NATIONAL DOSE ASSESSMENT WORKING GROUP

PAPER 7-03: ENVIRONMENT AGENCY'S INITIAL RADIOLOGICAL ASSESSMENT METHODOLOGY

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INTRODUCTION

1. 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. Responsibility for granting an authorisation rests with the Environment Agency in England and Wales, the Scottish Environment Protection Agency (SEPA) in Scotland and the Department of Environment in Northern Ireland.

2. The Euratom Basic Safety Standards (BSS) Directive 1996 [Ref 1] requires member states, as part of the planning process for licensing practices subject to the Directive (ie practices involving a risk from ionising radiation), to ensure that specified dose limits are not exceeded.

3. Directions on the Environment Agency (EA) and Scottish Environment Protection Agency (SEPA) [Refs 2, 3] require these Environment Agencies to ensure that doses to reference groups of the public do not exceed specified dose constraints, in discharging their functions in relation to the disposal of radioactive waste under RSA 93. There is equivalent legislation for Northern Ireland [Ref 4].

4. The Environment Agency, Scottish Environment Protection Agency and the Department of Environment in Northern Ireland in collaboration with the Food Standards Agency and National Radiological Protection Board (now Health Protection Agency - HPA) have developed and published principles and guidance for the prospective assessment of public doses [Ref 5]. This guidance recommends that the first step in undertaking a prospective assessment would be to carry out an initial radiological assessment using simple generic assumptions. If the resultant dose exceeded 20μSv/y, then a more detailed assessment, using site specific assumptions, should be undertaken.

5. This NDAWG paper describes an Initial Radiological Assessment methodology which has been developed by the Environment Agency for use by its Agency Officers and which is undergoing further development to lead to external publication. The methodology is primarily focused on non-nuclear or small users of radioactive substances.

6. This Environment Agency methodology is implemented though a series of spreadsheets and associated internal guidance. This paper fully describes the methodology such that it can be used by others. Example initial assessments are provided and a comparison made with guidance provided for undertaking detailed assessments by small users published by NRPB (now HPA) [Ref 6].

PURPOSE, SCOPE AND OVERVIEW OF INITIAL RADIOLOGICAL ASSESSMENT METHODOLOGY

7. The purpose of the Environment Agency's initial radiological assessment methodology is to:

   - Provide a system for undertaking an initial cautious prospective assessment of the dose arising from sources of radioactive waste discharge to the environment.
   - Identify those sources of discharge for which a more detailed assessment should be undertaken.

- Provide guidance for refining the initial assessment to make it more realistic.

8. The methodology can be applied to all premises which are authorised by the Environment Agency under RSA 93 to discharge radioactive waste to the environment:

   - to air;
   - to river;
   - to estuary/coastal water, and;
   - to sewer (and then on to river and estuary).

9. The methodology does not apply to the disposal of radioactive waste to land or discharges to lakes.

10. The methodology is based on the use of dose per unit release values (DPUR - units of μSv/y per Bq/y released) for different radionuclides, release routes (eg to air, water, sewer) and exposure pathways (eg external dose from deposited radionuclides).

11. These DPUR values are multiplied by the actual or proposed authorised limits to calculate the initial dose. Some scaling is allowed for to take account of site specific dispersion conditions arising during releases to air (different release heights), releases to river (river flow), releases to estuary (water exchange rate) and releases to sewer (raw sewage input rate).

PRODUCTION OF METHODOLOGY DATA

12. DPUR values have been calculated for releases to air, river, estuary or coastal waters and to sewer. The assessment calculations for the DPUR values have followed a conventional critical group approach as described in EC guidance [Ref 7] and the approach is similar to the calculations used to define Generalised Dose Constraints (GDC) [Refs 8, 9].

13. The DPUR values are derived for the worst age group of infant, child and adult.

14. The key assumptions which have been used to calculate DPUR for the Environment Agency's initial radiological assessment methodology are described in Appendices 1 to 4.

APPLICATION OF INITIAL ASSESSMENT METHODOLOGY

15. Separate initial radiological assessments may be made for releases to:

   - Air
   - River
   - Estuary or coastal waters
   - Sewer

Releases to air

16. The candidate critical group for releases to air and relevant exposure pathways are:

   - Local habitant
     – Inhalation of radionuclides in plume

  - External radiation from radionuclides in plume and deposited radionuclides
  - Consumption of food incorporating radionuclides

17. The detailed calculations to derive the initial dose for a local habitant are provided in Appendix 5. The dose is calculated by multiplying the activity released to air (Bq/y) by the total DPUR value for each nuclide (μSv/y per Bq/y) (see Table 1). The default stack height is ground-level.

18. A scaling factor may be applied (see Figure 1), if the release point is higher than ground level. There are separate scaling factors for the inhalation and external dose pathways and the food pathway. This is because the location of exposure of the local habitant is assumed to be nearer the release point than the location where they source their food.

Releases to river

19. The candidate critical groups for releases to river and relevant exposure pathways are:

- Member of angling family
  - External radiation from radionuclides deposited in sediments
  - Consumption of freshwater fish incorporating radionuclides
  - Consumption of drinking water containing radionuclides

- Irrigated food consumer
  - Consumption of food irrigated with river water and incorporating radionuclides

20. The detailed calculations to derive the initial dose for a member of an angling family and an irrigated food consumer are provided in Appendix 5. The dose is calculated by multiplying the activity released to river (Bq/y) by the total DPUR value for each nuclide (μSv/y per Bq/y) (see Tables 2 and 3).

21. The dose per unit release values are for a river flow rate of 1 m^3/s and this may be assumed as a default. However, the dose may be scaled by dividing by the known river flow rate (m^3/s), subject to a recommended maximum river flow rate of 100 m^3/s.

Releases to estuary or coastal waters

22. The candidate critical group for releases to an estuary or coastal water and relevant exposure pathways are:

- Fisherman
  - External radiation from radionuclides deposited in sediments
  - Consumption of fish incorporating radionuclides

23. The detailed calculations to derive the initial dose for a fisherman are provided in Appendix 5. The dose is calculated by multiplying the activity released to estuary or coastal water (Bq/y) by the total DPUR value for each nuclide (μSv/y per Bq/y) (see Table 4).

24. The DPUR values have been calculated for a water exchange rate of 100 m^3/s. The fisherman dose can be scaled for different exchange rates, by multiplying the dose by 100 m^3/s and then dividing by the assumed exchange rate (m^3/s). Typical exchange rates for different estuaries and coastal waters are shown in Table 5.

25. It is recommended that a default exchange rate of 30 m^3/s is assumed, if the exchange rate is not known and, in particular, if the release is to a small estuary on the east coast of Britain. The Seaton channel part of the Tees Estuary, with a surface area of 375000 m^2, an average tidal height change of 3.45 m and tidal cycle of 43200 s, has an exchange rate of about 30 m^3/s. For a large estuary on the west coast of Britain or a coastal area, a minimum exchange rate of 100 m^3/s may be more appropriate.

Releases to sewer

26. The candidate critical groups for releases to sewer and relevant exposure pathways are:

- STW worker
  - External radiation from radionuclides in raw sewage and sludge
  - Inadvertent inhalation and ingestion of raw sewage and sludge containing radionuclides

- Member of farming family living on land conditioned with sewage sludge
  - Consumption of food produced on land conditioned with sludge and incorporating radionuclides
  - External radiation from radionuclides deposited in sludge during spreading and subsequent occupancy on land
  - Inadvertent inhalation and ingestion of sludge containing radionuclides during spreading

- Child playing in brook which receives treated effluent from STW
  - External radiation from radionuclides deposited in sediments
  - Inadvertent consumption of water containing radionuclides

- Member of angling family (river receives treated effluent from STW)
  - External radiation from radionuclides deposited in sediments
  - Consumption of freshwater fish incorporating radionuclides
  - Consumption of water containing radionuclides

- Irrigated food consumer (river receives treated effluent from STW)
  - Consumption of food irrigated with river water and incorporating radionuclides

- Fisherman (estuary/coastal water receives treated effluent from STW, typically via a river)
  - External radiation from radionuclides deposited in sediments
  - Consumption of fish incorporating radionuclides

27. The detailed calculations to derive the initial dose for candidate critical groups associated with releases to sewer are provided in Appendix 5.

28. For the STW worker and member of a farming family, the dose is calculated by multiplying the activity released to sewer (Bq/y) by the total DPUR value for each nuclide (μSv/y per Bq/y) (see Tables 6 and 7). The dose per unit release values have been calculated for a raw sewage input rate to a sewage treatment works of 60 m^3/d. This raw sewage input rate represents a very small sewage treatment works and is likely to cause high doses to be predicted. Therefore, every effort should be made to obtain a realistic flow rate for the sewage treatment works. The STW worker dose or member of a farming family dose can be scaled by multiplying the dose by 60 m^3/d and then dividing by the raw sewage input rate (m^3/d).

29. For the child playing in the brook, the dose is calculated by multiplying the activity released to sewer (Bq/y) by the total DPUR value for each nuclide (μSv/y per Bq/y) (see Table 8) and by the sewage treatment works partitioning and decay factor (see Table 8). The dose per unit release values are for a brook flow rate of 1 m^3/s. If the brook flow rate is not known, a default of 0.2 m^3/s should be assumed. The dose is then scaled by dividing by the brook flow rate (m^3/s), subject to a recommended maximum brook flow rate of 10 m^3/s.

30. The dose to a member of an angling family or an irrigated food consumer is calculated by multiplying the activity released to sewer (Bq/y) by the total DPUR value for each nuclide (μSv/y per Bq/y) (see Tables 2 and 3) and by the sewage treatment works partitioning and decay factor (see Table 8). The dose per unit release values are for a river flow rate of 1 m^3/s and this may be assumed as a default. However, the dose may be scaled by dividing by the known river flow rate (m^3/s), subject to a recommended maximum river flow rate of 100 m^3/s.

31. The dose to a fisherman is calculated by multiplying the activity released to sewer (Bq/y) by the total DPUR value for each nuclide (μSv/y per Bq/y) (see Table 4) and by the sewage treatment works partitioning and decay factor (see Table 8). The dose per unit release values have been calculated for a water exchange rate of 100 m^3/s. It is recommended that a default exchange rate of 30 m^3/s is assumed, if the exchange rate is not known. Typical exchange rates for different estuaries and coastal waters are shown in Table 5. The fisherman dose is then scaled by multiplying the dose by 100 m^3/s and then dividing by the assumed exchange rate (m^3/s).

INTERNAL ENVIRONMENT AGENCY GUIDANCE

32. The Environment Agency has produced internal guidance on initial radiological assessment as part of the Agency's Management System. The purpose of this guidance is to establish whether a realistic assessment using site specific data is required. Such a realistic radiological assessment will usually be undertaken by the small user as part of the application for a new or varied RSA 93 authorisation.

33. The Environment Agency guidance provides links to excel spreadsheets which enables the initial assessments to be made. Unfortunately these spreadsheets cannot currently be made available externally as the arrangements for external release have yet to be satisfied and as yet there is no resource provision for managing external queries arising from the use of such spreadsheets. However, the Environment Agency has an intention to make the spreadsheets available externally, if these issues can be resolved.

34. The Environment Agency's initial radiological assessment guidance describes three main stages as follows:

- Stage 1 – Initial radiological assessment using default data. If assessed dose is > 20μSv/y, then proceed to Stage 2.
- Stage 2 – Initial radiological assessment using refined data. If assessed dose is > 20μSv/y, then proceed to Stage 3.
- Stage 3 – Determine need for site specific assessment.

Stage 1 - Initial radiological assessment using default data

35. Stage 1 of the Environment Agency's internal guidance requires that the source term is established. Specific information on the discharges to made to atmosphere, river, estuary and sewer expressed on an annual basis (ie Bq/y) are required. This may be in the form of current annual limits, the proposed limits or recent annual discharge returns. In some cases radionuclide specific information may not be available, the discharges may be expressed as other radionuclides, other beta/gamma etc. In these cases the most appropriate radionuclide should be selected.

36. The source terms or release data are entered into the appropriate release route spreadsheets which are set up with the default data as described in the section above on the application of the assessment methodology. There are separate spreadsheets for releases to air, river, estuary or coastal waters and sewer.

37. The total dose is obtained from each assessment spreadsheet. This is the dose for the worst age group of infant, child or adult.

38. If direct radiation exposure of the public from direct radiation from sources on the site (non-nuclear sites only) is known to occur (eg dose rate at site boundary above background) an assessment of direct radiation dose should be made.

39. Where discharges occur by more than one route (eg to air and to sewer) and/or direct radiation exposure occur from one site/premises, an initial assessment of total dose from all the discharges/exposures should be made by summing the initial assessment doses calculated for each discharge route and direct radiation.

40. If the total dose is less than or equal to 20μSv/y, then no further assessment is necessary. Otherwise the Environment Agency guidance states that there is a need to proceed to Stage 2.

Stage 2 – Initial radiological assessment using refined data

41. The main refinement that can be made is to take account of local dispersion in the air or water:

- ***Air*** – The initial assessment using default data assumes a ground level release. Stacks may discharge to atmosphere well above ground level. A graph of dispersion scaling factors is provided in the spreadsheet tool for releases to air to take account of different release heights (see Figure 1). One scaling factor can be applied to the inhalation and external radiation exposure pathways whilst another scaling factor is applied to the food consumption exposure pathways.

- ***River*** – *A* low default flow rate of 1 m^3/s assumed. Other site specific data can be entered. Higher volumetric flow will reduce the assessed dose.

- ***Estuary/coastal*** – A low default water exchange of 30 m^3/s assumed. Other site specific data can be entered (see Table 5). Higher exchange rates will reduce the assessed dose.

- ***Sewer*** – A very low default flow rate of 60 m^3/d assumed, which will lead to high assessed doses in most cases. Other site specific data can entered. Higher volumetric flow will reduce the assessed dose. Site specific dispersion data can also be entered for onward releases to a brook, river and estuary/coastal waters.

42. A further refinement is to review how realistic any use of the generic other alpha and other beta/gamma categories has been. If the other beta/gamma category is dominated by short-lived radionuclides with a half-life of a few days, then it may be more appropriate to assign the release to iodine-131.

43. If the total doses have been assessed from the sum of initial assessment results from more than one discharge route/mode and/or direct radiation exposure from one site, consideration should be given as to whether to refine the assessment by determining whether it is realistic to assume that a group exposed to one mode of discharge may also be exposed to another discharge mode and/or direct radiation and whether the initial dose assessment results should be considered separately.

44. In the initial assessment system, exposure to atmospheric discharges the nearest dwelling is considered to be a hundred metres from the discharge point. If direct radiation exposure occurs, the highest direct radiation exposure is also likely to occur close to the site (within a few hundred metres). Therefore where atmospheric discharges occur and direct radiation is important, the exposed group may be common and the estimated doses can be added.

45. In the initial assessment system, the location where aqueous discharges reach the environment has not been specified. However, unless liquid discharges reach the environment close to the site (within a few hundred metres) then overlap between groups exposed to atmospheric discharges (and/or direct radiation) and liquid discharges is less likely. In these cases, where a realistic assessment is to be made it may be appropriate to consider separate groups for discharges to atmosphere and aqueous discharges, or; aqueous discharges and direct radiation. Doses to each group should not be summed.

46. If the total dose is less than or equal to 20 μSv/y, then no further assessment is necessary. Otherwise the Environment Agency guidance states that there is a need to proceed to Stage 3.

Stage 3 – Determine need for a site specific radiological assessment

47. The Environment Agency's guidance states that if the total dose > 300 μSv/y, a site specific radiological assessment should be undertaken either by the operator or by the Agency. Any operator assessment should be reviewed to ensure appropriate assumptions and methods have been used and the calculations are correct. Such an assessment is necessary to ensure that regulatory decisions linked to the outcome of a radiological assessment (eg reduction in limits) are supported by a robust and defensible radiological assessment.

48. If the total dose is > 20 μSv/y and < 300 μSv/y. Further review of the initial assessment should be undertaken, taking into account:

- How close the assessed dose is to 300 μSv/y.
- Whether the discharges giving rise to the dose have already been constrained by best practicable means (BPM) and doses are as low as reasonably achievable (ALARA), (social and economic factors taken into account).
- Whether there is a need to present a realistic assessment to stakeholders rather than a generic and probably cautious assessment. This is likely to be the case for nuclear sites.
- Whether there are discharges from other premises/sites to the receiving environment (eg sewer) and the total dose from all the discharges > 300 μSv/y (particularly so if the total dose > 1000 μSv/y).

49. Table 9 provides information to help determine whether more realistic and less cautious assumptions can be made. For example, it may be possible to refine the assessment by removing exposure pathways that have been identified as invalid for the site and derive new dose per unit release data that can be used to reassess doses.

WORKED EXAMPLE OF INITIAL RADIOLOGICAL ASSESSMENT METHODOLOGY

50. A worked example of the application of the Environment Agency's initial radiological assessment methodology is provided in Appendix 6. This uses the example of a hospital with an authorisation to discharge to sewer and also to air.

COMPARISON OF METHODOLOGY WITH NRPB-W63

51. NRPB (now HPA) have published a revised version of their guidance to small users for undertaking radiological assessments, NRPB-W63 [Ref 6]. The results of assessments using the Environment Agency's methodology have been compared to NRPB-W63.

52. For releases to atmosphere, both methodologies use broadly similar approaches. The dispersion factors have been calculated from a gaussian plume model, the foodchain model is the same (NRPB Farmland model, Ref 10) and the habit data is the same (that used in PC Cream, Ref 11). Key differences are as follows:

Parameter	Agency methodology	NRPB-W63
• Distance to production of food	500 m	1000 m
• Age groups	Highest dose of adult, child or infant	Adult
• External radiation from plume	Shielding factor of 0.2 and finite model (PC Cream)	Shielding factor of 0.1 and semi-infinite/infinite model
• Groundshine	Included	Not included

53. The result of these differences is that:
- Agency methodology gives higher total doses where food (in particular milk) is important dose pathway (eg H-3, C-14, S-35 and I-131) because food production is closer and all age groups are considered.
- Agency methodology gives lower total doses for noble gases (eg Kr-85, Xe-133) because of the different external radiation model used.

54. For releases to rivers, again both methodologies use broadly similar approaches. A simple dilution model is used based on volumetric flow, sediment partitioning coefficients and concentration factors for fish. Key differences are as follows:

Parameter	Agency methodology	NRPB-W63
• Water flow rate	Default of 1 m^3/s	Default of 10 m^3/s (although results can be scaled)
• Age groups	Highest dose of adult, child or infant	Adult
• Drinking water treatment	No losses as a result of water treatment considered	Losses via water treatment are considered (up to a factor of 3)
• Fish consumption	10 kg/y[a]	20 kg/y
• CF for fish	There are differences for some nuclides, in particular:	
	C-14 2.2E4 Bq/kg per Bq/l	C-14 4.6E3 Bq/kg per Bq/l
	P-32 1.0E4 Bq/kg per Bq/l	P-32 5.0E3[b] Bq/kg per Bq/l
• External dose	Calculated from external dose coefficients and concentration in bed sediments	PC Cream dynamic model (assumes no deposition of I-131)

[a]This will be revised to 20 kg/y as part of future developments
[b]NRPB-W63 states a value of 5.0E3 Bq/kg per Bq/l, but example calculations suggest a value of 5.0E4 Bq/kg per Bq/l has been used.

55. The doses assessed by each methodology using the standard source term in NRPB-W63 is shown in Table 10. The result of the differences, assuming the same river flow rate, is that:

- Agency methodology gives higher doses where drinking water and is important (eg I-131) due to water treatment removal being excluded.
- Agency methodology gives higher doses for C-14 due to a higher CF for fish, despite lower consumption rate.
- Agency methodology gives lower doses to the example calculations for P-32 due to intake rate and an assumed lower CF for fish.

FUTURE DEVELOPMENTS TO METHODOLOGY

56. The Environment Agency has commissioned an R&D/Science project (P3-104) [Ref 12] to extend and improve the initial radiological assessment methodology. More radionuclides and fetal doses will be included. The revised methodology will be published externally, although it will not include a spreadsheet assessment tool at this stage.

57. The project is being undertaken by Serco Assurance and the outputs are being reviewed by NRPB/HPA. It is expected that the revised published methodology will be available in May 2006.

58. The revision of the methodology is likely to make the following key changes:

- ***Releases to atmosphere***:
  - Use of semi-infinite external dose coefficients for plume to enable scaling for different release heights.
  - Exclusion of resuspension (minor pathway)

- ***Releases to river***:
  - Increase in freshwater fish consumption rate from 10 kg/y to 20 kg/y.
  - Irrigated food transfer factors for more radionuclides.

- ***Releases to estuary or coastal water***:
  - Exclusion of seaspray (minor pathway)

- ***Releases to sewer***:
  - Full time occupancy for all age groups on farm where sewage sludge is spread, over soil which has incorporated sewage sludge. Lower occupancies currently assumed.
  - Sewage sludge conditioned land food transfer factors for more radionuclides.
  - Inclusion of vegetables grown on land conditioned with sewage sludge, but with 10 month delay.

59. The Environment Agency anticipates reviewing and updating the methodology on a regular basis (perhaps 2-3 years) to take account of on-going scientific developments. For example, the Environment Agency has an experimental R&D/Science project being undertaken by Enviros to derive more sewage sludge partitioning data where the data is currently quite poor.

SUMMARY AND CONCLUSIONS

60. Prospective radiological assessments are required to assess the dose to members of the public arising from authorised discharges of radioactive waste to the environment. The Environment Agency, Scottish Environment Protection Agency and the Department of Environment, Northern Ireland in collaboration with the Food Standards Agency and National Radiological Protection Board (now Health Protection Agency) have developed and published principles and guidance for the prospective assessment of public doses. This guidance recommends that the first step in undertaking a prospective assessment would be to carry out an initial radiological assessment using simple generic assumptions. If the resultant dose exceeded 20 μSv/y, then a more detailed assessment, using site specific assumptions, should be undertaken.

61. The Environment Agency has developed an initial radiological assessment methodology based on the use of dose per unit release data which have been derived using generic assumptions. The methodology provides for the inclusion of some site specific information to make the assessment more realistic, this being local factors affecting dispersion in air or water.

62. The methodology has been issued internally within the Environment Agency as part of the Agency's Management System and comprises guidance and a series of spreadsheet tools. The methodology is currently being extended and improved through an R&D/Science project. This will have the additional benefit of enabling external publication of the methodology. Release of the spreadsheet assessment tools externally is under consideration.

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Table 1 Dose per unit release data for local habitant arising from releases to air (*DPUR$_{lhab}$*)

Radionuclide	Surrogate radionuclide	Inhalation DPUR	External DPUR (cloud and deposited)	Food DPUR	Total DPUR	Worst age group
		µSv/y per Bq/y	µSv/y per Bq/y	µSv/y per Bq/y	µSv/y per Bq/y	
Tritium	-	6.7E-13	0.0E+00	1.5E-13	8.1E-13	adult
Tritium (Organically Bound)	Tritium	*6.7E-13*	*0.0E+00*	*1.5E-13*	*8.1E-13*	*adult*
Carbon-14	-	1.8E-11	4.8E-16	2.9E-11	4.8E-11	infant
Oxygen-15	Fluorine-18	*1.2E-12*	*1.1E-12*	*0.0E+00*	*2.4E-12*	*child*
Fluorine-18	-	1.2E-12	1.1E-12	0.0E+00	2.4E-12	child
Sodium-22	Sodium-24	*7.1E-12*	*5.2E-12*	*0.0E+00*	*1.2E-11*	*child*
Sodium-24	-	7.1E-12	5.2E-12	0.0E+00	1.2E-11	child
Phosphorus-32	-	3.3E-11	1.6E-11	5.3E-10	5.7E-10	infant
Phosphorus-33	Phosphorus-32	*3.3E-11*	*1.6E-11*	*5.3E-10*	*5.7E-10*	*infant*
Sulphur-35	-	2.0E-11	1.7E-15	3.6E-10	3.8E-10	infant
Chlorine-36	Sulphur-35	*2.0E-11*	*1.7E-15*	*3.6E-10*	*3.8E-10*	*infant*
Argon-41	-	0.0E+00	4.7E-13	0.0E+00	4.7E-13	child
Calcium-45	Strontium-90	*6.4E-10*	*2.5E-12*	*6.1E-10*	*1.3E-09*	*child*
Calcium-47	Strontium-90	*6.4E-10*	*2.5E-12*	*6.1E-10*	*1.3E-09*	*child*
Vanadium-48	Ruthenium-106	*5.2E-10*	*1.9E-10*	*1.1E-11*	*7.2E-10*	*child*
Chromium-51	-	8.4E-13	1.6E-12	1.8E-13	2.6E-12	child
Manganese-54	-	3.0E-11	4.2E-10	2.7E-11	4.8E-10	child
Manganese-56	Manganese-54	*3.0E-11*	*4.2E-10*	*2.7E-11*	*4.8E-10*	*child*
Iron-59	-	6.9E-11	9.2E-11	2.0E-11	1.8E-10	child
Cobalt-57	-	1.1E-11	4.8E-11	3.4E-12	6.2E-11	child
Cobalt-58	-	3.0E-11	1.2E-10	6.4E-12	1.6E-10	child
Cobalt-60	-	2.0E-10	5.2E-09	9.8E-11	5.5E-09	child
Gallium-67	Sodium-24	*7.1E-12*	*5.2E-12*	*0.0E+00*	*1.2E-11*	*child*
Selenium-75	-	2.6E-11	5.4E-11	1.1E-09	1.2E-09	infant
Bromine-82	-	1.3E-11	4.3E-11	7.6E-11	1.3E-10	infant
Krypton-79	Krypton-85m	*0.0E+00*	*7.2E-14*	*0.0E+00*	*7.2E-14*	*child*
Krypton-85	-	0.0E+00	9.0E-16	0.0E+00	9.0E-16	child
Krypton-85m	-	0.0E+00	7.2E-14	0.0E+00	7.2E-14	child
Rubidium-81/Krypton-81m	Krypton-85m	*0.0E+00*	*7.2E-14*	*0.0E+00*	*7.2E-14*	*child*
Strontium-89	-	1.1E-10	2.6E-11	7.4E-12	1.5E-10	child
Strontium-90	-	6.4E-10	2.5E-12	6.1E-10	1.3E-09	child
Yttrium-90	Strontium-90	*6.4E-10*	*2.5E-12*	*6.1E-10*	*1.3E-09*	*child*
Zirconium-95	-	8.6E-11	1.7E-10	1.1E-12	2.6E-10	child
Niobium-95	-	2.7E-11	4.9E-11	5.5E-13	7.7E-11	child
Technetium-99	-	5.6E-11	0.0E+00	7.1E-09	7.2E-09	infant
Technetium-99m	-	4.2E-13	1.3E-13	0.0E+00	5.5E-13	child
Ruthenium-103	-	4.4E-11	3.4E-11	7.1E-13	7.9E-11	child
Ruthenium-106	-	5.2E-10	1.9E-10	1.1E-11	7.2E-10	child
Indium-111	-	5.1E-12	4.2E-13	0.0E+00	5.5E-12	child
Indium-113m	Indium-111	*5.1E-12*	*4.2E-13*	*0.0E+00*	*5.5E-12*	*child*
Antimony-125	-	8.6E-11	5.6E-10	1.7E-11	6.7E-10	child
Iodine-123	Iodine-125	*7.2E-11*	*6.3E-12*	*3.4E-09*	*3.5E-09*	*infant*
Iodine-125	-	7.2E-11	6.3E-12	3.4E-09	3.5E-09	infant
Iodine-129	-	3.7E-10	1.1E-10	3.2E-08	3.2E-08	infant
Iodine-131	-	3.0E-10	4.4E-11	4.6E-09	4.9E-09	infant
Iodine-132	Iodine-135	*9.8E-12*	*1.2E-10*	*6.3E-13*	*1.3E-10*	*child*
Iodine-133	-	7.6E-11	7.4E-11	8.1E-11	2.3E-10	infant
Iodine-134	Iodine-135	*6.7E-11*	*1.7E-09*	*2.2E-10*	*2.0E-09*	*child*
Iodine-135	-	9.8E-12	1.2E-10	6.3E-13	1.3E-10	child

Table 1 Continued

Radionuclide	Surrogate radionuclide	Inhalation DPUR	External DPUR (cloud and deposited)	Food DPUR	Total DPUR	Worst age group
		μSv/y per Bq/y	μSv/y per Bq/y	μSv/y per Bq/y	μSv/y per Bq/y	
Xenon-133	-	0.0E+00	1.8E-14	0.0E+00	1.8E-14	child
Caesium-134	-	6.7E-11	1.7E-09	2.2E-10	2.0E-09	child
Caesium-136	-	2.5E-11	5.2E-11	1.9E-11	9.5E-11	child
Caesium-137	-	4.7E-11	3.0E-09	1.8E-10	3.2E-09	child
Barium-140	-	9.7E-11	6.3E-11	3.7E-12	1.6E-10	child
Lanthanum-140	-	2.5E-11	3.0E-11	0.0E+00	5.5E-11	child
Cerium-144	-	6.9E-10	1.6E-11	2.3E-11	7.3E-10	infant
Promethium-147	Ruthenium-106	*5.2E-10*	*1.9E-10*	*1.1E-11*	*7.2E-10*	*child*
Samarium-153	Sodium-24	*7.1E-12*	*5.2E-12*	*0.0E+00*	*1.2E-11*	*child*
Erbium-169	Sodium-24	*7.1E-12*	*5.2E-12*	*0.0E+00*	*1.2E-11*	*child*
Thallium-201	Sodium-24	*7.1E-12*	*5.2E-12*	*0.0E+00*	*1.2E-11*	*child*
Lead-210	-	2.0E-08	2.9E-12	5.5E-09	2.5E-08	child
Polonium-210	-	4.7E-08	1.3E-15	2.7E-08	7.4E-08	infant
Radon-222	-	1.2E-10	1.6E-16	0.0E+00	1.2E-10	child
Radium-226	-	6.1E-08	1.2E-08	3.3E-09	7.7E-08	child
Thorium-230	-	2.6E-07	6.1E-11	3.5E-10	2.6E-07	adult
Thorium-232	-	4.6E-07	2.0E-08	3.8E-10	4.8E-07	adult
Uranium-234	-	6.4E-08	3.7E-13	1.3E-10	6.4E-08	adult
Uranium-235	-	5.6E-08	6.3E-10	1.3E-10	5.7E-08	adult
Uranium-238	-	5.4E-08	9.9E-11	1.2E-10	5.4E-08	adult
Neptunium-237	-	4.2E-07	9.0E-10	4.2E-10	4.2E-07	adult
Plutonium-238	-	8.4E-07	1.3E-13	5.8E-10	8.4E-07	adult
Plutonium-239	-	9.1E-07	2.2E-13	6.3E-10	9.2E-07	adult
Plutonium-240	-	9.1E-07	1.7E-13	6.3E-10	9.2E-07	adult
Plutonium-241	-	1.7E-08	5.0E-13	1.1E-11	1.7E-08	adult
Plutonium-242	-	8.8E-07	2.7E-12	6.1E-10	8.8E-07	adult
Americium-241	-	7.7E-07	4.2E-11	5.6E-10	7.7E-07	adult
Americium-242	Americium-241	*7.7E-07*	*4.2E-11*	*5.6E-10*	*7.7E-07*	*adult*
Americium-243	-	7.4E-07	7.6E-10	5.6E-10	7.5E-07	adult
Curium-242	-	9.5E-08	2.1E-14	1.7E-11	9.5E-08	adult
Curium-243	Curium-244	*5.0E-07*	*5.7E-13*	*2.9E-10*	*5.0E-07*	*adult*
Curium-244	-	5.0E-07	5.7E-13	2.9E-10	5.0E-07	adult
Other alpha-emitting nuclides	Plutonium-239	*9.1E-07*	*2.2E-13*	*6.3E-10*	*9.2E-07*	*adult*
Other beta/gamma-emitting nuclides	Iodine-131	*3.0E-10*	*4.4E-11*	*4.6E-09*	*4.9E-09*	*infant*

Table 2 Dose per unit release data for anglers arising from releases to rivers (*$DPUR_{angler}$*) for a river flow rate of 1 m^3/s

Radionuclide	Surrogate radionuclide	External DPUR	Fish DPUR	Water DPUR	Total DPUR	Worst age group
		μSv/y per Bq/y	μSv/y per Bq/y	μSv/y per Bq/y	μSv/y per Bq/y	
Tritium	-	0.0E+00	1.4E-15	4.0E-13	4.0E-13	Infant[A]
Tritium (Organically Bound)	-	0.0E+00	2.7E-10	7.4E-13	2.7E-10	Adult
Carbon-14	-	0.0E+00	3.8E-09	1.0E-11	3.8E-09	Adult
Fluorine-18	-	6.3E-11	1.5E-13	9.2E-13	6.4E-11	Adult
Sodium-22	-	3.3E-08	1.9E-11	5.6E-11	3.4E-08	Adult
Sodium-24	-	1.4E-09	2.5E-12	7.6E-12	1.4E-09	Adult
Phosphorus-32	-	6.2E-16	8.1E-09	5.7E-11	8.1E-09	Child
Phosphorus-33	-	2.1E-15	8.1E-10	5.7E-12	8.1E-10	Child
Sulphur-35	-	1.4E-18	3.1E-11	4.0E-11	7.0E-11	Infant[A]
Chlorine-36	-	2.2E-13	3.0E-10	2.1E-11	3.2E-10	Child
Calcium-45	-	3.0E-14	2.6E-10	1.8E-11	2.8E-10	Child
Calcium-47	-	4.0E-10	4.7E-10	2.8E-11	9.0E-10	Adult
Vanadium-48	-	6.6E-09	7.0E-11	2.1E-11	6.7E-09	Adult
Chromium-51	-	7.0E-12	2.8E-13	4.8E-13	7.7E-12	Child
Manganese-54	-	1.4E-08	7.2E-12	4.3E-12	1.4E-08	Adult
Manganese-56	-	5.7E-09	2.6E-12	1.6E-12	5.7E-09	Adult
Iron-59	-	2.5E-10	5.3E-11	3.7E-11	3.4E-10	Child
Cobalt-57	-	1.2E-08	1.1E-11	2.2E-12	1.2E-08	Adult
Cobalt-58	-	1.6E-09	4.5E-11	1.0E-11	1.6E-09	Child
Cobalt-60	-	1.1E-08	2.9E-10	6.7E-11	1.1E-08	Child
Gallium-67	-	2.9E-11	2.3E-11	3.5E-12	5.6E-11	Adult
Selenium-75	-	5.3E-09	1.5E-10	4.6E-11	5.5E-09	Adult
Bromine-82	-	1.6E-10	6.8E-11	1.0E-11	2.4E-10	Adult
Strontium-89	-	2.3E-16	3.2E-11	1.4E-10	1.7E-10	Infant[A]
Strontium-90	-	2.7E-16	5.3E-10	6.2E-10	1.1E-09	Child
Yttrium-90	-	8.1E-19	1.4E-11	1.4E-10	1.6E-10	Infant[A]
Zirconium-95	-	4.8E-10	3.0E-13	6.2E-12	4.9E-10	Child
Niobium-95	-	1.8E-12	5.5E-09	1.1E-11	5.5E-09	Adult
Technetium-99	-	3.9E-16	2.3E-12	3.9E-11	4.1E-11	Infant[A]
Technetium-99m	-	4.9E-12	1.0E-13	4.2E-13	5.4E-12	Adult
Ruthenium-103	-	6.8E-11	1.9E-12	1.3E-11	8.3E-11	Child
Ruthenium-106	-	4.6E-12	1.2E-11	3.2E-10	3.3E-10	Infant[A]
Indium-111	-	7.6E-11	8.8E-10	5.3E-12	9.6E-10	Adult
Indium-113m	-	5.0E-11	8.5E-11	5.1E-13	1.4E-10	Adult
Antimony-125	-	9.4E-13	1.9E-13	4.9E-11	5.0E-11	Infant[A]
Iodine-123	-	2.7E-13	2.4E-12	1.5E-11	1.8E-11	Adult
Iodine-125	-	8.0E-12	1.9E-10	3.4E-10	5.4E-10	Child
Iodine-129	-	1.3E-11	1.4E-09	2.1E-09	3.5E-09	Adult
Iodine-131	-	7.0E-13	2.3E-10	1.5E-09	1.7E-09	Infant[A]
Iodine-132	-	1.4E-10	3.6E-12	5.3E-12	1.5E-10	Adult
Iodine-133	-	1.1E-12	5.5E-11	3.6E-10	4.1E-10	Infant[A]
Iodine-134	-	1.5E-10	1.3E-12	2.0E-12	1.5E-10	Adult
Iodine-135	-	9.3E-11	1.2E-11	1.7E-11	1.2E-10	Adult
Caesium-134	-	2.3E-09	1.1E-08	3.3E-10	1.4E-08	Adult
Caesium-136	-	3.6E-10	1.8E-09	5.3E-11	2.2E-09	Adult
Caesium-137	-	9.7E-10	7.6E-09	2.3E-10	8.8E-09	Adult
Barium-140	-	2.1E-12	2.1E-12	1.4E-10	1.4E-10	Adult
Lanthanum-140	-	8.6E-10	1.8E-11	3.5E-11	9.2E-10	Adult

Table 2 Continued

Radionuclide	Surrogate radionuclide	External DPUR	Fish DPUR	Water DPUR	Total DPUR	Worst age group
		μSv/y per Bq/y	μSv/y per Bq/y	μSv/y per Bq/y	μSv/y per Bq/y	
Cerium-144	-	3.3E-12	1.7E-11	1.5E-10	1.7E-10	Infant[A]
Promethium-147	-	4.3E-16	1.5E-12	1.3E-11	1.5E-11	Infant[A]
Samarium-153	-	4.0E-11	4.9E-12	1.2E-11	5.6E-11	Adult
Erbium-169	-	1.9E-14	1.3E-09	7.6E-12	1.3E-09	Child
Thallium-201	-	1.8E-10	1.6E-10	9.6E-13	3.4E-10	Adult
Lead-210	-	3.4E-12	1.8E-09	1.6E-08	1.8E-08	Infant[A]
Polonium-210	-	8.9E-15	1.1E-08	5.7E-08	6.8E-08	Infant[A]
Radium-226	-	3.0E-09	6.2E-09	8.7E-09	1.8E-08	Child
Thorium-230	-	4.7E-12	4.8E-09	2.9E-09	7.6E-09	Adult
Thorium-232	-	2.0E-12	5.2E-09	3.1E-09	8.3E-09	Adult
Uranium-234	-	1.5E-15	4.1E-11	1.1E-09	1.1E-09	Infant[A]
Uranium-235	-	1.8E-12	4.1E-11	1.1E-09	1.1E-09	Infant[A]
Uranium-238	-	3.2E-13	3.8E-11	9.9E-10	1.0E-09	Infant[A]
Neptunium-237	-	5.8E-10	4.8E-10	9.5E-10	2.0E-09	Adult
Plutonium-238	-	6.8E-11	4.1E-10	8.2E-10	1.3E-09	Adult
Plutonium-239	-	2.7E-11	4.5E-10	8.9E-10	1.4E-09	Adult
Plutonium-240	-	6.5E-11	4.5E-10	8.9E-10	1.4E-09	Adult
Plutonium-241	-	2.2E-13	8.6E-12	1.7E-11	2.6E-11	Adult
Plutonium-242	-	7.8E-11	4.3E-10	8.6E-10	1.4E-09	Adult
Americium-241	-	8.9E-10	8.9E-11	2.1E-10	1.2E-09	Adult
Americium-242	-	2.6E-12	1.4E-13	4.0E-13	3.2E-12	Child
Americium-243	-	6.3E-09	8.9E-11	2.1E-10	6.6E-09	Adult
Curium-242	-	1.6E-13	3.5E-12	3.7E-11	4.1E-11	Infant[A]
Curium-243	-	2.4E-49	7.0E-11	1.7E-10	2.4E-10	Adult
Curium-244	-	2.4E-49	5.6E-11	1.3E-10	1.9E-10	Adult
Other alpha-emitting nuclides	Radium-226	*3.0E-09*	*6.2E-09*	*8.7E-09*	*1.8E-08*	*Child*
Other beta/gamma-emitting nuclides	Caesium-137	*9.7E-10*	*7.6E-09*	*2.3E-10*	*8.8E-09*	*Adult*

[a] Infants are not anglers, but do eat some fish and drink water

Table 3 Dose per unit release data for irrigated food consumers arising from releases to rivers (*$DPUR_{ifood}$*) for a river flow rate of 1 m^3/s

Radionuclide	Surrogate radionuclide	Food DPUR	Total DPUR	Worst age group
		µSv/y per Bq/y	µSv/y per Bq/y	
Tritium	-	2.3E-14	2.3E-14	Adult
Tritium (Organically Bound)	-	5.5E-14	5.5E-14	Adult
Carbon-14	-	5.3E-12	5.3E-12	Adult
Fluorine-18	-	0.0E+00	0.0E+00	-
Sodium-22	Caesium-137	*4.3E-11*	*4.3E-11*	*Adult*
Sodium-24	-	0.0E+00	0.0E+00	-
Phosphorus-32	-	4.6E-11	4.6E-11	Infant
Phosphorus-33	-	4.3E-12	4.3E-12	Infant
Sulphur-35	-	3.4E-12	3.4E-12	Infant
Chlorine-36	Sulphur-35	*3.4E-12*	*3.4E-12*	*Infant*
Calcium-45	Strontium-90	*1.8E-10*	*1.8E-10*	*Child*
Calcium-47	Strontium-90	*1.8E-10*	*1.8E-10*	*Child*
Vanadium-48	Ruthenium-106	*7.6E-12*	*7.6E-12*	*Infant*
Chromium-51	-	2.4E-14	2.4E-14	Infant
Manganese-54	-	7.2E-13	7.2E-13	Adult
Manganese-56	-	0.0E+00	0.0E+00	-
Iron-59	-	1.6E-12	1.6E-12	Infant
Cobalt-57	-	2.6E-13	2.6E-13	Infant
Cobalt-58	-	6.1E-13	6.1E-13	Infant
Cobalt-60	-	5.3E-12	5.3E-12	Infant
Gallium-67	-	0.0E+00	0.0E+00	-
Selenium-75	-	1.0E-11	1.0E-11	Child
Bromine-82	-	4.6E-14	4.6E-14	Adult
Strontium-89	-	2.5E-12	2.5E-12	Infant
Strontium-90	-	1.8E-10	1.8E-10	Child
Yttrium-90	-	5.1E-13	5.1E-13	Infant
Zirconium-95	-	7.6E-13	7.6E-13	Infant
Niobium-95	-	3.8E-13	3.8E-13	Infant
Technetium-99	-	2.3E-10	2.3E-10	Infant
Technetium-99m	-	0.0E+00	0.0E+00	-
Ruthenium-103	-	5.4E-13	5.4E-13	Infant
Ruthenium-106	-	7.6E-12	7.6E-12	Infant
Indium-111	-	0.0E+00	0.0E+00	-
Indium-113m	-	0.0E+00	0.0E+00	-
Antimony-125	-	1.1E-12	1.1E-12	Infant
Iodine-123	-	0.0E+00	0.0E+00	-
Iodine-125	-	3.7E-11	3.7E-11	Child
Iodine-129	-	5.1E-10	5.1E-10	Child
Iodine-131	-	2.0E-11	2.0E-11	Infant
Iodine-132	-	0.0E+00	0.0E+00	-
Iodine-133	-	4.2E-13	4.2E-13	Infant
Iodine-134	-	0.0E+00	0.0E+00	-
Iodine-135	-	2.7E-14	2.7E-14	Infant
Caesium-134	-	5.5E-11	5.5E-11	Adult
Caesium-136	-	2.1E-12	2.1E-12	Adult
Caesium-137	-	4.3E-11	4.3E-11	Adult
Barium-140	-	1.4E-12	1.4E-12	Infant
Lanthanum-140	-	2.2E-13	2.2E-13	Infant

Table 3 Continued

Radionuclide	Surrogate radionuclide	Food DPUR	Total DPUR	Worst age group
		μSv/y per Bq/y	μSv/y per Bq/y	
Cerium-144	-	5.9E-12	5.9E-12	Infant
Promethium-147	-	3.0E-13	3.0E-13	Infant
Samarium-153	-	0.0E+00	0.0E+00	Adult
Erbium-169	Caesium-137	*4.3E-11*	*4.3E-11*	*Adult*
Thallium-201	-	0.0E+00	0.0E+00	-
Lead-210	-	1.2E-09	1.2E-09	Child
Polonium-210	-	5.4E-09	5.4E-09	Infant
Radium-226	-	3.9E-10	3.9E-10	Child
Thorium-230	-	1.8E-10	1.8E-10	Adult
Thorium-232	-	2.0E-10	2.0E-10	Adult
Uranium-234	-	4.5E-11	4.5E-11	Adult
Uranium-235	-	4.3E-11	4.3E-11	Adult
Uranium-238	-	4.1E-11	4.1E-11	Adult
Neptunium-237	-	1.0E-10	1.0E-10	Adult
Plutonium-238	-	2.0E-10	2.0E-10	Adult
Plutonium-239	-	2.2E-10	2.2E-10	Adult
Plutonium-240	-	2.2E-10	2.2E-10	Adult
Plutonium-241	-	3.9E-12	3.9E-12	Adult
Plutonium-242	-	2.1E-10	2.1E-10	Adult
Americium-241	-	1.8E-10	1.8E-10	Adult
Americium-242	-	0.0E+00	0.0E+00	Adult
Americium-243	-	1.8E-10	1.8E-10	Adult
Curium-242	-	1.1E-11	1.1E-11	Infant
Curium-243	-	1.3E-10	1.3E-10	Adult
Curium-244	-	9.6E-11	9.6E-11	Adult
Other alpha-emitting nuclides	Radium-226	*3.9E-10*	*3.9E-10*	*Child*
Other beta/gamma-emitting nuclides	Caesium-137	*4.3E-11*	*4.3E-11*	*Adult*

Table 4 Dose per unit release data for fishermen arising from releases to estuaries/coastal waters (*$DPUR_{fman}$*) for an exchange rate of 100 m^3/s

Radionuclide	Surrogate radionuclide	External DPUR	Fish / shellfish DPUR	Total DPUR	Worst age group
		μSv/y per Bq/y	μSv/y per Bq/y	μSv/y per Bq/y	
Tritium	-	0.0E+00	5.1E-16	5.1E-16	Adult
Tritium (Organically Bound)	Carbon-14	*2.0E-14*	*3.2E-10*	*3.2E-10*	*Adult*
Carbon-14	-	2.0E-14	3.2E-10	3.2E-10	Adult
Fluorine-18	Sodium-24	*2.5E-17*	*6.7E-17*	*9.2E-17*	*Adult*
Sodium-22	-	4.8E-14	1.3E-14	6.1E-14	Adult
Sodium-24	-	2.5E-17	6.7E-17	9.2E-17	Adult
Phosphorus-32	-	1.6E-18	5.0E-10	5.0E-10	Adult
Phosphorus-33	Phosphorus-32	*1.6E-18*	*5.0E-10*	*5.0E-10*	*Adult*
Sulphur-35	-	4.4E-18	4.1E-14	4.1E-14	Adult
Chlorine-36	Technetium-99	*1.4E-15*	*6.1E-11*	*6.1E-11*	*Adult*
Calcium-45	-	3.8E-16	4.4E-14	4.4E-14	Adult
Calcium-47	Calcium-45	*3.8E-16*	*4.4E-14*	*4.4E-14*	*Adult*
Vanadium-48	Ruthenium-106	*2.2E-13*	*8.9E-11*	*9.0E-11*	*Adult*
Chromium-51	-	9.6E-14	1.1E-13	2.0E-13	Adult
Manganese-54	-	4.4E-11	3.1E-12	4.8E-11	Adult
Manganese-56	Manganese-54	*4.4E-11*	*3.1E-12*	*4.8E-11*	*Adult*
Iron-59	-	6.3E-12	1.3E-10	1.4E-10	Adult
Cobalt-57	-	5.8E-12	1.8E-12	7.5E-12	Adult
Cobalt-58	-	1.2E-11	5.8E-12	1.8E-11	Adult
Cobalt-60	-	6.0E-10	3.0E-11	6.3E-10	Adult
Gallium-67	Sodium-24	*2.5E-17*	*6.7E-17*	*9.2E-17*	*Adult*
Selenium-75	-	3.4E-13	3.6E-10	3.6E-10	Adult
Bromine-82	Sulphur-35	*4.4E-18*	*4.1E-14*	*4.1E-14*	*Adult*
Strontium-89	-	9.6E-15	9.7E-14	1.1E-13	Adult
Strontium-90	-	1.2E-13	1.4E-12	1.5E-12	Adult
Yttrium-90	-	1.2E-14	3.5E-14	4.6E-14	Adult
Zirconium-95	-	1.9E-11	7.1E-13	1.9E-11	Adult
Niobium-95	-	4.7E-12	1.9E-13	4.9E-12	Adult
Technetium-99	-	1.4E-15	6.1E-11	6.1E-11	Adult
Technetium-99m	-	4.2E-19	3.2E-14	3.2E-14	Adult
Ruthenium-103	-	3.4E-14	6.8E-12	6.9E-12	Adult
Ruthenium-106	-	2.2E-13	8.9E-11	9.0E-11	Adult
Indium-111	Sodium-24	*2.5E-17*	*6.7E-17*	*9.2E-17*	*Adult*
Indium-113m	Sodium-24	*2.5E-17*	*6.7E-17*	*9.2E-17*	*Adult*
Antimony-125	-	3.0E-12	1.2E-11	1.5E-11	Adult
Iodine-123	Iodine-125	*3.6E-16*	*3.4E-12*	*3.4E-12*	*Adult*
Iodine-125	-	3.6E-16	3.4E-12	3.4E-12	Adult
Iodine-129	-	3.8E-15	3.2E-11	3.2E-11	Adult
Iodine-131	-	2.0E-16	2.1E-12	2.1E-12	Adult
Iodine-132	Iodine-133	*5.5E-18*	*6.3E-14*	*6.3E-14*	*Adult*
Iodine-133	-	5.5E-18	6.3E-14	6.3E-14	Adult
Iodine-134	Iodine-133	*5.5E-18*	*6.3E-14*	*6.3E-14*	*Adult*
Iodine-135	Iodine-133	*5.5E-18*	*6.3E-14*	*6.3E-14*	*Adult*
Caesium-134	-	2.2E-11	3.3E-11	5.6E-11	Adult
Caesium-136	-	3.1E-13	2.5E-12	2.8E-12	Adult
Caesium-137	-	3.3E-11	2.3E-11	5.6E-11	Adult
Barium-140	-	5.3E-13	3.0E-13	8.3E-13	Adult
Lanthanum-140	-	1.9E-16	0.0E+00	1.9E-16	Adult

Table 4 Continued

Radionuclide	Surrogate radionuclide	External DPUR	Fish / shellfish DPUR	Total DPUR	Worst age group
		µSv/y per Bq/y	µSv/y per Bq/y	µSv/y per Bq/y	
Cerium-144	-	3.0E-12	2.3E-12	5.3E-12	Adult
Promethium-147	-	7.9E-14	1.5E-13	2.2E-13	Adult
Samarium-153	Sodium-24	*2.5E-17*	*6.7E-17*	*9.2E-17*	*Adult*
Erbium-169	Sodium-24	*2.5E-17*	*6.7E-17*	*9.2E-17*	*Adult*
Thallium-201	Sodium-24	*2.5E-17*	*6.7E-17*	*9.2E-17*	*Adult*
Lead-210	-	2.9E-12	1.6E-09	1.6E-09	Adult
Polonium-210	-	2.0E-17	4.7E-10	4.7E-10	Adult
Radium-226	-	2.0E-10	3.6E-09	3.8E-09	Adult
Thorium-230	-	8.0E-12	7.1E-11	7.9E-11	Adult
Thorium-232	-	4.5E-10	1.2E-09	1.6E-09	Adult
Uranium-234	-	4.4E-14	1.3E-11	1.3E-11	Adult
Uranium-235	-	4.7E-12	1.2E-11	1.7E-11	Adult
Uranium-238	-	8.8E-13	1.2E-11	1.3E-11	Adult
Neptunium-237	-	2.9E-11	3.2E-10	3.4E-10	Adult
Plutonium-238	-	1.0E-12	1.1E-09	1.1E-09	Adult
Plutonium-239	-	4.3E-13	1.2E-09	1.2E-09	Adult
Plutonium-240	-	1.0E-12	1.2E-09	1.2E-09	Adult
Plutonium-241	-	2.7E-13	2.2E-11	2.3E-11	Adult
Plutonium-242	Plutonium-239	*4.3E-13*	*1.2E-09*	*1.2E-09*	*Adult*
Americium-241	-	2.5E-11	3.7E-10	4.0E-10	Adult
Americium-242	Americium-241	*2.5E-11*	*3.7E-10*	*4.0E-10*	*Adult*
Americium-243	-	1.7E-10	3.7E-10	5.4E-10	Adult
Curium-242	-	6.5E-14	2.9E-11	2.9E-11	Adult
Curium-243	-	7.7E-11	4.0E-10	4.8E-10	Adult
Curium-244	-	9.5E-13	3.2E-10	3.2E-10	Adult
Other alpha-emitting nuclides	Radium-226	*2.0E-10*	*3.6E-09*	*3.8E-09*	*Adult*
Other beta/gamma-emitting nuclides	Caesium-137	*3.3E-11*	*2.3E-11*	*5.6E-11*	*Adult*

Table 5 Typical exchange rates for coastal waters [Ref 7, 13]

Estuary or Coastal waters	Volumetric exchange (m^3/s)
Hartlepool Bay	130
Inner Tidal Thames	380
Suffolk coast	350
Weymouth Bay	1300
Upper Severn Estuary	130
Bristol Channel	3200
North Wales coast	1300
Ribble Estuary	130
Morecambe Bay	250
Cumbrian coast	2500

Table 6 Dose per unit release data for sewage treatment workers arising from releases to sewers ($DPUR_{stww}$) for a raw sewage input rate to STW of 60 m^3/d

Radionuclide	Surrogate radionuclide	External DPUR	Inadvertent inh and ing DPUR	Total DPUR	Worst age group
		µSv/y per Bq/y	µSv/y per Bq/y	µSv/y per Bq/y	
Tritium	-	0.0E+00	3.8E-14	3.8E-14	Adult
Tritium (Organically Bound)	-	0.0E+00	8.8E-14	8.8E-14	Adult
Carbon-14	-	0.0E+00	1.3E-12	1.3E-12	Adult
Fluorine-18	-	1.4E-09	3.2E-15	1.4E-09	Adult
Sodium-22	-	1.7E-07	4.8E-12	1.7E-07	Adult
Sodium-24	-	3.0E-08	1.2E-13	3.0E-08	Adult
Phosphorus-32	-	4.2E-10	1.3E-11	4.4E-10	Adult
Phosphorus-33	-	1.3E-12	1.6E-12	3.0E-12	Adult
Sulphur-35	-	6.4E-14	1.1E-12	1.2E-12	Adult
Chlorine-36	-	1.4E-11	1.6E-12	1.6E-11	Adult
Calcium-45	-	2.9E-13	1.1E-12	1.4E-12	Adult
Calcium-47	-	1.5E-08	9.8E-13	1.5E-08	Adult
Vanadium-48	-	4.3E-07	1.3E-11	4.3E-07	Adult
Chromium-51	-	1.3E-08	3.0E-13	1.3E-08	Adult
Manganese-54	-	1.1E-06	4.4E-12	1.1E-06	Adult
Manganese-56	-	4.7E-09	2.9E-14	4.7E-09	Adult
Iron-59	-	5.4E-07	1.6E-11	5.4E-07	Adult
Cobalt-57	-	6.0E-08	2.0E-12	6.0E-08	Adult
Cobalt-58	-	4.2E-07	6.5E-12	4.2E-07	Adult
Cobalt-60	-	1.2E-06	3.4E-11	1.2E-06	Adult
Gallium-67	-	1.7E-08	4.1E-13	1.7E-08	Adult
Selenium-75	-	1.1E-07	1.5E-11	1.1E-07	Adult
Bromine-82	-	2.3E-08	2.1E-13	2.3E-08	Adult
Strontium-89	-	4.7E-12	3.5E-12	8.2E-12	Adult
Strontium-90	-	2.0E-15	4.3E-11	4.3E-11	Adult
Yttrium-90	-	7.4E-11	1.3E-12	7.5E-11	Adult
Zirconium-95	-	1.5E-07	9.8E-12	1.5E-07	Adult
Niobium-95	-	8.1E-08	2.9E-12	8.1E-08	Adult
Technetium-99	-	6.2E-13	1.1E-12	1.7E-12	Adult
Technetium-99m	-	1.2E-09	4.2E-15	1.2E-09	Adult
Ruthenium-103	-	2.4E-08	9.8E-13	2.4E-08	Adult
Ruthenium-106	-	1.3E-08	1.1E-11	1.3E-08	Adult
Indium-111	-	4.0E-08	5.4E-13	4.0E-08	Adult
Indium-113m	-	7.6E-07	2.7E-15	7.6E-07	Adult
Antimony-125	-	1.3E-08	1.8E-12	1.3E-08	Adult
Iodine-123	-	2.7E-09	6.4E-14	2.7E-09	Adult
Iodine-125	-	7.8E-10	3.5E-11	8.2E-10	Adult
Iodine-129	-	7.3E-10	2.9E-10	1.0E-09	Adult
Iodine-131	-	2.0E-08	2.7E-11	2.0E-08	Adult
Iodine-132	-	8.3E-09	2.5E-14	8.3E-09	Adult
Iodine-133	-	9.7E-09	1.6E-12	9.7E-09	Adult
Iodine-134	-	3.7E-09	3.7E-15	3.7E-09	Adult
Iodine-135	-	1.4E-08	1.9E-13	1.4E-08	Adult
Caesium-134	-	2.5E-07	7.1E-11	2.5E-07	Adult
Caesium-136	-	2.0E-07	6.5E-12	2.0E-07	Adult
Caesium-137	-	9.0E-08	4.9E-11	9.0E-08	Adult
Barium-140	-	3.4E-09	2.5E-12	3.5E-09	Adult
Lanthanum-140	-	2.2E-08	8.2E-13	2.2E-08	Adult

Table 6 Continued

Radionuclide	Surrogate radionuclide	External DPUR	Inadver-tent inh and ing DPUR	Total DPUR	Worst age group
		μSv/y per Bq/y	μSv/y per Bq/y	μSv/y per Bq/y	
Cerium-144	-	1.5E-09	3.5E-11	1.5E-09	Adult
Promethium-147	-	9.9E-13	2.3E-12	3.2E-12	Adult
Samarium-153	-	4.8E-10	6.7E-13	4.8E-10	Adult
Erbium-169	-	1.3E-12	1.1E-12	2.4E-12	Adult
Thallium-201	-	5.9E-09	1.2E-13	5.9E-09	Adult
Lead-210	-	6.6E-10	7.6E-09	8.2E-09	Adult
Polonium-210	-	3.6E-12	1.3E-08	1.3E-08	Adult
Radium-226	-	4.6E-07	2.2E-09	4.6E-07	Adult
Thorium-230	-	4.4E-11	5.8E-09	5.8E-09	Adult
Thorium-232	-	1.9E-11	8.7E-09	8.8E-09	Adult
Uranium-234	-	9.2E-12	2.0E-10	2.1E-10	Adult
Uranium-235	-	1.1E-08	1.8E-10	1.1E-08	Adult
Uranium-238	-	2.0E-09	1.7E-10	2.2E-09	Adult
Neptunium-237	-	1.6E-09	4.0E-09	5.6E-09	Adult
Plutonium-238	-	1.6E-11	8.0E-09	8.0E-09	Adult
Plutonium-239	-	1.8E-11	8.7E-09	8.7E-09	Adult
Plutonium-240	-	1.7E-11	8.7E-09	8.7E-09	Adult
Plutonium-241	-	4.6E-13	1.6E-10	1.6E-10	Adult
Plutonium-242	-	1.7E-10	8.3E-09	8.5E-09	Adult
Americium-241	-	9.3E-09	1.3E-08	2.2E-08	Adult
Americium-242	-	4.0E-10	4.3E-13	4.1E-10	Adult
Americium-243	-	1.1E-07	1.2E-08	1.2E-07	Adult
Curium-242	-	1.9E-11	7.8E-10	8.0E-10	Adult
Curium-243	-	3.5E-08	5.4E-09	4.0E-08	Adult
Curium-244	-	6.0E-11	4.6E-09	4.7E-09	Adult
Other alpha-emitting nuclides	Radium-226	*4.6E-07*	*2.2E-09*	*4.6E-07*	*Adult*
Other beta/gamma-emitting nuclides	Strontium-90	*2.0E-15*	*4.3E-11*	*4.3E-11*	*Adult*

Table 7 Dose per unit release data for farming family living on sewage sludge conditioned land arising from releases to sewers ($DPUR_{farm}$) for a raw sewage input rate to STW of 60 m^3/d

Radionuclide	Surrogate radionuclide	Food DPUR	External DPUR	Inadver-tent inh and ing DPUR	Total DPUR	Worst age group
		μSv/y per Bq/y	μSv/y per Bq/y	μSv/y per Bq/y	μSv/y per Bq/y	
Tritium	-	8.0E-11	0.0E+00	1.5E-16	8.0E-11	Infant
Tritium (Organically Bound)	-	2.0E-10	0.0E+00	2.2E-13	2.0E-10	Infant
Carbon-14	-	8.0E-09	0.0E+00	2.9E-12	8.1E-09	Infant
Fluorine-18	-	0.0E+00	0.0E+00	0.0E+00	0.0E+00	-
Sodium-22	-	4.1E-08	1.4E-06	3.9E-11	1.4E-06	Adult
Sodium-24	-	0.0E+00	0.0E+00	0.0E+00	0.0E+00	-
Phosphorus-32	-	2.3E-07	2.7E-13	6.6E-13	2.3E-07	Infant
Phosphorus-33	-	6.9E-08	2.1E-15	2.0E-13	6.9E-08	Infant
Sulphur-35	-	2.3E-07	3.5E-16	4.1E-13	2.3E-07	Infant
Chlorine-36	-	3.3E-07	1.2E-12	7.6E-12	3.3E-07	Infant
Calcium-45	-	1.2E-07	3.0E-15	7.1E-13	1.2E-07	Infant
Calcium-47	-	1.3E-10	2.0E-13	7.4E-16	1.3E-10	Infant
Vanadium-48	-	5.4E-08	3.5E-10	5.7E-13	5.4E-08	Infant
Chromium-51	-	3.2E-10	2.8E-09	7.7E-14	3.1E-09	Adult
Manganese-54	-	9.7E-08	2.5E-06	1.0E-11	2.6E-06	Adult
Manganese-56	-	0.0E+00	0.0E+00	0.0E+00	0.0E+00	-
Iron-59	-	6.2E-08	2.0E-07	7.7E-12	2.6E-07	Adult
Cobalt-57	-	1.0E-08	1.2E-07	4.5E-12	1.3E-07	Adult
Cobalt-58	-	1.6E-08	2.5E-07	4.6E-12	2.6E-07	Adult
Cobalt-60	-	2.9E-07	8.1E-06	2.3E-10	8.4E-06	Adult
Gallium-67	-	6.0E-11	9.0E-14	1.3E-16	6.1E-11	Infant
Selenium-75	-	3.7E-06	1.1E-09	6.9E-12	3.7E-06	Infant
Bromine-82	-	9.4E-15	1.3E-17	0.0E+00	9.4E-15	Infant
Strontium-89	-	1.6E-09	1.4E-14	6.8E-13	1.6E-09	Infant
Strontium-90	-	2.9E-07	7.8E-17	4.3E-11	2.9E-07	Infant
Yttrium-90	-	7.7E-14	3.9E-17	5.0E-17	7.7E-14	Infant
Zirconium-95	-	6.4E-11	8.1E-08	7.8E-12	8.1E-08	Adult
Niobium-95	-	1.2E-11	2.2E-08	1.1E-12	2.2E-08	Adult
Technetium-99	-	4.9E-06	5.0E-14	5.8E-12	4.9E-06	Infant
Technetium-99m	-	0.0E+00	0.0E+00	0.0E+00	0.0E+00	-
Ruthenium-103	-	3.9E-13	5.4E-08	2.2E-12	5.4E-08	Adult
Ruthenium-106	-	1.5E-10	2.6E-08	2.5E-11	2.6E-08	Adult
Indium-111	-	3.1E-11	7.4E-14	5.7E-17	3.1E-11	Infant
Indium-113m	-	0.0E+00	0.0E+00	0.0E+00	0.0E+00	-
Antimony-125	-	1.3E-08	5.1E-08	7.4E-12	6.4E-08	Adult
Iodine-123	-	0.0E+00	0.0E+00	0.0E+00	0.0E+00	-
Iodine-125	-	1.2E-08	3.3E-12	5.5E-12	1.2E-08	Infant
Iodine-129	-	8.7E-07	6.7E-11	5.3E-10	8.7E-07	Infant
Iodine-131	-	7.5E-08	2.8E-12	3.1E-13	7.5E-08	Infant
Iodine-132	-	0.0E+00	0.0E+00	0.0E+00	0.0E+00	-
Iodine-133	-	4.0E-18	0.0E+00	0.0E+00	4.0E-18	Infant
Iodine-134	-	0.0E+00	0.0E+00	0.0E+00	0.0E+00	-
Iodine-135	-	0.0E+00	0.0E+00	0.0E+00	0.0E+00	-
Caesium-134	-	1.7E-07	1.0E-06	2.9E-10	1.2E-06	Adult
Caesium-136	-	8.0E-09	1.3E-08	4.9E-13	2.1E-08	Adult
Caesium-137	-	2.3E-07	7.9E-07	4.3E-10	1.0E-06	Adult
Barium-140	-	1.3E-09	1.2E-12	5.9E-14	1.3E-09	Infant
Lanthanum-140	-	8.1E-17	4.5E-14	2.8E-18	4.5E-14	Adult

Table 7 Continued

Radionuclide	Surrogate radionuclide	Food DPUR	External DPUR	Inadver-tent inh and ing DPUR	Total DPUR	Worst age group
		μSv/y per Bq/y	μSv/y per Bq/y	μSv/y per Bq/y	μSv/y per Bq/y	
Cerium-144	-	4.9E-08	3.0E-11	4.7E-11	4.9E-08	Infant
Promethium-147	-	1.3E-09	4.7E-14	5.4E-12	1.3E-09	Infant
Samarium-153	-	7.1E-16	1.1E-14	3.1E-17	1.2E-14	Adult
Erbium-169	-	5.9E-10	3.2E-16	1.9E-14	5.9E-10	Infant
Thallium-201	-	8.7E-12	1.5E-14	1.7E-17	8.7E-12	Infant
Lead-210	-	6.1E-06	5.8E-11	3.4E-08	6.1E-06	Infant
Polonium-210	-	4.1E-06	4.0E-14	9.7E-09	4.1E-06	Infant
Radium-226	-	4.7E-07	4.4E-06	2.2E-08	4.9E-06	Adult
Thorium-230	-	1.4E-07	4.5E-10	6.1E-08	2.0E-07	Adult
Thorium-232	-	1.5E-07	1.9E-10	9.4E-08	2.5E-07	Adult
Uranium-234	-	1.7E-08	7.5E-13	1.6E-10	1.8E-08	Infant
Uranium-235	-	6.1E-09	9.2E-08	1.5E-09	9.9E-08	Adult
Uranium-238	-	5.8E-09	1.6E-08	1.4E-09	2.3E-08	Adult
Neptunium-237	-	7.2E-07	1.6E-08	4.2E-08	7.8E-07	Adult
Plutonium-238	-	2.1E-07	1.5E-10	8.3E-08	3.0E-07	Adult
Plutonium-239	-	2.5E-07	1.8E-10	9.2E-08	3.4E-07	Adult
Plutonium-240	-	2.4E-07	1.7E-10	9.2E-08	3.3E-07	Adult
Plutonium-241	-	3.5E-09	3.9E-12	1.5E-09	5.0E-09	Adult
Plutonium-242	-	2.4E-07	1.7E-09	8.8E-08	3.3E-07	Adult
Americium-241	-	4.0E-07	9.6E-08	1.4E-07	6.3E-07	Adult
Americium-242	-	0.0E+00	0.0E+00	0.0E+00	0.0E+00	-
Americium-243	-	4.1E-07	1.1E-06	1.4E-07	1.6E-06	Adult
Curium-242	-	4.4E-10	2.6E-11	2.7E-09	3.2E-09	Adult
Curium-243	-	1.4E-07	3.2E-07	5.3E-08	5.1E-07	Adult
Curium-244	-	1.0E-07	5.3E-10	4.4E-08	1.5E-07	Adult
Other alpha-emitting nuclides	Radium-226	*4.7E-07*	*4.4E-06*	*2.2E-08*	*4.9E-06*	*Adult*
Other beta/gamma-emitting nuclides	Strontium-90	*2.9E-07*	*7.8E-17*	*4.3E-11*	*2.9E-07*	*Infant*

Table 8 Dose per unit release data for child playing in brook arising from releases to sewers (*$DPUR_{brook}$*) for a brook flow rate of 1 m^3/s and Sewage treatment works partitioning and decay factor (*f_{stw}*)

Radionuclide	Surrogate radionuclide	STW partition-ing and decay factor (f_{stw})	External DPUR µSv/y per Bq/y	Inadver-tent inh and ing DPUR µSv/y per Bq/y	Total DPUR µSv/y per Bq/y	Worst age group
Tritium	-	8.5E-01	0.0E+00	3.6E-15	3.6E-15	Child
Tritium (Organically Bound)	-	8.5E-01	0.0E+00	8.4E-15	8.4E-15	Child
Carbon-14	-	8.5E-01	0.0E+00	1.2E-13	1.2E-13	Child
Fluorine-18	-	2.8E-03	3.2E-11	1.4E-14	3.2E-11	Child
Sodium-22	-	9.0E-01	1.7E-08	8.1E-13	1.7E-08	Child
Sodium-24	-	4.5E-01	7.1E-10	1.1E-13	7.1E-10	Child
Phosphorus-32	-	1.9E-01	6.2E-16	8.1E-13	8.1E-13	Child
Phosphorus-33	-	2.0E-01	2.1E-15	8.1E-14	8.3E-14	Child
Sulphur-35	-	9.0E-01	2.3E-17	2.3E-13	2.3E-13	Child
Chlorine-36	-	9.0E-01	2.2E-13	3.0E-13	5.2E-13	Child
Calcium-45	-	9.0E-01	3.0E-14	2.6E-13	2.9E-13	Child
Calcium-47	-	8.2E-01	2.0E-10	4.4E-13	2.0E-10	Child
Vanadium-48	-	9.7E-02	3.3E-09	3.4E-13	3.3E-09	Child
Chromium-51	-	9.8E-02	7.0E-12	6.9E-15	7.0E-12	Child
Manganese-54	-	5.0E-01	1.4E-08	6.6E-14	1.4E-08	Child
Manganese-56	-	9.2E-03	2.9E-09	2.7E-14	2.9E-09	Child
Iron-59	-	9.9E-02	2.5E-10	5.3E-13	2.5E-10	Child
Cobalt-57	-	2.0E-01	5.8E-09	5.1E-14	5.8E-09	Child
Cobalt-58	-	2.0E-01	1.6E-09	1.5E-13	1.6E-09	Child
Cobalt-60	-	2.0E-01	1.1E-08	9.6E-13	1.1E-08	Child
Gallium-67	-	8.8E-02	1.5E-11	6.1E-14	1.5E-11	Child
Selenium-75	-	5.0E-01	2.7E-09	8.9E-13	2.7E-09	Child
Bromine-82	-	6.6E-01	8.0E-11	1.5E-13	8.0E-11	Child
Strontium-89	-	8.9E-01	3.9E-15	8.5E-13	8.6E-13	Child
Strontium-90	-	9.0E-01	2.7E-16	8.8E-12	8.8E-12	Child
Yttrium-90	-	7.7E-01	1.3E-17	8.1E-13	8.1E-13	Child
Zirconium-95	-	9.9E-02	4.8E-10	8.8E-14	4.8E-10	Child
Niobium-95	-	4.9E-01	1.8E-12	1.7E-13	2.0E-12	Child
Technetium-99	-	9.0E-01	6.6E-15	2.0E-13	2.1E-13	Child
Technetium-99m	-	1.9E-01	2.5E-12	6.8E-15	2.5E-12	Child
Ruthenium-103	-	8.9E-01	6.8E-11	1.9E-13	6.8E-11	Child
Ruthenium-106	-	9.0E-01	7.7E-11	1.9E-12	7.9E-11	Child
Indium-111	-	8.6E-02	3.8E-11	9.0E-14	3.8E-11	Child
Indium-113m	-	2.2E-04	2.5E-11	9.4E-15	2.5E-11	Child
Antimony-125	-	9.0E-01	1.6E-11	3.3E-13	1.6E-11	Child
Iodine-123	-	3.6E-01	4.5E-12	7.7E-14	4.6E-12	Child
Iodine-125	-	7.9E-01	8.0E-12	4.9E-12	1.3E-11	Child
Iodine-129	-	8.0E-01	6.6E-12	3.0E-11	3.6E-11	Child
Iodine-131	-	7.6E-01	1.2E-11	8.1E-12	2.0E-11	Child
Iodine-132	-	8.7E-03	6.8E-11	9.5E-14	6.8E-11	Child
Iodine-133	-	4.9E-01	1.9E-11	1.6E-12	2.0E-11	Child
Iodine-134	-	5.7E-06	7.6E-11	3.1E-14	7.6E-11	Child
Iodine-135	-	1.7E-01	4.7E-11	3.4E-13	4.7E-11	Child
Caesium-134	-	7.0E-01	2.3E-09	2.0E-12	2.3E-09	Child
Caesium-136	-	6.8E-01	3.6E-10	6.4E-13	3.6E-10	Child
Caesium-137	-	7.0E-01	9.7E-10	1.5E-12	9.7E-10	Child
Barium-140	-	8.7E-01	3.5E-11	8.5E-13	3.5E-11	Child
Lanthanum-140	-	7.0E-01	4.3E-10	6.2E-13	4.3E-10	Child

Table 8 Continued

Radionuclide	Surrogate radionuclide	STW partitioning and decay factor (f_{stw})	External DPUR	Inadvertent inh and ing DPUR	Total DPUR	Worst age group
			μSv/y per Bq/y	μSv/y per Bq/y	μSv/y per Bq/y	
Cerium-144	-	5.0E-01	5.5E-11	7.9E-13	5.5E-11	Child
Promethium-147	-	5.0E-01	7.2E-15	7.5E-14	8.2E-14	Child
Samarium-153	-	4.0E-01	2.0E-11	2.1E-13	2.0E-11	Child
Erbium-169	-	4.8E-01	1.9E-14	1.1E-13	1.3E-13	Child
Thallium-201	-	4.3E-01	9.2E-11	1.5E-14	9.2E-11	Child
Lead-210	-	1.0E-01	5.7E-11	1.6E-10	2.2E-10	Child
Polonium-210	-	1.0E-01	1.5E-13	3.3E-10	3.3E-10	Child
Radium-226	-	5.0E-01	3.0E-09	1.2E-10	3.1E-09	Child
Thorium-230	-	1.0E-01	2.3E-12	2.7E-11	3.0E-11	Child
Thorium-232	-	1.0E-01	9.9E-13	3.3E-11	3.4E-11	Child
Uranium-234	-	9.0E-01	2.5E-14	1.2E-11	1.2E-11	Child
Uranium-235	-	9.0E-01	3.0E-11	1.1E-11	4.1E-11	Child
Uranium-238	-	9.0E-01	5.4E-12	1.1E-11	1.6E-11	Child
Neptunium-237	-	5.0E-01	2.9E-10	7.9E-12	3.0E-10	Child
Plutonium-238	-	5.0E-01	6.8E-11	7.1E-12	7.5E-11	Child
Plutonium-239	-	5.0E-01	2.7E-11	8.0E-12	3.5E-11	Child
Plutonium-240	-	5.0E-01	6.5E-11	8.0E-12	7.3E-11	Child
Plutonium-241	-	5.0E-01	2.2E-13	1.5E-13	3.7E-13	Child
Plutonium-242	-	5.0E-01	7.8E-11	7.7E-12	8.5E-11	Child
Americium-241	-	1.0E-01	8.9E-10	2.0E-12	8.9E-10	Child
Americium-242	-	5.2E-02	2.6E-12	5.7E-15	2.6E-12	Child
Americium-243	-	1.0E-01	6.3E-09	2.0E-12	6.3E-09	Child
Curium-242	-	5.0E-01	2.7E-12	2.2E-13	2.9E-12	Child
Curium-243	-	5.0E-01	0.0E+00	1.5E-12	1.5E-12	Child
Curium-244	-	5.0E-01	0.0E+00	1.3E-12	1.3E-12	Child
Other alpha-emitting nuclides	Radium-226	*1.0E+00*	*3.0E-09*	*1.2E-10*	*3.1E-09*	Child
Other beta/gamma-emitting nuclides	Caesium-137	*1.0E+00*	*9.7E-10*	*1.5E-12*	*9.7E-10*	Child

Table 9 Factors to help determine the need for a site specific assessment

Parameter	Default data for initial radiological assessment	Comments
Releases to air		
Stack height	0 m	Stacks may be higher. Effect of higher stacks on ground level air concentration: Up to a factor of 100 lower.
Meteorolog-ical data	50% D, uniform wind rose	50% D is a cautious choice of stability category and may result in an overestimate of air concentration by up to a factor of 2. Gaussian plume model is conservative compared to ADMS, by up to a factor of 2.
Population groups	Local habitants - Living 100 m from release point; consuming locally produced milk, cow meat, sheep meat, cow and sheep offal, green vegetables, root vegetables, fruit produced at 300 m from the release point	Site may not be located in an agricultural area, the range of foods consumed may be lower. Milk is the highest consumed food.
Habits (food consumption rates)	High rate consumption across full range of locally produced foods.	The rates of consumption are likely to be lower. The range of locally produced foods consumed may be restricted by type of land around the site.
Releases to river		
Population groups	Angling family - Long periods on the river bank, consume fish from the river and drinking water from the river.	Drinking water may be blended with other waters. Drinking water may be stored in reservoirs for long periods prior to consumption. Water will be treated prior to consumption with some removal of radionuclides.
	Irrigated food consumers - Consume root and green vegetables irrigated with river water.	There may be no crops which are produced with irrigated water.
Habits (food consumption rates)	High consumption rates of fish: 10 kg/y by adults, 5 kg/y by children and 1 kg/y by infants. Up to 1000 h/y on river bank High consumption rates of vegetables.	Fish consumption rates may be lower especially if rivers are populated with coarse fish (1-2 kg/y more common). Consumption rates of locally produced irrigated vegetables may be lower.
Releases to estuary/coastal waters		
Population groups	Fishing family who spend long periods on intertidal areas and who consume seafoods at high rates.	Site specific habit data may indicate lower consumption rates for fish/shellfish.
Habits (occupancy rates)	Adults spend 2000 h/y on intertidal sediment; children 300 h/y; and infants 30 h/y.	Young children and infants may spend little time on intertidal areas around the site.
Habits (fish and shellfish consumption rates)	Adults are assumed to consume 100 kg/y of fish and 40 kg/y of shellfish.	Habits surveys may show that consumption of fish and shellfish is lower.

Table 9 Continued

Parameter	Default data for initial radiological assessment	Comments
Releases to sewer		
Sewage treatment works	Decay of radioactivity - Mean sludge residence time in STW of 656 h assumed.	Radioactive decay prior to reaching STW may also be taken into account and longer delays prior to application on land.
Disposal route for sludge	Sludge assumed to be disposed of to pasture to condition soil.	Sludge may be incinerated, disposed of to landfill or used in landscaping or forests.
Population groups	Sewage worker at STW	No human contact with sewage may be possible, if process is enclosed.
	Farming family at farm receiving treated sewage sludge, assumes spread on farmland at 8 $kg/m^2/y$.	Sludge may be spread at a lower application rate.
	Children playing in brook	Children may not be able to access the brook.
	Angling family and irrigated food consumers	As river discharge exposed groups above.
	Fishing family - Exposed to discharges to estuary or coastal waters.	As estuary/coastal waters discharge exposed groups above.
Habits	Sewage treatment worker: 2000 h/y at works.	Occupancy for up to 2000 h/y, 1 m from sewage tanks is cautious. Occupancy is likely to be lower
	Farming family at farm receiving treated sewage sludge, assumes 100% grazing of affected land by animals and high intakes of animal products 100% from the land. High occupancy by adult of treated pasture.	The rates of consumption are likely to be lower and not sustainable over one year. The range of locally produced foods consumed may be restricted by type of land around the site and area of land available. Cows may be indoors in winter - not grazing affected pasture and sheep have their diet augmented with feed.
	Children playing in brook – inadvertent water consumption rates of 5 litre/y	Inadvertent consumption rate of water may be much lower.
	Angling family and irrigated food consumer – habits as river above	As river discharge exposed groups above.
	Fishing family exposed to discharges to estuary or coastal waters.	As estuary/coastal waters discharge exposed groups above.

Table 10 Doses from releases to river assessed using Environment Agency methodology and NRPB-W63 [Ref 6] (assuming river flow rate of 10 m^3/s)

Nuclide	Discharge MBq/y	Total dose μSv/y		Reason
		Agency	W-63	
C-14	1.0E+04	3.8 (adult)	1.6 (adult)	Fish CF
P-32	6.0E+03	4.9 (child)	44 (adult)	Fish CF & intake rate
P-33	6.0E+03	0.5 (child)	4.4 (adult)	Fish CF & intake rate
I-131	1.9E+05	32 (infant)	8.0 (adult)	Drinking water clean up
Total		41	58	

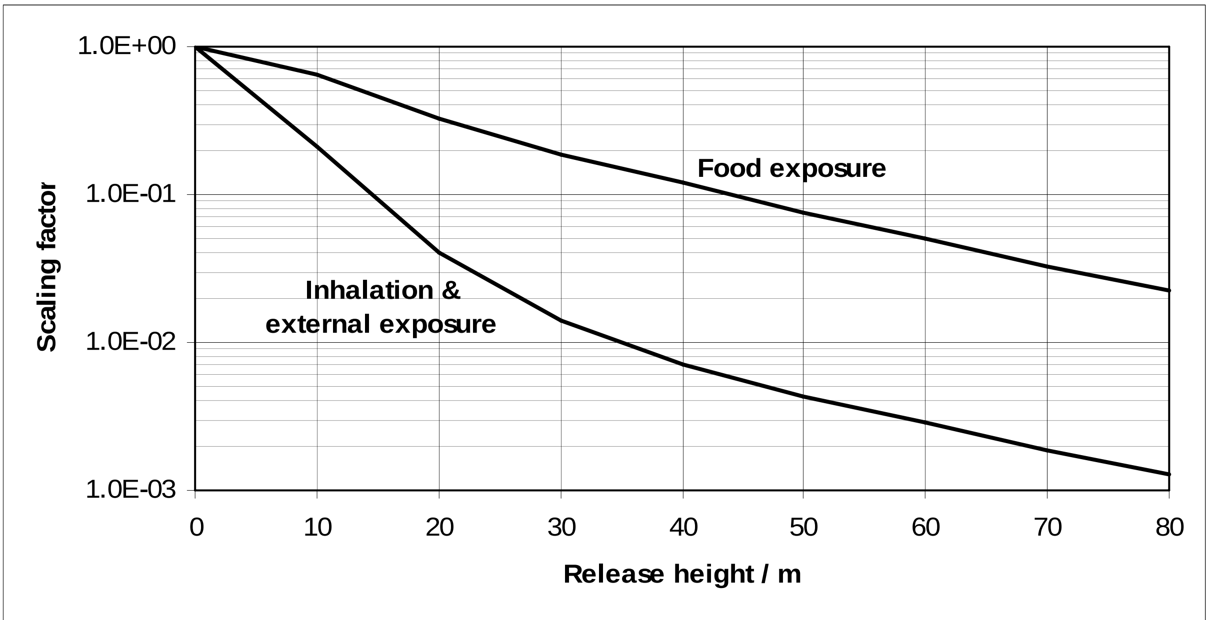

Figure 1 Scaling factors for different release heights for releases to air ($f_{inh\&ext}$, f_{food})[a]

[a]The scaling factors for the inhalation and external dose pathways have been derived from the maximum ground-level concentration for each release height (at a distance no closer than 100 m to the release point) divided by the maximum ground-level concentration for a ground-level release at 100 m (7 10^{-5} Bq/m^3 per Bq/s). Similarly, the scaling factors for the food dose pathway are derived from the maximum ground-level concentration for each release height (at a distance no closer than 500 m to the release point) divided by the maximum ground-level concentration for a ground-level release at 500 m (4 10^{-6} Bq/m^3 per Bq/s).

APPENDIX 1 – RELEASES TO AIR

The dose per unit release data were calculated for local habitants (adults, children and infants). The parameters values used to derive the DPUR are shown in Table A1.1. The following exposure pathways were included:

- Inhalation (including resuspension) of air containing radionuclides
- External radiation (gamma and beta) from plume
- External radiation (gamma and beta) from deposited radionuclides
- Consumption of milk, cow meat, sheep meat, cow and sheep offal, green vegetables, root vegetables and fruit containing radionuclides

The PC Cream [Ref A1.1] code was used to calculate the doses for a unit release. Many of the default PC Cream data were used along with assumptions from the NRPB Generalised Dose Constraints (GDC) [Ref A1.2, A1.3]. However, there were the following variations:

- The atmospheric dispersion module (Plume) within PC Cream was run for an effective release height of 10 m and the distance to the exposed person was 300 m as this is the minimum distance in PC Cream. The air concentrations for each nuclide were then scaled by the dispersion factors given in Table A1.1, derived from NRPB-R91 [Ref A1.4] for a ground level release and a distance to the exposed person of 100 m.
- PC Cream is not able to calculate doses for F-18 and Tc-99m. The DPUR for these nuclides were calculated for an inhalation dose and external exposure to the plume. Inhalation dose coefficients from the EC Basic Safety Standards [Ref A1.5] and external dose coefficients from FGR 12 [Ref A1.6] were used in the calculations.

References

A1.1. A Mayall, T Cabianca, C Attwood, C A Fayers, J G Smith, J Penfold, D Steadman, G Martin, T P Morris and J R Simmonds (1997). *PC-CREAM Installing and using the PC system for assessing the radiological impact of routine releases*. EUR 17791 EN, NRPB-SR296.

A1.2. J G Titley, C A Attwood and J R Simmonds (2000). Generalised Derived Constraints for Radioisotopes of Strontium, Ruthenium, Iodine, Caesium, Plutonium, Americium and Curium. *Doc NRPB*, **11(2)**, 1-41.

A1.3. M P Harvey and J R Simmonds (2002). Generalised Derived Constraints for Radioisotopes of Polonium, Lead, Radium and Uranium. *Doc NRPB*, **13(2)**, 1-38.

A1.4. R H Clarke (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.

A1.5. Council Directive 96/29/Euratom of 13 May 1996 *Laying Down Basic Safety Standards for the Protection of the Health of Workers and the General Public Against the Dangers Arising from Ionizing Radiation*. Official Journal of the European Communities, L159, Volume 39, 29 June 1996.

A1.6. K F Eckerman and J C Ryman (1993). *External Exposure to Radionuclides in Air, Water and Soil*. Federal Guidance Report 12. EPA Report 402-R-93-081. Washington, DC.

A1.7. K R Smith and A L Jones (2003). Generalised Habit Data for Radiological Assessments. NRPB W41.

Table A1.1 Parameter assumptions for deriving DPUR for releases to air

Parameter	Value	Comment
Dispersion coefficients	Exposed person 7 10^{-5} Bq/m^3 per Bq/s Food production 4 10^{-6} Bq/m^3 per Bq/s These relate to a ground-level release, 50%D, uniform wind rose, a distance to the exposed person of 100 m and a distance to the food production area of 500 m.	Dispersion factors taken from NRPB-R91 [Ref A1.4]. DPUR data were scaled by the ratio of these dispersion factor to those assessed by PC Cream 98. Effective release height and distance assumptions are the same as the NRPB GDCs [Ref A1.2, A1.3]
Deposition velocity and washout coefficient	0.01 ms^{-1} for I 0.001 ms^{-1} for everything else except H-3 and C-14.	PC Cream 98 defaults
Food transfer factors	As calculated by PC Farmland	PC Cream 98 default suite of codes
Food consumption rates	Infant Cow meat 10 kg/y Milk 320 kg/y Cow liver 2.75 kg/y Sheep meat 3 kg/y Sheep liver 2.75 kg/y Green veg 15 kg/y Root veg 45 kg/y Fruit 35 kg/y Child Cow meat 30 kg/y Milk 240 kg/y Cow liver 5 kg/y Sheep meat 10 kg/y Sheep liver 5 kg/y Green veg 35 kg/y Root veg 95 kg/y Fruit 50 kg/y Adult Cow meat 45 kg/y Milk 240 kg/y Cow liver 10 kg/y Sheep meat 25 kg/y Sheep liver 10 kg/y Green veg 80 kg/y Root veg 130 kg/y Fruit 75 kg/y	PC Cream 98 defaults, except infant consumption of cow and sheep liver for which NRPB-W41 [Ref A1.7] selected.
Resuspension	Default settings in Resus in PC Cream	PC Cream 98 suite of codes Resuspension is rarely an important pathway for atmospheric discharges.
External irradiation from plume	PC Cream 98 default data except: F-18 4.56e-14 Sv/s per Bq/m^3 Tc-99m 5.25e-15 Sv/s per Bq/m^3	
External irradiation from deposited radionuclides	Default settings in Granis in PC Cream	PC Cream 98 suite of codes
Breathing rates	m^3/y m^3/s Infant 1900 6.1 10^{-5} Child 5600 1.8 10^{-4} Adult 8100 2.6 10^{-4}	NRPB-W41 [Ref A1.7]

Table A1.1 Continued

Parameter	Value	Comment
Occupancy at habitation and percentage of time indoors	Occupancy h/y; % indoor Infant 8760 0.9 Child 8760 0.8 Adult 8760 0.9	
Shielding factors	Cloud 0.2 Deposited 0.1	PC Cream 98 defaults
Dose coefficients	PC Cream default data, except for H-3 and C-14.	Default BSS used for H-3 and C-14.
Integration period for doses	50y	
Age group	Worst selected from infant, child and adult	Fetal doses not included

APPENDIX 2 – RELEASES TO RIVER

The dose per unit release data were calculated for an angling family (adults, children and infants) and persons consuming food irrigated by river water. The following exposure pathways were included:

Angling family:
- Consumption of water containing radionuclides
- Consumption of fish containing radionuclides
- External radiation (gamma & beta) from sediment

Consumption of irrigated food:
- Consumption of green vegetables and root vegetables containing radionuclides

The dose calculations for water consumption, fish consumption and exposure to sediments were performed using both PC Cream [Ref A2.1] for those radionuclides which are included in this code and by spreadsheet calculation, using a number of models, for the remainder. Table A2.1 shows whether PC Cream or other calculations were used to derive the DPUR for the angling family.

The DPUR for consumption of irrigated food were calculated by separate models using spreadsheets.

Angling family DPUR calculated using PC Cream

The PC Cream Assessor dynamic rivers model was used, with one river compartment. The code was set up to give an effective flow rate of 10 m^3/s. However, all data was then scaled by 10 to equate to an effective flow rate of 1 m^3/s. The set up parameters for PC Cream are shown in Table A2.2 and Table A2.3.

Water concentrations calculated by PC Cream are shown in Table A2.4. Doses per unit release values from consumption of water, fish and exposure to external radiation were then calculated by PC Cream.

Angling family DPUR calculated by other models

For those radionuclides which were not assessed by PC Cream, the filtered water concentrations were calculated using the NRPB-M744 methodology [Ref A2.2] for a unit release, assuming an effective flow rate of 1 m^3/s. Calculated filtered water concentrations are shown in Table A2.4. The fish concentrations per unit release were calculated from the filtered water concentrations per unit release multiplied by the fish concentration factors (Table A2.3). The sediment concentrations per unit release were calculated from the filtered water concentrations per unit release multiplied by the sediment partitioning coefficients (K_d) (Table A2.3).

DPUR factors were then calculated using habit data in Table A2.2, ingestion dose coefficients from the EC Basic Safety Standards [Ref A2.3] and external dose coefficients from FGR 12 [Ref A2.4] (see Table A2.5). For the external dose rate over sediments containing radionuclides, it was assumed that the radionuclides with a short half-live were only mixed to a depth of 1 cm (see Table A2.5).

Irrigated food consumers DPUR

The DPUR for irrigated food consumers were calculated from the filtered water concentrations per unit release (Table A2.4), the application rate of irrigation water

(Table A2.2), the transfer factors to vegetables per unit deposition (Table A2.6), consumption rates of vegetables (Table A2.2) and the ingestion dose coefficients from the EC Basic Safety Standards [Ref A2.3].

References

A2.1. A Mayall, T Cabianca, C Attwood, C A Fayers, J G Smith, J Penfold, D Steadman, G Martin, T P Morris and J R Simmonds (1997). *PC-CREAM Installing and using the PC system for assessing the radiological impact of routine releases*. EUR 17791 EN, NRPB-SR296.

A2.2. C E McDonnell (1996). Assessment of the Radiological Consequences of Accumulation and Disposal of Radioactive Wastes by Small Users of Radioactive Materials. NRPB-M744.

A2.3. Council Directive 96/29/Euratom of 13 May 1996 *Laying Down Basic Safety Standards for the Protection of the Health of Workers and the General Public Against the Dangers Arising from Ionizing Radiation*. Official Journal of the European Communities, L159, Volume 39, 29 June 1996.

A2.4. K F Eckerman and J C Ryman (1993). *External Exposure to Radionuclides in Air, Water and Soil*. Federal Guidance Report 12. EPA Report 402-R-93-081. Washington, DC.

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Table A2.1 Method for calculation of angling family DPUR

Nuclide	DPUR calculated by PC Cream	DPUR Calculated by spreadsheet	Nuclide	DPUR calculated by PC Cream	DPUR Calculated by spreadsheet
Tritium	✓		Iodine-129	✓	✓ (external)[a]
Tritium (Organically Bound)		✓	Iodine-131	✓	✓ (external)[a]
Carbon-14	✓		Iodine-132	✓	✓ (external)[a]
Fluorine-18		✓	Iodine-133	✓	✓ (external)[a]
Sodium-22		✓	Iodine-134	✓	✓ (external)[a]
Sodium-24		✓	Iodine-135	✓	✓ (external)[a]
Phosphorus-32	✓	✓ (external)[a]	Caesium-134	✓	
Phosphorus-33		✓	Caesium-136	✓	
Sulphur-35	✓	✓ (external)[a]	Caesium-137	✓	
Chlorine-36		✓	Barium-140		✓
Calcium-45		✓	Lanthanum-140		✓
Calcium-47		✓	Cerium-144	✓	
Vanadium-48		✓	Promethium-147		✓
Chromium-51	✓		Samarium-153		✓
Manganese-54	✓		Erbium-169		✓
Manganese-56		✓	Thallium-201		✓
Iron-59	✓		Lead-210		✓
Cobalt-57		✓	Polonium-210		✓
Cobalt-58	✓		Radium-226	✓	✓ (external)[a]
Cobalt-60	✓		Thorium-230		✓
Gallium-67		✓	Thorium-232		✓
Selenium-75		✓	Uranium-234	✓	✓ (external)[a]
Bromine-82		✓	Uranium-235	✓	✓ (external)[a]
Strontium-89	✓		Uranium-238	✓	✓ (external)[a]
Strontium-90	✓		Neptunium-237		✓
Yttrium-90	✓		Plutonium-238	✓	
Zirconium-95	✓		Plutonium-239	✓	
Niobium-95	✓		Plutonium-240	✓	
Technetium-99	✓	✓ (external)[a]	Plutonium-241	✓	
Technetium-99m		✓	Plutonium-242	✓	
Ruthenium-103	✓		Americium-241	✓	
Ruthenium-106	✓	✓ (external)[a]	Americium-242	✓	
Indium-111		✓	Americium-243	✓	
Indium-113m		✓	Curium-242	✓	
Antimony-125	✓		Curium-243	✓	
Iodine-123		✓	Curium-244	✓	
Iodine-125	✓	✓ (external)[a]			

[a]External dose rate only was calculated by separate models, as PC Cream external dose rates were not available.

Table A2.2 Parameter assumptions for deriving DPUR for releases to river

Parameter	Value	Comment
River flow	1 m^3/s	PC Cream runs were actually undertaken for a velocity of 2.00E+00 m/s (6.31E+07 m/y), combined with the river width and depth, to give a flow rate of 10 m^3/s. However, all DPUR data was subsequently increased by a factor of ten for a flow rate of 1 m^3/s.
Velocity of bed sediment flow	3.17E-05 m/s 1.00E+03 m/y	PC Cream defaults
Suspended sediment load	4.00E-02 kg/m^3 4.00E-05 t/m^3	PC Cream defaults
River length	5.00E+02 m	PC Cream defaults
Width	5.00E+00 m	PC Cream defaults
Water depth	1.00E+00 m	PC Cream defaults
Bed sediment depth	3.00E-01 m	PC Cream defaults
Dry sediment density	1.50E+03 kg/m^3 1.50E+00 t/m^3	PC Cream defaults
Water concentrations	See Table A2.4	
Occupancy on river	Occupancy h/y Infant 30 Child 500 Adult 1000	NRPB-W41 [Ref A2.5]
Consumption rates	Fish kg/y, Water kg/y Infant 1, 260 Child 5, 350 Adult 10, 600	NRPB-W41 [Ref A2.5]
Fish CF	see Table A2.3	
Sediment kd	see Table A2.3	
Ingestion dose coefficients	PC Cream defaults	
External dose coefficients	see Table A2.5	
Irrigation rate	0.1 m^3 per m^2/y	
Food transfer factors for irrigated food	See Table A2.6	
Consumption rates for irrigated food	Infant Green veg 15 kg/y Root veg 45 kg/y Child Green veg 35 kg/y Root veg 95 kg/y Adult Green veg 80 kg/y Root veg 130 kg/y	NRPB-W41 [Ref A2.5]

Table A2.3 Freshwater fish CF and sediment Kd

Nuclide	Fish CF		Sediment Kd	
	Value (Bq/kg per Bq/l)	Source of data	Value (Bq/kg per Bq/l)	Source of data
Tritium	9.0E-01	PC Cream	3.0E-02	PC Cream
Tritium (Organically Bound)	2.2E+04	Same as C-14	2.0E+03	Same as C-14
Carbon-14	2.2E+04	Short term release R&D [Ref A2.6] (PC Cream default of 4.55E+03)	2.0E+03	PC Cream
Fluorine-18	1.0E+01	NCRP 123 I [Ref A2.7]	3.0E+02	Same as iodine
Sodium-22	2.0E+01	IAEA 364 [Ref A2.8]	2.0E+03	Same as caesium
Sodium-24	2.0E+01	IAEA 364 [Ref A2.8]	2.0E+03	Same as caesium
Phosphorus-32	1.0E+04	Short term release R&D [Ref A2.6] (PC Cream default of 5.0E+04)	1.0E+03	PC Cream
Phosphorus-33	1.0E+04	Short term release R&D [Ref A2.6]	1.0E+03	PC Cream
Sulphur-35	2.0E+02	PC Cream	3.0E+03	PC Cream
Chlorine-36	1.0E+03	NCRP 123 I [Ref A2.7]	3.0E+02	Same as iodine
Calcium-45	1.0E+03	NCRP 123 I [Ref A2.7]	2.0E+03	Same as strontium
Calcium-47	1.0E+03	NCRP 123 I [Ref A2.7]	2.0E+03	Same as strontium
Vanadium-48	2.0E+02	NCRP 123 I [Ref A2.7]	2.0E+04	Same as chromium
Chromium-51	4.0E+01	PC Cream	2.0E+04	PC Cream
Manganese-54	1.0E+02	PC Cream	5.0E+04	PC Cream
Manganese-56	1.0E+02	PC Cream	5.0E+04	PC Cream
Iron-59	1.0E+02	PC Cream	1.0E+04	PC Cream
Cobalt-57	3.0E+02	PC Cream	2.0E+04	PC Cream
Cobalt-58	3.0E+02	PC Cream	2.0E+04	PC Cream
Cobalt-60	3.0E+02	PC Cream	2.0E+04	PC Cream
Gallium-67	4.0E+02	NCRP 123 I [Ref A2.7]	1.0E+03	Same as zinc
Selenium-75	2.0E+02	NCRP 123 I [Ref A2.7]	1.8E+03	IAEA 364 [Ref A2.8] - Organic soil
Bromine-82	4.0E+02	IAEA 364 [Ref A2.8]	3.0E+02	Same as iodine
Strontium-89	6.0E+01	PC Cream	2.0E+03	PC Cream
Strontium-90	6.0E+01	PC Cream	2.0E+03	PC Cream
Yttrium-90	2.5E+01	PC Cream	4.0E+03	PC Cream
Zirconium-95	3.3E+00	PC Cream	6.0E+04	PC Cream
Niobium-95	3.0E+04	PC Cream	1.0E+02	PC Cream
Technetium-99	1.5E+01	PC Cream	2.0E+02	PC Cream
Technetium-99m	1.5E+01	PC Cream	2.0E+02	PC Cream
Ruthenium-103	1.0E+01	PC Cream	7.0E+03	PC Cream
Ruthenium-106	1.0E+01	PC Cream	7.0E+03	PC Cream
Indium-111	1.0E+04	NCRP 123 I [Ref A2.7]	1.0E+03	Same as zinc
Indium-113m	1.0E+04	NCRP 123 I [Ref A2.7]	1.0E+03	Same as zinc
Antimony-125	1.0E+00	PC Cream	5.0E+02	PC Cream
Iodine-123	4.0E+01	Short term release R&D[Ref A2.6] (PC Cream default of 20)	3.0E+02	PC Cream
Iodine-125	4.0E+01	Short term release R&D [Ref A2.6] (PC Cream default of 20)	3.0E+02	PC Cream
Iodine-129	4.0E+01	Short term release R&D [Ref A2.6] (PC Cream default of 20)	3.0E+02	PC Cream
Iodine-131	4.0E+01	Short term release R&D [Ref A2.6] (PC Cream default of 20)	3.0E+02	PC Cream
Iodine-132	4.0E+01	Short term release R&D [Ref A2.6] (PC Cream default of 20)	3.0E+02	PC Cream

Table A2.3 Continued

Nuclide	Fish CF		Sediment Kd	
	Value (Bq/kg per Bq/l)	Source of data	Value (Bq/kg per Bq/l)	Source of data
Iodine-133	4.0E+01	Short term release R&D [Ref A2.6] (PC Cream default of 20)	3.0E+02	PC Cream
Iodine-134	4.0E+01	Short term release R&D [Ref A2.6] (PC Cream default of 20)	3.0E+02	PC Cream
Iodine-135	4.0E+01	Short term release R&D [Ref A2.6] (PC Cream default of 20)	3.0E+02	PC Cream
Caesium-134	2.0E+03	PC Cream	2.0E+03	PC Cream
Caesium-136	2.0E+03	PC Cream	2.0E+03	PC Cream
Caesium-137	2.0E+03	PC Cream	2.0E+03	PC Cream
Barium-140	4.0E+00	IAEA 364 [Ref A2.8]	2.0E+03	Same as strontium
Lanthanum-140	3.0E+01	IAEA 364 [Ref A2.8]	2.0E+03	Same as strontium
Cerium-144	3.0E+01	PC Cream	3.0E+04	PC Cream
Promethium-147	3.0E+01	IAEA 364 [Ref A2.8]	5.0E+03	IAEA 364 [Ref A2.8]
Samarium-153	2.5E+01	NCRP 123 I [Ref A2.7]	5.0E+03	Same as promethium
Erbium-169	1.2E+04	NCRP 123 I [Ref A2.7]	5.0E+03	Same as promethium
Thallium-201	1.0E+04	NCRP 123 I [Ref A2.7]	2.2E+04	Same as lead
Lead-210	3.0E+01	IAEA 364 [Ref A2.8]	2.2E+04	IAEA 364 [Ref A2.8] - Organic soil kd
Polonium-210	5.0E+01	IAEA 364 [Ref A2.8]	6.6E+03	IAEA 364 [Ref A2.8] - Organic soil kd
Radium-226	5.0E+01	PC Cream	5.0E+02	PC Cream
Thorium-230	1.0E+02	IAEA 364 [Ref A2.8]	1.0E+04	IAEA 364 [Ref A2.8]
Thorium-232	1.0E+02	IAEA 364 [Ref A2.8]	1.0E+04	IAEA 364 [Ref A2.8]
Uranium-234	1.0E+01	PC Cream	5.0E+01	PC Cream
Uranium-235	1.0E+01	PC Cream	5.0E+01	PC Cream
Uranium-238	1.0E+01	PC Cream	5.0E+01	PC Cream
Neptunium-237	3.0E+01	IAEA 364 [Ref A2.8] (PC Cream default of 3.5)	3.0E+04	RP 72 [Ref A2.9]
Plutonium-238	3.0E+01	IAEA 364 [Ref A2.8] (PC Cream default of 3.5)	1.0E+05	PC Cream
Plutonium-239	3.0E+01	IAEA 364 [Ref A2.8] (PC Cream default of 3.5)	1.0E+05	PC Cream
Plutonium-240	3.0E+01	IAEA 364 [Ref A2.8] (PC Cream default of 3.5)	1.0E+05	PC Cream
Plutonium-241	3.0E+01	IAEA 364 [Ref A2.8] (PC Cream default of 3.5)	1.0E+05	PC Cream
Plutonium-242	3.0E+01	IAEA 364 [Ref A2.8] (PC Cream default of 3.5)	1.0E+05	PC Cream
Americium-241	2.5E+01	PC Cream	4.0E+05	PC Cream
Americium-242	2.5E+01	PC Cream	4.0E+05	PC Cream
Americium-243	2.5E+01	PC Cream	4.0E+05	PC Cream
Curium-242	2.5E+01	PC Cream	4.0E+05	PC Cream
Curium-243	2.5E+01	PC Cream	4.0E+05	PC Cream
Curium-244	2.5E+01	PC Cream	4.0E+05	PC Cream

Table A2.4 Water concentrations per unit release

Nuclide	Water concentration for river flow of 1 m^3/s (Bq/l per Bq/y)	Source of data
Tritium	3.2E-11	PC Cream
Tritium (Organically Bound)	2.9E-11	Same as C-14
Carbon-14	2.9E-11	PC Cream
Fluorine-18	3.1E-11	Calc by NRPB-M744 method [Ref A2.2]
Sodium-22	2.9E-11	Calc by NRPB-M744 method [Ref A2.2]
Sodium-24	2.9E-11	Calc by NRPB-M744 method [Ref A2.2]
Phosphorus-32	3.1E-11	PC Cream
Phosphorus-33	3.0E-11	Calc by NRPB-M744 method [Ref A2.2]
Sulphur-35	2.8E-11	PC Cream
Chlorine-36	3.1E-11	Calc by NRPB-M744 method [Ref A2.2]
Calcium-45	2.9E-11	Calc by NRPB-M744 method [Ref A2.2]
Calcium-47	2.9E-11	Calc by NRPB-M744 method [Ref A2.2]
Vanadium-48	1.8E-11	Calc by NRPB-M744 method [Ref A2.2]
Chromium-51	1.8E-11	PC Cream
Manganese-54	1.0E-11	PC Cream
Manganese-56	1.1E-11	Calc by NRPB-M744 method [Ref A2.2]
Iron-59	2.3E-11	PC Cream
Cobalt-57	1.8E-11	Calc by NRPB-M744 method [Ref A2.2]
Cobalt-58	1.8E-11	PC Cream
Cobalt-60	1.8E-11	PC Cream
Gallium-67	3.0E-11	Calc by NRPB-M744 method [Ref A2.2]
Selenium-75	3.0E-11	Calc by NRPB-M744 method [Ref A2.2]
Bromine-82	3.1E-11	Calc by NRPB-M744 method [Ref A2.2]
Strontium-89	2.9E-11	PC Cream
Strontium-90	2.9E-11	PC Cream
Yttrium-90	2.7E-11	PC Cream
Zirconium-95	9.3E-12	PC Cream
Niobium-95	3.2E-11	PC Cream
Technetium-99	3.1E-11	PC Cream
Technetium-99m	3.1E-11	Calc by NRPB-M744 method [Ref A2.2]
Ruthenium-103	2.5E-11	PC Cream
Ruthenium-106	2.5E-11	PC Cream
Indium-111	3.0E-11	Calc by NRPB-M744 method [Ref A2.2]
Indium-113m	3.0E-11	Calc by NRPB-M744 method [Ref A2.2]
Antimony-125	3.1E-11	PC Cream
Iodine-123	3.1E-11	Calc by NRPB-M744 method [Ref A2.2]
Iodine-125	3.1E-11	PC Cream
Iodine-129	3.1E-11	PC Cream
Iodine-131	3.1E-11	PC Cream
Iodine-132	3.1E-11	PC Cream
Iodine-133	3.1E-11	PC Cream
Iodine-134	3.0E-11	PC Cream
Iodine-135	3.1E-11	PC Cream
Caesium-134	2.9E-11	PC Cream
Caesium-136	2.9E-11	PC Cream
Caesium-137	2.9E-11	PC Cream
Barium-140	2.9E-11	Calc by NRPB-M744 method [Ref A2.2]
Lanthanum-140	2.9E-11	Calc by NRPB-M744 method [Ref A2.2]
Cerium-144	1.4E-11	PC Cream
Promethium-147	2.6E-11	Calc by NRPB-M744 method [Ref A2.2]
Samarium-153	2.6E-11	Calc by NRPB-M744 method [Ref A2.2]
Erbium-169	2.6E-11	Calc by NRPB-M744 method [Ref A2.2]
Thallium-201	1.7E-11	Calc by NRPB-M744 method [Ref A2.2]
Lead-210	1.7E-11	Calc by NRPB-M744 method [Ref A2.2]

Table A2.4 Continued

Nuclide	Water concentration for river flow of 1 m^3/s (Bq/l per Bq/y)	Source of data
Polonium-210	2.5E-11	Calc by NRPB-M744 method [Ref A2.2]
Radium-226	3.1E-11	PC Cream
Thorium-230	2.3E-11	Calc by NRPB-M744 method [Ref A2.2]
Thorium-232	2.3E-11	Calc by NRPB-M744 method [Ref A2.2]
Uranium-234	3.2E-11	PC Cream
Uranium-235	3.2E-11	PC Cream
Uranium-238	3.2E-11	PC Cream
Neptunium-237	1.4E-11	Calc by NRPB-M744 method [Ref A2.2]
Plutonium-238	5.9E-12	PC Cream
Plutonium-239	5.9E-12	PC Cream
Plutonium-240	5.9E-12	PC Cream
Plutonium-241	5.9E-12	PC Cream
Plutonium-242	5.9E-12	PC Cream
Americium-241	1.8E-12	PC Cream
Americium-242	1.8E-12	PC Cream
Americium-243	1.8E-12	PC Cream
Curium-242	1.9E-12	PC Cream
Curium-243	1.9E-12	PC Cream
Curium-244	1.9E-12	PC Cream

Table A2.5 External dose coefficients

Nuclide	External Dose Coefficient (Sv/h per Bq/kg)	Source of data
Tritium	-	Calculated by PC Cream
Tritium (Organically Bound)	0.00E+00	
Carbon-14	-	Calculated by PC Cream
Fluorine-18	6.71E-12	FGR-12 [Ref A2.4] top 1cm
Sodium-22	5.70E-10	NRPB-M744 now NRPB-W63 [Ref A2.10]
Sodium-24	2.41E-11	FGR-12 [Ref A2.4] top 1cm
Phosphorus-32	7.17E-14	FGR-12 [Ref A2.4] top 1cm
Phosphorus-33	1.37E-16	FGR-12 [Ref A2.4] top 1cm
Sulphur-35	2.36E-16	FGR 12 [Ref A2.4] infinite
Chlorine-36	4.79E-14	FGR 12 [Ref A2.4] infinite
Calcium-45	1.03E-15	FGR 12 [Ref A2.4] infinite
Calcium-47	6.78E-12	FGR-12 [Ref A2.4] top 1cm
Vanadium-48	1.87E-11	FGR-12 [Ref A2.4] top 1cm
Chromium-51	-	Calculated by PC Cream
Manganese-54	-	Calculated by PC Cream
Manganese-56	1.08E-11	FGR-12 [Ref A2.4] top 1cm
Iron-59	-	Calculated by PC Cream
Cobalt-57	3.30E-11	NRPB-M744 now NRPB-W63 [Ref A2.10]
Cobalt-58	-	Calculated by PC Cream
Cobalt-60	-	Calculated by PC Cream
Gallium-67	9.64E-13	FGR-12 [Ref A2.4] top 1cm
Selenium-75	1.00E-10	NRPB-M744 now NRPB-W63 [Ref A2.10]
Bromine-82	1.71E-11	FGR-12 [Ref A2.4] top 1cm
Strontium-89	-	Calculated by PC Cream
Strontium-90	-	Calculated by PC Cream
Yttrium-90	-	Calculated by PC Cream
Zirconium-95	-	Calculated by PC Cream
Niobium-95	-	Calculated by PC Cream

Table A2.5 Continued

Nuclide	External Dose Coefficient (Sv/h per Bq/kg)	Source of data
Technetium-99	2.09E-15	FGR 12 [Ref A2.4] infinite
Technetium-99m	7.80E-13	FGR-12 [Ref A2.4] top 1cm
Ruthenium-103	-	Calculated by PC Cream
Ruthenium-106	4.30E-11	NRPB GDC [Ref A2.11]
Indium-111	2.48E-12	FGR-12 [Ref A2.4] top 1cm
Indium-113m	1.65E-12	FGR-12 [Ref A2.4] top 1cm
Antimony-125	-	Calculated by PC Cream
Iodine-123	9.66E-13	FGR-12 [Ref A2.4] top 1cm
Iodine-125	1.70E-12	NRPB GDC [Ref A2.11]
Iodine-129	1.40E-12	NRPB GDC [Ref A2.11]
Iodine-131	2.49E-12	FGR-12 [Ref A2.4] top 1cm
Iodine-132	1.48E-11	FGR-12 [Ref A2.4] top 1cm
Iodine-133	3.99E-12	FGR-12 [Ref A2.4] top 1cm
Iodine-134	1.70E-11	FGR-12 [Ref A2.4] top 1cm
Iodine-135	1.00E-11	FGR-12 [Ref A2.4] top 1cm
Caesium-134	-	Calculated by PC Cream
Caesium-136	-	Calculated by PC Cream
Caesium-137	-	Calculated by PC Cream
Barium-140	1.18E-12	FGR-12 [Ref A2.4] top 1cm
Lanthanum-140	1.47E-11	FGR-12 [Ref A2.4] top 1cm
Cerium-144	-	Calculated by PC Cream
Promethium-147	1.09E-16	FGR-12 [Ref A2.4] top 1cm
Samarium-153	2.99E-13	FGR-12 [Ref A2.4] top 1cm
Erbium-169	2.88E-16	FGR-12 [Ref A2.4] top 1cm
Thallium-201	4.95E-13	FGR-12 [Ref A2.4] top 1cm
Lead-210	3.10E-13	NRPB GDC [Ref A2.12]
Polonium-210	1.80E-15	NRPB GDC [Ref A2.12]
Radium-226	3.80E-10	NRPB GDC [Ref A2.12]
Thorium-230	2.06E-14	FGR 12 [Ref A2.4] infinite
Thorium-232	8.78E-15	FGR 12 [Ref A2.4] infinite
Uranium-234	3.11E-14	NRPB GDC [Ref A2.12]
Uranium-235	3.79E-11	NRPB GDC [Ref A2.12]
Uranium-238	6.78E-12	NRPB GDC [Ref A2.12]
Neptunium-237	1.34E-12	FGR 12 [Ref A2.4] infinite
Plutonium-238	-	Calculated by PC Cream
Plutonium-239	-	Calculated by PC Cream
Plutonium-240	-	Calculated by PC Cream
Plutonium-241	-	Calculated by PC Cream
Plutonium-242	-	Calculated by PC Cream
Americium-241	-	Calculated by PC Cream
Americium-242	-	Calculated by PC Cream
Americium-243	-	Calculated by PC Cream
Curium-242	-	Calculated by PC Cream
Curium-243	-	Calculated by PC Cream
Curium-244	-	Calculated by PC Cream

Table A2.6 Food transfer factors for irrigated food[a]

Nuclide	Activity concentration in foods per unit deposition for 50y application of irrigation water (Bq/kg or Bq/l per $Bq/m^2/y$)		Source of data
	Green veg	Root veg	
Tritium	1.95E-03	1.95E-03	From TRIF [Ref A2.13]
Tritium (Organically Bound)	1.95E-03	1.95E-03	From TRIF [Ref A2.13]
Carbon-14	1.37E-02	1.37E-02	Assumed to be 7 times H-3 based on difference for other food types
Fluorine-18	-	-	No data – short half-life
Sodium-22	-	-	No data – short half-life
Sodium-24	-	-	No data – short half-life
Phosphorus-32	1.99E-03	1.62E-02	PC Cream for atmospheric
Phosphorus-33	1.99E-03	1.62E-02	P-33 same as P-32
Sulphur-35	3.93E-03	3.10E-03	PC Cream for atmospheric
Chlorine-36	-	-	No data – short half-life
Calcium-45	-	-	No data – short half-life
Calcium-47	-	-	No data – short half-life
Vanadium-48	-	-	No data – short half-life
Chromium-51	2.21E-03	6.78E-08	PC Cream for atmospheric
Manganese-54	3.61E-03	2.50E-04	PC Cream for atmospheric
Manganese-56	-	-	No data – short half-life
Iron-59	2.62E-03	1.77E-06	PC Cream for atmospheric
Cobalt-57	3.36E-03	2.57E-05	PC Cream for atmospheric
Cobalt-58	2.90E-03	8.11E-06	PC Cream for atmospheric
Cobalt-60	3.64E-03	1.62E-04	PC Cream for atmospheric
Gallium-67	-	-	No data – short half-life
Selenium-75	4.59E-03	3.87E-03	PC Cream for atmospheric
Bromine-82	3.23E-04	6.02E-06	PC Cream for atmospheric
Strontium-89	2.79E-03	2.57E-05	GDC for atmospheric [Ref A2.11]
Strontium-90	1.96E-02	2.79E-03	GDC for atmospheric [Ref A2.11]
Yttrium-90	5.36E-04	1.61E-07	PC Cream for atmospheric
Zirconium-95	2.84E-03	2.40E-06	PC Cream for atmospheric
Niobium-95	2.46E-03	4.12E-06	PC Cream for atmospheric
Technetium-99	2.90E-01	2.37E-01	PC Cream for atmospheric
Technetium-99m	-	-	No data – short half-life
Ruthenium-103	2.44E-03	3.80E-06	GDC for atmospheric [Ref A2.11]
Ruthenium-106	3.17E-03	3.01E-05	GDC for atmospheric [Ref A2.11]
Indium-111	-	-	No data – short half-life
Indium-113m	-	-	No data – short half-life
Antimony-125	3.55E-03	8.81E-05	PC Cream for atmospheric
Iodine-123	-	-	No data – short half-life
Iodine-125	3.17E-03	2.82E-03	GDC for atmospheric [Ref A2.11]
Iodine-129	6.02E-03	6.65E-03	GDC for atmospheric [Ref A2.11]
Iodine-131	1.30E-03	3.49E-04	GDC for atmospheric [Ref A2.11]
Iodine-132	-	-	No data – short half-life
Iodine-133	1.96E-04	1.49E-06	GDC for atmospheric [Ref A2.11]
Iodine-134	-	-	No data – short half-life
Iodine-135	6.43E-05	8.14E-08	PC Cream for atmospheric
Caesium-134	4.12E-03	4.44E-03	GDC for atmospheric [Ref A2.11]
Caesium-136	1.77E-03	6.02E-04	GDC for atmospheric [Ref A2.11]
Caesium-137	4.75E-03	5.07E-03	GDC for atmospheric [Ref A2.11]

Table A2.6 Continued

Nuclide	Activity concentration in foods per unit deposition for 50y application of irrigation water (Bq/kg or Bq/l per Bq/m^2/y)		Source of data
	Green veg	Root veg	
Barium-140	1.61E-03	6.53E-07	PC Cream for atmospheric
Lanthanum-140	3.58E-04	2.96E-08	PC Cream for atmospheric
Cerium-144	3.17E-03	2.22E-06	PC Cream for atmospheric
Promethium-147	3.30E-03	2.35E-05	PC Cream for atmospheric
Samarium-153	-	-	No data – short half-life
Erbium-169	-	-	No data – short half-life
Thallium-201	-	-	No data – short half-life
Lead-210	4.12E-03	5.07E-04	GDC for atmospheric [Ref A2.12]
Polonium-210	3.80E-03	3.07E-03	GDC for atmospheric [Ref A2.12]
Radium-226	4.12E-03	9.82E-05	GDC for atmospheric [Ref A2.12]
Thorium-230	3.36E-03	4.66E-05	PC Cream for atmospheric
Thorium-232	3.36E-03	4.66E-05	PC Cream for atmospheric
Uranium-234	3.49E-03	9.19E-05	GDC for atmospheric [Ref A2.12]
Uranium-235	3.49E-03	9.19E-05	GDC for atmospheric [Ref A2.12]
Uranium-238	3.49E-03	9.19E-05	GDC for atmospheric [Ref A2.12]
Neptunium-237	3.52E-03	9.32E-05	PC Cream for atmospheric
Plutonium-238	3.49E-03	3.80E-06	GDC for atmospheric [Ref A2.11]
Plutonium-239	3.49E-03	4.75E-06	GDC for atmospheric [Ref A2.11]
Plutonium-240	3.49E-03	4.75E-06	GDC for atmospheric [Ref A2.11]
Plutonium-241	3.17E-03	1.87E-06	GDC for atmospheric [Ref A2.11]
Plutonium-242	3.49E-03	4.75E-06	GDC for atmospheric [Ref A2.11]
Americium-241	3.49E-03	7.29E-06	GDC for atmospheric [Ref A2.11]
Americium-242	0.00E+00	0.00E+00	GDC for atmospheric [Ref A2.11]
Americium-243	3.49E-03	7.29E-06	GDC for atmospheric [Ref A2.11]
Curium-242	3.04E-03	4.12E-08	GDC for atmospheric [Ref A2.11]
Curium-243	3.49E-03	1.68E-06	GDC for atmospheric [Ref A2.11]
Curium-244	3.17E-03	1.30E-06	GDC for atmospheric [Ref A2.11]

[a]NRPB GDC [Refs A2.11 & A2.12] have food transfer factors for irrigation. However, there appears to be some inconsistencies between the data for isotopes of the same element and atmospheric data have been used instead.

APPENDIX 3 – RELEASES TO ESTUARY OR COASTAL WATERS

The dose per unit release data were calculated for a fisherman (adults, children and infants). The parameters values used to derive the DPUR are shown in Table A3.1. The following exposure pathways were included:

- Consumption of fish and shellfish containing radionuclides
- External radiation (gamma and beta) from sediment
- Inhalation of seaspray containing radionuclides (a minor pathway)

The dose calculations were performed using the PC Cream code [Ref A3.1]. A local compartment based on Springfields (ie Ribble Estuary) default data was selected. This was modified with a suspended sediment concentration for Heysham as this was found to give higher water concentrations [Ref A3.2].

The volumetric exchange rate was adjusted to 100 m^3/s. This minimum exchange rate was selected since work as part of the Environment Agency Science project P3-104 [Ref A3.2] demonstrated that the water concentrations predicted by the DORIS code in PC Cream were not linearly dependent upon the exchange rate, below 100 m^3/s.

Three sets of PC Cream runs were undertaken to be separate out the dose contribution from radionuclides such as Am-241 which will be released, but will also grow-in from releases of Pu-241.

PC Cream does not allow occupancy data to be entered separately for adults, children and infants and the adult results had to be scaled by the ratio of the occupancies given in Table A3.1 to derive DPUR for infants and children.

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A3.3. J R Simmonds, G Lawson and A Mayall (1995). *Methodology for assessing the radiological consequences of routine releases of radionuclides to the environment*. European Commission, Luxembourg, EUR 15760 EN, Radiation Protection 72.

A3.4. K R Smith and A L Jones (2003). Generalised Habit Data for Radiological Assessments. NRPB W41.

Table A3.1 Parameter assumptions for deriving DPUR for releases to estuary or coastal waters

Parameter	Value	Comment
Volume (m^3)	2.00E+08	RP 72 – Springfields [Ref A3.3]
Depth (m)	1.00E+01	RP 72 – Springfields [Ref A3.3]
Actual Coastline length (m)	1.00E+04	Default data from DORIS (PCCREAM98 marine dispersion model)
Coastline length entered into DORIS (m)	1.00E+04	Default data from DORIS (PCCREAM98 marine dispersion model)
Volumetric exchange (m^3 y^{-1})	3.20E+09	RP 72 Equates to 100 m^3/s [Ref A3.3]
Suspended sediment load (t m^{-3})	1.00E-05	RP 72 – Heysham [Ref A3.3]
Sedimentation rate (t m^{-2} y^{-1})	5.00E-03	RP 72 – Springfields [Ref A3.3]
Dry sediment density (t m^{-3})	2.60E+00	RP 72 – Default value [Ref A3.3]
Bioturbation rate (lakes and coastal waters) (m^2 y^{-1})	3.60E-05	RP 72 – Default value [Ref A3.3]
Diffusion rate (sediment diffusion coefficient) (m^2 y^{-1})	3.15E-02	RP 72 – default value [Ref A3.3]
Regional Compartment Used	Liverpool and Morecambe Bays Regional Marine Compartment	RP 72 – Springfields or Heysham [Ref A3.3]
Consumption rates	Infant kg/y local regional fish 5 0.5 0.5 crust 0 1 0 mollusc 0 1 0 Child kg/y local regional fish 20 0.5 0.5 crust 5 1 0 mollusc 5 1 0 Adult kg/y local regional fish 100 0.5 0.5 crust 20 1 0 mollusc 20 1 0	NRPB-W41 [Ref A3.4]
Occupancy on sediment	h/y local regional Infant 30 0.5 0.5 Child 300 0.5 0.5 Adult 2000 0.5 0.5	NRPB-W41 [Ref A3.4]
Fishing nets	h/y local regional Infant 0 0 0 Child 0 1 0 Adult 2000 0.5 0.5	NRPB-W41 [Ref A3.4]
Fish concentration factor (Bq/kg per Bq/l)	PC Cream defaults	
Kd (m^3/te)	PC Cream defaults	
Dose coefficients	PC Cream defaults	

APPENDIX 4 – RELEASES TO SEWER

The dose per unit release data were calculated for the following groups:

- STW worker
- Family living on land conditioned with sewage sludge
- Child playing in brook receiving treated effluent from STW
- Angling family, consumers of irrigated food and fishermen in estuaries/coastal waters are also included through use of DPUR calculated for direct discharge to rivers or estuaries/coastal waters. In the initial radiological assessment methodology these are scaled by factors to take account of partitioning of radionuclides to sewage sludge and radioactive decay.

The parameters values used to derive the DPUR are shown in Table A4.1 and all calculations were performed by spreadsheet. The following exposure pathways were included:

STW worker:
- External irradiation from raw sewage and sludge
- Inadvertent inhalation of raw sewage and sludge containing radionuclides
- Inadvertent consumption of raw sewage and sludge containing radionuclides

Farming family living on land conditioned with sewage sludge:
- Consumption of milk, cow meat, sheep meat, cow and sheep offal containing radionuclides grown on sewage sludge conditioned land
- External irradiation during spreading of sludge and during subsequent work/occupancy on sludge conditioned land
- Inadvertent inhalation of sludge during spreading of sludge to land and inhalation of soil incorporating sludge during subsequent work/occupancy on land
- Inadvertent ingestion of sludge during spreading of sludge to land and inadvertent ingestion of soil containing sludge during subsequent work/occupancy on land.

Child playing in brook:
- Inadvertent consumption of water containing radionuclides
- External radiation (gamma & beta) from sediment

DPUR for STW workers

The concentration of radionuclides in raw sewage per unit release were calculated by a simple dilution model using the flow rate of raw sewage into the sewage treatment works (60 m^3/d). Radioactive decay was taken into account and the integrated average concentration was calculated using the factors in Table A4.2.

The concentration of radionuclides in sludge per unit release was calculated from the raw sewage concentrations, ratio of % solids in sludge to % solids in raw sewage (Table A4.1), density of sludge (Table A4.1), integrated average concentration factor to take account of radioactive decay (Table A4.2) and sludge partitioning factors (Table A4.3). Where referencable data were not available for sludge partitioning factors, the organic soil K_d values [Ref A4.1] were used to estimate the partitioning fractions. A partitioning factor of 0.1 in sludge was assumed if the organic soil K_d <1000; 0.9 if K_d>5000, otherwise a partitioning factor of 0.5 was assumed.

The external DPUR factors were then calculated from raw sewage and sludge radionuclide concentrations per unit release, occupancy data (Table A4.1) and external dose rate coefficients (Table A4.4).

Inadvertent ingestion and inhalation DPUR were calculated from raw sewage and sludge radionuclide concentrations per unit release, airborne sludge mass concentration (Table A4.1), inadvertent ingestion and inhalation rates (Table A4.1), occupancy data (Table A4.1) and ingestion and inhalation dose coefficients from PC Cream [Ref A4.2].

DPUR for farming family living on sludge conditioned land

The Safe Sludge Matrix allows the surface spreading of advanced treated sludge to pasture and for cows to be returned to that pasture within about 1 month of the sludge being spread [Ref A4.3]. The DPUR have been assessed on this basis. The Safe Sludge Matrix requires greater delays before food can be produced on land which has been conditioned with sludge treated to a lower standard. This is likely to lead to lower doses.

The concentrations of radionuclides in food grown on sludge conditioned land per unit release have been calculated from the sludge concentrations per unit release, factors to take account of radioactive decay prior to disposal of sludge from the sewage treatment works (Table A4.2), a spreading rate of sludge to land (Table A4.1) and food transfer factors (Table A4.5). The source of the food transfer factors is shown in Table A4.5.

Concentrations of radionuclides in sludge conditioned soil per unit release were calculated from the sludge concentrations per unit release, factors to take account of radioactive decay prior to disposal of sludge from the sewage treatment works (Table A4.2), a spreading rate of sludge to land (Table A4.1) and soil concentration factors (Table A4.6). The source of the soil concentration factors is shown in Table A4.6.

The DPUR for consumption of food were calculated from the food concentrations per unit release, the consumption rates for food (Table A4.1) and ingestion dose coefficients from PC Cream [Ref A4.2].

External DPUR values during sludge spreading were calculated from the sludge concentrations per unit release, factors to take account of radioactive decay prior to disposal of sludge from the sewage treatment works (Table A4.2), occupancy data (Table A4.1) and external dose rate coefficients (Table A4.4).

External DPUR values from sludge conditioned soil were calculated from soil concentrations per unit release, occupancy data (Table A4.1) and external dose rate coefficients (Table A4.4).

Inadvertent ingestion and inhalation of sludge DPUR during sludge spreading were calculated from sludge concentrations per unit release, factors to take account of radioactive decay prior to disposal of sludge from the sewage treatment works (Table A4.2), airborne sludge mass concentration during spreading (Table A4.1), inadvertent ingestion and inhalation rates (Table A4.1), occupancy data (Table A4.1) and ingestion and inhalation dose coefficients from PC Cream [Ref A4.2].

DPUR for inadvertent ingestion and inhalation of soil containing sludge were calculated from soil concentrations per unit release, airborne soil mass concentration (Table A4.1), inadvertent ingestion and inhalation rates (Table A4.1), occupancy data (Table A4.1) and ingestion and inhalation dose coefficients from PC Cream [Ref A4.2].

DPUR for child playing in brook

Many sewage treatment works discharge treated effluent into a brook before it reaches a larger river or estuary. These brooks are usually too small for drinking water to be abstracted or for fish to be caught and consumed. However, children may play in the brook and receive doses from external irradiation and inadvertent consumption of drinking water.

The DPUR for external radiation were the same as those for the angling family, but for a child only. The DPUR for consumption of drinking water were the water consumption DPUR for the angling family, scaled by the ratio of inadvertent water consumption (Table A4.1) and the annual drinking water consumption rate (see Appendix 2).

References

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A4.3. ADAS (2001). The Safe Sludge Matrix. Guidelines for the application of sewage sludge to agricultural land, Third Edition, Agricultural Development & Advisory Service.

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Table A4.1 Parameter assumptions for deriving DPUR for releases to sewer

Parameter	Value	Comment
Sewage treatment works parameters	Flow raw sewage 60 m^3/d Density of raw sewage 1 te/m^3 % solid content of raw sewage 0.05% % solid content of treated sludge 5% Density of sludge 1 te/m^3 Airborne sludge conc 10^{-7} kg/m^3 Mean effluent residence time 15h Mean sludge residence time 656 h	NRPB GDC [Ref A4.4 and A4.5] (for all)
Decay of radionuclides	See Table A4.2 Time integrated average decay used for assessing doses to workers from raw sewage/treated effluent and sludge. Decay to point at leaving STW used to calculated activity in treated effluent and decay to point that sludge leaves STW used to calculated concentrations in sludge disposed of on farm.	
Farm sludge spreading data	Spreading rate sludge to land 8 kg/m^2/y Airborne sludge conc (spreading) 10^{-4} kg/m^3 Airborne soil conc 10^{-7} kg/m^3	NRPB GDC [Ref A4.4] NRPB-W41 [Ref A4.6] NRPB GDC [Ref A4.4]
Partitioning data for radionuclides to sludge	See Table A4.3	
Habit data – sewage worker	Occupancy adj sewage tanks 1500 h/y Occupancy adj sludge tanks 500 h/y Inadvertent sludge inhalation rate 1.19 m^3/h Inadvertent sludge ingestion rate 5 10^{-6} kg/h	Total of 2000 h/y occupancy NRPB GDC [Ref A4.4] NRPB GDC [Ref A4.4]
Occupancy habit data – farming family	Spreading h/y, Over pasture h/y Infant 0, 20 Child 0, 200 Adult 20, 2000	Spreading assumes about 3 working days per year. Adult occupancy over pasture is a standard working year, child occupancy are based on 10% and 1% of this.
Inhalation and ingestion rates for soil and sludge – farming family	Inh rate m^3/h, Ing rate kg/h Infant 0.22, 5 10^{-5} Child 0.64, 1 10^{-5} Adult 0.92, 5 10^{-6}	NRPB-W41 [Ref A4.6]

Table A4.1 Continued

Parameter	Value	Comment
Food consumption rates – farming family	Infant Cow meat 10 kg/y Cow liver 2.75 kg/y Milk 320 kg/y Sheep meat 3 kg/y Sheep liver 2.75 kg/y Child Cow meat 30 kg/y Cow liver 5 kg/y Milk 240 kg/y Sheep meat 10 kg/y Sheep liver 5 kg/y Adult Cow meat 45 kg/y Cow liver 10 kg/y Milk 240 kg/y Sheep meat 25 kg/y Sheep liver 10 kg/y	NRPB-W41 [Ref A4.6]
Dose coefficients – external radiation	see Table A4.4	
Dose coefficients – inhalation and ingestion	PC Cream defaults	
Food activity concentration per unit deposit	see Table A4.5	
Soil concentration per unit deposit	See Table A4.6	GDC [Refs A4.4, A4.5] or calculation of soil conc per unit deposit based on RP-72 equations [Ref A4.7]
Child in brook water consumption rates	Consumption rate l/y Child 5	Same water DPUR as for angler, but scaled for this water consumption

Table A4.2 Factors to take account of radionuclide decay

Nuclide	Half-life (h)	lambda (per h)	Raw Sewage Time integrated average decay factor at STW for exposure of workers to raw sewage	Treated Effluent Factor for decay to release from STW	Sludge Time integrated average decay factor at STW for exposure of workers to sludge	Sludge Factor for decay to release from STW for disposal
Tritium	1.08E+05	6.41E-06	1.00E+00	1.00E+00	9.98E-01	9.96E-01
Tritium (Organically Bound)	1.08E+05	6.41E-06	1.00E+00	1.00E+00	9.98E-01	9.96E-01
Carbon-14	4.99E+07	1.39E-08	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Fluorine-18	1.80E+00	3.85E-01	1.73E-01	3.10E-03	3.96E-03	1.96E-110
Sodium-22	8.21E+07	8.45E-09	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Sodium-24	1.50E+01	4.62E-02	7.21E-01	5.00E-01	3.30E-02	6.84E-14
Phosphorus-32	3.43E+02	2.02E-03	9.85E-01	9.70E-01	5.54E-01	2.66E-01
Phosphorus-33	6.10E+02	1.14E-03	9.92E-01	9.83E-01	7.05E-01	4.74E-01
Sulphur-35	2.10E+03	3.30E-04	9.98E-01	9.95E-01	8.99E-01	8.05E-01
Chlorine-36	2.64E+09	2.63E-10	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Calcium-45	3.91E+03	1.77E-04	9.99E-01	9.97E-01	9.44E-01	8.90E-01
Calcium-47	1.09E+02	6.38E-03	9.54E-01	9.09E-01	2.35E-01	1.53E-02
Vanadium-48	3.90E+02	1.78E-03	9.87E-01	9.74E-01	5.90E-01	3.11E-01
Chromium-51	6.65E+02	1.04E-03	9.92E-01	9.84E-01	7.24E-01	5.05E-01
Manganese-54	7.50E+03	9.24E-05	9.99E-01	9.99E-01	9.70E-01	9.41E-01
Manganese-56	2.60E+00	2.67E-01	2.45E-01	1.83E-02	5.72E-03	1.12E-76
Iron-59	1.07E+03	6.49E-04	9.95E-01	9.90E-01	8.14E-01	6.53E-01
Cobalt-57	6.50E+03	1.07E-04	9.99E-01	9.98E-01	9.66E-01	9.32E-01
Cobalt-58	1.70E+03	4.08E-04	9.97E-01	9.94E-01	8.77E-01	7.65E-01
Cobalt-60	4.62E+04	1.50E-05	1.00E+00	1.00E+00	9.95E-01	9.90E-01
Gallium-67	7.92E+01	8.75E-03	9.37E-01	8.77E-01	1.74E-01	3.21E-03
Selenium-75	2.88E+03	2.41E-04	9.98E-01	9.96E-01	9.25E-01	8.54E-01
Bromine-82	3.36E+01	2.06E-02	8.60E-01	7.34E-01	7.39E-02	1.33E-06
Strontium-89	1.21E+03	5.72E-04	9.96E-01	9.91E-01	8.34E-01	6.87E-01
Strontium-90	2.55E+05	2.72E-06	1.00E+00	1.00E+00	9.99E-01	9.98E-01
Yttrium-90	6.40E+01	1.08E-02	9.23E-01	8.50E-01	1.41E-01	8.21E-04
Zirconium-95	1.54E+03	4.51E-04	9.97E-01	9.93E-01	8.66E-01	7.44E-01
Niobium-95	8.44E+02	8.22E-04	9.94E-01	9.88E-01	7.73E-01	5.83E-01
Technetium-99	1.87E+09	3.71E-10	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Technetium-99m	6.60E+00	1.05E-01	5.03E-01	2.07E-01	1.45E-02	1.20E-30
Ruthenium-103	9.43E+02	7.35E-04	9.95E-01	9.89E-01	7.93E-01	6.17E-01
Ruthenium-106	8.84E+03	7.84E-05	9.99E-01	9.99E-01	9.75E-01	9.50E-01
Indium-111	6.72E+01	1.03E-02	9.26E-01	8.57E-01	1.48E-01	1.15E-03
Indium-113m	1.70E+00	4.08E-01	1.63E-01	2.21E-03	3.74E-03	6.88E-117
Antimony-125	2.43E+04	2.86E-05	1.00E+00	1.00E+00	9.91E-01	9.81E-01
Iodine-123	1.30E+01	5.33E-02	6.88E-01	4.49E-01	2.86E-02	6.45E-16
Iodine-125	1.44E+03	4.80E-04	9.96E-01	9.93E-01	8.58E-01	7.30E-01
Iodine-129	1.38E+11	5.04E-12	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Iodine-131	1.93E+02	3.59E-03	9.74E-01	9.48E-01	3.84E-01	9.48E-02
Iodine-132	2.30E+00	3.01E-01	2.19E-01	1.09E-02	5.06E-03	1.38E-86
Iodine-133	2.08E+01	3.33E-02	7.87E-01	6.07E-01	4.57E-02	3.21E-10
Iodine-134	8.77E-01	7.91E-01	8.43E-02	7.07E-06	1.93E-03	5.53E-226
Iodine-135	6.61E+00	1.05E-01	5.04E-01	2.07E-01	1.45E-02	1.33E-30
Caesium-134	1.80E+04	3.84E-05	1.00E+00	9.99E-01	9.88E-01	9.75E-01
Caesium-136	3.14E+02	2.20E-03	9.84E-01	9.67E-01	5.29E-01	2.35E-01
Caesium-137	2.63E+05	2.64E-06	1.00E+00	1.00E+00	9.99E-01	9.98E-01
Barium-140	3.06E+02	2.27E-03	9.83E-01	9.67E-01	5.20E-01	2.26E-01
Lanthanum-140	4.03E+01	1.72E-02	8.81E-01	7.72E-01	8.86E-02	1.25E-05
Cerium-144	6.82E+03	1.02E-04	9.99E-01	9.98E-01	9.67E-01	9.36E-01
Promethium-147	2.30E+04	3.02E-05	1.00E+00	1.00E+00	9.90E-01	9.80E-01

Table A4.2 Continued

Nuclide	Half-life (h)	lambda (per h)	Raw Sewage Time integrated average decay factor at STW for exposure of workers to raw sewage	Treated Effluent Factor for decay to release from STW	Sludge Time integrated average decay factor at STW for exposure of workers to sludge	Sludge Factor for decay to release from STW for disposal
Samarium-153	4.67E+01	1.48E-02	8.97E-01	8.00E-01	1.03E-01	5.91E-05
Erbium-169	2.23E+02	3.11E-03	9.77E-01	9.54E-01	4.27E-01	1.30E-01
Thallium-201	7.20E+01	9.63E-03	9.31E-01	8.66E-01	1.58E-01	1.81E-03
Lead-210	1.95E+05	3.55E-06	1.00E+00	1.00E+00	9.99E-01	9.98E-01
Polonium-210	3.32E+03	2.09E-04	9.98E-01	9.97E-01	9.35E-01	8.72E-01
Radium-226	1.40E+07	4.95E-08	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Thorium-230	6.75E+08	1.03E-09	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Thorium-232	1.23E+14	5.63E-15	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Uranium-234	2.14E+09	3.24E-10	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Uranium-235	6.17E+12	1.12E-13	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Uranium-238	3.91E+13	1.77E-14	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Neptunium-237	1.87E+10	3.70E-11	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Plutonium-238	7.69E+05	9.02E-07	1.00E+00	1.00E+00	1.00E+00	9.99E-01
Plutonium-239	2.11E+08	3.29E-09	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Plutonium-240	5.73E+07	1.21E-08	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Plutonium-241	1.26E+05	5.49E-06	1.00E+00	1.00E+00	9.98E-01	9.96E-01
Plutonium-242	3.30E+09	2.10E-10	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Americium-241	3.79E+06	1.83E-07	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Americium-242	1.60E+01	4.33E-02	7.36E-01	5.23E-01	3.52E-02	4.71E-13
Americium-243	6.46E+07	1.07E-08	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Curium-242	3.91E+03	1.77E-04	9.99E-01	9.97E-01	9.44E-01	8.90E-01
Curium-243	2.50E+05	2.78E-06	1.00E+00	1.00E+00	9.99E-01	9.98E-01
Curium-244	1.59E+05	4.37E-06	1.00E+00	1.00E+00	9.99E-01	9.97E-01
Thorium-234	5.78E+02	1.20E-03	9.91E-01	9.82E-01	6.92E-01	4.56E-01

Table A4.3 Sewage sludge partitioning factors

Radionuclide	Fraction to Sludge[a]	Fraction to Treated effluent	Reference source	Organic soil Kd where required[b]
Tritium	0.15	0.85	NRPB-W32 [Ref A4.8]	N/A
Tritium (Organically Bound)	0.15	0.85	NRPB-W32 [Ref A4.8]	N/A
Carbon-14	0.15	0.85	NRPB-W32 [Ref A4.8]	N/A
Fluorine-18	0.10	0.90	Anglian study [Ref A4.9]	N/A
Sodium-22	0.10	0.90	NRPB-W32 [Ref A4.8]	N/A
Sodium-24	0.10	0.90	NRPB-W32 [Ref A4.8]	N/A
Phosphorus-32	0.80	0.20	Cardiff Assessment [Ref A4.10]	N/A
Phosphorus-33	0.80	0.20	Cardiff Assessment [Ref A4.10]	N/A
Sulphur-35	0.10	0.90	NRPB-W32 [Ref A4.8]	N/A
Chlorine-36	0.10	0.90	NRPB-W32 [Ref A4.8]	N/A
Calcium-45	0.10	0.90	Based on organic soil Kd[a]	110
Calcium-47	0.10	0.90	Based on organic soil Kd[a]	110
Vanadium-48	0.90	0.10	Anglian study [Ref A4.9]	N/A
Chromium-51	0.90	0.10	NRPB-W32 [Ref A4.8]	N/A
Manganese-54	0.50	0.50	NRPB-W32 [Ref A4.8]	N/A
Manganese-56	0.50	0.50	NRPB-W32 [Ref A4.8]	N/A
Iron-59	0.90	0.10	NRPB-W32 [Ref A4.8]	N/A
Cobalt-57	0.80	0.20	NRPB-W32 [Ref A4.8]	N/A

Table A4.3 Continued

Radionuclide	Fraction to Sludge[a]	Fraction to Treated effluent	Reference source	Organic soil Kd where required[b]
Cobalt-58	0.80	0.20	NRPB-W32 [Ref A4.8]	N/A
Cobalt-60	0.80	0.20	NRPB-W32 [Ref A4.8]	N/A
Gallium-67	0.90	0.10	Anglian study [Ref A4.9]	N/A
Selenium-75	0.50	0.50	NRPB-W32 [Ref A4.8]	N/A
Bromine-82	0.10	0.90	Based on organic soil Kd[a]	180
Strontium-89	0.10	0.90	NRPB-W32 [Ref A4.8]	N/A
Strontium-90	0.10	0.90	NRPB-W32 [Ref A4.8]	N/A
Yttrium-90	0.10	0.90	Same as strontium	N/A
Zirconium-95	0.90	0.10	Based on organic soil Kd[a]	7300
Niobium-95	0.50	0.50	Based on organic soil Kd[a]	2000
Technetium-99	0.10	0.90	Based on organic soil Kd[a]	1.5
Technetium-99m	0.10	0.90	Based on organic soil Kd[a]	1.5
Ruthenium-103	0.10	0.90	NRPB-W32 [Ref A4.8]	N/A
Ruthenium-106	0.10	0.90	NRPB-W32 [Ref A4.8]	N/A
Indium-111	0.90	0.10	Same as gallium	N/A
Indium-113m	0.90	0.10	Same as gallium	N/A
Antimony-125	0.10	0.90	Based on organic soil Kd[a]	540
Iodine-123	0.20	0.80	NRPB-W32 [Ref A4.8]	N/A
Iodine-125	0.20	0.80	NRPB-W32 [Ref A4.8]	N/A
Iodine-129	0.20	0.80	NRPB-W32 [Ref A4.8]	N/A
Iodine-131	0.20	0.80	NRPB-W32 [Ref A4.8]	N/A
Iodine-132	0.20	0.80	NRPB-W32 [Ref A4.8]	N/A
Iodine-133	0.20	0.80	NRPB-W32 [Ref A4.8]	N/A
Iodine-134	0.20	0.80	NRPB-W32 [Ref A4.8]	N/A
Iodine-135	0.20	0.80	NRPB-W32 [Ref A4.8]	N/A
Caesium-134	0.30	0.70	NRPB-W32 [Ref A4.8]	N/A
Caesium-136	0.30	0.70	NRPB-W32 [Ref A4.8]	N/A
Caesium-137	0.30	0.70	NRPB-W32 [Ref A4.8]	N/A
Barium-140	0.10	0.90	Same as strontium	N/A
Lanthanum-140	0.10	0.90	Same as strontium	N/A
Cerium-144	0.50	0.50	Based on organic soil Kd[a]	3000
Promethium-147	0.50	0.50	Same as samarium	N/A
Samarium-153	0.50	0.50	Based on organic soil Kd[a]	3000
Erbium-169	0.50	0.50	Same as samarium	N/A
Thallium-201	0.50	0.50	Same as lead	N/A
Lead-210	0.90	0.10	NRPB-W32 [Ref A4.8]	N/A
Polonium-210	0.90	0.10	Based on organic soil Kd[a]	6600
Radium-226	0.50	0.50	Based on organic soil Kd[a]	2400
Thorium-230	0.90	0.10	Based on organic soil Kd[a]	89000
Thorium-232	0.90	0.10	Based on organic soil Kd[a]	89000
Uranium-234	0.10	0.90	Based on organic soil Kd[a]	400
Uranium-235	0.10	0.90	Based on organic soil Kd[a]	400
Uranium-238	0.10	0.90	Based on organic soil Kd[a]	400
Neptunium-237	0.50	0.50	Based on organic soil Kd[a]	1200
Plutonium-238	0.50	0.50	Based on organic soil Kd[a]	1800
Plutonium-239	0.50	0.50	Based on organic soil Kd[a]	1800
Plutonium-240	0.50	0.50	Based on organic soil Kd[a]	1800
Plutonium-241	0.50	0.50	Based on organic soil Kd[a]	1800
Plutonium-242	0.50	0.50	Based on organic soil Kd[a]	1800
Americium-241	0.90	0.10	Based on organic soil Kd[a]	110000
Americium-242	0.90	0.10	Based on organic soil Kd[a]	110000
Americium-243	0.90	0.10	Based on organic soil Kd[a]	110000
Curium-242	0.50	0.50	Based on organic soil Kd[a]	1200
Curium-243	0.50	0.50	Based on organic soil Kd[a]	1200
Curium-244	0.50	0.50	Based on organic soil Kd[a]	1200

[a] Where no data assumed to be 0.1 in sludge for organic soil Kd <1000; 0.9 if Kd>5000, otherwise 0.5.
[b] IAEA Tech doc 364 [Ref A4.1]

Table A4.4 External dose coefficients

Nuclide	External Dose (Sv/h per Bq/kg)	Source	Nuclide	External Dose (Sv/h per Bq/kg)	Source
Tritium	0.00E+00	-	Iodine-129	1.40E-12	GDC [Ref A4.4]
Tritium (Organically Bound)	0.00E+00	-	Iodine-131	8.10E-11	GDC [Ref A4.4]
Carbon-14	0.00E+00	-	Iodine-132	4.80E-10	GDC [Ref A4.4]
Fluorine-18	1.08E-10	FGR 12 [Ref A4.11]	Iodine-133	1.30E-10	GDC [Ref A4.4]
Sodium-22	5.70E-10	NRPB-M744 [A4.12]	Iodine-134	5.60E-10	GDC [Ref A4.4]
Sodium-24	5.26E-10	FGR 12 [Ref A4.11]	Iodine-135	3.50E-10	GDC [Ref A4.4]
Phosphorus-32	3.92E-13	FGR 12 [Ref A4.11]	Caesium-134	3.30E-10	GDC [Ref A4.4]
Phosphorus-33	9.68E-16	FGR 12 [Ref A4.11]	Caesium-136	4.60E-10	GDC [Ref A4.4]
Sulphur-35	2.36E-16	FGR 12 [Ref A4.11]	Caesium-137	1.20E-10	GDC [Ref A4.4]
Chlorine-36	4.79E-14	FGR 12 [Ref A4.11]	Barium-140	1.85E-11	FGR 12 [Ref A4.11]
Calcium-45	1.03E-15	FGR 12 [Ref A4.11]	Lanthanum-140	2.75E-10	FGR 12 [Ref A4.11]
Calcium-47	1.26E-10	FGR 12 [Ref A4.11]	Cerium-144	1.25E-12	FGR 12 [Ref A4.11]
Vanadium-48	3.36E-10	FGR 12 [Ref A4.11]	Promethium-147	8.28E-16	FGR 12 [Ref A4.11]
Chromium-51	8.50E-12	NRPB-M744 [A4.12]	Samarium-153	2.69E-12	FGR 12 [Ref A4.11]
Manganese-54	9.36E-10	FGR 12 [Ref A4.11]	Erbium-169	2.33E-15	FGR 12 [Ref A4.11]
Manganese-56	2.03E-10	FGR 12 [Ref A4.11]	Thallium-201	2.40E-11	NRPB-M744 [A4.12]
Iron-59	3.10E-10	NRPB-M744 [A4.12]	Lead-210	3.10E-13	GDC [Ref A4.5]
Cobalt-57	3.30E-11	NRPB-M744 [A4.12]	Polonium-210	1.80E-15	GDC [Ref A4.5]
Cobalt-58	2.50E-10	NRPB-M744 [A4.12]	Radium-226	3.80E-10	GDC [Ref A4.5]
Cobalt-60	6.50E-10	NRPB-M744 [A4.12]	Thorium-230	2.06E-14	FGR 12 [Ref A4.11]
Gallium-67	4.10E-11	NRPB-M744 [A4.12]	Thorium-232	8.78E-15	FGR 12 [Ref A4.11]
Selenium-75	1.00E-10	NRPB-M744 [A4.12]	Uranium-234	3.11E-14	GDC [Ref A4.5]
Bromine-82	2.98E-10	FGR 12 [Ref A4.11]	Uranium-235	3.79E-11	GDC [Ref A4.5]
Strontium-89	1.80E-14	GDC [Ref A4.4]	Uranium-238	6.78E-12	GDC [Ref A4.5]
Strontium-90	6.70E-18	GDC [Ref A4.4]	Neptunium-237	1.34E-12	FGR 12 [Ref A4.11]
Yttrium-90	7.74E-13	FGR 12 [Ref A4.11]	Plutonium-238	1.30E-14	GDC [Ref A4.4]
Zirconium-95	8.17E-11	FGR 12 [Ref A4.11]	Plutonium-239	1.50E-14	GDC [Ref A4.4]
Niobium-95	8.53E-11	FGR 12 [Ref A4.11]	Plutonium-240	1.40E-14	GDC [Ref A4.4]
Technetium-99	2.09E-15	FGR 12 [Ref A4.11]	Plutonium-241	3.80E-16	GDC [Ref A4.4]
Technetium-99m	3.30E-11	NRPB-M744 [A4.12]	Plutonium-242	1.40E-13	GDC [Ref A4.4]
Ruthenium-103	9.80E-11	GDC [Ref A4.4]	Americium-241	4.40E-12	GDC [Ref A4.4]
Ruthenium-106	4.30E-11	GDC [Ref A4.4]	Americium-242	3.30E-12	GDC [Ref A4.4]
Indium-111	1.10E-10	NRPB-M744 [A4.12]	Americium-243	5.00E-11	GDC [Ref A4.4]
Indium-113m	4.03E-08	FGR 12 [Ref A4.11]	Curium-242	1.70E-14	GDC [Ref A4.4]
Antimony-125	4.39E-11	FGR 12 [Ref A4.11]	Curium-243	2.90E-11	GDC [Ref A4.4]
Iodine-123	4.50E-11	NRPB-M744 [A4.12]	Curium-244	5.00E-14	GDC [Ref A4.4]
Iodine-125	1.70E-12	GDC [Ref A4.4]			

Table A4.5 Food transfer factors

Nuclide	Transfer factor for 50 year application of sludge (Bq/kg or Bq/l per Bq/m^2/y)					Source of data
	Cow meat	Cow offal	Milk	Sheep Meat	Sheep Offal	
Tritium	7.82E-04	7.82E-04	9.05E-04	1.19E-03	1.19E-03	Data from Cardiff Assessment [Ref A4.10]
Tritium (Organically Bound)	7.82E-04	7.82E-04	9.05E-04	1.19E-03	1.19E-03	Data from Cardiff Assessment [Ref A4.10]
Carbon-14	5.04E-03	4.96E-03	2.48E-03	1.25E-02	8.36E-03	Data from Cardiff Assessment [Ref A4.10]
Fluorine-18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	No data
Sodium-22	5.60E-03	5.60E-03	1.20E-02	9.30E-03	9.30E-03	Unpublished data from NRPB
Sodium-24	3.36E-06	3.36E-06	7.20E-06	5.58E-06	5.58E-06	Same as sodium-22
Phosphorus-32	3.90E-03	3.90E-03	4.60E-03	7.60E-03	3.00E-03	Unpublished data from NRPB
Phosphorus-33	8.50E-03	8.40E-03	8.10E-03	1.70E-02	6.60E-03	Unpublished data from NRPB
Sulphur-35	2.00E-01	2.00E-01	3.10E-02	4.75E-01	1.89E-01	PC Cream atmospheric
Chlorine-36	2.00E-01	2.00E-01	3.10E-02	4.75E-01	1.89E-01	Same as S-35
Calcium-45	1.30E-02	1.30E-02	2.30E-02	1.40E-02	1.40E-02	Unpublished data from NRPB
Calcium-47	4.16E-04	4.16E-04	7.36E-04	4.48E-04	4.48E-04	Based on Ca-45 weighted by ratio of soil concs
Vanadium-48	1.57E-03	1.57E-03	1.38E-03	2.68E-03	2.68E-03	Same as Cr-51
Chromium-51	1.57E-03	1.57E-03	1.38E-03	2.68E-03	2.68E-03	PC Cream atmospheric
Manganese-54	6.08E-03	2.41E-01	3.96E-03	1.04E-02	4.09E-01	PC Cream atmospheric
Manganese-56	2.74E-06	1.09E-04	1.79E-06	4.70E-06	1.84E-04	Based on Mn-54 weighted by ratio of soil concs
Iron-59	1.75E-05	6.94E-02	2.27E-04	2.89E-05	8.65E-02	PC Cream atmospheric
Cobalt-57	5.13E-04	5.13E-02	1.84E-03	8.05E-04	8.05E-02	PC Cream atmospheric
Cobalt-58	2.20E-04	2.20E-02	1.62E-03	3.68E-04	3.68E-02	PC Cream atmospheric
Cobalt-60	9.25E-04	9.25E-02	2.24E-03	1.38E-03	1.38E-01	PC Cream atmospheric
Gallium-67	1.57E-03	1.57E-03	1.38E-03	2.68E-03	2.68E-03	Same as Cr-51
Selenium-75	8.37E-02	2.09E+00	1.03E-02	1.43E-01	2.86E+00	PC Cream atmospheric
Bromine-82	1.18E-06	1.17E-05	2.33E-03	1.38E-06	1.38E-05	PC Cream atmospheric
Strontium-89	2.20E-05	2.20E-05	1.10E-04	2.40E-05	2.40E-05	GDC [Ref A4.4]
Strontium-90	7.20E-04	7.20E-04	3.40E-03	4.70E-04	4.70E-04	GDC [Ref A4.4]
Yttrium-90	3.64E-08	3.64E-07	3.99E-06	4.75E-08	4.75E-07	PC Cream atmospheric
Zirconium-95	7.07E-06	7.10E-06	7.92E-06	1.35E-05	1.35E-05	PC Cream atmospheric
Niobium-95	1.74E-06	1.74E-06	7.26E-06	2.93E-06	2.94E-06	PC Cream atmospheric
Technetium-99	6.72E-01	2.69E+00	6.72E-01	4.31E+00	1.30E+01	PC Cream atmospheric
Technetium-99m	1.77E-04	7.10E-04	1.77E-04	1.14E-03	3.42E-03	Based on Tc-99 weighted by ratio of soil concs
Ruthenium-103	1.50E-06	1.50E-06	1.20E-08	4.30E-06	4.30E-06	GDC [Ref A4.4]
Ruthenium-106	4.70E-05	4.70E-05	8.80E-08	1.00E-04	1.00E-04	GDC [Ref A4.4]
Indium-111	1.57E-03	1.57E-03	1.38E-03	2.68E-03	2.68E-03	Same as Cr-51

Table A4.5 Continued

Nuclide	Transfer factor for 50 year application of sludge (Bq/kg or Bq/l per Bq/m^2/y)					Source of data
	Cow meat	Cow offal	Milk	Sheep Meat	Sheep Offal	
Indium-113m	3.98E-05	3.98E-05	3.50E-05	6.80E-05	6.81E-05	Based on In-111 weighted by ratio of soil concs
Antimony-125	1.01E-03	1.01E-01	1.05E-04	2.11E-03	2.11E-01	PC Cream atmospheric
Iodine-123	7.04E-07	7.04E-07	1.14E-06	2.28E-06	2.28E-06	Based on I-125 weighted by ratio of soil concs
Iodine-125	7.40E-05	7.40E-05	1.20E-04	2.40E-04	2.40E-04	GDC [Ref A4.4]
Iodine-129	9.90E-04	9.90E-04	1.50E-03	8.30E-03	8.30E-03	GDC [Ref A4.4]
Iodine-131	7.83E-04	7.83E-04	1.84E-03	1.00E-03	1.00E-03	PC Cream atmospheric
Iodine-132	9.40E-06	9.40E-06	2.22E-05	1.21E-05	1.21E-05	Based on I-131 weighted by ratio of soil concs
Iodine-133	3.52E-05	3.52E-05	1.20E-04	2.15E-05	2.15E-05	PC Cream atmospheric
Iodine-134	1.48E-06	1.48E-06	5.07E-06	9.08E-07	9.08E-07	Based on I-133 weighted by ratio of soil concs
Iodine-135	2.47E-06	2.47E-06	9.76E-06	1.21E-06	1.21E-06	PC Cream atmospheric
Caesium-134	4.60E-03	4.60E-03	9.20E-04	1.00E-02	1.00E-02	GDC [Ref A4.4]
Caesium-136	4.40E-03	4.40E-03	1.99E-03	8.94E-03	8.94E-03	PC Cream atmospheric
Caesium-137	8.30E-03	8.30E-03	1.60E-03	2.30E-02	2.30E-02	GDC [Ref A4.4]
Barium-140	7.61E-05	7.61E-05	2.74E-04	1.19E-04	1.20E-04	PC Cream atmospheric
Lanthanum-140	2.90E-07	1.16E-05	2.52E-06	3.64E-07	1.46E-05	PC Cream atmospheric
Cerium-144	5.48E-05	1.09E-02	1.78E-05	6.72E-05	1.34E-02	PC Cream atmospheric
Promethium-147	6.72E-04	5.36E-03	1.94E-05	5.74E-04	3.42E-03	PC Cream atmospheric
Samarium-153	2.90E-07	1.16E-05	2.52E-06	3.64E-07	1.46E-05	Same as La-140
Erbium-169	7.61E-05	7.61E-05	2.74E-04	1.19E-04	1.20E-04	Same as Ba-140
Thallium-201	1.57E-03	1.57E-03	1.38E-03	2.68E-03	2.68E-03	Same as Cr-51
Lead-210	3.50E-04	7.10E-04	1.30E-04	5.20E-04	1.00E-03	GDC [Ref A4.5]
Polonium-210	4.00E-05	1.10E-03	1.70E-06	3.40E-04	4.10E-03	GDC [Ref A4.5]
Radium-226	2.80E-04	2.80E-04	2.30E-04	5.90E-04	5.90E-04	GDC [Ref A4.5]
Thorium-230	7.07E-05	7.07E-04	5.23E-06	6.81E-05	6.81E-04	PC Cream atmospheric
Thorium-232	7.07E-05	7.07E-04	5.23E-06	6.81E-05	6.81E-04	PC Cream atmospheric
Uranium-234	3.70E-05	3.70E-05	1.10E-04	2.00E-04	2.00E-04	GDC [Ref A4.5]
Uranium-235	3.70E-05	3.70E-05	1.10E-04	2.00E-04	2.00E-04	GDC [Ref A4.5]
Uranium-238	3.70E-05	3.70E-05	1.10E-04	2.00E-04	2.00E-04	GDC [Ref A4.5]
Neptunium-237	2.02E-04	2.47E-02	3.64E-06	1.37E-04	9.79E-03	PC Cream atmospheric
Plutonium-238	2.00E-05	2.40E-03	1.40E-06	3.50E-05	2.50E-03	GDC [Ref A4.4]
Plutonium-239	2.10E-05	2.60E-03	1.50E-06	3.70E-05	2.60E-03	GDC [Ref A4.4]
Plutonium-240	2.10E-05	2.50E-03	1.50E-06	3.70E-05	2.60E-03	GDC [Ref A4.4]
Plutonium-241	1.40E-05	1.80E-03	1.00E-06	2.90E-05	2.10E-03	GDC [Ref A4.4]
Plutonium-242	2.10E-05	2.60E-03	1.50E-06	3.70E-05	2.60E-03	GDC [Ref A4.4]
Americium-241	2.60E-05	3.10E-03	1.90E-06	3.80E-05	2.70E-03	GDC [Ref A4.4]
Americium-242	1.66E-08	1.98E-06	1.21E-09	2.43E-08	1.73E-06	Based on Am-241 weighted by ratio of soil concs
Americium-243	2.60E-05	3.20E-03	1.90E-06	3.80E-05	2.80E-03	GDC [Ref A4.4]
Curium-242	4.60E-07	5.50E-05	3.30E-08	2.20E-06	1.60E-04	GDC [Ref A4.4]
Curium-243	2.10E-05	2.50E-03	1.50E-06	3.40E-05	2.40E-03	GDC [Ref A4.4]
Curium-244	1.90E-05	2.30E-03	1.30E-06	3.20E-05	2.30E-03	GDC [Ref A4.4]

Table A4.6 Soil concentration factors

Nuclide	Soil conc per unit deposition for 50y (top 1 cm) (Bq/kg per Bq/m^2/y)	Source of data	Nuclide	Soil conc per unit deposition for 50y (top 1 cm) (Bq/kg per Bq/m^2/y)	Source of data
Tritium	5.90E-04	Based on Agency R&D P288 [Ref A4.13]	Iodine-129	3.30E-01	GDC [Ref A4.4]
Tritium (Organically Bound)	3.30E-01	Based on Agency R&D P288 [Ref A4.13]	Iodine-131	2.52E-03	RP-72[a] [Ref A4.7]
Carbon-14	3.30E-01	Based on Agency R&D P288 [Ref A4.13]	Iodine-132	3.03E-05	RP-72[a] [Ref A4.7]
Fluorine-18	2.37E-05	RP-72[a] [Ref A4.7]	Iodine-133	2.74E-04	RP-72[a] [Ref A4.7]
Sodium-22	3.29E-01	RP-72[a] [Ref A4.7]	Iodine-134	1.15E-05	RP-72[a] [Ref A4.7]
Sodium-24	1.98E-04	RP-72[a] [Ref A4.7]	Iodine-135	8.71E-05	RP-72[a] [Ref A4.7]
Phosphorus-32	4.46E-03	RP-72[a] [Ref A4.7]	Caesium-134	1.40E-01	GDC [Ref A4.4]
Phosphorus-33	7.84E-03	RP-72[a] [Ref A4.7]	Caesium-136	4.09E-03	RP-72[a] [Ref A4.7]
Sulphur-35	2.55E-02	RP-72[a] [Ref A4.7]	Caesium-137	3.00E-01	GDC [Ref A4.4]
Chlorine-36	3.29E-01	RP-72[a] [Ref A4.7]	Barium-140	3.98E-03	RP-72[a] [Ref A4.7]
Calcium-45	4.46E-02	RP-72[a] [Ref A4.7]	Lanthanum-140	5.30E-04	RP-72[a] [Ref A4.7]
Calcium-47	1.43E-03	RP-72[a] [Ref A4.7]	Cerium-144	7.06E-02	RP-72[a] [Ref A4.7]
Vanadium-48	5.06E-03	RP-72[a] [Ref A4.7]	Promethium-147	1.58E-01	RP-72[a] [Ref A4.7]
Chromium-51	8.53E-03	RP-72[a] [Ref A4.7]	Samarium-153	6.14E-04	RP-72[a] [Ref A4.7]
Manganese-54	7.60E-02	RP-72[a] [Ref A4.7]	Erbium-169	2.91E-03	RP-72[a] [Ref A4.7]
Manganese-56	3.43E-05	RP-72[a] [Ref A4.7]	Thallium-201	9.46E-04	RP-72[a] [Ref A4.7]
Iron-59	1.35E-02	RP-72[a] [Ref A4.7]	Lead-210	2.85E-01	GDC [Ref A4.5]
Cobalt-57	6.80E-02	RP-72[a] [Ref A4.7]	Polonium-210	3.85E-02	GDC [Ref A4.5]
Cobalt-58	2.10E-02	RP-72[a] [Ref A4.7]	Radium-226	3.19E-01	GDC [Ref A4.5]
Cobalt-60	2.14E-01	RP-72[a] [Ref A4.7]	Thorium-230	3.29E-01	RP-72[a] [Ref A4.7]
Gallium-67	1.04E-03	RP-72[a] [Ref A4.7]	Thorium-232	3.29E-01	RP-72[a] [Ref A4.7]
Selenium-75	3.40E-02	RP-72[a] [Ref A4.7]	Uranium-234	3.3E-01	GDC [Ref A4.5]
Bromine-82	4.42E-04	RP-72[a] [Ref A4.7]	Uranium-235	3.3E-01	GDC [Ref A4.5]
Strontium-89	1.50E-02	GDC [Ref A4.4]	Uranium-238	3.2E-01	GDC [Ref A4.5]
Strontium-90	1.60E-01	GDC [Ref A4.4]	Neptunium-237	3.29E-01	RP-72[a] [Ref A4.7]
Yttrium-90	8.41E-04	RP-72[a] [Ref A4.7]	Plutonium-238	3.2E-01	GDC [Ref A4.4]
Zirconium-95	1.91E-02	RP-72[a] [Ref A4.7]	Plutonium-239	3.3E-01	GDC [Ref A4.4]
Niobium-95	1.08E-02	RP-72[a] [Ref A4.7]	Plutonium-240	3.3E-01	GDC [Ref A4.4]
Technetium-99	3.29E-01	RP-72[a] [Ref A4.7]	Plutonium-241	2.8E-01	GDC [Ref A4.4]
Technetium-99m	8.69E-05	RP-72[a] [Ref A4.7]	Plutonium-242	3.3E-01	GDC [Ref A4.4]
Ruthenium-103	1.20E-01	GDC [Ref A4.4]	Americium-241	3.3E-01	GDC [Ref A4.4]
Ruthenium-106	8.60E-02	GDC [Ref A4.4]	Americium-242	2.11E-04	RP-72[a] [Ref A4.7]
Indium-111	8.83E-04	RP-72[a] [Ref A4.7]	Americium-243	3.3E-01	GDC [Ref A4.4]
Indium-113m	2.24E-05	RP-72[a] [Ref A4.7]	Curium-242	4.5E-02	GDC [Ref A4.4]
Antimony-125	1.62E-01	RP-72[a] [Ref A4.7]	Curium-243	3.0E-01	GDC [Ref A4.4]
Iodine-123	1.71E-04	RP-72[a] [Ref A4.7]	Curium-244	2.9E-01	GDC [Ref A4.4]
Iodine-125	1.80E-02	GDC [Ref A4.4]			

[a] Calculated using equation in RP 72 [Ref A4.7]

APPENDIX 5 – DETAILED APPLICATION OF METHODOLOGY

Releases to air

The dose to **local habitants** arising from releases to air is calculated as follows:

$$D_{lhab} = D_{lhab,inh} + D_{lhab,ext} + D_{lhab,food}$$

where: D_{lhab} is the total dose to a local habitant (μSv/y)
$D_{lhab,inh}$ is the inhalation dose to a local habitant (μSv/y)
$D_{lhab,ext}$ is the external dose (plume and deposited activity) to a local habitant (μSv/y)
$D_{lhab,food}$ is the food dose to a local habitant (μSv/y)

$$D_{lhab,inh} = \sum^{\text{all nuclides}} A_{air}\ DPUR_{lhab,inh}\ f_{inh\&ext}$$

where: A_{air} is the activity released to air (Bq/y)
$DPUR_{lhab,inh}$ is the inhalation dose per unit release to a local habitant (μSv/y per Bq/y) (see Table 1)
$f_{inh\&ext}$ is the scaling factor for inhalation & external dose pathways for different release heights (see Figure 1)

$$D_{lhab,ext} = \sum^{al\ \ln nuclides} A_{air}\ DPUR_{lhab,ext}\ f_{inh\&ext}$$

where: A_{air} is the activity released to air (Bq/y)
$DPUR_{lhab,ext}$ is the external dose per unit release to a local habitant (μSv/y per Bq/y) (see Table 1)
$f_{inh\&ext}$ is the scaling factor for inhalation & external dose pathways for different release heights (see Figure 1)

$$D_{lhab,food} = \sum^{\text{all nuclides}} A_{air}\ DPUR_{lhab,food}\ f_{food}$$

where: A_{air} is the activity released to air (Bq/y)
$DPUR_{lhab,food}$ is the external dose per unit release to a local habitant (μSv/y per Bq/y) (see Table 1)
f_{food} is the scaling factor for food dose pathway for different release heights (see Figure 1)

Releases to river

The dose to a **member of an angling family** arising from releases to rivers is calculated as follows:

$$D_{angler} = D_{angler,ext} + D_{angler,fish} + D_{angler,wtr}$$

where: D_{angler} is the total dose to a member of an angling family (μSv/y)
$D_{angler,ext}$ is the external dose to a member of an angling family (μSv/y)
$D_{angler,fish}$ is the fish dose to a member of an angling family (μSv/y)
$D_{angler,wtr}$ is the water dose to a member of an angling family (μSv/y)

$$D_{angler,ext} = \sum^{\text{all nuclides}} \frac{A_{riv}\ DPUR_{angler,ext}}{v_{riv}}$$

where: A_{riv} is the activity released to river (Bq/y)
$DPUR_{angler,ext}$ is the external dose per unit release to a member of an angling family for a 1 m^3/s river flow (μSv/y per Bq/y) (see Table 2)
v_{riv} is the river flow rate (default of 1 m^3/s, maximum of 100 m^3/s)

$$D_{angler,fish} = \sum^{\text{all nuclides}} \frac{A_{riv}\ DPUR_{angler,fish}}{v_{riv}}$$

where: A_{riv} is the activity released to river (Bq/y)
$DPUR_{angler,fish}$ is the fish dose per unit release to a member of an angling family for a 1 m^3/s river flow (μSv/y per Bq/y) (see Table 2)
v_{riv} is the river flow rate (default of 1 m^3/s, maximum of 100 m^3/s)

$$D_{angler,wtr} = \sum^{\text{all nuclides}} \frac{A_{riv}\ DPUR_{angler,wtr}}{v_{riv}}$$

where: A_{riv} is the activity released to river (Bq/y)
$DPUR_{angler,wtr}$ is the water dose per unit release to a member of an angling family for a 1 m^3/s river flow (μSv/y per Bq/y) (see Table 2)
v_{riv} is the river flow rate (default of 1 m^3/s, maximum of 100 m^3/s)

The dose to an **irrigated food consumer** arising from releases to rivers is calculated as follows:

$$D_{ifood} = \sum^{\text{all nuclides}} \frac{A_{riv}\ DPUR_{ifood}}{v_{riv}}$$

where: D_{ifood} is the dose to an irrigated food consumer (μSv/y)
A_{riv} is the activity released to river (Bq/y)
$DPUR_{ifood}$ is the dose per unit release to an irrigated food consumer for a 1 m^3/s river flow (μSv/y per Bq/y) (see Table 3)
v_{riv} is the river flow rate (default of 1 m^3/s, maximum of 100 m^3/s)

Releases to estuary/coastal waters

The dose to a **fisherman** arising from releases to an estuary or coastal water is calculated as follows:

$$D_{fman} = D_{fman,ext} + D_{fman,fish}$$

where: D_{fman} is the total dose to a fisherman (μSv/y)
$D_{fman,ext}$ is the external dose to a fisherman (μSv/y)

$D_{fman,fish}$ is the fish dose to a fisherman (μSv/y)

$$D_{fman,ext} = \sum^{\text{all nuclides}} \frac{A_{est}\ DPUR_{fman,ext}\ 100\ \text{m}^3/\text{s}}{v_{est}}$$

where: A_{est} is the activity released to an estuary or coastal water (Bq/y)
$DPUR_{fman,ext}$ is the external dose per unit release to a fisherman for an exchange rate of 100 m^3/s (μSv/y per Bq/y) (see Table 4)
v_{est} is the estuary or coastal water exchange rate (default of 30 m^3/s) (see Table 5)

$$D_{fman,fish} = \sum^{\text{all nuclides}} \frac{A_{est}\ DPUR_{fman,fish}\ 100\ \text{m}^3/\text{s}}{v_{est}}$$

where: A_{est} is the activity released to an estuary or coastal water (Bq/y)
$DPUR_{fman,fish}$ is the fish dose per unit release to a fisherman for an exchange rate of 100 m^3/s (μSv/y per Bq/y) (see Table 4)
v_{est} is the estuary or coastal water exchange rate (default of 30 m^3/s) (see Table 5)

Releases to sewer

The dose to an **STW worker** arising from releases to sewer is calculated as follows:

$$D_{stww} = D_{stww,ext} + D_{stww,inad}$$

where: D_{stww} is the total dose to an STW worker (μSv/y)
$D_{stww,ext}$ is the external dose to an STW worker (μSv/y)
$D_{stww,inad}$ is the inadvertent inhalation and ingestion dose to an STW worker (μSv/y)

$$D_{stww,ext} = \sum^{\text{all nuclides}} \frac{A_{swr}\ DPUR_{stww,ext}\ 60\ \text{m}^3/\text{d}}{v_{swr}}$$

where: A_{swr} is the activity released to sewer (Bq/y)
$DPUR_{stww,ext}$ is the external dose per unit release to an STW worker for a raw sewage input rate to STW of 60 m^3/d (μSv/y per Bq/y) (see Table 6)
v_{swr} is the raw sewage input rate to STW (default of 60 m^3/d)

$$D_{stww,inad} = \sum^{\text{all nuclides}} \frac{A_{swr}\ DPUR_{stww,inad}\ 60\ \text{m}^3/\text{d}}{v_{swr}}$$

where: A_{swr} is the activity released to sewer (Bq/y)
$DPUR_{stww,inad}$ is the inadvertent inhalation and ingestion dose per unit release to an STW worker for a raw sewage input rate to STW of 60 m^3/d (μSv/y per Bq/y) (see Table 6)
v_{swr} is the raw sewage input rate to STW (default of 60 m^3/d)

The dose to a **member of a farming family** (living on land conditioned with sewage sludge) arising from releases to sewer is calculated as follows:

$$D_{farm} = D_{farm,\,food} + D_{farm,ext} + D_{farm,inad}$$

where: D_{farm} is the total dose to member of a farming family (μSv/y)
$D_{farm,food}$ is the food dose to member of a farming family (μSv/y)
$D_{farm,ext}$ is the external dose to member of a farming family (μSv/y)
$D_{farm,inad}$ is the inadvertent inhalation and ingestion dose to member of a farming family (μSv/y)

$$D_{farm,\,food} = \sum^{\text{all nuclides}} \frac{A_{swr}\ DPUR_{farm,\,food}\ 60\ \mathrm{m^3/d}}{v_{swr}}$$

where: A_{swr} is the activity released to sewer (Bq/y)
$DPUR_{farm,food}$ is the food dose per unit release to a member of a farming family for a raw sewage input rate to STW of 60 m^3/d (μSv/y per Bq/y) (see Table 7)
v_{swr} is the raw sewage input rate to STW (default of 60 m^3/d)

$$D_{farm,ext} = \sum^{\text{all nuclides}} \frac{A_{swr}\ DPUR_{farm,ext}\ 60\ \mathrm{m^3/d}}{v_{swr}}$$

where: A_{swr} is the activity released to sewer (Bq/y)
$DPUR_{farm,ext}$ is the external dose per unit release to a member of a farming family for a raw sewage input rate to STW of 60 m^3/d (μSv/y per Bq/y) (see Table 7)
v_{swr} is the raw sewage input rate to STW (default of 60 m^3/d)

$$D_{farm,inad} = \sum^{\text{all nuclides}} \frac{A_{swr}\ DPUR_{farm,inad}\ 60\ \mathrm{m^3/d}}{v_{swr}}$$

where: A_{swr} is the activity released to sewer (Bq/y)
$DPUR_{farm,ext}$ is the inadvertent inhalation and ingestion dose per unit release to a member of a farming family for a raw sewage input rate to STW of 60 m^3/d (μSv/y per Bq/y) (see Table 7)
v_{swr} is the raw sewage input rate to STW (default of 60 m^3/d)

The dose to a **child playing in a brook** arising from releases to sewer is calculated as follows:

$$D_{brook} = D_{brook,ext} + D_{brook,inad}$$

where: D_{brook} is the total dose to a child playing in brook (μSv/y)
$D_{brook,ext}$ is the external dose to a child playing in brook (μSv/y)
$D_{brook,inad}$ is the inadvertent water consumption dose to a child playing in brook (μSv/y)

$$D_{brook,ext} = \sum^{\text{all nuclides}} \frac{A_{swr}\ DPUR_{brook,ext}\ f_{swr}}{v_{brk}}$$

where: A_{swr} is the activity released to river (Bq/y)

$DPUR_{brook,ext}$ is the external dose per unit release to a child playing in brook for a 1 m^3/s brook flow (μSv/y per Bq/y) (see Table 8)
f_{swr} is the sewage treatment works partitioning and decay factor (see Table 8)
v_{brk} is the brook flow rate (default of 0.2 m^3/s, maximum of 10 m^3/s)

$$D_{brook,inad} = \sum^{\text{all nuclides}} \frac{A_{swr}\ DPUR_{brook,inad}\ f_{swr}}{v_{brk}}$$

where: A_{swr} is the activity released to river (Bq/y)
$DPUR_{brook,inad}$ is the inadvertent water consumption dose per unit release to a child playing in brook for a 1 m^3/s brook flow (μSv/y per Bq/y) (see Table 8)
f_{swr} is the sewage treatment works partitioning and decay factor (see Table 8)
v_{brk} is the brook flow rate (default of 0.2 m^3/s, maximum of 10 m^3/s)

The dose to a **member of an angling family** arising from releases to sewer is calculated as follows:

$$D_{angler} = D_{angler,ext} + D_{angler,fish} + D_{angler,wtr}$$

where: D_{angler} is the total dose to a member of an angling family (μSv/y)
$D_{angler,ext}$ is the external dose to a member of an angling family (μSv/y)
$D_{angler,fish}$ is the fish dose to a member of an angling family (μSv/y)
$D_{angler,wtr}$ is the water dose to a member of an angling family (μSv/y)

$$D_{angler,ext} = \sum^{\text{all nuclides}} \frac{A_{swr}\ DPUR_{angler,ext}\ f_{swr}}{v_{riv}}$$

where: A_{swr} is the activity released to sewer (Bq/y)
$DPUR_{angler,ext}$ is the external dose per unit release to a member of an angling family for a 1 m^3/s river flow (μSv/y per Bq/y) (see Table 2)
f_{swr} is the sewage treatment works partitioning and decay factor (see Table 8)
v_{riv} is the river flow rate (default of 1 m^3/s, maximum of 100 m^3/s)

$$D_{angler,fish} = \sum^{\text{all nuclides}} \frac{A_{swr}\ DPUR_{angler,fish}\ f_{swr}}{v_{riv}}$$

where: A_{swr} is the activity released to sewer (Bq/y)
$DPUR_{angler,fish}$ is the fish dose per unit release to a member of an angling family for a 1 m^3/s river flow (μSv/y per Bq/y) (see Table 2)
f_{swr} is the sewage treatment works partitioning and decay factor (see Table 8)
v_{riv} is the river flow rate (default of 1 m^3/s, maximum of 100 m^3/s)

$$D_{angler,wtr} = \sum^{\text{all nuclides}} \frac{A_{swr}\ DPUR_{angler,wtr}\ f_{swr}}{v_{riv}}$$

where: A_{swr} is the activity released to sewer (Bq/y)

$DPUR_{angler,wtr}$ is the water dose per unit release to a member of an angling family for a 1 m^3/s river flow (μSv/y per Bq/y) (see Table 2)
f_{swr} is the sewage treatment works partitioning and decay factor (see Table 8)
v_{riv} is the river flow rate (default of 1 m^3/s, maximum of 100 m^3/s)

The dose to an **irrigated food consumer** arising from releases to sewer is calculated as follows:

$$D_{ifood} = \sum^{\text{all nuclides}} \frac{A_{swr}\ dpur_{ifood}\ f_{swr}}{v_{riv}}$$

where: D_{ifood} is the dose to an irrigated food consumer (μSv/y)
A_{swr} is the activity released to sewer (Bq/y)
$DPUR_{ifood}$ is the dose per unit release to an irrigated food consumer for a 1 m^3/s river flow (μSv/y per Bq/y) (see Table 3)
f_{swr} is the sewage treatment works partitioning and decay factor (see Table 8)
v_{riv} is the river flow rate (default of 1 m^3/s, maximum of 100 m^3/s)

The dose to a **fisherman** arising from releases to sewer is calculated as follows:

$$D_{fman} = D_{fman,ext} + D_{fman,fish}$$

where: D_{fman} is the total dose to a fisherman (μSv/y)
$D_{fman,ext}$ is the external dose to a fisherman (μSv/y)
$D_{fman,fish}$ is the fish dose to a fisherman (μSv/y)

$$D_{fman,ext} = \sum^{\text{all nuclides}} \frac{A_{swr}\ DPUR_{fman,ext}\ f_{swr}\, 100\ \mathrm{m^3/s}}{v_{est}}$$

where: A_{swr} is the activity released to sewer (Bq/y)
$DPUR_{fman,ext}$ is the external dose per unit release to a fisherman for an exchange rate of 100 m^3/s (μSv/y per Bq/y) (see Table 4)
f_{swr} is the sewage treatment works partitioning and decay factor (see Table 8)
v_{est} is the estuary or coastal water exchange rate (default of 30 m^3/s) (see Table 5)

$$D_{fman,fish} = \sum^{\text{all nuclides}} \frac{A_{swr}\ DPUR_{fman,fish}\ f_{swr}\ 100\ \mathrm{m^3/s}}{v_{est}}$$

where: A_{swr} is the activity released to sewer (Bq/y)
$DPUR_{fman,fish}$ is the fish dose per unit release to a fisherman for an exchange rate of 100 m^3/s (μSv/y per Bq/y) (see Table 4)
f_{swr} is the sewage treatment works partitioning and decay factor (see Table 8)
v_{est} is the estuary or coastal water exchange rate (default of 30 m^3/s) (see Table 5)

APPENDIX 6 – EXAMPLE INITIAL DOSE ASSESSMENT CALCULATION

A hospital in the Thames Valley has an incinerator permitted to discharge 5 GBq/y of carbon-14 to air and an authorisation permitting the discharge of 1.44 TBq/y of Iodine-131 to sewer.

Stage 1 - Initial radiological assessment using default data

The initial radiological assessment results using default data are as follows:

Release to air (C-14):

Population groups	Limit (Bq/y)	total DPUR (μSv/y per Bq/y)	Dispersion correction for default	Dose (μSv/y)
Local habitants	5.0E+09	4.8E-11	-	2.4E-01

Release to sewer (I-131):

Population group	Limit (Bq/y)	total DPUR (μSv/y per Bq/y)	Dispersion correction for default	STW partitioning & decay factor	Dose (μSv/y)
STW worker dose at STW	1.44E+12	2.0E-08	-	-	2.9E+04
Farming family dose (sewage sludge to land)		7.5E-08	-	-	1.1E+05
Child playing in brook		2.0E-11	1/0.2 = 5	7.6E-01	1.1E+02
Angling family dose (river)		1.7E-09	-	7.6E-01	1.9E+03
Irrigated food consumer dose (river water)		2.0E-11	-	7.6E-01	2.2E+01
Fisherman dose (estuary/coastal)		2.1E-12	100/30 = 3.3	7.6E-01	7.7E+00
Worst					**1.1E+05**

For the release to air the dose is 0.24 μSv/y. For release to sewer, the highest dose of 11000 μSv/y is predicted for a farming family consuming food produced on their land which has been conditioned with sewage sludge. Without further information, the farming family should be assumed to live near to the hospital. The total dose is 11000 μSv/y. This is much greater than 20 μSv/y and refined data should be used for the release to sewer (Stage 2).

Stage 2 – Initial radiological assessment using refined data

The refinements required relate to discharges to sewer. The main refinements are to determine which sewage treatment works receives the releases to sewer and establish the average annual raw sewage flow. The treated effluent from the sewage treatment works flows to a brook which then enters the lower reaches of the freshwater Thames and then goes into the Thames Estuary. After periods of dry weather the brook flow is maintained by the treated effluent from the sewage treatment works. Downstream of where the brook joins the freshwater Thames, the Thames is a source of drinking water and is used by a large number of anglers for coarse fishing. The coarse fish are mostly thrown back.

Refined flow rate data has been established are as follows:

Raw throughput of sewage to STW:	30,000 m^3/d
Average volumetric flow rate in the brook:	0.3 m^3/s
Average volumetric flow rate in River Thames:	30 m^3/s
Average water exchange rate in the Thames estuary:	30 m^3/s

The flows through the works are 5000 times higher than the default for the initial assessment of 60 m^3/d. The greater dilution means that the estimated doses will be much reduced.

Release to sewer (I-131):

Population group	Limit (Bq/y)	total DPUR (μSv/y per Bq/y)	Dispersion scaling	STW partitioning & decay factor	Dose (μSv/y)
STW worker dose at STW	1.44E+12	2.0E-08	60/30000 = 0.002	-	5.8E+01
Farming family dose (sewage sludge to land)		7.5E-08	60/30000 = 0.002	-	2.2E+02
Child playing in brook		2.0E-11	1/0.3 = 3.3	7.6E-01	7.3E+01
Angling family dose (river)		1.7E-09	1/30 = 0.033	7.6E-01	6.2E+01
Irrigated food consumer dose (river water)		2.0E-11	1/30 = 0.033	7.6E-01	7.3E-01
Fisherman dose (estuary/coastal)		2.1E-12	100/30 = 3.3	7.6E-01	7.7E+00
Worst					2.2E+02

The highest dose is still for the farming family, but has now been assessed as 220 μSv/y. As this is still greater than 20 μSv/y, it is necessary to consider if a detailed site specific assessment is required (Stage 3).

Stage 3 – Determine need for a site specific radiological assessment

In this example the assessed dose from stage 2 is closer to 300 μSv/y than to 20 μSv/y. Taking this into account, a further review is required.

The highest dose is via sewage sludge applied to land. The review should therefore considers this part of the assessment first. The initial radiological assessment assumes surface spreading of the sludge onto pasture. Given that there are a number of restrictions controlling the application of sewage sludge to land, in particular higher treatment standards are required for sludge applied to agricultural land which might prevent application. Suitable agricultural land may not be available. The water company may dispose of the sludge in other ways. Options include incineration, landfill and land reclamation. In addition the sludges from one works may be transferred to another for further treatment.

If the STW treatment does not reach the standards required for application to agricultural land and the water company does not intend to upgrade the STW, direct application of the sludge to pasture is unlikely in the next 5 years. In such a case, the doses from sewage sludge applied to land would not be valid.

If the sludges are incinerated, an initial radiological assessment for releases to air from the incineration of sewage sludge is required. Account can be taken of decay of iodine-131 prior to incineration of the sewage sludge and partitioning of the I-131 during treatment.

If the doses to the farming family from sludge are disregarded, the next highest dose is 73 μSv/y to a child playing in the brook and 62 μSv/y to an angling family on the river Thames. These doses are still greater than 20 μSv/y and less than 300 μSv/y, but the assessed dose is nearer to 20 μSv/y than to 300 μSv/y.

Further information on whether children can have access to the brook and also habit data on coarse fish consumed from the River Thames could be used to make the assessment more realistic.

Monitoring of this area may be required for reassurance purposes, including dose rate monitoring, analysis of iodine-131 concentrations in sediment and fish if there is any evidence of consumption.

This information will help a decision on whether a site specific assessment should be made.