+04
Pu-241	1.1E+05	5.9E+01	9.6E+03
Pu-242	1.1E+05	1.5E+02	1.1E+04
Am-241	1.1E+05	2.3E+02	1.3E+04
Am-242	4.8E+03	9.2E-03	5.2E+02
Am-243	1.1E+05	2.4E+02	1.3E+04
Cm-242	9.7E+04	1.2E+00	8.6E+03
Cm-243	1.1E+05	4.4E+01	1.1E+04
Cm-244	1.1E+05	4.1E+01	1.1E+04

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

Radionuclide	Activity concentration (Bq kg^{-1} per Bq y^{-1})*		
	Green veg.	Root veg.	Fruit
H-3	5.1E-12	5.1E-12	5.1E-12
H-3 organic	1.1E-12	1.1E-12	1.1E-12
C-14	2.3E-10	1.8E-10	2.3E-10
Na-22	1.5E-11	1.3E-11	7.3E-12
Na-24	4.5E-13	2.4E-15	4.0E-13
P-32	6.3E-12	5.1E-11	4.2E-12
P-33	8.5E-12	4.7E-12	5.1E-12
S-35	1.2E-11	9.8E-12	6.6E-12
Cl-36	9.2E-10	7.5E-10	4.8E-11
Ca-45	1.3E-11	2.9E-13	1.7E-12
Ca-47	2.7E-12	6.4E-15	5.4E-13
V-48	5.8E-12	4.9E-15	1.1E-12
Cr-51	7.0E-12	2.1E-16	6.6E-13
Mn-52	3.0E-12	1.2E-14	6.2E-13
Mn-54	1.1E-11	7.9E-13	2.2E-12
Fe-55	1.1E-11	2.4E-14	1.8E-12
Fe-59	8.3E-12	5.6E-15	1.5E-12
Co-56	9.4E-12	2.8E-14	1.6E-12
Co-57	1.1E-11	8.1E-14	1.8E-12
Co-58	9.2E-12	2.6E-14	1.6E-12
Co-60	1.2E-11	5.1E-13	4.4E-12
Ni-63	1.4E-11	2.5E-12	3.1E-11
Zn-65	1.6E-11	3.0E-12	3.6E-12
Ga-67	2.0E-12	2.1E-17	4.2E-13
Se-75	1.5E-11	1.2E-11	7.0E-12
Br-82	1.0E-12	1.9E-14	8.7E-13
Rb-83	1.1E-11	8.7E-12	6.5E-12
Sr-89	9.0E-12	7.1E-14	1.5E-12
Sr-90	6.2E-11	8.9E-12	1.3E-11
Y-90	1.7E-12	5.1E-16	3.6E-13
Zr-95	9.0E-12	7.6E-15	1.6E-12
Nb-95	7.8E-12	1.3E-14	1.4E-12
Mo-99	1.7E-12	5.3E-16	3.7E-13
Tc-99	9.2E-10	7.5E-10	3.0E-09
Tc-99m	2.1E-13	2.1E-14	1.6E-13
Ru-103	7.8E-12	1.0E-14	7.2E-13
Ru-106	1.0E-11	9.2E-14	8.9E-13
Ag-110m	1.2E-11	1.2E-12	2.2E-12
In-111	1.8E-12	1.5E-17	3.8E-13
Sb-125	1.1E-11	2.8E-13	2.5E-12
I-123	4.0E-13	1.4E-15	3.5E-13
I-125	1.0E-11	7.4E-12	6.2E-12
I-129	1.9E-11	1.8E-11	2.8E-11
I-131	4.1E-12	8.7E-13	3.1E-12
I-133	6.2E-13	4.7E-15	5.4E-13
I-135	2.0E-13	2.6E-16	1.8E-13

Table F.9 continued

Radionuclide	Activity concentration (Bq kg^{-1} per Bq y^{-1})*		
	Green veg.	Root veg.	Fruit
Cs-134	1.3E-11	1.2E-11	7.3E-12
Cs-136	5.7E-12	1.9E-12	4.0E-12
Cs-137	1.5E-11	1.4E-11	7.5E-12
Ba-140	5.1E-12	2.1E-15	9.9E-13
La-140	1.1E-12	9.4E-17	2.4E-13
Ce-141	7.4E-12	8.4E-16	6.9E-13
Ce-144	1.0E-11	7.0E-15	8.9E-13
Pm-147	1.0E-11	7.5E-14	1.1E-12
Sm-153	1.3E-12	3.6E-17	1.4E-13
Eu-152	1.1E-11	3.4E-13	4.0E-12
Eu-154	1.1E-11	2.4E-13	2.7E-12
Eu-155	1.1E-11	1.4E-13	1.6E-12
Er-169	4.2E-12	2.1E-16	4.2E-13
Lu-177	3.4E-12	1.4E-16	3.5E-13
Au-198	1.7E-12	1.8E-16	1.8E-13
Tl-201	1.9E-12	1.1E-13	1.6E-12
Pb-210	1.3E-11	1.6E-12	1.8E-11
Po-210	1.2E-11	9.8E-12	6.8E-12
Ra-223	4.8E-12	7.1E-16	9.4E-13
Ra-226	1.4E-11	3.1E-13	3.7E-11
Th-230	1.1E-11	1.5E-13	2.7E-12
Th-232	1.1E-11	1.5E-13	2.7E-12
Th-234	6.7E-12	3.1E-16	6.3E-13
U-234	1.1E-11	3.0E-13	4.6E-12
U-235	1.1E-11	3.0E-13	4.6E-12
U-238	1.1E-11	3.0E-13	4.6E-12
Np-237	1.1E-11	3.0E-13	8.2E-12
Pu-238	1.1E-11	1.2E-14	1.0E-12
Pu-239	1.1E-11	1.5E-14	1.1E-12
Pu-240	1.1E-11	1.5E-14	1.1E-12
Pu-241	1.1E-11	5.9E-15	9.6E-13
Pu-242	1.1E-11	1.5E-14	1.1E-12
Am-241	1.1E-11	2.3E-14	1.3E-12
Am-242	4.8E-13	9.2E-19	5.3E-14
Am-243	1.1E-11	2.4E-14	1.3E-12
Cm-242	9.7E-12	1.2E-16	8.6E-13
Cm-243	1.1E-11	4.4E-15	1.1E-12
Cm-244	1.1E-11	4.1E-15	1.1E-12

*for a river flow rate of 1 m^3 s^{-1}

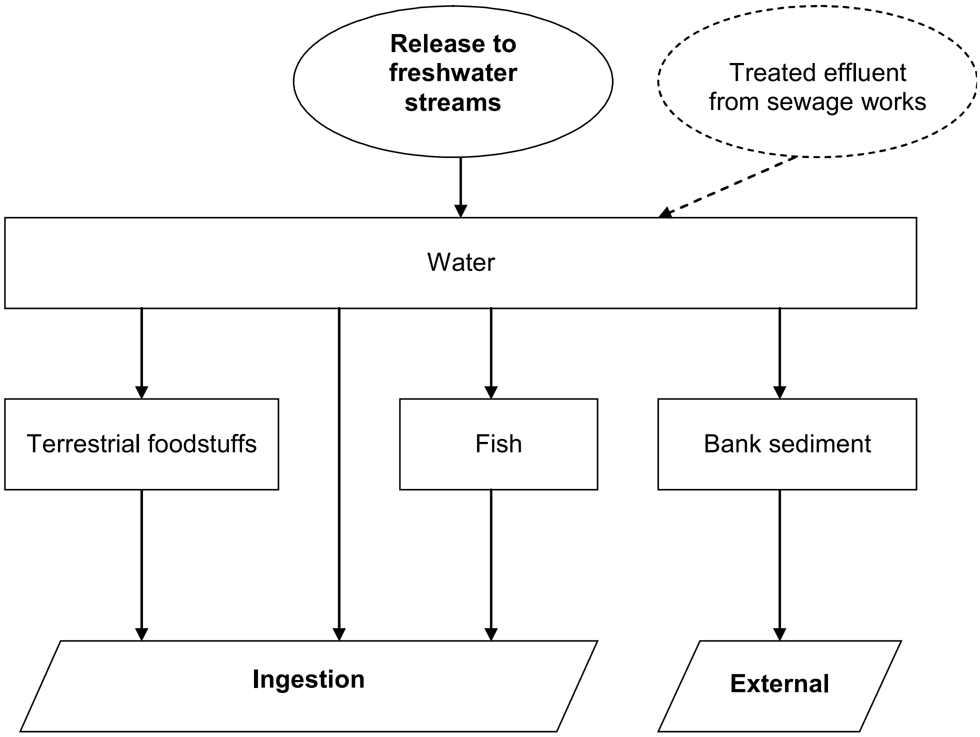

Figure F.1 Flow diagram of river pathways

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

G.1 Source term

Releases can take place directly to a public sewer, where a variety of treatment processes result in the partitioning of the radionuclides between liquid effluent and sewage sludge. The liquid effluent can then be discharged into freshwater streams and rivers or the estuarine and coastal environments. As a result the impact on river and coastal exposure groups (see Appendices E and F) might 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 population groups

The following exposed population groups were considered.

Sewage treatment workers (adult only)
Relevant pathways are:

- external radiation from radionuclides in raw sewage and sewage sludge;
- internal irradiation from the inadvertent inhalation of raw sewage and sewage sludge;
- internal irradiation 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^{-1}) 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. Average 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 land conditioning (not considered for radionuclides with half-lives of less than 4 days)
Relevant pathways are:

- external radiation from radionuclides in sludge conditioned soil;
- internal irradiation from the inadvertent inhalation of resuspended soil;
- internal irradiation from the inadvertent ingestion of soil;
- internal irradiation from the consumption of appropriate food types produced on sludge conditioned land.

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.

Figure G.1 shows the resulting matrix of pathways that were evaluated. An additional exposure group was evaluated, specifically for assessing exposure following treated effluent being discharged into a small stream or brook.

Children playing in brook carrying treated effluent (children only)
Relevant pathways are:

- external radiation from radionuclides in river bank sediments;
- internal irradiation from the inadvertent ingestion of brook water;
- internal irradiation 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 river water and river 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. A representative occupancy rate of 500 h y^{-1} and inadvertent sediment ingested rate of 10 mg h^{-1} were adopted [G.3]. A value of 10 ml h^{-1} was assumed for the inadvertent ingestion of river water, based on a value of 0.7 ml h^{-1} 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.

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.

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 (Bq kg^{-1} per Bq y^{-1})
	Q	is discharge rate (Bq y^{-1})
	V	is volumetric flow rate of the sewage treatment works (l y^{-1})
	ρ_{raw}	is density of raw sewage (kg l^{-1})

A representative flow rate of 60 m^3 d^{-1} (2.2E+07 l y^{-1}) 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 656 hours for conditioned sewage sludge, including 306 hours assumed for digestion and processing and 350 hours for storage [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-02 Bq kg^{-1} per Bq y^{-1} discharged for all radionuclides, assuming a density of 1 kg l^{-1} of raw sewage.

For the partitioning of the radionuclides between the sewage sludge and liquid effluent, experimental or field study data was used as available. 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^{-1}) were assumed to remain mainly in the liquid effluent (90% liquid, 10% sludge);
- radionuclides with a high partition coefficient (>5,000 l kg^{-1}) 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 sludge and organic soil are listed in Table G.5, together with relevant data sources.

The activity concentration in treated effluent per unit discharge is given by:

$$C_{eff} = C_{raw} \; F_{eff}$$

where	C_{eff}	is activity concentration in the liquid effluent per unit discharge (Bq kg^{-1} per Bq y^{-1})
	C_{raw}	is activity concentration in unfiltered raw sewage (Bq kg^{-1} per Bq y^{-1})
	F_{eff}	is fraction of activity which remains in the liquid effluent (see Table G.5)

The production of sewage sludge involves separating and concentrating some of the suspended solids present in the sewage sludge. 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 per unit discharge is given by:

$$C_{slu} = C_{raw} \; F_{slu} \; \frac{SS_{slu}}{SS_{raw}}$$

where C_{slu} is activity concentration in the sludge (Bq kg^{-1} per Bq y^{-1})
C_{raw} is activity concentration in unfiltered raw sewage (Bq kg^{-1} per Bq y^{-1})
F_{slu} is fraction of activity in the sludge (see Table G.5)
SS_{slu} is suspended solid content of the sludge (%)
SS_{raw} is suspended solid content of the raw sewage (%)

For pathways resulting from exposure to raw sewage and sewage sludge at the sewage treatment works average 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^{-1})
$f(t)$ = $C_0 \; e^{-\lambda\, t}$
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^{-1})
λ is decay constant (h^{-1})

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.

To calculate activity concentrations in the sewage sludge as it is applied to agricultural soils, decay during the 656 h residence time was included.

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. Activity concentration and doses resulting from the discharge of the effluent into a small brook were derived as detailed in Appendix F. The parameters characterising the brook are shown in Table G.8. 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 the activity concentration in the effluent was converted to a discharge rate as follows:

$$Q_{eff} = C_{eff}\ V$$

where Q_{eff} is discharge rate of activity from the sewage treatment works per unit discharge into the sewage treatment works (Bq y^{-1} per Bq y^{-1})

C_{eff} is activity concentration in the liquid effluent per unit discharge rate (Bq l^{-1} per Bq y^{-1})

V is volumetric flow rate of the sewage treatment works (l y^{-1})

The discharge rates of activity in the liquid effluent per unit release are shown in Table G.9. Water and sediment concentrations in the small brook per unit release into the sewage treatment works 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 contaminated soil listed in Eckerman and Leggett and Eckerman and Ryman [G.4,G.5] were used and converted from a volume source (Bq m^{-3}) to a source per unit mass basis (Bq kg^{-1}), applying a soil density of 1,600 kg m^{-3} [G.5]. 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 measured per unit sewage/sludge mass rather than per unit volume [G.6]. It was cautiously assumed that an exposure geometry of an infinite horizontal extend could be applied.

External exposure from raw sewage and 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^{-1} to sewage, for which the average integrated activity concentration over the transit time of the liquid effluent (15 h) has been calculated, was assumed. The sewage was assumed not to be partitioned and therefore to contain all of the activity. For the dose from the sludge tanks an exposure time of 500 h y^{-1} to sludge, for which the average integrated activity concentration over the time for digestion and storage (656 h) has been calculated, was assumed. The sludge was assumed to contain only the activity left after partitioning from the liquid phase.

Dose coefficients for daughters 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 656 hours was taken as a benchmark, rather than the effluent residency time of 15 hours. This has been carried out for the following parent/daughter(s): ^{47}Ca/^{47}Sc, ^{90}Sr/^{90}Y, ^{99}Mo/^{99m}Tc, ^{106}Ru/^{106}Rh, ^{137}Cs/^{137m}Ba, ^{140}Ba/^{140}La, ^{144}Ce/^{144}Pr, ^{210}Pb/^{210}Bi/^{210}Po, ^{223}Ra through to ^{208}Tl, ^{226}Ra/^{222}Rn through to ^{210}Pb, ^{234}Th/^{234m}Pa/^{234}Pa, ^{235}U/^{231}Th, ^{238}U/^{234}Th/^{234m}Pa/^{234}Pa and ^{234}Am/^{239}Np.

The resulting dose rates for external exposure above raw sewage and sludge per unit activity concentration in raw sewage or sludge are shown in Table G.11.

G.4.2 External exposure from sludge conditioned soil

To calculate the dose rates from external exposure above agricultural soil conditioned with sewage sludge, effective dose coefficients above contaminated soil of an infinite depth, listed in Eckerman and Leggett and Eckerman and Ryman [G.4,G.5], were applied to the soil concentrations (see Section G.4.1). Dose rates were converted from a volume source (Bq m^{-3}) to a source per unit mass basis (Bq kg^{-1}), applying a soil density of 1,600 kg m^{-3} [G.5]. Dose factors were summed for the following parent/daughter(s): $^{47}Ca/^{47}Sc$, $^{90}Sr/^{90}Y$, $^{95}Zr/^{95}Nb$, $^{99}Mo/^{99m}Tc$, $^{106}Ru/^{106}Rh$, $^{137}Cs/^{137m}Ba$, $^{140}Ba/^{140}La$, $^{144}Ce/^{144}Pr$, $^{210}Pb/^{210}Bi/^{210}Po$, ^{223}Ra through to ^{208}Tl, $^{226}Ra/^{222}Rn$ through to ^{210}Pb, $^{232}Th/^{228}Ra$ through to ^{208}Tl, $^{234}Th/^{234m}Pa/^{234}Pa$, $^{235}U/^{231}Th$, $^{238}U/^{234}Th/^{234m}Pa/^{234}Pa$, $^{237}Np/^{233}Pa$, $^{242}Am/^{242}Cm$ and $^{234}Am/^{239}Np$.

The resulting dose rates for external exposure above conditioned soil per unit activity concentration are shown in Table G.12.

G.4.3 External dose rates per unit release

The effective dose rates from external exposure to raw sewage and sludge tanks or 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^{-1} per Bq kg^{-1})

$DR_{ext\_sewage(u)}$ is external dose rate per unit activity concentration in raw sewage, sludge, conditioned soil or sediments (µSv h^{-1} per Bq kg^{-1})

A is activity concentration in raw sewage, sludge, conditioned soil or sediments (Bq kg^{-1} per Bq y^{-1})

The resulting external dose rates per unit release are shown in Table G.13.

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 and liver, milk and sheep meat and liver) and green and root 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.7,G.8].

In contrast to atmospheric deposition, a fraction of which is intercepted by the plant surfaces, for the application of sewage sludge no direct contamination of the pasture or vegetables was assumed. 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.9]. 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) [G.10,G.11] was used to derive concentration factors in terrestrial foodstuffs per unit deposition rate, as a consequence of applying sewage sludge to agricultural land. 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% (default for atmospheric deposition onto pasture 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 very close to the factors calculated for the sewage GDCs and GDLs, by an average factor of 1.5. Food concentration factors calculated for GDCs and GDLs were used where available.

Table G.14 lists the activity concentrations in foodstuffs in the 50^{th} year per unit application rate of sewage sludge.

Activity concentrations per unit deposition rate in the top 1 cm of 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.15. The resulting soil concentrations in the 50^{th} year are shown in Table G.16 and these were used to calculate inadvertent ingestion and inhalation and external exposure.

G.5.2 Equilibrium modelling for ^{3}H and ^{14}C

For ^{3}H and ^{14}C the activity concentrations in soil and animal products resulting from the application of sewage sludge were taken from Jones *et al*. [G.8]. Activity concentrations per unit deposition rate for tritium were calculated using the TRIF model, 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 here to organically bound tritium. This is likely to be cautious because of the timescale involved for the OBT to be converted to HTO by soil microbes, which in turn will be converted to OBT after plant uptake. Activity concentrations per unit deposition rate for ^{14}C were calculated including degassing losses resulting from the application of wet sewage sludge and soil root uptake [G.8]. The activity concentrations for ^{3}H 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 ^{14}C, in the absence of any better data, the specific activity concentrations per unit deposition rate from the irrigated water pathway has 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 food products or soil grown on land conditioned with sewage sludge per unit discharge into the sewage treatment works (Bq kg^{-1} per Bq y^{-1})
	$C_{food(u)}$	is activity concentration in food products or soil per unit deposition rate (Bq kg^{-1} per Bq m^{-2} s^{-1})
	I_{app}	is application rate of sewage sludge (kg s^{-1} per m^{2})
	C_{slu}	is activity concentration in sewage sludge per unit discharge into the sewage treatment works (Bq kg^{-1} per Bq y^{-1})

The resulting activity concentrations in terrestrial foodstuffs are shown in Table G.17 and in the top 1 cm of conditioned soil in Table G.18.

G.6 Method to calculate DPUR factors

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^{-1} per Bq y^{-1})
	DR_{ext}	is external dose rate from the relevant material (μSv h^{-1} per Bq y^{-1})
	$H_{occ,a}$	is occupancy for the age group considered above the relevant material (h y^{-1})

The DPUR factors for external irradiation 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^{-1} per Bq y^{-1})
	DR_{ext}	is external dose rate from activity in conditioned soil (μSv h^{-1} per Bq y^{-1})
	$H_{occ,a}$	is total occupancy time for the age group considered (h y^{-1})
	$F_{ind,a}$	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^{-1} per Bq y^{-1})
	A_{food}	is activity concentration in the foodstuff (Bq kg^{-1} per Bq y^{-1})
	$I_{food,a}$	is ingestion rate of the foodstuff for the age group considered (kg y^{-1})
	$DF_{ing,a}$	is ingestion dose coefficient for the age group considered (μSv Bq^{-1})

The DPUR factors for inadvertent ingestion of brook water or sediments were calculated as follows:

$$DPUR_{brook} = A_{brook}\ I_{brook}\ H_{occ} DF_{ing}$$

where	$DPUR_{brook}$	is dose per unit release factor from the inadvertent ingestion of brook water or sediment for a child (μSv y^{-1} per Bq y^{-1})
	A_{brook}	is activity concentration in the brook sediment or water (Bq kg^{-1} or l^{-1} per Bq y^{-1})
	I_{brook}	is ingestion rate of the brook sediment or water for a child (kg h^{-1} or l h^{-1})
	H_{occ}	is occupancy time of a child by the brook (h y^{-1})
	DF_{ing}	is ingestion dose coefficient for a child (μSv Bq^{-1})

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 dose per unit release factor from the inadvertent ingestion of raw sewage or sludge for an adult (μSv y^{-1} per Bq y^{-1})
	A_{sew}	is activity concentration in the raw sewage or sludge (Bq kg^{-1} per Bq y^{-1})
	I_{sew}	is inadvertent ingestion rate of raw sewage or sludge (kg h^{-1})
	H_{occ}	is occupancy time by either the raw sewage tanks or the sludge tank (h y^{-1})
	$DF_{ing,a}$	is ingestion dose coefficient for an adult (μSv Bq^{-1})

The DPUR factors for the inadvertent inhalation of raw sewage or sewage sludge 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 dose per unit release factor from the inadvertent inhalation of raw sewage or sludge for an adult (μSv y^{-1} per Bq y^{-1})

A_{sew} is activity concentration in the raw sewage or sludge (Bq kg^{-1} per Bq y^{-1})

B_{work} is breathing rate of an adult sewage worker (m^3 h^{-1})

C_{air_sew} is airborne concentration of raw sewage or sludge (kg m^{-3})

H_{occ} is occupancy time by either the raw sewage tanks or the sludge tank (h y^{-1})

$DF_{inh,a}$ is inhalation dose coefficient for an adult (μSv Bq^{-1})

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 dose per unit release factor from the inadvertent ingestion of conditioned soil for the age group considered (μSv y^{-1} per Bq y^{-1})

A_{soil} is activity concentration in the conditioned soil (Bq kg^{-1} per Bq y^{-1})

$I_{soil\_ing,a}$ is inadvertent ingestion rate of conditioned soil for the age group considered (kg h^{-1})

$F_{ind,a}$ is fraction of time spent indoors for age group considered

$H_{occ,a}$ is total occupancy time for the age group considered (h y^{-1})

$DF_{ing,a}$ is ingestion dose coefficient for the age group considered (μSv Bq^{-1})

The DPUR factors for the inadvertent inhalation sludge conditioned soil 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 dose per unit release factor from the inadvertent inhalation of sludge conditioned soil for the age group considered (μSv y^{-1} per Bq y^{-1})

A_{soil} is activity concentration in the soil (Bq kg^{-1} per Bq y^{-1})

B_a is breathing rate of the age group considered (m^3 h^{-1})

C_{air_soil} is airborne concentration of soil (kg m^{-3})

$F_{ind,a}$ is fraction of time spent indoors for age group considered

$H_{occ,a}$ is total occupancy time for the age group considered (h y^{-1})

$DF_{inh,a}$ is inhalation dose coefficient for the age group considered (μSv Bq^{-1})

The resulting DPUR factors are listed in Table 22 in the main report for the sewage treatment exposure group, Tables 24–27 for the farming family exposure group and Table 28 for the children playing in brook exposure group.

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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})	1,500	see Section G.2
Occupancy adjacent sludge tanks (h y^{-1})	500	see Section G.2
Sewage worker inhalation rate (m^3 h^{-1})	1.2	[G.12]
Inadvertent sludge ingestion rate (kg h^{-1})	5.0E-06	[G.2]

Table G.2 Habit data for farming family exposure group

	Infant	Child	Adult	Comment
Food consumption rates (kg y^{-1})				[G.12]
Cow meat	10	30	45	
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^{-1})	0.22	0.64	0.92	[G.12]
Inadvertent ingestion rate (kg h^{-1})	8.4E-08	3.4E-08	1.6E-08	[G.7]
Occupancy (h y^{-1})	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.7]

Table G.3 Habit data for children playing in brook exposure group

	Child playing in brook	Comment
Occupancy (h y^{-1})	500	[G.12]
Inadvertent ingestion rate of water (ml h^{-1})	10	see Section G.2
Inadvertent ingestion rate of sediment (mg h^{-1})	10	[G.12]

Table G.4 Parameters characterising the sewage treatment works

	Value	Comment
Flow rate raw sewage (m^3 d^{-1})	60	[G.2]
Effluent residence time (h)	15	[G.2]
Sludge processing time (h)	306	[G.2]
Sludge storage time (h)	350	[G.2]
Total sludge residence time (h)	656	[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})	1	[G.2]
Airborne concentration of sewage or sludge at sewage treatment works (kg m^{-3})	1.0E-07	[G.2]

Table G.5 Partitioning coefficients for sewage

Radio-nuclide	Fraction of activity concentration			K_d for organic soil (l kg^{-1})	
	Sludge	Effluent	Comment	K_d	Comment
H-3	0.15	0.85	[G.12]		
H-3 organic	0.15	0.85	[G.16]		
C-11	0.15	0.85	[G.12]		
C-14	0.15	0.85	[G.12]		
F-18	0.1	0.9	[G.15]		
Na-22	0.1	0.9	[G.12]		
Na-24	0.1	0.9	[G.12]		
P-32	0.8	0.2	[G.13]	110	[G.14]
P-33	0.8	0.2	[G.13]	110	[G.14]
S-35	0.1	0.9	[G.12]		
Cl-36	0.1	0.9	[G.12]		
Ca-45	0.8	0.2	[G.12]	110	[G.14]
Ca-47	0.8	0.2	[G.12]	110	[G.14]
V-48	0.9	0.1	As Nb+		
Cr-51	0.9	0.1	[G.12]	270	[G.14]
Mn-52	0.5	0.5	[G.12]	490	[G.14]
Mn-54	0.5	0.5	[G.12]	490	[G.14]
Mn-56	0.5	0.5	[G.12]	490	[G.14]
Fe-55	0.9	0.1	[G.12]	4,900	[G.14]
Fe-59	0.9	0.1	[G.12]	4,900	[G.14]
Co-56	0.8	0.2	[G.12]	990	[G.14]
Co-57	0.8	0.2	[G.12]	990	[G.14]
Co-58	0.8	0.2	[G.12]	990	[G.14]
Co-60	0.8	0.2	[G.12]	990	[G.14]
Ni-63	0.5	0.5	based on organic soil*	1,100	[G.14]
Zn-65	0.5	0.5	based on organic soil*	1,600	[G.14]
Ga-67	0.9	0.1	[G.15]	400	based on Si [G.12]+
Se-75	0.5	0.5	[G.12]	1,800	[G.14]
Br-82	0.1	0.9	based on organic soil*	180	[G.14]
Rb-82	0.8	0.2	[G.12]	670	[G.14]
Rb-83	0.8	0.2	[G.12]	670	[G.14]
Sr-89	0.1	0.9	[G.12]	150	[G.14]
Sr-90	0.1	0.9	[G.12]	150	[G.14]
Y-90	0.1	0.9	as Sr+		
Zr-95	0.9	0.1	based on organic soil*	7,300	[G.14]
Nb-95	0.5	0.5	based on organic soil*	2,000	[G.14]
Mo-99	0.1	0.9	based on organic soil*	27	[G.14]
Tc-99	0.1	0.9	based on organic soil*	1.5	[G.14]
Tc-99m	0.1	0.9	based on organic soil*	1.5	[G.14]
Ru-103	0.1	0.9	[G.12]	66,000	[G.14]
Ru-106	0.1	0.9	[G.12]	66,000	[G.14]
Ag-110m	0.9	0.1	based on organic soil*	15,000	[G.14]
In-111	0.9	0.1	as Ga+		
In-113m	0.9	0.1	as Ga+		
Sb-125	0.8	0.2	[G.12]	540	[G.14]
I-123	0.2	0.8	[G.12]	27	[G.14]
I-125	0.2	0.8	[G.12]	27	[G.14]
I-129	0.2	0.8	[G.12]	27	[G.14]

Table G.5 continued

Radio-nuclide	Fraction of activity concentration			K_d for organic soil (l kg[-1])	
	Sludge	Effluent	Comment	K_d	Comment
I-131	0.2	0.8	[G.12]	27	[G.14]
I-132	0.2	0.8	[G.12]	27	[G.14]
I-133	0.2	0.8	[G.12]	27	[G.14]
I-134	0.2	0.8	[G.12]	27	[G.14]
I-135	0.2	0.8	[G.12]	27	[G.14]
Cs-134	0.3	0.7	[G.12]	270	[G.14]
Cs-136	0.3	0.7	[G.12]	270	[G.14]
Cs-137	0.3	0.7	[G.12]	270	[G.14]
Ba-140	0.1	0.9	as Sr+		
La-140	0.1	0.9	as Sr+		
Ce-141	0.5	0.5	based on organic soil*	3,000	[G.14]
Ce-144	0.5	0.5	based on organic soil*	3,000	[G.14]
Pm-147	0.5	0.5	as Sm+		
Sm-153	0.5	0.5	based on organic soil*	3,000	[G.14]
Eu-152	0.5	0.5	based on organic soil*	3,000	based on Ce
Eu-154	0.5	0.5	based on organic soil*	3,000	based on Ce
Eu-155	0.5	0.5	based on organic soil*	3,000	based on Ce
Er-169	0.5	0.5	as Sm+		
Lu-177	0.5	0.5	based on organic soil*	3,000	based on Ce
Au-198	0.5	0.5	based on organic soil*	3,000	based on Ce
Tl-201	0.5	0.5	as Sm+		
Pb-210	0.9	0.1	[G.12]	22,000	[G.14]
Po-210	0.9	0.1	based on organic soil*	6,600	[G.14]
Ra-223	0.5	0.5	based on organic soil*	2,400	[G.14]
Ra-226	0.5	0.5	based on organic soil*	2,400	[G.14]
Th-230	0.9	0.1	based on organic soil*	89,000	[G.14]
Th-232	0.9	0.1	based on organic soil*	89,000	[G.14]
Th-234	0.9	0.1	based on organic soil*	89,000	[G.14]
U-234	0.1	0.9	based on organic soil*	400	[G.14]
U-235	0.1	0.9	based on organic soil*	400	[G.14]
U-238	0.1	0.9	based on organic soil*	400	[G.14]
Np-237	0.5	0.5	based on organic soil*	1,200	[G.14]
Pu-238	0.5	0.5	based on organic soil*	1,800	[G.14]
Pu-239	0.5	0.5	based on organic soil*	1,800	[G.14]
Pu-240	0.5	0.5	based on organic soil*	1,800	[G.14]
Pu-241	0.5	0.5	based on organic soil*	1,800	[G.14]
Pu-242	0.5	0.5	based on organic soil*	1,800	[G.14]
Am-241	0.9	0.1	based on organic soil*	110,000	[G.14]
Am-242	0.9	0.1	based on organic soil*	110,000	[G.14]
Am-243	0.9	0.1	based on organic soil*	110,000	[G.14]
Cm-242	0.9	0.1	based on organic soil*	12,000	[G.14]
Cm-243	0.9	0.1	based on organic soil*	12,000	[G.14]
Cm-244	0.9	0.1	based on organic soil*	12,000	[G.14]

+see Appendix C
*see discussion in Section G.3

Table G.6 Activity concentrations in raw sewage and sludge at the sewage treatment works per unit release rate

Radionuclide	Raw sewage Average time-integrated decay (Bq kg^{-1} per Bq y^{-1})*	Sludge Average time-integrated decay (Bq kg^{-1} per Bq y^{-1})*
H-3	4.5E-08	6.8E-07
H-3 organic	4.5E-08	6.8E-07
C-11	1.5E-09	5.1E-10
C-14	4.5E-08	6.8E-07
F-18	8.0E-09	1.8E-09
Na-22	4.5E-08	4.5E-07
Na-24	3.3E-08	1.5E-08
P-32	4.5E-08	2.0E-06
P-33	4.5E-08	2.6E-06
S-35	4.5E-08	4.1E-07
Cl-36	4.5E-08	4.5E-07
Ca-45	4.5E-08	3.4E-06
Ca-47	4.3E-08	8.6E-07
V-48	4.5E-08	2.4E-06
Cr-51	4.5E-08	3.0E-06
Mn-52	4.4E-08	6.5E-07
Mn-54	4.5E-08	2.2E-06
Mn-56	1.1E-08	1.3E-08
Fe-55	4.5E-08	4.1E-06
Fe-59	4.5E-08	3.3E-06
Co-56	4.5E-08	3.2E-06
Co-57	4.5E-08	3.5E-06
Co-58	4.5E-08	3.2E-06
Co-60	4.5E-08	3.6E-06
Ni-63	4.5E-08	2.3E-06
Zn-65	4.5E-08	2.2E-06
Ga-67	4.3E-08	7.0E-07
Se-75	4.5E-08	2.1E-06
Br-82	3.9E-08	3.5E-08
Rb-82	9.5E-11	1.7E-10
Rb-83	4.5E-08	3.3E-06
Sr-89	4.5E-08	3.8E-07
Sr-90	4.5E-08	4.5E-07
Y-90	4.2E-08	6.4E-08
Zr-95	4.5E-08	3.5E-06
Nb-95	4.5E-08	1.8E-06
Mo-99	4.2E-08	6.6E-08
Tc-99	4.5E-08	4.5E-07
Tc-99m	2.2E-08	6.0E-09
Ru-103	4.5E-08	3.6E-07
Ru-106	4.5E-08	4.4E-07
Ag-110m	4.5E-08	3.9E-06
In-111	4.2E-08	6.1E-07
In-113m	7.2E-09	1.5E-08

Table G.6 continued

Radionuclide	Raw sewage Average time integrated decay ($Bq\ kg^{-1}$ per $Bq\ y^{-1}$)*	Sludge Average time integrated decay ($Bq\ kg^{-1}$ per $Bq\ y^{-1}$)*
Sb-125	4.5E-08	3.6E-06
I-123	3.1E-08	2.6E-08
I-125	4.5E-08	7.8E-07
I-129	4.5E-08	9.1E-07
I-131	4.4E-08	3.5E-07
I-132	9.9E-09	4.6E-09
I-133	3.6E-08	4.2E-08
I-134	3.8E-09	1.8E-09
I-135	2.3E-08	1.3E-08
Cs-134	4.5E-08	1.3E-06
Cs-136	4.5E-08	7.2E-07
Cs-137	4.5E-08	1.4E-06
Ba-140	4.5E-08	2.4E-07
La-140	4.0E-08	4.0E-08
Ce-141	4.5E-08	1.7E-06
Ce-144	4.5E-08	2.2E-06
Pm-147	4.5E-08	2.3E-06
Sm-153	4.1E-08	2.3E-07
Eu-152	4.5E-08	2.3E-06
Eu-154	4.5E-08	2.3E-06
Eu-155	4.5E-08	2.3E-06
Er-169	4.4E-08	9.7E-07
Lu-177	4.4E-08	7.6E-07
Au-198	4.2E-08	3.2E-07
Tl-201	4.2E-08	3.6E-07
Pb-210	4.5E-08	4.1E-06
Po-210	4.5E-08	3.8E-06
Ra-223	4.5E-08	1.1E-06
Ra-226	4.5E-08	2.3E-06
Th-230	4.5E-08	4.1E-06
Th-232	4.5E-08	4.1E-06
Th-234	4.5E-08	2.8E-06
U-234	4.5E-08	4.5E-07
U-235	4.5E-08	4.5E-07
U-238	4.5E-08	4.5E-07
Np-237	4.5E-08	2.3E-06
Pu-238	4.5E-08	2.3E-06
Pu-239	4.5E-08	2.3E-06
Pu-240	4.5E-08	2.3E-06
Pu-241	4.5E-08	2.3E-06
Pu-242	4.5E-08	2.3E-06
Am-241	4.5E-08	4.1E-06
Am-242	3.3E-08	1.4E-07
Am-243	4.5E-08	4.1E-06
Cm-242	4.5E-08	3.9E-06
Cm-243	4.5E-08	4.1E-06
Cm-244	4.5E-08	4.1E-06

*for a raw sewage flow rate into the sewage treatment works of 60 $m^3\ d^{-1}$

Table G.7 Activity concentrations in liquid effluent and treated sewage sludge per unit release rate

Radionuclide	Treated effluent*	Treated sludge*		
	Decay to leaving sewage works (Bq l^{-1} discharged from sewage works per Bq y^{-1})	Decay to leaving sewage works (Bq kg^{-1} per Bq y^{-1})	Decay to animals grazing (Bq kg^{-1} per Bq y^{-1})	Decay to vegetable harvest (Bq kg^{-1} per Bq y^{-1})
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-14	3.9E-08	6.8E-07	6.8E-07	6.8E-07
Na-22	4.1E-08	4.5E-07	4.4E-07	3.6E-07
Na-24	2.0E-08	nc	nc	nc
P-32	8.8E-09	9.7E-07	3.5E-07	nc
P-33	8.9E-09	1.7E-06	9.7E-07	nc
S-35	4.1E-08	3.7E-07	3.1E-07	3.4E-08
Cl-36	4.1E-08	4.5E-07	4.5E-07	4.5E-07
Ca-45	9.1E-09	3.2E-06	3.0E-06	9.0E-07
Ca-47	8.3E-09	5.6E-08	2.2E-09	nc
V-48	4.4E-09	1.3E-06	5.2E-07	nc
Cr-51	4.5E-09	2.1E-06	1.2E-06	nc
Mn-52	2.1E-08	7.7E-08	5.7E-09	nc
Mn-54	2.3E-08	2.1E-06	2.0E-06	1.1E-06
Fe-55	4.5E-09	4.0E-06	4.0E-06	3.3E-06
Fe-59	4.5E-09	2.7E-06	1.9E-06	2.5E-08
Co-56	9.0E-09	2.9E-06	2.4E-06	2.0E-07
Co-57	9.1E-09	3.4E-06	3.2E-06	1.6E-06
Co-58	9.0E-09	2.8E-06	2.3E-06	1.5E-07
Co-60	9.1E-09	3.6E-06	3.6E-06	3.2E-06
Ni-63	2.3E-08	2.3E-06	2.3E-06	2.3E-06
Zn-65	2.3E-08	2.1E-06	2.0E-06	9.0E-07
Ga-67	4.0E-09	nc	nc	nc
Se-75	2.3E-08	1.9E-06	1.7E-06	3.4E-07
Br-82	3.0E-08	nc	nc	nc
Rb-83	9.0E-09	2.9E-06	2.5E-06	2.6E-07
Sr-89	4.1E-08	3.1E-07	2.3E-07	5.1E-09
Sr-90	4.1E-08	4.5E-07	4.5E-07	4.4E-07
Y-90	3.5E-08	nc	nc	nc
Zr-95	4.5E-09	3.0E-06	2.4E-06	1.2E-07
Nb-95	2.2E-08	1.3E-06	8.8E-07	3.6E-09
Mo-99	3.5E-08	nc	nc	nc
Tc-99	4.1E-08	4.5E-07	4.5E-07	4.5E-07
Tc-99m	7.3E-09	nc	nc	nc
Ru-103	4.0E-08	2.8E-07	1.9E-07	1.4E-09
Ru-106	4.1E-08	4.3E-07	4.2E-07	2.5E-07
Ag-110m	4.5E-09	3.8E-06	3.6E-06	1.7E-06
In-111	3.9E-09	nc	nc	nc
Sb-125	9.1E-09	3.6E-06	3.5E-06	2.9E-06
I-123	1.7E-08	nc	nc	nc
I-125	3.6E-08	6.6E-07	5.2E-07	2.1E-08
I-129	3.6E-08	9.1E-07	9.1E-07	9.1E-07
I-131	3.4E-08	8.6E-08	1.4E-08	nc
I-133	2.2E-08	nc	nc	nc
I-135	7.5E-09	nc	nc	nc

Table G.7 continued

Radionuclide	Treated effluent*	Treated sludge*		
	Decay to leaving sewage works (Bq l^{-1} discharged from sewage works per Bq y^{-1})	Decay to leaving sewage works (Bq kg^{-1} per Bq y^{-1})	Decay to animals grazing (Bq kg^{-1} per Bq y^{-1})	Decay to vegetable harvest (Bq kg^{-1} per Bq y^{-1})
Cs-134	3.2E-08	1.3E-06	1.3E-06	1.0E-06
Cs-136	3.1E-08	3.2E-07	1.1E-07	nc
Cs-137	3.2E-08	1.4E-06	1.4E-06	1.3E-06
Ba-140	4.0E-08	1.0E-07	3.3E-08	nc
La-140	3.2E-08	nc	nc	nc
Ce-141	2.2E-08	1.3E-06	8.1E-07	2.1E-09
Ce-144	2.3E-08	2.1E-06	2.0E-06	1.0E-06
Pm-147	2.3E-08	2.2E-06	2.2E-06	1.8E-06
Sm-153	1.8E-08	nc	nc	nc
Eu-152	2.3E-08	2.3E-06	2.3E-06	2.2E-06
Eu-154	2.3E-08	2.3E-06	2.2E-06	2.1E-06
Eu-155	2.3E-08	2.2E-06	2.2E-06	2.0E-06
Er-169	2.2E-08	3.0E-07	6.2E-08	nc
Lu-177	2.13E-08	1.35E-07	1.5E-08	nc
Au-198	1.9E-08	nc	nc	nc
Tl-201	2.0E-08	nc	nc	nc
Pb-210	4.5E-09	4.1E-06	4.1E-06	4.0E-06
Po-210	4.5E-09	3.6E-06	3.2E-06	7.9E-07
Ra-223	2.19E-08	4.33E-07	1.2E-07	nc
Ra-226	2.3E-08	2.3E-06	2.3E-06	2.3E-06
Th-230	4.5E-09	4.1E-06	4.1E-06	4.1E-06
Th-232	4.5E-09	4.1E-06	4.1E-06	4.1E-06
Th-234	4.5E-09	1.9E-06	1.0E-06	nc
U-234	4.1E-08	4.5E-07	4.5E-07	4.5E-07
U-235	4.1E-08	4.5E-07	4.5E-07	4.5E-07
U-238	4.1E-08	4.5E-07	4.5E-07	4.5E-07
Np-237	2.3E-08	2.3E-06	2.3E-06	2.3E-06
Pu-238	2.3E-08	2.3E-06	2.3E-06	2.3E-06
Pu-239	2.3E-08	2.3E-06	2.3E-06	2.3E-06
Pu-240	2.3E-08	2.3E-06	2.3E-06	2.3E-06
Pu-241	2.3E-08	2.3E-06	2.3E-06	2.2E-06
Pu-242	2.3E-08	2.3E-06	2.3E-06	2.3E-06
Am-241	4.5E-09	4.1E-06	4.1E-06	4.1E-06
Am-242	2.4E-09	nc	nc	nc
Am-243	4.5E-09	4.1E-06	4.1E-06	4.1E-06
Cm-242	4.5E-09	3.6E-06	3.3E-06	1.0E-06
Cm-243	4.5E-09	4.1E-06	4.1E-06	4.0E-06
Cm-244	4.5E-09	4.1E-06	4.1E-06	4.0E-06

nc = not considered because of short half-life
*for a raw sewage flow rate into the sewage treatment works of 60 m^3 d^{-1}

Table G.8 Parameters characterising the brook

	Value	Comment
Brook flow rate (m^3 s^{-1})	0.1	
Suspended sediment load (kg l^{-1})	4.0E-05	[G.2]

Table G.9 Discharge rate of radionuclides from the sewage treatment works per unit release rate into sewage treatment works

Radionuclide	Discharge rate (Bq y^{-1} discharge from STW per Bq y^{-1} of discharge into STW)
H-3	8.5E-01
H-3 organic	8.5E-01
C-14	8.5E-01
Na-22	9.0E-01
Na-24	4.5E-01
P-32	1.9E-01
P-33	2.0E-01
S-35	8.9E-01
Cl-36	9.0E-01
Ca-45	2.0E-01
Ca-47	1.8E-01
V-48	9.7E-02
Cr-51	9.8E-02
Mn-52	4.6E-01
Mn-54	5.0E-01
Fe-55	1.0E-01
Fe-59	9.9E-02
Co-56	2.0E-01
Co-57	2.0E-01
Co-58	2.0E-01
Co-60	2.0E-01
Ni-63	5.0E-01
Zn-65	5.0E-01
Ga-67	8.7E-02
Se-75	5.0E-01
Br-82	6.7E-01
Rb-83	2.0E-01
Sr-89	8.9E-01
Sr-90	9.0E-01
Y-90	7.6E-01
Zr-95	9.9E-02
Nb-95	4.9E-01
Mo-99	7.7E-01
Tc-99	9.0E-01
Tc-99m	1.6E-01
Ru-103	8.9E-01
Ru-106	9.0E-01
Ag-110m	9.9E-02
In-111	8.5E-02
Sb-125	2.0E-01
I-123	3.6E-01
I-125	7.9E-01
I-129	8.0E-01
I-131	7.6E-01
I-133	4.8E-01
I-135	1.7E-01

Table G.9 continued

Radionuclide	Discharge rate (Bq y^{-1} discharge from STW per Bq y^{-1} of discharge into STW)
Cs-134	7.0E-01
Cs-136	6.7E-01
Cs-137	7.0E-01
Ba-140	8.7E-01
La-140	6.9E-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
Au-198	4.2E-01
Tl-201	4.3E-01
Pb-210	1.0E-01
Po-210	9.9E-02
Ra-223	4.8E-01
Ra-226	5.0E-01
Th-230	1.0E-01
Th-232	1.0E-01
Th-234	9.8E-02
U-234	9.0E-01
U-235	9.0E-01
U-238	9.0E-01
Np-237	5.0E-01
Pu-238	5.0E-01
Pu-239	5.0E-01
Pu-240	5.0E-01
Pu-241	5.0E-01
Pu-242	5.0E-01
Am-241	1.0E-01
Am-242	5.2E-02
Am-243	1.0E-01
Cm-242	9.9E-02
Cm-243	1.0E-01
Cm-244	1.0E-01

Table G.10 Activity concentration in unfiltered brook water and bank sediments per unit release rate into sewage treatment works

Radionuclide	Activity concentration in unfiltered brook water (Bq l^{-1} per Bq y^{-1} of discharge into STW)*	Activity concentration in brook bank sediments (Bq kg^{-1} per Bq y^{-1} of discharge into STW)*
H-3	2.7E-10	8.0E-12
H-3 organic	2.7E-10	8.0E-12
C-14	2.7E-10	4.9E-07
Na-22	2.8E-10	1.7E-09
Na-24	1.4E-10	8.5E-10
P-32	6.1E-11	5.8E-08
P-33	6.2E-11	5.9E-08
S-35	2.8E-10	7.4E-07
Cl-36	2.8E-10	0.0E+00
Ca-45	6.3E-11	1.1E-07
Ca-47	5.7E-11	1.0E-07
V-48	3.1E-11	3.1E-09
Cr-51	3.1E-11	3.1E-07
Mn-52	1.5E-10	2.1E-06
Mn-54	1.6E-10	2.3E-06
Fe-55	3.2E-11	2.1E-07
Fe-59	3.1E-11	2.1E-07
Co-56	6.3E-11	6.3E-07
Co-57	6.3E-11	6.3E-07
Co-58	6.3E-11	6.3E-07
Co-60	6.3E-11	6.3E-07
Ni-63	1.6E-10	1.6E-06
Zn-65	1.6E-10	1.5E-07
Ga-67	2.8E-11	5.5E-09
Se-75	1.6E-10	1.5E-07
Br-82	2.1E-10	0.0E+00
Rb-83	6.3E-11	4.2E-07
Sr-89	2.8E-10	5.1E-07
Sr-90	2.8E-10	5.2E-07
Y-90	2.4E-10	8.0E-07
Zr-95	3.1E-11	4.7E-07
Nb-95	1.6E-10	1.6E-08
Mo-99	2.4E-10	2.3E-07
Tc-99	2.8E-10	5.6E-08
Tc-99m	5.1E-11	1.0E-08
Ru-103	2.8E-10	1.5E-06
Ru-106	2.8E-10	1.5E-06
Ag-110m	3.2E-11	6.2E-09
In-111	2.7E-11	4.5E-07
Sb-125	6.3E-11	3.1E-08
I-123	1.1E-10	3.4E-08
I-125	2.5E-10	7.4E-08
I-129	2.5E-10	7.5E-08
I-131	2.4E-10	7.1E-08
I-133	1.5E-10	4.5E-08
I-135	5.2E-11	1.5E-08

Table G.10 continued

Radionuclide	Activity concentration in unfiltered brook water (Bq l^{-1} per Bq y^{-1} of discharge into STW)*	Activity concentration in brook bank sediments (Bq kg^{-1} per Bq y^{-1} of discharge into STW)*
Cs-134	2.2E-10	4.0E-07
Cs-136	2.1E-10	3.9E-07
Cs-137	2.2E-10	4.0E-07
Ba-140	2.7E-10	1.1E-06
La-140	2.2E-10	2.6E-06
Ce-141	1.6E-10	1.9E-06
Ce-144	1.6E-10	1.9E-06
Pm-147	1.6E-10	6.3E-07
Sm-153	1.3E-10	1.5E-06
Eu-152	1.6E-10	1.9E-06
Eu-154	1.6E-10	1.9E-06
Eu-155	1.6E-10	1.9E-06
Er-169	1.5E-10	1.8E-06
Lu-177	1.5E-10	1.8E-06
Au-198	1.3E-10	1.6E-06
Tl-201	1.4E-10	1.4E-06
Pb-210	3.2E-11	1.6E-07
Po-210	3.1E-11	1.6E-07
Ra-223	1.5E-10	7.4E-08
Ra-226	1.6E-10	7.7E-08
Th-230	3.2E-11	2.1E-07
Th-232	3.2E-11	2.1E-07
Th-234	3.1E-11	2.1E-07
U-234	2.8E-10	1.4E-08
U-235	2.8E-10	1.4E-08
U-238	2.8E-10	1.4E-08
Np-237	1.6E-10	1.6E-09
Pu-238	1.6E-10	2.6E-06
Pu-239	1.6E-10	2.6E-06
Pu-240	1.6E-10	2.6E-06
Pu-241	1.6E-10	2.6E-06
Pu-242	1.6E-10	2.6E-06
Am-241	3.2E-11	6.0E-07
Am-242	1.6E-11	3.1E-07
Am-243	3.2E-11	6.0E-07
Cm-242	3.1E-11	6.0E-07
Cm-243	3.2E-11	6.0E-07
Cm-244	3.2E-11	6.0E-07

*for a raw sewage flow rate into the sewage treatment works of 60 m^3 d^{-1} and a brook flow rate of 0.1 m^3 s^{-1}

Table G.11 External dose rates above tanks per unit activity concentration

Radionuclide	External dose rate (µSv h^{-1} per Bq kg^{-1})		
	Parent	Parent and all daughters	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	
Zn-65	1.1E-04	1.1E-04	
Ga-67	2.1E-05	2.1E-05	
Se-75	5.6E-05	5.6E-05	
Br-82	4.8E-04	4.8E-04	
Rb-82	1.9E-04	1.9E-04	
Rb-83	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-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. Tc-99 not included since much longer half-life
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-125	3.7E-07	3.7E-07	

Table G.11 continued

Radionuclide	External dose rate (µSv h^{-1} per Bq kg^{-1})		
	Parent	Parent and all daughters	Comments
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	
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
Po-210	1.5E-09	1.5E-09	
Ra-223	1.7E-05	3.2E-04	Rn-219 through to Tl-208 included
Ra-226	9.0E-07	3.3E-04	Rn-222 through to Pb-210 included
Th-230	3.3E-08	3.3E-08	
Th-232	1.4E-08	1.4E-08	
Th-234	6.6E-07	4.4E-06	Pa-234m and Pa-234 included, half-life of rest of chain 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	4.4E-06	Th-234, etc. 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 above conditioned soil per unit activity concentration

Radionuclide	External dose rate (μSv h^{-1} per Bq kg^{-1})		
	Parent	Parent and all daughters	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	4.0E-04	4.0E-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	
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	
Zn-65	1.1E-04	1.1E-04	
Se-75	5.6E-05	5.6E-05	
Rb-83	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
Zr-95	1.3E-04	2.7E-04	Nb-95 included since significant decay in 1 year
Nb-95	1.4E-04	1.4E-04	
Tc-99	3.3E-09	3.3E-09	
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	
Sb-125	7.0E-05	7.0E-05	
I-125	3.7E-07	3.7E-07	
I-129	2.9E-07	2.9E-07	
I-131	6.2E-05	6.2E-05	
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
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	
Eu-152	2.0E-04	2.0E-04	
Eu-154	2.2E-04	2.2E-04	
Eu-155	5.0E-06	5.0E-06	

Table G.12 continued

Radionuclide	External dose rate (μSv h^{-1} per Bq kg^{-1})		
	Parent	Parent and all daughters	Comments
Er-169	3.7E-09	3.7E-09	
Lu-177	4.5E-06	4.5E-06	
Pb-210	6.1E-08	2.3E-07	Bi-210 and Po-210 included
Po-210	1.5E-09	1.5E-09	
Ra-223	1.7E-05	3.2E-04	Rn-219 through to Tl-208 included
Ra-226	9.0E-07	3.3E-04	Rn-222 through to Pb-210 included
Th-230	3.3E-08	3.3E-08	
Th-232	1.4E-08	4.7E-04	Ra-228 through to Tl-208 included
Th-234	6.6E-07	4.4E-06	Pa-234m and Pa-234 included, half-life of rest of chain 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	4.4E-06	Th-234, etc. included
Np-237	2.1E-06	3.1E-05	Pa-233 only included
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-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.13 External dose rates per unit release rate

Radionuclide	External dose rates ($\mu Sv\ h^{-1}$ per $Bq\ y^{-1}$)*			
	Raw sewage tanks	Sludge tanks	Conditioned soil	Brook bank sediments+
H-3	0.0E+00	0.0E+00	0.0E+00	0.0E+00
H-3 organic	0.0E+00	0.0E+00	0.0E+00	0.0E+00
C-11	2.6E-13	8.8E-14	nc	nc
C-14	1.5E-17	2.3E-16	5.7E-17	3.3E-17
F-18	1.4E-12	3.2E-13	nc	nc
Na-22	1.8E-11	1.8E-10	2.2E-10	1.4E-13
Na-24	2.8E-11	1.3E-11	nc	2.3E-14
P-32	2.8E-14	1.3E-12	2.2E-14	7.3E-15
P-33	7.0E-17	4.0E-15	1.7E-16	1.8E-17
S-35	1.7E-17	1.5E-16	2.8E-17	5.6E-17
Cl-36	3.5E-15	3.5E-14	9.2E-14	0.0E+00
Ca-45	7.5E-17	5.6E-15	1.9E-15	3.8E-17
Ca-47	9.3E-12	1.8E-10	1.4E-13	8.3E-13
V-48	2.4E-11	1.3E-09	2.8E-11	3.3E-13
Cr-51	2.2E-13	1.5E-11	7.0E-13	3.1E-13
Mn-52	2.8E-11	4.1E-10	6.9E-13	4.9E-11
Mn-54	6.8E-12	3.3E-10	1.9E-10	6.7E-11
Mn-56	3.6E-12	4.2E-12	nc	nc
Fe-55	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Fe-59	1.0E-11	7.4E-10	6.4E-11	9.3E-12
Co-56	3.1E-11	2.2E-09	3.7E-10	8.7E-11
Co-57	6.4E-13	4.9E-11	2.6E-11	1.8E-12
Co-58	7.8E-12	5.5E-10	8.1E-11	2.2E-11
Co-60	2.2E-11	1.7E-09	2.9E-09	6.0E-11
Ni-63	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Zn-65	4.9E-12	2.4E-10	1.1E-10	3.2E-12
Ga-67	8.9E-13	1.5E-11	nc	5.6E-15
Se-75	2.6E-12	1.2E-10	3.0E-11	1.7E-12
Br-82	1.9E-11	1.7E-11	nc	nc
Rb-82	1.8E-14	3.3E-14	nc	nc
Rb-83	3.8E-12	2.8E-10	5.0E-11	7.1E-12
Sr-89	2.1E-14	1.8E-13	1.7E-14	4.8E-14
Sr-90	5.7E-14	5.7E-13	7.5E-13	1.3E-13
Y-90	5.2E-14	7.9E-14	nc	1.2E-13
Zr-95	5.9E-12	4.6E-10	1.2E-10	2.5E-11
Nb-95	6.2E-12	2.4E-10	1.6E-11	4.2E-13
Mo-99	1.7E-12	2.6E-12	nc	4.1E-13
Tc-99	1.5E-16	1.5E-15	4.0E-15	3.8E-17
Tc-99m	3.4E-13	9.3E-14	nc	8.3E-15
Ru-103	3.6E-12	2.9E-11	2.1E-12	2.3E-11
Ru-106	1.7E-12	1.7E-11	1.1E-11	1.1E-11
Ag-110m	2.3E-11	2.0E-09	9.6E-10	6.2E-13
In-111	2.4E-12	3.4E-11	nc	1.2E-12
In-113m	3.0E-13	6.1E-13	nc	nc
Sb-125	3.2E-12	2.5E-10	3.3E-10	4.3E-13
I-123	6.3E-13	5.3E-13	nc	3.5E-14
I-125	1.7E-14	2.9E-13	3.5E-14	5.4E-15
I-129	1.3E-14	2.7E-13	7.0E-13	4.4E-15

Table G.13 continued

Radionuclide	External dose rates ($\mu Sv\ h^{-1}$ per $Bq\ y^{-1}$)*			
	Raw sewage tanks	Sludge tanks	Conditioned soil	Brook bank sediments+
I-131	2.8E-12	2.2E-11	1.1E-13	1.9E-13
I-132	4.1E-12	1.9E-12	nc	nc
I-133	3.8E-12	4.4E-12	nc	1.9E-13
I-134	1.8E-12	8.4E-13	nc	nc
I-135	6.9E-12	4.0E-12	nc	1.7E-13
Cs-134	1.2E-11	3.7E-10	4.0E-10	2.2E-11
Cs-136	1.7E-11	2.8E-10	4.1E-12	5.8E-12
Cs-137	4.5E-12	1.3E-10	3.2E-10	7.9E-12
Ba-140	2.1E-11	1.1E-10	1.5E-12	1.9E-11
La-140	1.8E-11	1.8E-11	nc	4.1E-11
Ce-141	4.0E-13	1.5E-11	9.0E-13	3.3E-12
Ce-144	4.6E-13	2.2E-11	1.2E-11	3.8E-12
Pm-147	6.0E-17	3.0E-15	3.7E-15	1.7E-16
Sm-153	1.8E-13	1.0E-12	nc	4.8E-13
Eu-152	9.3E-12	4.6E-10	1.0E-09	7.7E-11
Eu-154	1.0E-11	5.1E-10	1.0E-09	8.5E-11
Eu-155	2.3E-13	1.1E-11	1.9E-11	1.9E-12
Er-169	1.7E-16	3.6E-15	2.6E-17	5.6E-16
Lu-177	2.0E-13	3.4E-12	1.0E-14	4.1E-13
Au-198	2.8E-12	2.2E-11	nc	4.6E-12
Tl-201	3.2E-13	2.7E-12	nc	7.2E-13
Pb-210	1.0E-14	9.4E-13	2.2E-12	7.3E-15
Po-210	6.9E-17	5.8E-15	1.7E-15	4.8E-17
Ra-223	1.4E-11	3.6E-10	4.0E-12	8.5E-13
Ra-226	1.5E-11	7.4E-10	2.0E-09	5.0E-12
Th-230	1.5E-15	1.4E-13	3.6E-13	1.4E-15
Th-232	6.4E-16	5.7E-14	5.1E-09	2.0E-11
Th-234	2.0E-13	1.2E-11	4.8E-13	1.8E-13
U-234	4.8E-16	4.8E-15	1.3E-14	3.0E-17
U-235	9.7E-13	9.7E-12	2.6E-11	6.0E-14
U-238	2.0E-13	2.0E-12	5.2E-12	1.2E-14
Np-237	9.7E-14	4.9E-12	1.9E-10	9.8E-15
Pu-238	1.6E-16	8.2E-15	2.1E-14	1.9E-15
Pu-239	3.7E-16	1.8E-14	4.9E-14	4.3E-15
Pu-240	1.6E-16	7.9E-15	2.1E-14	1.8E-15
Pu-241	7.4E-18	3.7E-16	8.1E-16	8.6E-17
Pu-242	1.4E-16	7.0E-15	1.8E-14	1.6E-15
Am-241	5.2E-14	4.7E-12	1.2E-11	1.4E-13
Am-242	4.6E-14	2.0E-13	nc	2.7E-14
Am-243	1.1E-12	1.0E-10	2.7E-10	3.0E-12
Cm-242	1.8E-16	1.5E-14	5.1E-15	4.8E-16
Cm-243	7.5E-13	6.7E-11	1.6E-10	2.0E-12
Cm-244	1.3E-16	1.1E-14	2.6E-14	3.3E-16

nc = not considered due to short half-life
*for a raw sewage flow rate into the sewage treatment works of 60 $m^3\ d^{-1}$
+for a brook flow rate of 0.1 $m^3\ s^{-1}$

Table G.14 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^{-1} or l^{-1} per Bq m^{-2} s^{-1})						
	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-14*	1.3E+06	1.3E+06	8.3E+05	8.3E+05	4.0E+05	2.3E+06	1.8E+06
Na-22	6.7E+05	6.7E+05	4.1E+05	4.1E+05	8.3E+04	1.9E+04	1.8E+04
P-32*	2.4E+05	9.6E+04	1.2E+05	1.2E+05	1.4E+05	nc	nc
P-33*	5.2E+05	2.1E+05	2.7E+05	2.7E+05	2.6E+05	nc	nc
S-35*	4.7E+06	1.9E+06	2.7E+06	2.7E+06	4.2E+05	1.7E+04	1.6E+04
Cl-36	2.0E+07	2.0E+07	1.7E+07	1.7E+07	3.4E+06	9.2E+06	7.5E+06
Ca-45	2.6E+03	2.6E+03	2.6E+03	2.6E+03	1.2E+04	3.2E+04	2.9E+03
Ca-47	5.3E+01	5.3E+01	5.0E+01	5.0E+01	3.7E+02	nc	nc
V-48	2.1E+00	2.1E+00	1.2E+00	1.2E+00	9.0E+00	nc	nc
Cr-51*	1.4E+03	1.4E+03	2.7E+02	2.7E+02	2.4E+02	nc	nc
Mn-52	1.1E+03	3.8E+04	7.5E+02	2.7E+04	2.2E+03	nc	nc
Mn-54*	8.2E+04	3.7E+06	5.9E+04	2.7E+06	4.5E+04	1.1E+04	7.9E+03
Fe-55	1.5E+03	4.5E+04	8.4E+02	3.4E+06	1.0E+03	3.7E+03	8.1E+01
Fe-59	5.7E+01	1.7E+03	2.6E+01	1.1E+05	3.4E+02	2.8E+03	5.1E+00
Co-56	1.0E+03	1.0E+05	5.0E+02	5.0E+04	3.4E+03	3.3E+03	2.1E+02
Co-57*	2.8E+03	2.8E+05	1.2E+03	1.2E+05	4.3E+03	4.2E+03	6.9E+02
Co-58*	4.8E+02	4.8E+04	1.7E+02	1.7E+04	1.3E+03	3.2E+03	1.9E+02
Co-60*	1.2E+04	1.2E+06	6.5E+03	6.5E+05	1.6E+04	8.7E+03	5.0E+03
Ni-63	2.4E+01	2.4E+02	5.7E+01	5.7E+02	1.8E+02	2.9E+04	2.5E+04
Zn-65*	7.8E+04	7.8E+04	9.0E+04	9.0E+04	1.1E+06	6.4E+04	3.1E+04
Se-75*	2.6E+06	5.2E+07	1.9E+06	4.6E+07	2.3E+05	3.4E+04	3.2E+04
Rb-83	5.7E+04	5.7E+04	3.9E+04	3.9E+04	5.7E+04	5.9E+03	4.4E+03
Sr-89*	7.6E+02	7.6E+02	6.9E+02	6.9E+02	3.5E+03	7.1E+03	7.1E+02
Sr-90*	1.5E+04	1.5E+04	2.3E+04	2.3E+04	1.1E+05	5.2E+05	8.8E+04
Zr-95	3.0E+01	3.0E+01	1.1E+01	1.1E+01	1.3E+01	3.0E+03	3.6E+00
Nb-95	5.9E+00	5.9E+00	3.0E+00	3.0E+00	1.2E+01	2.7E+03	1.0E+02
Tc-99	1.4E+08	4.1E+08	2.1E+07	8.5E+07	2.1E+07	9.2E+06	7.5E+06
Ru-103*	1.4E+02	1.4E+02	4.7E+01	4.7E+01	3.8E-01	2.7E+03	1.1E+02
Ru-106*	3.2E+03	3.2E+03	1.5E+03	1.5E+03	2.8E+00	4.3E+03	9.4E+02
Ag-110m	2.6E+04	7.8E+06	2.1E+04	8.2E+06	7.2E+05	1.6E+04	1.3E+04
Sb-125*	1.5E+04	1.5E+06	5.5E+05	5.4E+05	5.6E+02	6.3E+03	2.6E+03
I-125*	7.6E+03	7.6E+03	2.3E+03	2.3E+03	3.8E+03	3.8E+03	2.2E+03
I-129*	2.6E+05	2.6E+05	3.1E+04	3.1E+04	4.7E+04	6.3E+04	6.2E+04
I-131	1.7E+03	1.7E+03	1.2E+03	1.2E+03	2.8E+03	nc	nc
Cs-134*	3.2E+05	3.2E+05	1.5E+05	1.5E+05	2.9E+04	5.7E+03	4.3E+03
Cs-136	1.6E+04	1.6E+04	7.4E+03	7.4E+03	3.4E+03	nc	nc
Cs-137*	7.3E+05	7.3E+05	2.6E+05	2.6E+05	5.0E+04	1.7E+04	1.6E+04
Ba-140	2.0E+02	2.0E+02	1.1E+02	1.1E+02	4.0E+02	nc	nc
Ce-141	1.9E+01	3.8E+03	9.1E+00	1.8E+03	2.1E+01	2.5E+03	9.5E+00
Ce-144	2.8E+02	5.6E+04	1.4E+02	2.7E+04	4.4E+01	3.4E+03	7.2E+01
Pm-147	4.1E+03	2.5E+04	2.9E+03	2.4E+04	8.5E+01	4.2E+03	7.5E+02
Eu-152	8.1E+03	4.9E+04	8.6E+03	6.9E+04	1.4E+02	6.9E+03	3.4E+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	2.8E+00	5.6E+02	1.6E+00	3.2E+02	1.3E+01	nc	nc
Lu-177	1.6E+00	3.2E+02	9.8E-01	2.0E+02	1.1E+01	nc	nc

Table G.14 continued

Radio-nuclide	Activity concentration in foodstuffs produced on soil conditioned with sewage sludge in 50th year (Bq kg^{-1} or l^{-1} per Bq m^{-2} s^{-1})						
	Sheep meat	Sheep liver	Cow meat	Cow liver	Cow milk	Green veg	Root veg
Pb-210*	1.6E+04	3.2E+04	1.1E+04	2.2E+04	4.1E+03	1.9E+04	1.6E+04
Po-210*	1.1E+04	1.3E+05	1.3E+03	3.5E+04	5.4E+01	3.9E+03	2.4E+03
Ra-223	2.1E+02	2.1E+02	1.2E+02	1.2E+02	3.0E+02	nc	nc
Ra-226*	1.9E+04	1.9E+04	8.8E+03	8.8E+03	7.3E+03	3.3E+04	2.9E+03
Th-230	7.5E+02	7.5E+03	4.3E+02	4.3E+03	3.2E+01	5.1E+03	1.5E+03
Th-232	7.5E+02	7.5E+03	4.3E+02	4.3E+03	3.2E+01	5.1E+03	1.5E+03
Th-234	6.0E+00	6.0E+01	3.0E+00	3.0E+01	4.7E+00	nc	nc
U-234*	6.3E+03	6.3E+03	1.2E+03	1.2E+03	3.5E+03	6.6E+03	2.9E+03
U-235*	6.3E+03	6.3E+03	1.2E+03	1.2E+03	3.5E+03	6.6E+03	2.9E+03
U-238*	6.3E+03	6.3E+03	1.2E+03	1.2E+03	3.5E+03	6.6E+03	2.9E+03
Np-237	1.9E+03	1.4E+05	2.6E+03	3.2E+05	4.8E+01	9.5E+03	2.9E+03
Pu-238*	1.1E+03	7.9E+04	6.3E+02	7.6E+04	4.4E+01	3.6E+03	1.2E+02
Pu-239*	1.2E+03	8.2E+04	6.6E+02	8.2E+04	4.7E+01	3.6E+03	1.5E+02
Pu-240*	1.2E+03	8.2E+04	6.6E+02	7.9E+04	4.7E+01	3.6E+03	1.5E+02
Pu-241*	9.2E+02	6.6E+04	4.4E+02	5.7E+04	3.2E+01	3.5E+03	5.9E+01
Pu-242*	1.2E+03	8.2E+04	6.6E+02	8.2E+04	4.7E+01	3.6E+03	1.5E+02
Am-241*	1.2E+03	8.5E+04	8.2E+02	9.8E+04	6.0E+01	3.8E+03	2.3E+02
Am-243*	1.2E+03	8.8E+04	8.2E+02	1.0E+05	6.0E+01	3.8E+03	2.4E+02
Cm-242*	6.9E+01	5.0E+03	1.5E+01	1.7E+03	1.0E+00	3.2E+03	1.2E+00
Cm-243	1.2E+03	8.3E+04	7.9E+02	9.7E+04	1.4E+01	3.7E+03	5.3E+01
Cm-244*	1.0E+03	7.3E+04	6.0E+02	7.3E+04	4.1E+01	3.6E+03	4.1E+01

* animal food concentration factors taken from GDCs and GDLs [G.2,G.7,G.8]
nc = not considered due to short half-life

Table G.15 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)	300	[G.9]
Spreading rate of sludge to land (kg m^{-2} y^{-1})	8	[G.2]
Density of soil (kg m^{-3})	1,250	
Transfer of strontium to next soil layer (y^{-1})	0.464	[G.11]
Transfer of other radionuclides to next soil layer (y^{-1})	0.243	[G.11]
Airborne soil concentration (kg m^{-3})	1.0E-07	[G.11]

Table G.16 Activity concentrations in soil per unit deposition rate of sewage sludge

Radionuclide	Soil concentration in 50th year (Bq kg^{-1} per Bq m^{-2} s^{-1})
H-3*	8.5E+03
H-3 organic*	8.5E+03
C-14*	9.7E+05
Na-22	5.0E+06
P-32	1.4E+05
P-33	2.5E+05
S-35	8.0E+05
Cl-36	1.0E+07
Ca-45	1.4E+06
Ca-47	4.5E+04
V-48	1.6E+05
Cr-51	2.7E+05
Mn-52	5.5E+04
Mn-54	2.4E+06
Fe-55	5.1E+06
Fe-59	4.3E+05
Co-56	7.3E+05
Co-57	2.1E+06
Co-58	6.6E+05
Co-60	6.7E+06
Ni-63	1.0E+07
Zn-65	2.0E+06
Se-75	1.1E+06
Rb-83	7.9E+05
Sr-89	4.6E+05
Sr-90	5.2E+06
Zr-95	6.0E+05
Nb-95	3.4E+05
Tc-99	1.0E+07
Ru-103	3.8E+05
Ru-106	2.7E+06
Ag-110m	2.0E+06
Sb-125	5.1E+06
I-125	5.7E+05
I-129	1.0E+07
I-131	8.0E+04
Cs-134	4.4E+06
Cs-136	1.3E+05
Cs-137	9.5E+06
Ba-140	1.3E+05
Ce-141	3.1E+05
Ce-144	2.2E+06
Pm-147	5.0E+06

Table G.16 continued

Radionuclide	Soil concentration in 50th year (Bq kg^{-1} per Bq m^{-2} s^{-1})
Eu-152	8.6E+06
Eu-154	7.8E+06
Eu-155	6.6E+06
Er-169	9.2E+04
Lu-177	6.6E+04
Pb-210	9.2E+06
Po-210	1.2E+06
Ra-223	1.1E+05
Ra-226	1.0E+07
Th-230	1.0E+07
Th-232	1.0E+07
Th-234	2.3E+05
U-234	1.0E+07
U-235	1.0E+07
U-238	1.0E+07
Np-237	1.0E+07
Pu-238	1.0E+07
Pu-239	1.0E+07
Pu-240	1.0E+07
Pu-241	8.7E+06
Pu-242	1.0E+07
Am-241	1.0E+07
Am-243	1.0E+07
Cm-242	1.4E+06
Cm-243	9.4E+06
Cm-244	9.0E+06

*for H-3 and C-14 activity concentrations in soil were taken from [G.8]

Table G.17 Activity concentration in terrestrial foodstuffs grown in soil conditioned with sludge per unit release rate

Radio-nuclide	Activity concentration (Bq kg^{-1} per Bq y^{-1})*						
	Green veg.	Root veg.	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk
H-3	nc	nc	4.2E-09	4.2E-09	2.7E-09	2.7E-09	3.1E-09
H-3 organic	nc	nc	3.1E-10	3.1E-10	2.0E-10	2.0E-10	1.7E-10
C-14	3.9E-07	3.2E-07	2.3E-07	2.3E-07	1.4E-07	1.4E-07	6.9E-08
Na-22	1.7E-09	1.6E-09	7.4E-08	7.4E-08	4.6E-08	4.6E-08	9.2E-09
P-32	nc	nc	2.1E-08	8.5E-09	1.1E-08	1.1E-08	1.3E-08
P-33	nc	nc	1.3E-07	5.2E-08	6.6E-08	6.6E-08	6.3E-08
S-35	1.5E-10	1.4E-10	3.7E-07	1.5E-07	2.1E-07	2.1E-07	3.3E-08
Cl-36	1.1E-06	8.6E-07	2.3E-06	2.3E-06	2.0E-06	2.0E-06	3.9E-07
Ca-45	7.3E-09	6.6E-10	2.0E-09	2.0E-09	1.9E-09	1.9E-09	9.2E-09
Ca-47	nc	nc	3.0E-14	3.0E-14	2.8E-14	2.8E-14	2.1E-13
V-48	nc	nc	2.8E-13	2.8E-13	1.5E-13	1.5E-13	1.2E-12
Cr-51	nc	nc	4.4E-10	4.4E-10	8.3E-11	8.3E-11	7.3E-11
Mn-52	nc	nc	1.6E-12	5.5E-11	1.1E-12	3.8E-11	3.2E-12
Mn-54	3.2E-09	2.2E-09	4.3E-08	1.9E-06	3.1E-08	1.4E-06	2.3E-08
Fe-55	3.1E-09	6.7E-11	1.5E-09	4.5E-08	8.5E-10	3.4E-06	1.0E-09
Fe-59	1.8E-11	3.2E-14	2.8E-11	8.4E-10	1.3E-11	5.1E-08	1.7E-10
Co-56	1.7E-10	1.1E-11	6.3E-10	6.3E-08	3.0E-10	3.0E-08	2.1E-09
Co-57	1.7E-09	2.7E-10	2.3E-09	2.3E-07	9.8E-10	9.8E-08	3.5E-09
Co-58	1.2E-10	7.1E-12	2.7E-10	2.7E-08	1.0E-10	1.0E-08	7.4E-10
Co-60	7.1E-09	4.1E-09	1.1E-08	1.1E-06	5.9E-09	5.9E-07	1.4E-08
Ni-63	1.6E-08	1.4E-08	1.4E-11	1.4E-10	3.3E-11	3.3E-10	1.0E-10
Zn-65	1.5E-08	6.9E-09	3.9E-08	3.9E-08	4.5E-08	4.5E-08	5.3E-07
Se-75	3.0E-09	2.8E-09	1.1E-06	2.3E-05	8.1E-07	2.0E-05	9.9E-08
Rb-83	3.9E-10	2.9E-10	3.5E-08	3.6E-08	2.5E-08	2.5E-08	3.6E-08
Sr-89	9.1E-12	9.1E-13	4.5E-11	4.5E-11	4.1E-11	4.1E-11	2.1E-10
Sr-90	5.9E-08	1.0E-08	1.7E-09	1.7E-09	2.6E-09	2.6E-09	1.2E-08
Zr-95	9.0E-11	1.1E-13	1.8E-11	1.8E-11	6.9E-12	6.9E-12	7.7E-12
Nb-95	2.5E-12	9.4E-14	1.3E-12	1.3E-12	6.6E-13	6.6E-13	2.8E-12
Tc-99	1.1E-06	8.6E-07	1.6E-05	4.7E-05	2.4E-06	9.8E-06	2.4E-06
Ru-103	9.6E-13	4.0E-14	6.7E-12	6.7E-12	2.3E-12	2.3E-12	1.9E-14
Ru-106	2.7E-10	5.8E-11	3.3E-10	3.3E-10	1.6E-10	1.6E-10	2.9E-13
Ag-110m	6.7E-09	5.2E-09	2.3E-08	7.1E-06	1.9E-08	7.5E-06	6.6E-07
Sb-125	4.6E-09	1.9E-09	1.4E-08	1.4E-06	4.9E-07	4.8E-07	5.0E-10
I-125	2.0E-11	1.1E-11	1.0E-09	1.0E-09	3.1E-10	3.1E-10	5.0E-10
I-129	1.5E-08	1.4E-08	6.0E-08	6.0E-08	7.2E-09	7.2E-09	1.1E-08
I-131	nc	nc	6.0E-12	6.0E-12	4.2E-12	4.2E-12	9.9E-12
Cs-134	1.5E-09	1.1E-09	1.0E-07	1.0E-07	4.8E-08	4.8E-08	9.6E-09
Cs-136	nc	nc	4.4E-10	4.4E-10	2.0E-10	2.0E-10	9.0E-11
Cs-137	5.8E-09	5.4E-09	2.5E-07	2.5E-07	9.0E-08	9.0E-08	1.7E-08
Ba-140	nc	nc	1.7E-12	1.7E-12	9.2E-13	9.3E-13	3.3E-12
Ce-141	1.3E-12	5.1E-15	3.9E-12	7.8E-10	1.9E-12	3.7E-10	4.3E-12
Ce-144	8.8E-10	1.9E-11	1.4E-10	2.8E-08	6.9E-11	1.4E-08	2.2E-11
Pm-147	1.9E-09	3.4E-10	2.3E-09	1.4E-08	1.6E-09	1.3E-08	4.7E-11
Eu-152	3.8E-09	1.8E-09	4.7E-09	2.8E-08	4.9E-09	4.0E-08	8.2E-11
Eu-154	3.2E-09	1.3E-09	4.1E-09	2.5E-08	4.1E-09	3.2E-08	7.4E-11
Eu-155	2.5E-09	7.1E-10	3.3E-09	2.0E-08	2.8E-09	2.3E-08	6.2E-11
Er-169	nc	nc	4.4E-14	8.8E-12	2.5E-14	5.1E-12	2.0E-13
Lu-177	nc	nc	6.3E-15	1.3E-12	3.8E-15	7.6E-13	4.2E-14

Table G.17 continued

Radio-nuclide	Activity concentration (Bq kg^{-1} per Bq y^{-1})*						
	Green veg.	Root veg.	Sheep meat	Sheep liver	Cow meat	Cow liver	Milk
Pb-210	1.9E-08	1.6E-08	1.7E-08	3.3E-08	1.1E-08	2.3E-08	4.2E-09
Po-210	7.9E-10	4.9E-10	8.7E-09	1.1E-07	1.0E-09	2.8E-08	4.4E-11
Ra-223	nc	nc	6.3E-12	6.3E-12	3.6E-12	3.6E-12	9.4E-12
Ra-226	1.9E-08	1.7E-09	1.1E-08	1.1E-08	5.1E-09	5.1E-09	4.2E-09
Th-230	5.3E-09	1.5E-09	7.7E-10	7.7E-09	4.4E-10	4.4E-09	3.3E-11
Th-232	5.3E-09	1.5E-09	7.7E-10	7.7E-09	4.4E-10	4.4E-09	3.3E-11
Th-234	nc	nc	1.5E-12	1.5E-11	7.7E-13	7.7E-12	1.2E-12
U-234	7.5E-10	3.4E-10	7.3E-10	7.3E-10	1.3E-10	1.3E-10	4.0E-10
U-235	7.5E-10	3.4E-10	7.3E-10	7.3E-10	1.3E-10	1.3E-10	4.0E-10
U-238	7.5E-10	3.4E-10	7.3E-10	7.3E-10	1.3E-10	1.3E-10	4.0E-10
Np-237	5.5E-09	1.7E-09	1.1E-09	7.9E-08	1.5E-09	1.9E-07	2.7E-11
Pu-238	2.1E-09	7.0E-11	6.4E-10	4.5E-08	3.6E-10	4.4E-08	2.5E-11
Pu-239	2.1E-09	8.5E-11	6.7E-10	4.7E-08	3.8E-10	4.7E-08	2.7E-11
Pu-240	2.1E-09	8.5E-11	6.7E-10	4.7E-08	3.8E-10	4.5E-08	2.7E-11
Pu-241	2.0E-09	3.3E-11	5.2E-10	3.8E-08	2.5E-10	3.3E-08	1.8E-11
Pu-242	2.1E-09	8.5E-11	6.7E-10	4.7E-08	3.8E-10	4.7E-08	2.7E-11
Am-241	3.9E-09	2.4E-10	1.2E-09	8.8E-08	8.5E-10	1.0E-07	6.2E-11
Am-243	3.9E-09	2.4E-10	1.2E-09	9.2E-08	8.5E-10	1.0E-07	6.2E-11
Cm-242	8.3E-10	3.1E-13	5.9E-11	4.3E-09	1.2E-11	1.5E-09	8.8E-13
Cm-243	3.7E-09	5.4E-11	1.2E-09	8.6E-08	8.2E-10	1.0E-07	1.5E-11
Cm-244	3.6E-09	4.1E-11	1.0E-09	7.5E-08	6.2E-10	7.5E-08	4.2E-11

nc = not considered due to short half-life
*for a raw sewage flow rate into the sewage treatment works of 60 m^3 d^{-1}

Table G.18 Activity concentration in top 1 cm of soil conditioned with sludge per unit release rate

Radionuclide	Activity concentration (Bq kg^{-1} per Bq y^{-1})*
H-3	1.5E-09
H-3 organic	1.5E-09
C-14	1.7E-07
Na-22	5.6E-07
P-32	3.4E-08
P-33	1.1E-07
S-35	7.5E-08
Cl-36	1.2E-06
Ca-45	1.2E-06
Ca-47	6.3E-10
V-48	5.1E-08
Cr-51	1.4E-07
Mn-52	1.1E-09
Mn-54	1.3E-06
Fe-55	5.1E-06
Fe-59	2.9E-07
Co-56	5.3E-07
Co-57	1.8E-06
Co-58	4.7E-07
Co-60	6.2E-06

Table G.18 continued

Radionuclide	Activity concentration (Bq kg^{-1} per Bq y^{-1})*
Ni-63	5.8E-06
Zn-65	1.1E-06
Se-75	5.3E-07
Rb-83	5.9E-07
Sr-89	3.6E-08
Sr-90	6.0E-07
Zr-95	4.6E-07
Nb-95	1.1E-07
Tc-99	1.2E-06
Ru-103	2.7E-08
Ru-106	3.0E-07
Ag-110m	1.9E-06
Sb-125	4.6E-06
I-125	9.5E-08
I-129	2.4E-06
I-131	1.7E-09
Cs-134	1.5E-06
Cs-136	1.1E-08
Cs-137	3.3E-06
Ba-140	3.3E-09
Ce-141	1.0E-07
Ce-144	1.2E-06
Pm-147	2.8E-06
Eu-152	4.9E-06
Eu-154	4.5E-06
Eu-155	3.8E-06
Er-169	6.9E-09
Lu-177	2.3E-09
Pb-210	9.5E-06
Po-210	1.1E-06
Ra-223	1.2E-08
Ra-226	6.0E-06
Th-230	1.1E-05
Th-232	1.1E-05
Th-234	1.1E-07
U-234	1.2E-06
U-235	1.2E-06
U-238	1.2E-06
Np-237	6.0E-06
Pu-238	5.8E-06
Pu-239	6.0E-06
Pu-240	6.0E-06
Pu-241	5.0E-06
Pu-242	6.0E-06
Am-241	1.1E-05
Am-243	1.1E-05
Cm-242	1.3E-06
Cm-243	9.8E-06
Cm-244	9.3E-06

*for a raw sewage flow rate into the sewage treatment works of 60 m^3 d^{-1}

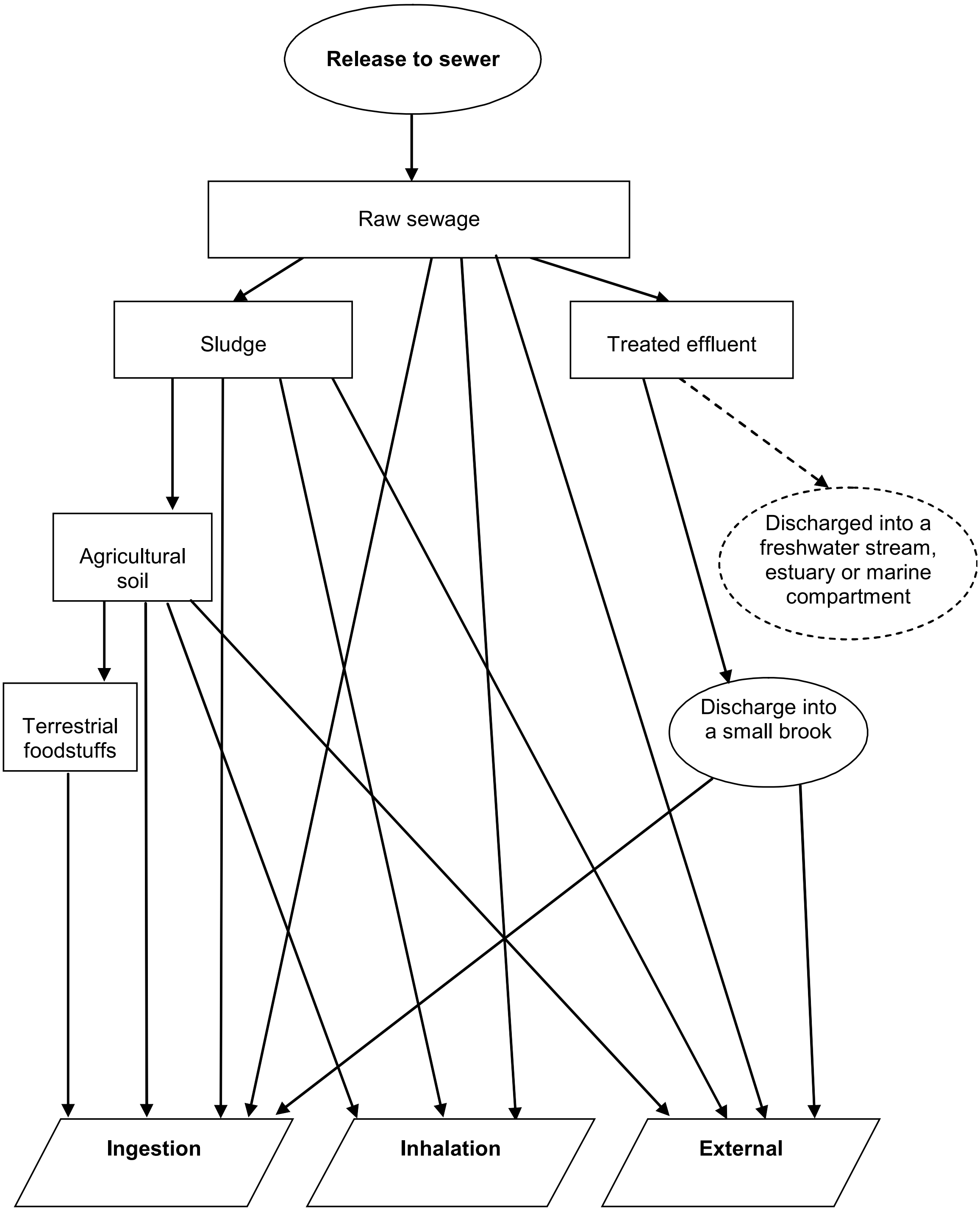

Figure G.1 Flow diagram of sewage pathways

We welcome views from our users, stakeholders and the public, including comments about the content and presentation of this report. If you are happy with our service, please tell us about it. It helps us to identify good practice and rewards our staff. If you are unhappy with our service, please let us know how we can improve it.