NDAWG
National Dose Assessment Working Group

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Short term Releases to the Rivers

NDAWG Short-term Release Sub-group

SUMMARY

The NDAWG short term release sub-group has recommended general guidance for assessing short term releases to rivers to inform the process of proposing or setting short term limits or notification levels. Included in this guidance are the key parameter assumptions for cautious and realistic assessments of short term releases to rivers.

Dose per unit short term release to river data have been calculated for some radionuclides using the recommended cautious and realistic assumptions. These have been used to assess doses to members of an angling family and irrigated food consumers for generic discharge scenarios. This has showed that where there are monthly limits proposed or in place, doses for a realistic short term release assessment are unlikely to be more than a factor of three higher than the continuous release assessment. Where there are only 12 month limits, then doses for a realistic short term release assessment are unlikely to be more than a factor of 20 higher than the continuous release assessment.

Case studies have been undertaken for a hospital discharging into the River Aire in Leeds, a nuclear site discharging into the River Thames and a pharmaceutical research company discharging into the River Cam in Cambridge. These assessments show that the realistic dose for a short term release assessment is within a factor of three of the dose from the continuous release assessment.

The NDAWG short term releases group has recommended that a dose assessment for short term releases to rivers is unlikely to be required if there are monthly limits proposed or in place for releases to freshwater or sewer and the annual dose to the critical group from a continuous release at twelve times the monthly limits is less than or equal to 0.1 mSv.

CONTENTS

1 INTRODUCTION

1.1 The Environmental Permitting Regulations (EPR 10) and Radioactive Substances Act 1993 (RSA 93) provide 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, EPR 10 and RSA 93 require prior permitting or authorisation for the disposal or discharge of radioactive waste to the environment. Responsibility for granting a permit or authorisation rests with the Environment Agency (in England and Wales), the Scottish Environment Protection Agency (SEPA) and the Northern Ireland Environment Agency (referred to as the Environment Agencies).

1.2 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.

1.3 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].

1.4 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 the Radiation Protection Division of the Health Protection Agency – HPA-RPD) have developed and published principles and guidance for the prospective assessment of public doses [Ref 5]. Included is a principle requiring the assessment of operational short term releases of radionuclides. Operational (ie, routine, planned or reasonably foreseeable) short term releases which are higher than normal releases, can occur as a result of a number of reasons, including variations in site production, restricted nuclear medicine treatment days within hospitals or particular projects (eg, decommissioning activities, research using particular radionuclides).

1.5 This paper provides guidance and recommendations for assessing doses from planned or expected short term releases to river to inform the process of proposing or setting short term limits or notification levels. A separate NDAWG guidance note is available on assessing short term releases [Ref 6].

2 PATTERN OF DISCHARGES TO RIVERS

2.1 In England and Wales, there are about 600 EPR 10 permits which ultimately lead to discharges of radioactive substances to rivers. The majority of these permitted discharges are from non-nuclear users and are nearly always via a sewage treatment works. In Scotland, around 20 authorisations eventually lead to discharges to rivers. The vast majority of authorised discharges to water are to marine or estuarine environments.

2.2 Nearly all non-nuclear discharge permits or authorisations have monthly limits, rather than annual or 12-monthly limits. The main exception being the oil and gas industry which discharges to the marine environment. Some of the highest discharges to sewers and hence rivers are from nuclear medicine practices in hospitals, in particular thyroid ablation therapy using radioiodine [Ref 7]. Thyroid ablation therapy is usually undertaken once or twice per week. Discharges to sewer will peak within a few days of administration of the radioiodine. The peaks in the discharges will be flattened to a certain extent as a result of the discharges passing through a sewage treatment works.

2.3 In England and Wales, a few permits allow direct discharges to river (albeit after some site waste water treatment) and these include discharges from the UKAEA Harwell and Winfrith sites. The pattern of discharges from UKAEA Harwell is illustrated in Figures 1 and 2. These discharge limits have 12-month rolling discharge limits and quarterly notification levels.

2.4 As well as variations in the magnitude of discharges over time, there is the potential for variations in the chemical form of the radionuclide which is released. This may result, for example, from the production of different batches of radiopharmaceuticals.

3 GENERAL ASSESSMENT GUIDANCE

3.1 NDAWG recommends the following key guidance points for assessing prospective doses from short-term releases to the atmosphere:

- An operational short term release is a larger than normal release (≥2% of 12-monthly discharges) that occurs over a relatively short period of time (≤1 day). It is an actual or expected release that can be reasonably foreseen to occur or is planned. No short term release assessment is required if it can be demonstrated that no release ≥2% of the 12-monthly discharge can be released in a period of ≤1 day. For a normally uniform discharge profile, this equates to about 1 week's discharge being released in 1 day or less. Releases that occur over longer periods of time (eg, 5 days) may be considered as a continuous release, so long as the daily release during that period does not exceed 2% of the 12-month actual or expected discharges.

- A short term release assessment should be undertaken, where the annual dose from a continuous release to the critical group dose exceeds 0.02 mSv [Ref 5] and there is the potential for operational short term releases.

- The dose calculated using continuous release assessment assumptions will be the benchmark, best estimate dose that is reported for an authorised discharge. The short term release assessment provides an analysis of the uncertainty and variability in the continuous release assessment.

- Realistic assumptions should be used for short term release assessments, if the annual dose exceeds 0.02 mSv [Ref 5]. These assumptions should be in keeping with the recommendations of ICRP [Ref 8] such that the dose to the individual considered is representative of the most exposed individuals in the population.

- The dose assessed for operational short term releases at proposed notification levels or limits should be compared with the annual source constraint (maximum of 0.3 mSv) and the annual dose limit (1 mSv), taking into account other relevant contributions [Ref 5]. Other contributions will include the dose from any continuous releases for the remainder of the 12 month period.

- Doses from short term releases should be assessed for the first year following the short term release. It is not necessary to consider the cumulative effective of short term releases over a number of years as it is highly unlikely that the same exposed groups will be affected. The doses from cumulative effects of discharges over a number of years are adequately considered by a continuous release assessment.

4 ASSESSMENT ASSUMPTIONS

4.1 The assumptions for a realistic or cautious assessment of a short term release to river, as recommended by the NDAWG short term releases subgroup, are shown in Table 1. The Principles document [Ref 5] states that assessments should be realistic, hence these are the ones which should ideally be used. Cautious assumptions may be used for the purposes of an initial assessment.

4.2 The source term used in the short term release assessment will depend upon the limits or notification levels proposed or in place. The most common for releases to river and sewer are 12-month rolling limits, quarterly notification levels and monthly limits.

4.3 Where there are no short term notification levels or limits proposed or in place, it may be appropriate to initially make a cautious assessment by assuming a single release of all radionuclides at the 12-month limits. No further assessment will then be necessary if the doses are acceptable. For a more realistic assessment, short term release scenarios should be identified based on expected or planned releases. It will be necessary to carry out a short term release assessment for each of the different release scenarios. Each short term release scenario should take account of the number of releases per year. However, the number of releases per year should be modified by the probability of the release coinciding with a one month period of both low flow and high occupancy (ie, 1/12), subject to a minimum number of releases of one per year.

4.4 It would not generally be appropriate to assume more than one release every 12 months, as the likelihood of a number of short term releases coinciding with periods of low flow, occupancy by anglers, fish being exposed to radionuclides and these fish being caught is quite remote. However, careful consideration may be required for regular short term releases (eg, scheduled every Friday) where there is the potential for co-incidence with habits (eg, angling club meet every Saturday). Where fish or water is stored for remaining annual consumption, then only one short term release should be assessed.

4.5 Where there are quarterly notification levels or monthly limits proposed or in place, then for a realistic assessment it is necessary to identify which radionuclides are likely to be released together (eg, due to particular site operations/activities). Short term release assessments should then be carried out for each group of radionuclides, by assuming that the radionuclides are released at their quarterly notification levels or monthly limits. As discussed above, it is generally not necessary to assume more than one short term release every 12 months, unless there is evidence of co-incidence of releases and habits.

4.6 The dose from any remaining releases up to the 12-monthly limits should be assessed as a continuous release and added to the short term release dose.

4.7 The short term release assessment should take account of the chemical form of the radionuclide, if a particular chemical form is more likely to be released as a short term release.

5 ASSESSMENT METHODOLOGY

5.1 Dose per unit short term release values for an angling family and irrigated food consumers from a short term release to river have been calculated for a range of radionuclides using the assumptions in Table 1 (see Appendix A). Both cautious and realistic dose per unit short term release values have been calculated for the angling family, but just realistic values for the irrigated food consumers as the cautious and realistic assumptions are broadly similar for this population group. These dose per unit release factors have been calculated for the first year following the release.

5.2 The methodology and parameters used to calculate these dose per unit release values for a river flow of 1 m^3/s are detailed in Appendix A. Some of the methodologies and data used to calculate these dose per unit release values have been sourced from Reference 9. The appendix highlights the fact that there are number of cautious assumptions in the dose assessment for the consumption of drinking water.

5.3 The cautious dose to a member of the angling family for a short term release of a particular radionuclide may be calculated by multiplying the quantity of activity released in the short term release (Bq), by the cautious angling family dose per unit short term release value (microsievert per Bq released) and dividing by the 5th percentile river flow rate (m^3/s). The 5th percentile river flow rate is recommended for use in cautious short term release assessments (Table 1).

5.4 The realistic dose to a member of the angling family for a short term release of a particular radionuclide may be calculated by multiplying the quantity of activity released in the short term release (Bq), by the realistic angling family dose per unit short term release value (microsievert per Bq released) and dividing by the 25th percentile river flow rate (m^3/s). The 25th percentile river flow rate is recommended for use in realistic short term release assessments (Table 1).

5.5 The realistic dose to an irrigated food consumer for a short term release of a particular radionuclide may be calculated by multiplying the quantity of activity released in the short term release (Bq), by the realistic irrigated food consumer dose per unit short term release value (microsievert per Bq released) and dividing by the 25th percentile river flow rate (m^3/s).

5.6 Dose per unit release values for a continuous release are available in the Environment Agency's initial radiological assessment methodology [Ref 10]. These values are based on a river flow of 1 m^3/s. The annual dose, assuming a continuous release, for individual members of a particular population group and radionuclide, may be calculated by multiplying the annual discharge of activity (Bq) by the appropriate dose per unit continuous release value and dividing by the mean river flow rate (m^3/s). Doses arising from continuous discharges for the remainder of the year, following the short term release, may be calculated in the same way.

6 GENERIC RELEASE SCENARIOS

6.1 Doses have been assessed for the following three generic short-term release scenarios to compare to the doses assuming a continuous release:

- ***Scenario 1 – 12 month limits only***. All radionuclides cautiously assumed to be released at 12 month limits in a short term release. No further discharges for remainder of year.
- ***Scenario 2 – Quarterly notification levels***. All radionuclides cautiously assumed to be released at their quarterly notification levels in a short term release. Remainder of 12 month limits released continuously over the rest of the year.
- ***Scenario 3 – Monthly limits.*** All radionuclides cautiously assumed to be released at their monthly limits in a short term release. Remaining 11 months of discharges released continuously throughout rest of year.

6.2 The source terms for the short-term releases for these scenarios and for the continuous release are shown in Table 2. Both the total short term release (short term plus remaining continuous release throughout the year) and the continuous release during the year equates to a unit release of 1 TBq.

6.3 The doses to an angling family and irrigated food consumers have been calculated using the cautious and realistic dose per unit short release values in Appendix A and the dose per unit continuous release values from Reference 10.

6.4 To calculate doses for a short term release, it is necessary to use a defined river flow rate. The 25th percentile and 5th percentile river flow rates are recommended for the realistic and cautious short term release assessment (see Table 1). The continuous release assessment uses the mean river flow rate. The ratio of the mean flow rate to the 25th percentile and 5th percentile flow rates for a number of rivers in England, Wales and Scotland which receive radioactive discharges via sewage treatment works are shown in Table 3. It can be seen that the ratios of the mean to the 25th percentile flow rate range from 1.7 – 5.1 and the ratios of the mean to the 5th percentile flow rate range from 2.3 – 8.2. There are larger ratios between the mean flow rate and the 25th percentile and 5th percentile flow rates for upland streams or streams with a tendency to dry out (eg, chalk streams). However, these types of streams will not receive authorised discharges of radioactive substances.

6.5 The following river flow rates have been assumed for the generic release scenarios, which are at the higher end of the ratios of the mean to 25th percentile and mean to 5th percentile flow rates:

- Mean river flow rate 1 m^3/s
- 25th percentile flow rate 0.2 m^3/s
- 5th percentile flow rate 0.1 m^3/s

6.6 Cautious doses assessed for an angling family for the three generic short term release scenarios are shown in Tables 4, 5 and 6 and compared with the continuous release assessment dose. The ratios of cautious short term to continuous dose are shown in Figure 3. On the basis of a cautious assessment, the total short term release dose to the angling family could be a factor of 2 – 420 times higher than a continuous release assessment, depending on the release scenario and radionuclide. The release scenario in which the 12 month authorised limit is released as a single short term release gives higher doses, than if there are monthly limits, as would be expected.

6.7 Realistic doses for an angling family for the three generic short term release scenarios are shown in Tables 7, 8 and 9. The ratios of realistic short term to continuous dose are provided in these tables and also in Figure 4. On the basis of a realistic assessment, the short term release dose to the angling family could be a factor of 1.1 – 160 times higher than a continuous release assessment.

6.8 As for the cautious assessment, the release scenario in which the 12 month authorised limit is released as a single short term release gives higher doses, than if there are monthly limits. The 12 month authorised limits only scenario gives realistic short term release doses which are a factor of 2 – 20 greater than the continuous release scenario for all radionuclides, except americium-241. The monthly limits scenario gives realistic short term release doses which are a factor of 1.1 – 2.6 higher than the continuous release scenario for all radionuclides, except americium-241.

6.9 Americium-241 has much higher doses for the short term release assessment, compared with the continuous release assessment. This is because the continuous release assessment dose per unit data [Ref 10] assumes a much higher value of the sediment partitioning coefficient (400 000 Bq/kg per Bq/l) than the realistic short term release assessment data (5000 Bq/kg per Bq/l). This sediment partitioning coefficient is used to take account of losses of radionuclide activity to the suspended sediment phase, leaving a residual 'filtered' or dissolved water activity concentration. It is this filtered water activity concentration which is used to calculate the activity concentration of radionuclides in fish for the realistic short term releases assessments (unfiltered water is used to calculated maximum fish concentrations). A higher sediment partitioning coefficient value leads to a lower filtered radionuclide water activity concentration. The sediment partitioning coefficient used to calculate the continuous release assessment data [Ref 10] is not consistent with the International Atomic Energy Agency (IAEA) recommended value of 5000 Bq/kg per Bq/l [Ref 11]. Hence, it is recommended that the americium-241 sediment partitioning value used in freshwater assessments is reviewed as part of future updates to Reference 10. There are currently only two authorised discharges of americium-241 to freshwater and hence this is unlikely to be a major issue.

6.10 The radionuclides with the higher ratios are those where the dose is dominated by consumption of fish containing radionuclides. The short term release assumptions, both uptake into fish and consumption rates, tend to lead to proportionately higher doses in these cases. However, it should also be noted that the variations in published fish concentration factors [Refs 9, 11] between the mean and highest values is about a factor of ten or more. Hence this variability is equivalent to the variations between doses assessed for a short term release and a continuous release for most radionuclides.

6.11 It is worth noting that continuous release assessments for discharges to river usually assume that occupancy of river banks and freshwater fish catches and consumption are uniform throughout the year. There is some evidence to suggest that angling activities are more common in the summer months than other months [Ref 12]:

- Summer 41%
- Spring 24%
- Winter 15%
- Autumn 20%

6.12 This would mean that higher river occupancy would coincide with the period when river flows are generally at their lowest (see Figure 5 for River Thames in Reading and River Aire in Leeds). However, the larger number of angling activities during the summer will be due to more people participating in angling activities as well as particular individuals participating more often. The committed high occupancy angler will be more concerned about the quality of the fishing than the weather and may not show a strong seasonal preference. Data on the consumption of freshwater fish does not show any significant variation across different seasons (Table 10), although the source of fish is likely to be dominated by farmed fish. Farmed fish will not be significantly affected by discharges to the river due to fish being fed with processed food derived from a number of sources. The game fish season for salmon and trout extends from early spring to late autumn and is hence reasonably spread throughout a large part of the year. Overall, there is no strong evidence to suggest that higher occupancies and fish consumption rates are strongly correlated with lower river flows in the summer months. Hence, there is no strong reason to change the normal continuous release assessment assumptions.

6.13 Realistic doses for irrigated food consumers for short term releases to river for Scenario 1 (12 month limits only) are shown in Table 11. On the basis of these realistic doses, the short term dose to the irrigated food consumers could be a factor of about 30 times higher than a continuous release assessment, if the annual authorised limit was released as a single short term release. The doses to the angling family are greater than the doses to the irrigated food consumers for short term releases, for the radionuclides considered (Table 11). This is the same as has been found for the continuous release assessment.

6.14 In summary, it can be concluded, that where there are monthly limits proposed or in place, doses for a realistic short term release assessment are unlikely to be more than a factor of three higher than the continuous release assessment. Where there are only 12 month limits, then doses for a realistic short term release assessment are unlikely to be more than a factor of 20 higher than the continuous release assessment.

7 CASE STUDIES

7.1 Short term release dose assessments have been undertaken for three case studies:

- Case Study 1 – Hospital discharging to River Aire (monthly limits).
- Case Study 2 – Nuclear site discharging to River Thames (quarterly notification levels).
- Case Study 3 – Pharmaceutical research company discharging to River Cam (monthly limits).

7.2 Case Study 1 – Hospital in Leeds

7.2.1 Discharges at the authorised limits from a hospital in Leeds have been used in this case study, as this is illustrative of one of the situations of most practical interest. The discharges limits are provided in Table 12. The discharges are made to sewer and discharge into the River Aire at Leeds via a Sewage Treatment Works. The dose to an angling family from hospital discharges tends to be dominated by iodine-131. The iodine-131 limit for this hospital in Leeds is

50 GBq/month compared with a range of limits for other hospitals from 0.005 GBq/month to 625 GBq/month. The average limit is about 38 GBq/month and the median, 8 GBq/month.

7.2.2 Cautious and realistic short term release doses have been calculated for an angling family using the methodology in Section 5. In both case, all the radionuclides were cautiously assumed to be discharged at their monthly discharge limits in a single short term release, followed by 11 months of continuous releases (see Table 12). Doses have also been calculated for a continuous release assessment, for discharges at 12 lots of monthly limits (see Table 12), using the initial radiological assessment methodology [Ref 10]. River flow data for the River Aire at Leeds have been used (gauging station 27028 [Ref 13], see Figure 6):

- Mean river flow rate 15 m^3/s
- 25th percentile flow rate 5 m^3/s
- 5th percentile flow rate 3.3 m^3/s

7.2.3 The cautious and realistic short term release doses are shown in Table 13 and 14 respectively and in Figure 7. The dose for the short term release (ie, 1 month limits), assessed in a cautious manner is 97 μSv, compared with 20 μSv for a realistic assessment.

7.2.4 The total annual dose for the cautious short term release (including remaining discharges in the year) is 160 μSv compared with a realistic total annual dose for a short term release of 82 μSv. The total annual dose for a continuous release assessment is 68 μSv. The doses for the cautious assessment and the realistic assessment are 2.4 times and 1.2 times the continuous release assessment dose respectively.

7.3 Case Study 2 – Nuclear site discharging to River Thames

7.3.1 Discharges at the authorised limits from a nuclear site have been used in this case study. The discharges limits are provided in Table 15. The discharges are made directly into the River Thames.

7.3.2 Cautious and realistic short term release doses have been calculated for an angling family using the methodology in Section 5. In both cases, all the radionuclides were cautiously assumed to be discharged at their quarterly notification levels in a single short term release, followed by 9 months of continuous releases (see Table 15). This remaining discharge is the difference between the annual limits and the quarterly notification levels. Doses have also been calculated for a continuous release assessment, for discharges at the annual limits (see Table 15), using the initial radiological assessment methodology [Ref 10]. River flow data for the River Thames at Sutton Courtenay have been used (gauging station 39046 [Ref 13], see Figure 8):

- Mean river flow rate 26 m^3/s
- 25th percentile flow rate 6 m^3/s
- 5th percentile flow rate 2.3 m^3/s

7.3.3 The cautious and realistic short term release doses are shown in Table 16 and 17 respectively and in Figure 9.

7.3.4 The total annual dose for the cautious short term release (including remaining discharges in the year) is 4.1 μSv compared with a realistic total annual dose for a short term release of 1.8 μSv. The total annual dose for a continuous release assessment is 0.71 μSv. The doses for the cautious assessment and the realistic assessment are 5.8 times and 2.5 times the continuous release assessment dose respectively. It should be noted that a short term release assessment would not actually be required for this case study as the annual dose for a continuous release is less than 0.02 mSv/y (see Section 3).

7.4 Case Study 3 – Pharmaceutical research company in Cambridge

7.4.1 Discharges at the authorised limits from a pharmaceutical research company in Cambridge have been used in this case study. The discharges limits are provided in Table 18. The discharges are made to sewer and discharge into the River Cam at Cambridge via a Sewage Treatment Works.

7.4.2 Cautious and realistic short term release doses have been calculated for an angling family using the methodology in Section 5. In both cases, all the radionuclides were cautiously assumed to be discharged at their monthly discharge limits in a single short term release, followed by 11 months of continuous releases (see Table 18). Doses have also been calculated for a continuous release assessment, for discharges at 12 lots of monthly limits (see Table 18), using the initial radiological assessment methodology [Ref 10]. River flow data for the River Cam at Cambridge have been used (gauging station 33003 [Ref 13], see Figure 10):

- Mean river flow rate 3.6 m^3/s
- 25^{th} percentile flow rate 1.6 m^3/s
- 5^{th} percentile flow rate 0.91 m^3/s

7.4.3 The cautious and realistic short term release doses are shown in Table 19 and 20 respectively and in Figure 11.

7.4.4 The total annual dose for the cautious short term release (including remaining discharges in the year) is 180 μSv compared with a realistic total annual dose for a short term release of 130 μSv. The total annual dose for a continuous release assessment is 120 μSv. The doses for the cautious assessment and the realistic assessment are 1.5 times and 1.1 times the continuous release assessment dose respectively.

7.4.5 The continuous and short term release assessment doses in this case study are relatively high, with doses from phosphorus-32 providing the greatest contribution to the total dose. This is due to the relatively high fish concentration factor for phosphorus-32 and the high offspring dose coefficients. The realistic dose for the short term release is not much higher than the continuous release dose assessment as the short term release assessment methodology uses a kinetic model which takes account of radioactive decay of phosphorus-32 as it moves through the food chain.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 The NDAWG short term release sub-group has recommended general guidance for assessing short term releases to rivers to inform the process of proposing or setting short term limits or notification levels. Included in this guidance are the key parameter assumptions for cautious and realistic assessments of short term releases to rivers.

8.2 Dose per unit short term release data have been calculated for some radionuclides using the recommended cautious and realistic assumptions. These have been used to assess doses to members of an angling family and irrigated food consumers for generic discharge scenarios. This has showed that where there are monthly limits proposed or in place, doses for a realistic short term release assessment are unlikely to be more than a factor of three higher than the continuous release assessment. Where there are only 12 month limits, then doses for a realistic short term release assessment are unlikely to be more than a factor of 20 higher than the continuous release assessment.

8.3 Case studies have been undertaken for a hospital discharging into the River Aire in Leeds, a nuclear site discharging into the River Thames and a pharmaceutical research company discharging into the River Cam in Cambridge. These assessments show that the realistic dose for a short term release assessment is within a factor of three of the dose from the continuous release assessment.

8.4 Hence, if the annual dose for a continuous release is less than about 0.02 mSv, the annual dose constraint of 0.3 mSv is unlikely to be exceeded for a short term release. This confirms that a short term release assessment is only necessary, where the continuous release annual dose to the critical group dose exceeds 0.02 mSv.

8.5 The NDAWG short term releases group also recommends that a dose assessment for short term releases to rivers is unlikely to be required if there are monthly limits proposed or in place for releases to freshwater or sewer and the annual dose to the critical group from a continuous release at twelve times the monthly limits is less than or equal to 0.1 mSv.

9 FUTURE WORK

9.1 The freshwater sediment partitioning coefficient used for americium-241 in continuous release assessments should be reviewed and any guidance documents updates as necessary.

10 ACKNOWLEDGEMENTS

10.1 The authors are indebted to the valuable comments provided by Professor Steve Jones, Dr Mike Thorne and Mr Mike Harvey.

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12 TABLES

Table 1 Assumptions for assessing short term releases to rivers

Key assessment parameter	Annual average dose – continuous release	Realistic short term release	Cautious short term release
Source term (see Appendix B for example application)			
Limits – 12 month limits only (ie, no short term limits/notification levels)	All radionuclides at 12- month limits continuously throughout 12 month period	Specific release scenarios based on the expected or planned short term releases of different radionuclides. The number of such releases in a year should take account of the probability of the releases occurring in a one month period of both low flow and high occupancy (eg, 1/12 for seasonally independent releases), subject to a minimum of one release per year. The remaining releases up to 12-month limits assessed as continuous release.	Single short term release of all radionuclides at 12-month limit.
Limits – 12 month limits and quarterly notification levels	All radionuclides at 12- month limits continuously throughout 12 month period	Separate sets of single short term releases for the groups of radionuclides which would be expected or planned to be released together in a short term release. The radionuclides in each group will be released at their quarterly notification levels. The remaining releases up to 12-month limits assessed as continuous release.	Single short term release of all radionuclides at quarterly notification level and remaining releases up to 12-month limits assessed as continuous release.
Limits – monthly limits	All radionuclides at 12- monthly limits continuously throughout 12 month period	Separate sets of single short term releases for the groups of radionuclides which would be expected to be released together in a short term release. The radionuclides in each group will be released at their 1 month limits. The remaining releases up to 12-month limits assessed as continuous release.	Single short term release of all radionuclides at 1 month limit and remaining releases up to 12-month limits assessed as continuous release.
Chemical form	Typical or mean chemical form throughout the year	Typical chemical form which may be released.	Worst case chemical form.
Release duration	Continuous over year	1 day	30 min
River flow	Annual average flow	25th percentile flow or average summer flow	5th percentile flow

Table 1 Continued

Key assessment parameter	Annual average dose – continuous release	Realistic short term release	Cautious short term release
Water concentration for consumption	Annual average concentration	Integrated concentration for release in summer.	Maximum dose for: (1) Integrated concentration for release in summer, or; (2) Average water concentration over first day
Water consumption rate	Annual critical group consumption rate	Summer critical group consumption rate and mean consumption rate for remainder of year	Maximum dose for: (1) Summer critical group consumption rate and mean consumption rate for remainder of year, or; (2) Daily critical consumption rate
Fish concentrations	Equilibrium concentration	Integrated fish concentration for release in summer, taking account of higher metabolism with higher temperatures in summer	Maximum dose for: (1) Integrated fish concentration for release in summer, taking account of higher metabolism with higher temperatures in summer, or; (2) Max fish concentration for release in summer, taking account of higher metabolism with higher temperatures in summer
Fish consumption rate	Annual critical group consumption rate	Summer critical group consumption rate and mean consumption rate for remainder of year	Maximum dose for: (1) Summer critical group consumption rate and mean consumption rate for remainder of year, or; (2) Critical daily catch rate, assumed to be stored and eaten according to critical daily consumption rate - take account of radioactive decay
Sediment concentrations	Equilibrium concentration	Integrated sediment concentration for release in summer	Maximum dose for: (1) Integrated sediment concentration for release in summer or (2) Max sediment concentration

Table 1 Continued

Key assessment parameter	Annual average dose – continuous release	Realistic short term release	Cautious short term release
Sediment exposure	Annual critical group occupancy rate	Summer critical group occupancy rate and mean occupancy rate for remainder of year	Maximum dose for: (1) Summer critical group occupancy rate and mean occupancy rate for remainder of year or (2) Critical daily occupancy rate
Water concentration for irrigated foods	Annual average concentration	Integrated concentration for release in summer	Maximum dose for: (1) Integrated concentration for release in summer, or; (2) Max water concentration
Irrigation rate	Annual rate	Irrigation rate for summer	Maximum dose for: (1) Summer irrigation rate, or; (2) Critical daily irrigation rate
Irrigated food concentrations	Equilibrium concentration	Integrated food concentrations for release in summer	Integrated food concentrations for release in summer
Irrigated food consumption rates	Annual critical group consumption rate	Summer critical group consumption rate	Summer critical group consumption rate

Table 2 Generic release source terms for all radionuclides

Scenario	Short term release			Continuous release (Bq/y)
	Short term release (Bq)	Continuous release for remainder of year (Bq/y)	Total release (Bq/y)	
Scenario 1 - 12 month limits only	1	0	1	1
Scenario 2 - Quarterly notification levels	0.25	0.75	1	1
Scenario 3 - Monthly limits	0.083	0.917	1	1

Table 3 Rivers flows in England, Wales and Scotland

River	Sewage Treatment Works	Mean flow (m^3/s)	25^{th} perc-entile flow (m^3/s)	5^{th} perc-entile flow (m^3/s)	Ratio of mean to 25^{th} per-centile	Ratio of mean to 5^{th} per-centile
River Grwyne at Millbrook	Abergavenny STW	2.0	0.4	0.32	5.1	6.4
River Exe at Thorverton	Exeter STW	16.1	4	1.97	4.0	8.2
River Lee at Feildes Weir	Rye Meads	4.4	1.2	0.59	3.7	7.6
River Thames at Reading	Reading STW	36.9	10	5.0	3.7	7.4
River Almond at Craigiehall	Livingston WWTW	6.0	1.7	0.96	3.5	6.2
River Eden at Sheepmount	Carlisle STW	51.8	16	9.67	3.2	5.4
River Dee at Eccleston Ferry	Chester STW	38.2	12	10.2	3.2	3.7
River Clyde at Daldowie	Daldowie WWTW	48.6	15	9.5	3.2	5.1
River Severn at Haw Bridge	Gloucester STW	106	35	19.6	3.0	5.4
Great Stour at Wye	Ashford STW	2.3	0.8	0.53	2.8	4.2
River Skerne at South Park	Darlington STW	1.6	0.6	0.36	2.7	4.4
River Aire at Armley	Knostrop STW	15.0	5	3.32	3.0	4.5
River Cam at Bottisham	Cambridge STW	3.6	1.6	0.91	2.3	4.0
River Tame at Water Orton	Minworth Birmingham STW	5.5	3.2	2.36	1.7	2.3

Table 4 Angling family doses per unit release for 12 month limits only (cautious short term release assessment)

Radionuclide	Short term release dose			Continuous release dose (μSv/y)	Ratio of short term to continuous release
	Short term release (μSv)	Continuous release for remainder of year (μSv/y)	Total release (μSv/y)		
Tritium	2.4E-11	0.0E+00	2.4E-11	6.0E-13	4.0E+01
Carbon-14	1.2E-07	0.0E+00	1.2E-07	1.0E-08	1.2E+01
Phosphorus-32	2.9E-06	0.0E+00	2.9E-06	1.5E-07	2.0E+01
Cobalt-60	1.3E-07	0.0E+00	1.3E-07	3.0E-08	4.3E+00
Zinc-65	4.5E-07	0.0E+00	4.5E-07	1.2E-08	3.6E+01
Strontium-89	7.1E-09	0.0E+00	7.1E-09	6.3E-10	1.1E+01
Strontium-90	3.5E-08	0.0E+00	3.5E-08	2.2E-09	1.6E+01
Iodine-125	2.2E-08	0.0E+00	2.2E-08	6.6E-10	3.3E+01
Iodine-131	6.4E-08	0.0E+00	6.4E-08	1.7E-09	3.8E+01
Caesium-134	3.3E-07	0.0E+00	3.3E-07	2.5E-08	1.3E+01
Caesium-137	2.4E-07	0.0E+00	2.4E-07	1.6E-08	1.4E+01
Uranium-234	5.2E-08	0.0E+00	5.2E-08	2.5E-09	2.1E+01
Uranium-235	5.0E-08	0.0E+00	5.0E-08	2.4E-09	2.1E+01
Uranium-238	4.8E-08	0.0E+00	4.8E-08	2.3E-09	2.1E+01
Plutonium-238	1.8E-07	0.0E+00	1.8E-07	1.9E-09	9.5E+01
Plutonium-239	2.0E-07	0.0E+00	2.0E-07	2.1E-09	9.5E+01
Plutonium-240	2.0E-07	0.0E+00	2.0E-07	2.1E-09	9.5E+01
Americium-241	2.7E-06	0.0E+00	2.7E-06	6.4E-09	4.2E+02

Table 5 Angling family doses per unit release for quarterly notification levels (cautious short term release assessment)

Radionuclide	Short term release dose			Continuous release dose (μSv/y)	Ratio of short term to continuous release
	Short term release (μSv)	Continuous release for remainder of year (μSv/y)	Total release (μSv/y)		
Tritium	6.0E-12	4.5E-13	6.5E-12	6.0E-13	1.1E+01
Carbon-14	3.1E-08	7.7E-09	3.9E-08	1.0E-08	3.8E+00
Phosphorus-32	7.2E-07	1.1E-07	8.3E-07	1.5E-07	5.7E+00
Cobalt-60	3.3E-08	2.3E-08	5.5E-08	3.0E-08	1.8E+00
Zinc-65	1.1E-07	9.4E-09	1.2E-07	1.2E-08	9.8E+00
Strontium-89	1.8E-09	4.7E-10	2.2E-09	6.3E-10	3.6E+00
Strontium-90	8.8E-09	1.6E-09	1.0E-08	2.2E-09	4.7E+00
Iodine-125	5.4E-09	4.9E-10	5.9E-09	6.6E-10	9.0E+00
Iodine-131	1.6E-08	1.3E-09	1.7E-08	1.7E-09	1.0E+01
Caesium-134	8.2E-08	1.9E-08	1.0E-07	2.5E-08	4.0E+00
Caesium-137	5.9E-08	1.2E-08	7.1E-08	1.6E-08	4.4E+00
Uranium-234	1.3E-08	1.9E-09	1.5E-08	2.5E-09	6.0E+00
Uranium-235	1.2E-08	1.8E-09	1.4E-08	2.4E-09	6.0E+00
Uranium-238	1.2E-08	1.7E-09	1.4E-08	2.3E-09	6.0E+00
Plutonium-238	4.6E-08	1.5E-09	4.8E-08	1.9E-09	2.5E+01
Plutonium-239	5.0E-08	1.6E-09	5.2E-08	2.1E-09	2.5E+01
Plutonium-240	5.0E-08	1.6E-09	5.2E-08	2.1E-09	2.5E+01
Americium-241	6.7E-07	4.8E-09	6.8E-07	6.4E-09	1.1E+02

Table 6 Angling family doses per unit release for monthly limits (cautious short term release assessment)

Radionuclide	Short term release dose			Continuous release dose (μSv/y)	Ratio of short term to continuous release
	Short term release (μSv)	Continuous release for remainder of year (μSv/y)	Total release (μSv/y)		
Tritium	2.0E-12	5.5E-13	2.6E-12	6.0E-13	4.3E+00
Carbon-14	1.0E-08	9.4E-09	2.0E-08	1.0E-08	1.9E+00
Phosphorus-32	2.4E-07	1.3E-07	3.7E-07	1.5E-07	2.6E+00
Cobalt-60	1.1E-08	2.8E-08	3.9E-08	3.0E-08	1.3E+00
Zinc-65	3.7E-08	1.1E-08	4.9E-08	1.2E-08	3.9E+00
Strontium-89	5.9E-10	5.7E-10	1.2E-09	6.3E-10	1.9E+00
Strontium-90	2.9E-09	2.0E-09	4.9E-09	2.2E-09	2.2E+00
Iodine-125	1.8E-09	6.0E-10	2.4E-09	6.6E-10	3.7E+00
Iodine-131	5.3E-09	1.5E-09	6.9E-09	1.7E-09	4.1E+00
Caesium-134	2.7E-08	2.3E-08	5.0E-08	2.5E-08	2.0E+00
Caesium-137	2.0E-08	1.5E-08	3.5E-08	1.6E-08	2.1E+00
Uranium-234	4.3E-09	2.3E-09	6.6E-09	2.5E-09	2.7E+00
Uranium-235	4.1E-09	2.2E-09	6.3E-09	2.4E-09	2.7E+00
Uranium-238	4.0E-09	2.1E-09	6.1E-09	2.3E-09	2.7E+00
Plutonium-238	1.5E-08	1.8E-09	1.7E-08	1.9E-09	8.8E+00
Plutonium-239	1.7E-08	1.9E-09	1.9E-08	2.1E-09	8.8E+00
Plutonium-240	1.7E-08	1.9E-09	1.9E-08	2.1E-09	8.8E+00
Americium-241	2.2E-07	5.8E-09	2.3E-07	6.4E-09	3.6E+01

Table 7 Angling family doses per unit release for 12 month limits only (realistic short term release assessment)

Radionuclide	Short term release dose			Continuous release dose (μSv/y)	Ratio of short term to continuous release
	Short term release (μSv)	Continuous release for remainder of year (μSv/y)	Total release (μSv/y)		
Tritium	3.8E-12	0.0E+00	3.8E-12	6.0E-13	6.3E+00
Carbon-14	6.2E-08	0.0E+00	6.2E-08	1.0E-08	6.0E+00
Phosphorus-32	6.2E-07	0.0E+00	6.2E-07	1.5E-07	4.2E+00
Cobalt-60	6.5E-08	0.0E+00	6.5E-08	3.0E-08	2.1E+00
Zinc-65	9.9E-08	0.0E+00	9.9E-08	1.2E-08	7.9E+00
Strontium-89	3.0E-09	0.0E+00	3.0E-09	6.3E-10	4.8E+00
Strontium-90	1.6E-08	0.0E+00	1.6E-08	2.2E-09	7.1E+00
Iodine-125	4.3E-09	0.0E+00	4.3E-09	6.6E-10	6.6E+00
Iodine-131	9.9E-09	0.0E+00	9.9E-09	1.7E-09	5.8E+00
Caesium-134	1.6E-07	0.0E+00	1.6E-07	2.5E-08	6.4E+00
Caesium-137	1.2E-07	0.0E+00	1.2E-07	1.6E-08	7.2E+00
Uranium-234	1.9E-08	0.0E+00	1.9E-08	2.5E-09	7.7E+00
Uranium-235	1.8E-08	0.0E+00	1.8E-08	2.4E-09	7.7E+00
Uranium-238	1.8E-08	0.0E+00	1.8E-08	2.3E-09	7.7E+00
Plutonium-238	3.9E-08	0.0E+00	3.9E-08	1.9E-09	2.0E+01
Plutonium-239	4.2E-08	0.0E+00	4.2E-08	2.1E-09	2.0E+01
Plutonium-240	4.2E-08	0.0E+00	4.2E-08	2.1E-09	2.0E+01
Americium-241	1.0E-06	0.0E+00	1.0E-06	6.4E-09	1.6E+02

Table 8 Angling family doses per unit release for quarterly notification levels (realistic short term release assessment)

Radionuclide	Short term release dose			Continuous release dose (μSv/y)	Ratio of short term to continuous release
	Short term release (μSv)	Continuous release for remainder of year (μSv/y)	Total release (μSv/y)		
Tritium	9.5E-13	4.5E-13	1.4E-12	6.0E-13	2.3E+00
Carbon-14	1.6E-08	7.7E-09	2.3E-08	1.0E-08	2.3E+00
Phosphorus-32	1.5E-07	1.1E-07	2.6E-07	1.5E-07	1.8E+00
Cobalt-60	1.6E-08	2.3E-08	3.9E-08	3.0E-08	1.3E+00
Zinc-65	2.5E-08	9.4E-09	3.4E-08	1.2E-08	2.7E+00
Strontium-89	7.4E-10	4.7E-10	1.2E-09	6.3E-10	1.9E+00
Strontium-90	3.9E-09	1.6E-09	5.5E-09	2.2E-09	2.5E+00
Iodine-125	1.1E-09	4.9E-10	1.6E-09	6.6E-10	2.4E+00
Iodine-131	2.5E-09	1.3E-09	3.7E-09	1.7E-09	2.2E+00
Caesium-134	4.1E-08	1.9E-08	6.0E-08	2.5E-08	2.3E+00
Caesium-137	2.9E-08	1.2E-08	4.2E-08	1.6E-08	2.5E+00
Uranium-234	4.8E-09	1.9E-09	6.6E-09	2.5E-09	2.7E+00
Uranium-235	4.6E-09	1.8E-09	6.4E-09	2.4E-09	2.7E+00
Uranium-238	4.4E-09	1.7E-09	6.1E-09	2.3E-09	2.7E+00
Plutonium-238	9.7E-09	1.5E-09	1.1E-08	1.9E-09	5.8E+00
Plutonium-239	1.1E-08	1.6E-09	1.2E-08	2.1E-09	5.8E+00
Plutonium-240	1.1E-08	1.6E-09	1.2E-08	2.1E-09	5.8E+00
Americium-241	2.6E-07	4.8E-09	2.7E-07	6.4E-09	4.2E+01

Table 9 Angling family doses per unit release for monthly limits (realistic short term release assessment)

Radionuclide	Short term release dose			Continuous release dose (μSv/y)	Ratio of short term to continuous release
	Short term release (μSv)	Continuous release for remainder of year (μSv/y)	Total release (μSv/y)		
Tritium	3.2E-13	5.5E-13	8.6E-13	6.0E-13	1.4E+00
Carbon-14	5.2E-09	9.4E-09	1.5E-08	1.0E-08	1.4E+00
Phosphorus-32	5.1E-08	1.3E-07	1.8E-07	1.5E-07	1.3E+00
Cobalt-60	5.4E-09	2.8E-08	3.3E-08	3.0E-08	1.1E+00
Zinc-65	8.2E-09	1.1E-08	2.0E-08	1.2E-08	1.6E+00
Strontium-89	2.5E-10	5.7E-10	8.2E-10	6.3E-10	1.3E+00
Strontium-90	1.3E-09	2.0E-09	3.3E-09	2.2E-09	1.5E+00
Iodine-125	3.6E-10	6.0E-10	9.6E-10	6.6E-10	1.5E+00
Iodine-131	8.2E-10	1.5E-09	2.4E-09	1.7E-09	1.4E+00
Caesium-134	1.4E-08	2.3E-08	3.7E-08	2.5E-08	1.4E+00
Caesium-137	9.8E-09	1.5E-08	2.5E-08	1.6E-08	1.5E+00
Uranium-234	1.6E-09	2.3E-09	3.9E-09	2.5E-09	1.6E+00
Uranium-235	1.5E-09	2.2E-09	3.7E-09	2.4E-09	1.6E+00
Uranium-238	1.5E-09	2.1E-09	3.5E-09	2.3E-09	1.6E+00
Plutonium-238	3.2E-09	1.8E-09	5.0E-09	1.9E-09	2.6E+00
Plutonium-239	3.5E-09	1.9E-09	5.5E-09	2.1E-09	2.6E+00
Plutonium-240	3.5E-09	1.9E-09	5.5E-09	2.1E-09	2.6E+00
Americium-241	8.7E-08	5.8E-09	9.3E-08	6.4E-09	1.5E+01

Table 10 Freshwater fish consumption in the UK[a]

Period	Number of consumers	Median Consumption rate (g/day)	97.5% Consumption rate (g/day)
Jan to March	13	21.1	39.5
April to June	28	22.1	46.8
July to Sept	6	24.5	32.8[b]
Oct to Dec	5	23.5	36.7[b]

[a]Reference 14.

[b]Given the low number of consumers, the 97.5% consumption rate will not be robust.

Table 11 Irrigated food consumer doses per unit release for 12 month limits only (realistic short term release assessment)

Radionuclide	Short term release dose			Continuous release dose (μSv/y)	Ratio of total short term to continu-ous release	Ratio irrigated food consu-mer to angler (total short term)
	Short term release (μSv)	Continuous release for remainder of year (μSv/y)	Total release (μSv/y)			
Tritium	1.1E-12	4.4E-14	1.2E-12	4.4E-14	2.6E+01	3.1E-01
Carbon-14	1.2E-09	4.8E-11	1.2E-09	4.8E-11	2.5E+01	2.0E-02
Phosphorus-32	4.4E-09	1.8E-10	4.6E-09	1.8E-10	2.5E+01	7.4E-03
Cobalt-60	1.9E-10	9.5E-12	2.0E-10	9.5E-12	2.1E+01	3.1E-03
Zinc-65	2.0E-10	8.1E-12	2.1E-10	8.1E-12	2.5E+01	2.1E-03
Strontium-89	2.4E-10	1.0E-11	2.5E-10	1.0E-11	2.5E+01	8.5E-02
Strontium-90	7.2E-09	3.0E-10	7.5E-09	3.0E-10	2.5E+01	4.8E-01
Iodine-125	1.1E-09	4.3E-11	1.1E-09	4.3E-11	2.5E+01	2.5E-01
Iodine-131	9.3E-10	3.8E-11	9.7E-10	3.8E-11	2.6E+01	9.9E-02
Caesium-134	1.5E-09	6.0E-11	1.5E-09	6.0E-11	2.5E+01	9.3E-03
Caesium-137	1.1E-09	4.6E-11	1.2E-09	4.6E-11	2.6E+01	1.0E-02
Uranium-234	1.5E-09	6.1E-11	1.6E-09	6.1E-11	2.6E+01	8.4E-02
Uranium-235	1.5E-09	5.9E-11	1.5E-09	5.9E-11	2.6E+01	8.4E-02
Uranium-238	1.4E-09	5.6E-11	1.5E-09	5.6E-11	2.6E+01	8.4E-02
Plutonium-238	2.4E-09	2.1E-10	2.6E-09	2.1E-10	1.2E+01	6.7E-02
Plutonium-239	2.6E-09	2.3E-10	2.8E-09	2.3E-10	1.2E+01	6.7E-02
Plutonium-240	2.6E-09	2.3E-10	2.8E-09	2.3E-10	1.2E+01	6.7E-02
Americium-241	4.6E-09	1.9E-10	4.8E-09	1.9E-10	2.5E+01	4.6E-03

Table 12 Case Study 1 - Hospital discharge limits[a]

Radionuclide	Monthly limit	Annual Limit	Short term release		Continuous release (Bq/y)
			Short term release (Bq)	Continuous release for remainder of year (Bq/y)	
Iodine-125	1 GBq	-	1.0E+09	1.1E+10	1.2E+10
Iodine-131	50 GBq	-	5.0E+10	5.5E+11	6.0E+11

[a]Based on the limits for a hospital in Leeds. Limits are only included for radionuclides where there are short term dose per unit release data.

Table 13 Case Study 1 - Hospital doses for cautious short term release assessment compared with continuous release assessment

Radionuclide	Short term release dose			Continuous release dose (μSv/y)
	Short term release (μSv)	Continuous release for remainder of year (μSv/y)	Total (μSv/y)	
Iodine-125	6.5E-01	4.8E-01	1.1E+00	5.3E-01
Iodine-131	9.6E+01	6.2E+01	1.6E+02	6.8E+01
Total (2 sig fig)	9.7E+01	6.3E+01	1.6E+02	6.8E+01

Table 14 Case Study 1 - Hospital doses for realistic short term release assessment compared with continuous release assessment

Radionuclide	Short term release dose			Continuous release dose (μSv/y)
	Short term release (μSv)	Continuous release for remainder of year (μSv/y)	Total (μSv/y)	
Iodine-125	1.7E-01	4.8E-01	6.6E-01	5.3E-01
Iodine-131	2.0E+01	6.2E+01	8.2E+01	6.8E+01
Total (2 sig fig)	2.0E+01	6.3E+01	8.2E+01	6.8E+01

Table 15 Case Study 2 - Nuclear site discharge limits[a]

Radionuclide	Quarterly notification levels	Annual Limit	Short term release		Continuous release (Bq/y)
			Short term release (Bq)	Continuous release for remainder of year (Bq/y)	
Cobalt-60	50 MBq	120 MBq	5.0E+07	7.0E+07	1.2E+08
Strontium-90	750 MBq	2.6 GBq	7.5E+08	1.9E+09	2.6E+09
Caesium-137	200 MBq	540 MBq	2.0E+08	3.4E+08	5.4E+08
Plutonium-239	20 MBq	50 MBq	2.0E+07	3.0E+07	5.0E+07

[a]Based on the limits for a nuclear site which discharges to River Thames. Limits are only included for radionuclides where there are short term dose per unit release data.

Table 16 Case Study 2 - Nuclear site doses for cautious short term release assessment compared with continuous release assessment

Radionuclide	Short term release dose			Continuous release dose (μSv/y)
	Short term release (μSv)	Continuous release for remainder of year (μSv/y)	Total (μSv/y)	
Cobalt-60	2.8E-01	8.3E-02	3.7E-01	1.4E-01
Strontium-90	1.1E+00	1.6E-01	1.3E+00	2.3E-01
Caesium-137	2.1E+00	2.2E-01	2.3E+00	3.4E-01
Plutonium-239	1.7E-01	2.5E-03	1.8E-01	4.1E-03
Total (2 sig fig)	3.7E+00	4.6E-01	4.1E+00	7.1E-01

Table 17 Case Study 2 - Nuclear site doses for realistic short term release assessment compared with continuous release assessment

Radionuclide	Short term release dose			Continuous release dose (μSv/y)
	Short term release (μSv)	Continuous release for remainder of year (μSv/y)	Total (μSv/y)	
Cobalt-60	1.1E-01	8.3E-02	1.9E-01	1.4E-01
Strontium-90	3.9E-01	1.6E-01	5.5E-01	2.3E-01
Caesium-137	7.8E-01	2.2E-01	1.0E+00	3.4E-01
Plutonium-239	2.8E-02	2.5E-03	3.1E-02	4.1E-03
Total (2 sig fig)	1.3E+00	4.6E-01	1.8E+00	7.1E-01

Table 18 Case Study 3 – Pharmaceutical research company discharge limits[a]

Radionuclide	Monthly Limits	Annual Limit	Short term release		Continuous release (Bq/y)
			Short term release (Bq)	Continuous release for remainder of year (Bq/y)	
Tritium	600 MBq	-	6.0E+08	6.6E+09	7.2E+09
Carbon-14	600 MBq	-	6.0E+08	6.6E+09	7.2E+09
Phosphorus-32	200 MBq	-	2.0E+08	2.2E+09	2.4E+09
Iodine-125	50 MBq	-	5.0E+07	5.5E+08	6.0E+08

[a]Based on the limits for a pharmaceutical research company which discharges to the River Cam. Limits are only included for radionuclides where there are short term dose per unit release data.

Table 19 Case Study 3 – Pharmaceutical research company doses for cautious short term release assessment compared with continuous release assessment

Radionuclide	Short term release dose			Continuous release dose (μSv/y)
	Short term release (μSv)	Continuous release for remainder of year (μSv/y)	Total (μSv/y)	
Tritium	1.6E-03	1.1E-03	2.7E-03	1.2E-03
Carbon-14	8.2E+00	1.9E+01	2.7E+01	2.0E+01
Phosphorus-32	6.4E+01	8.8E+01	1.5E+02	9.6E+01
Iodine-125	1.2E-01	9.9E-02	2.2E-01	1.1E-01
Total (2 sig fig)	7.2E+01	1.1E+02	1.8E+02	1.2E+02

Table 20 Case Study 3 – Pharmaceutical research company doses for realistic short term release assessment compared with continuous release assessment

Radionuclide	Short term release dose			Continuous release dose (μSv/y)
	Short term release (μSv)	Continuous release for remainder of year (μSv/y)	Total (μSv/y)	
Tritium	2.8E-04	1.1E-03	1.4E-03	1.2E-03
Carbon-14	4.7E+00	1.9E+01	2.3E+01	2.0E+01
Phosphorus-32	1.5E+01	8.8E+01	1.0E+02	9.6E+01
Iodine-125	2.7E-02	9.9E-02	1.3E-01	1.1E-01
Total (2 sig fig)	2.0E+01	1.1E+02	1.3E+02	1.2E+02

13 FIGURES

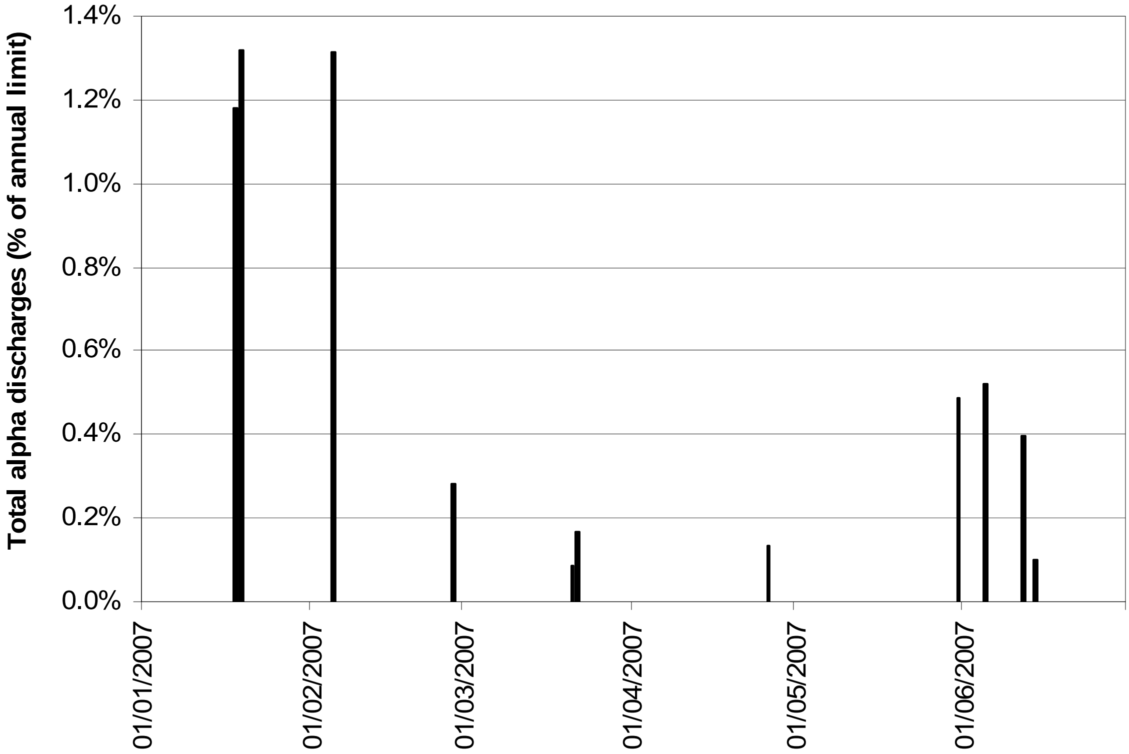


Figure 1 Total alpha discharge pattern from UKAEA Harwell to River Thames

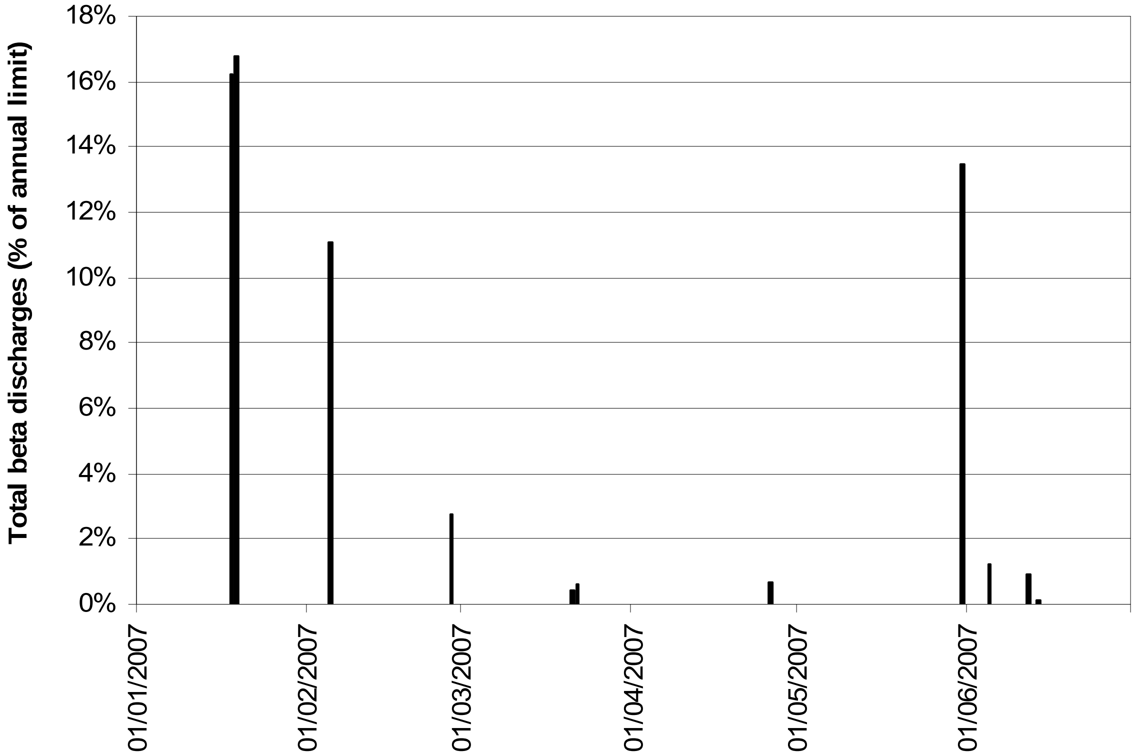


Figure 2 Total beta discharge pattern from UKAEA Harwell to River Thames

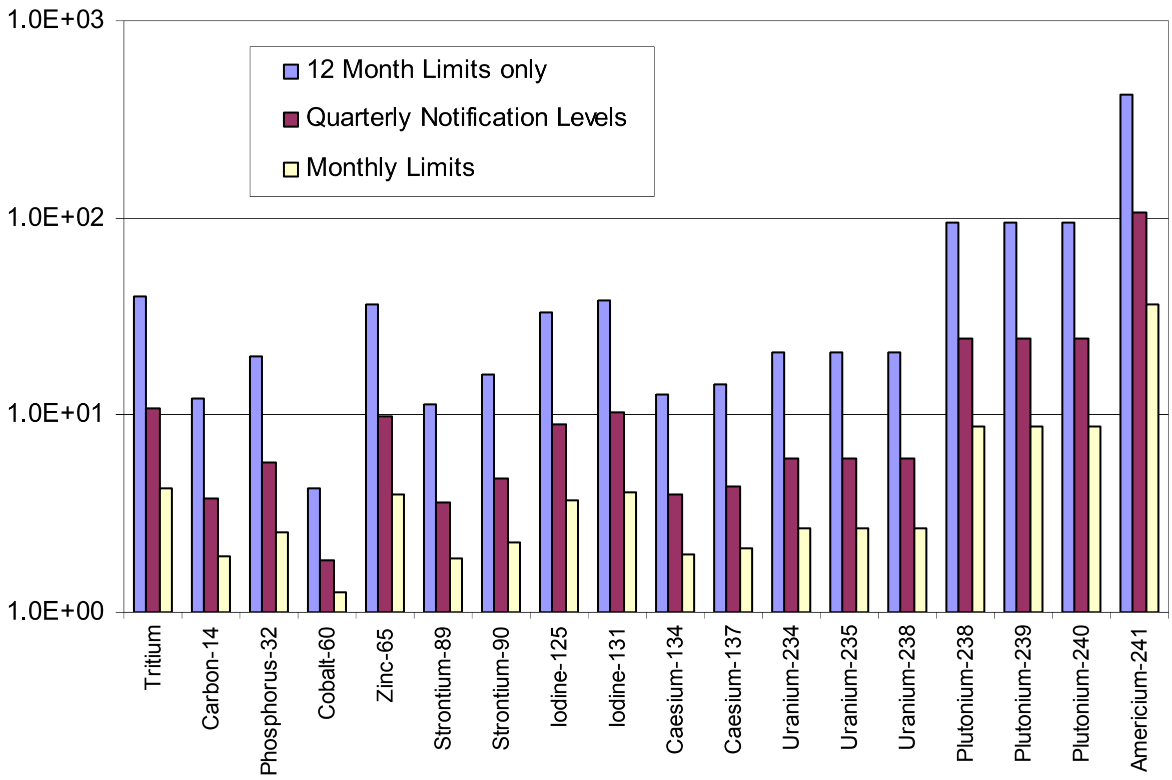


Figure 3 Ratios of dose from generic short term releases using cautious assumptions to continuous release

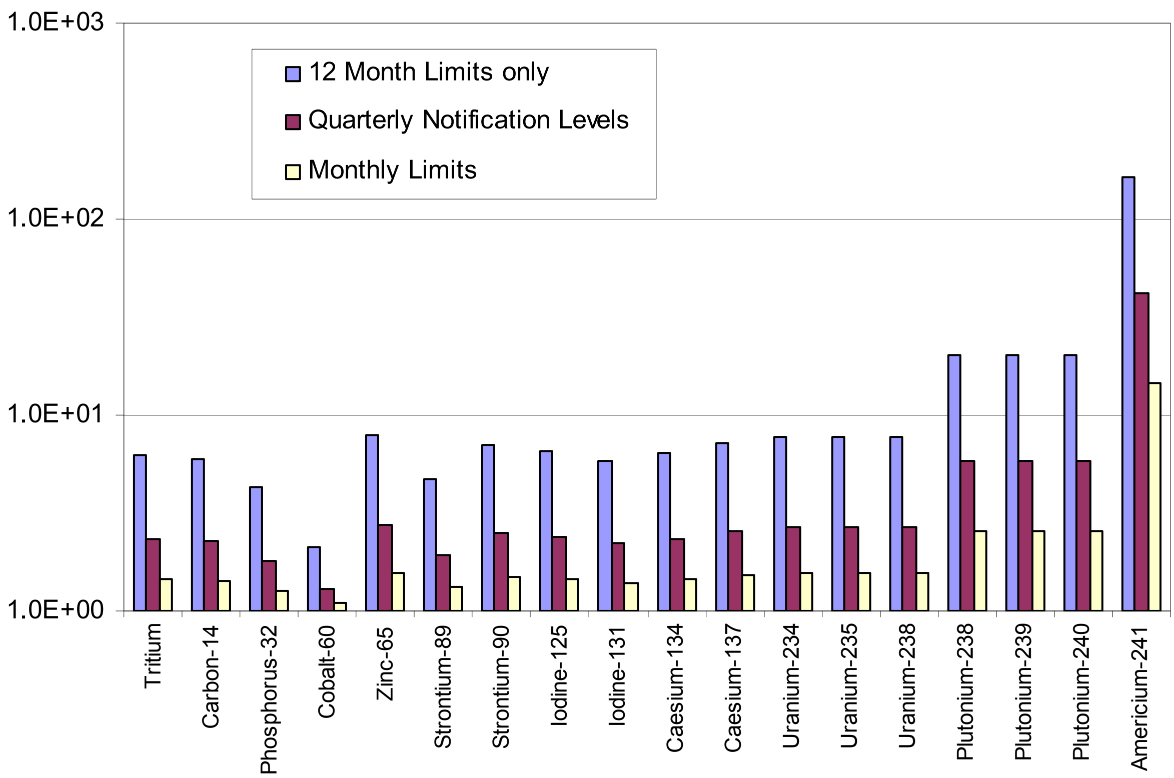
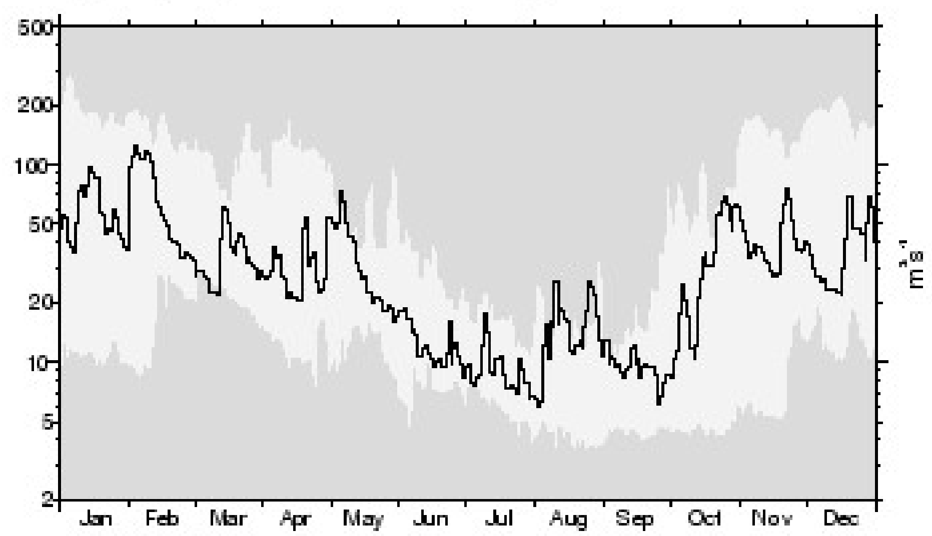


Figure 4 Ratios of dose from generic short term releases using realistic assumptions to continuous release

(a)



(b)

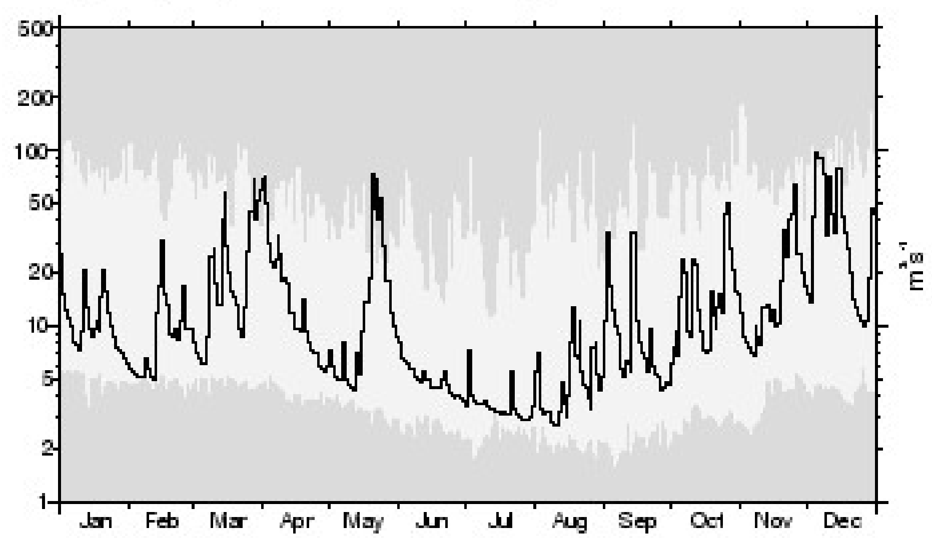


Figure 5 River water flow

(a) Water flow at Reading, River Thames (white area are maximum and minimum daily mean flows from 1992 to 2003; line is daily mean flow for 2004)

(b)Water flow at Armley, River Aire (white area are maximum and minimum daily mean flows from 1961 to 2006; line is daily mean flow for 2006)

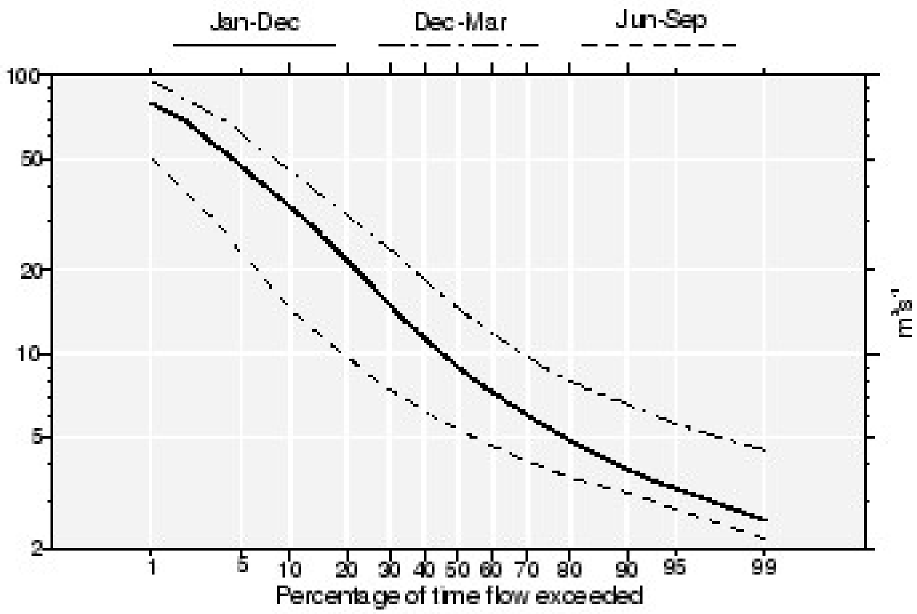


Figure 6 Percentile flow rates for River Aire at Armley [Ref 13]

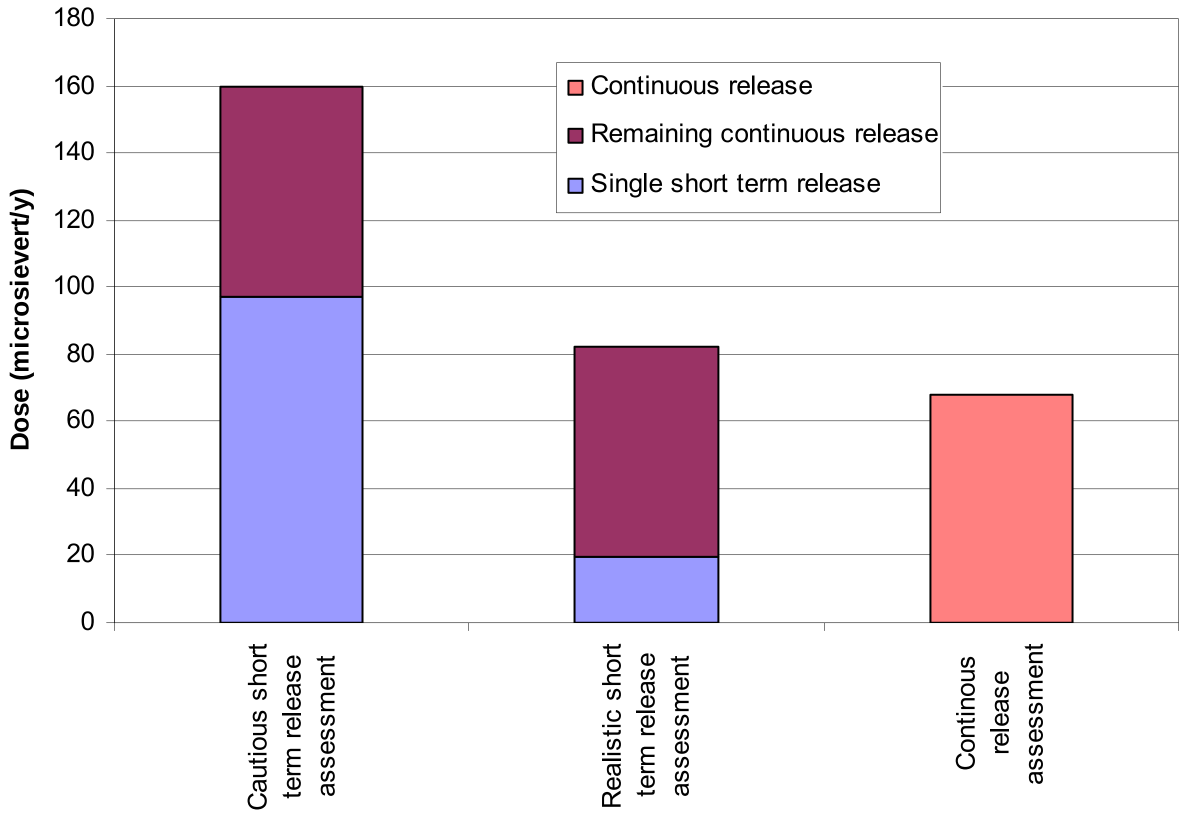


Figure 7 Case Study 1 Hospital – comparison of short term and continuous release dose assessments

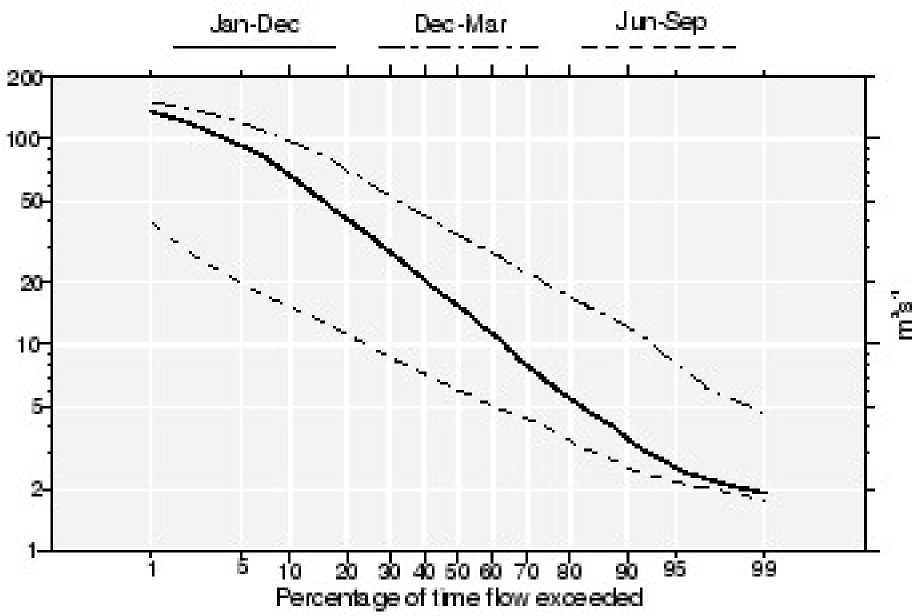


Figure 8 Percentile flow rates for River Thames at Sutton Courtenay [Ref 13]

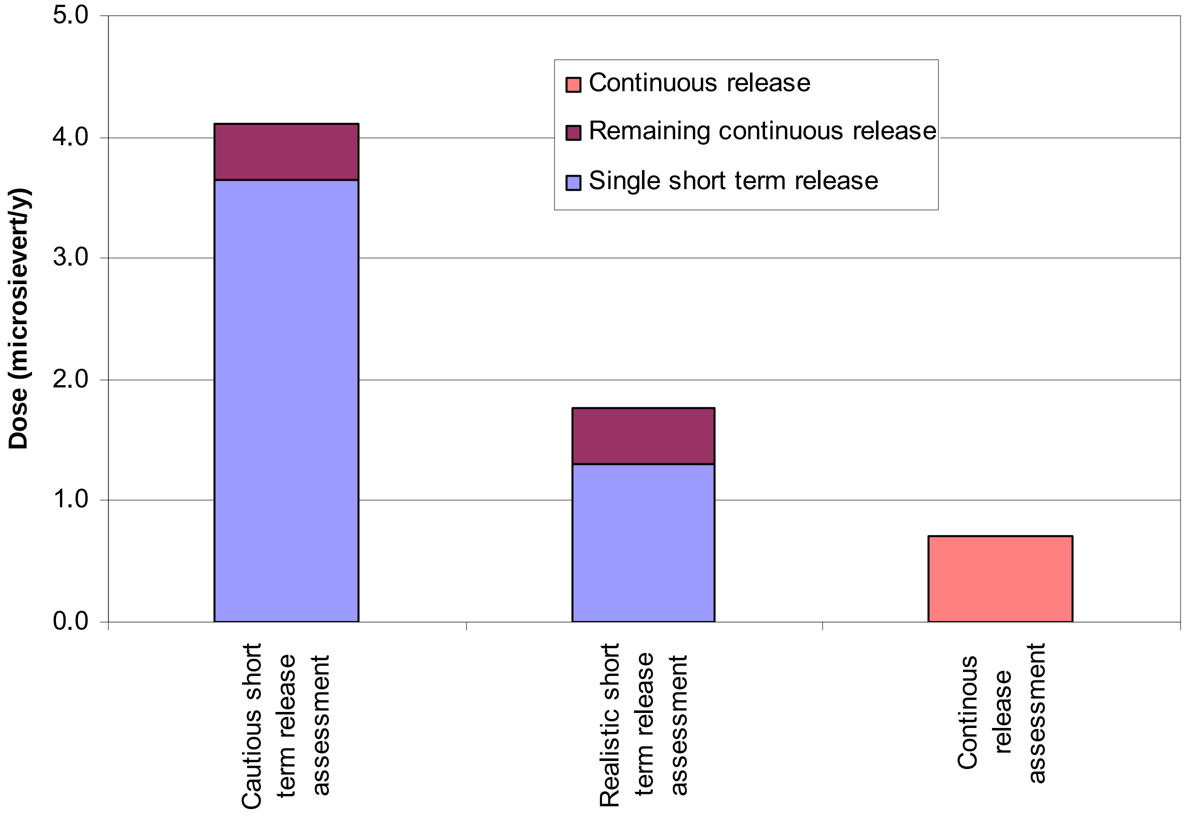


Figure 9 Case Study 2 Nuclear site – comparison of short term and continuous release dose assessments

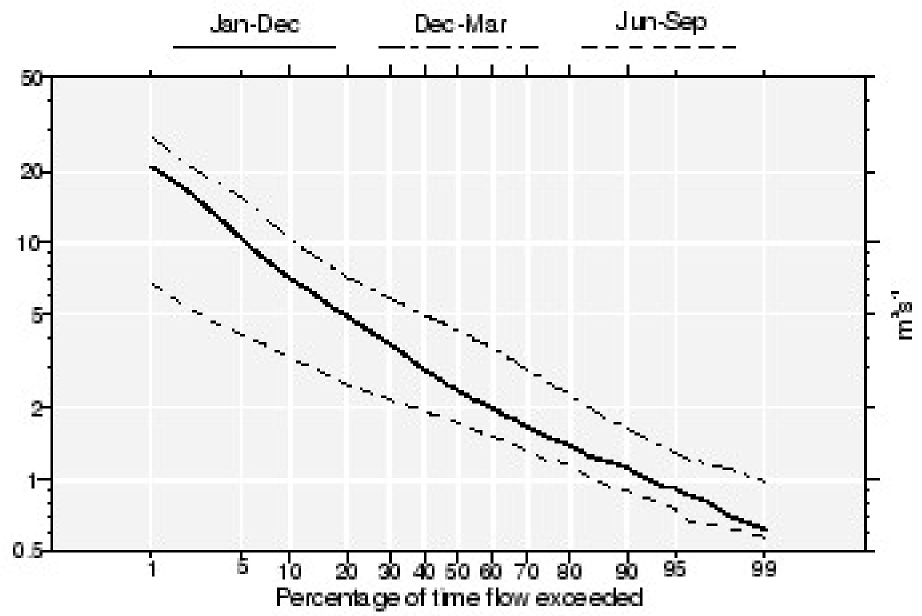


Figure 10 Percentile flow rates for River Cam at Bottisham [Ref 13]

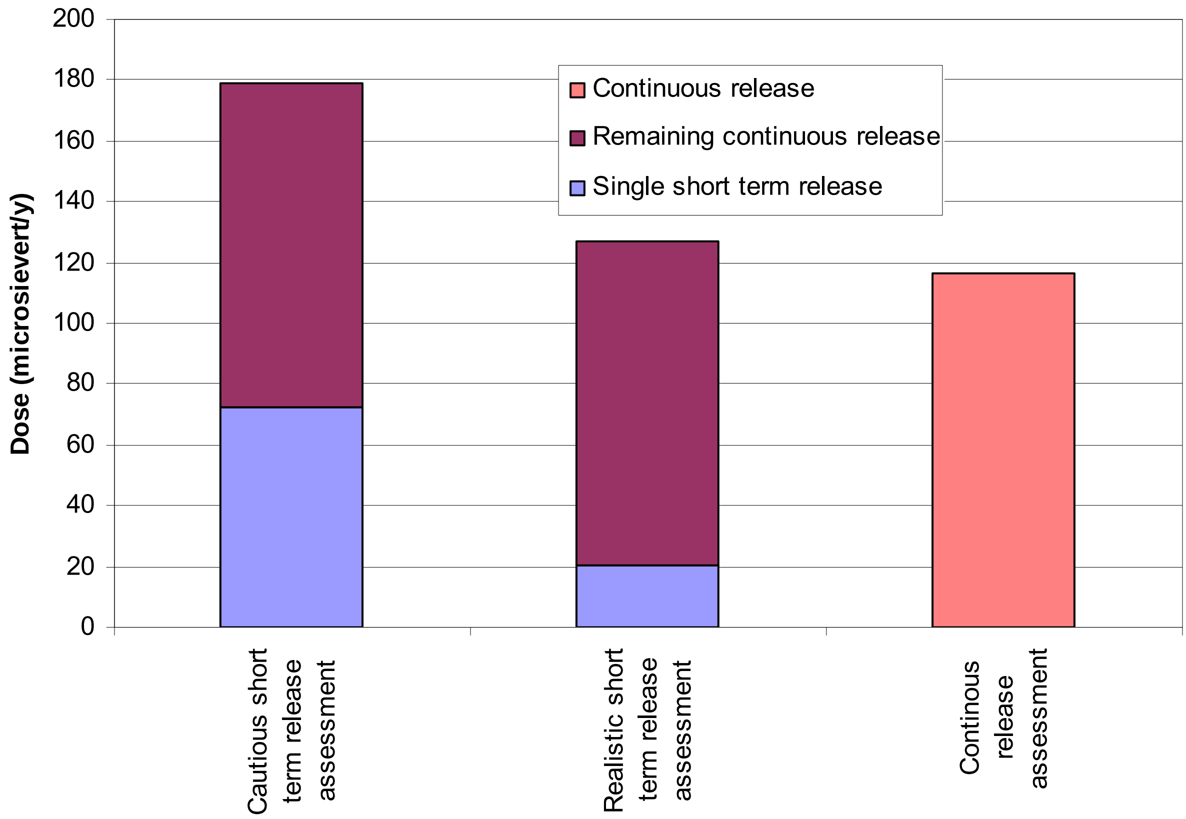


Figure 11 Pharmaceutical research company – comparison of short term and continuous release dose assessments

APPENDIX A DOSE PER UNIT RELEASE DATA FOR SHORT TERM RELEASES TO RIVER

A1 Introduction

Cautious and realistic dose per unit short term release (dpur) values have been calculated for releases of radionuclides for a river flow rate of 1 m^3/s.

A2 Methodology

The parameters used to calculate the realistic and cautious dose per unit short term release data are shown in Table A1, with references to Tables A2 – A9.

The realistic total doses per unit short term release (dpur) to an angling family member, for each radionuclide and age group were calculated as follows:

Total angling dpur (Sv/Bq) =	integrated water dpur (Sv/Bq) + integrated fish dpur (Sv/Bq) + integrated sediment external dpur (Sv/Bq)
Integrated water dpur (Sv/Bq) =	integrated filtered water conc (summer) (Bq d/l per Bq) x consumption rate (summer) (l/d) x dose coefficient (Sv/Bq) + integrated filtered water conc (remaining 9 months) (Bq d/l per Bq) x consumption rate (remaining 9 months) (l/d) x dose coefficient (Sv/Bq) +
Integrated fish dpur (Sv/Bq) =	integrated fish conc (summer) (Bq d/kg per Bq) x consumption rate (summer) (kg/d) x dose coefficient (Sv/Bq) + integrated fish conc (remaining 9 months) (Bq d/kg per Bq) x consumption rate (remaining 9 months) (kg/d) x dose coefficient (Sv/Bq) +
Integrated sediment external dpur (Sv/Bq) =	integrated sediment conc (summer) (Bq d/kg per Bq) x occupancy rate (summer) (h/d) x sediment external dose rate (Sv/h per Bq/kg) +

integrated sediment conc (remaining 9 months) (Bq d/kg per Bq) x
occupancy rate (remaining 9 months) (h/d) x
sediment external dose rate (Sv/h per Bq/kg)

The cautious total doses per unit short term release (dpur) to an angling family member, for each radionuclide and age group, were calculated as follows:

Total angling dpur (Sv/Bq) = maximum of integrated water dpur or first day water dpur (Sv/Bq) +
maximum of integrated fish dpur or max fish dpur (Sv/Bq) +
maximum of integrated sediment external dpur or max sediment external dpur (Sv/Bq)

First day water dpur (Sv/Bq) = average 1st day water conc (Bq/l per Bq) x
critical daily consumption (l) x
dose coefficient (Sv/Bq)

Max fish dpur (Sv/Bq) = max fish conc (Bq/kg per Bq) x
critical daily consumption (kg) x
dose coefficient (Sv/Bq)

Max external sediment dpur (Sv/Bq) = max sediment conc (Bq/kg per Bq) x
critical daily occupancy (h) x
sediment external dose rate (Sv/h per Bq/kg)

The realistic total dose per unit short term release (dpur) to an irrigated food consuming family member, for each radionuclide and age group, is calculated as follows:

Total irrigated food dpur (Sv/Bq) = green veg dpur (Sv/Bq) +
root veg dpur (Sv/Bq) +
fruit dpur (Sv/Bq)

Green veg dpur (Sv/Bq) = integrated water conc (Bq d/l per Bq) x
irrigation rate (l/m^2/s) x
integrated green veg conc per unit deposition (Bq s/kg per Bq/m^2) x
critical consumption rate (kg/d) x
dose coefficient (Sv/Bq)

Root veg dpur (Sv/Bq) = integrated water conc (Bq d/l per Bq) x irrigation rate (l/m^2/s) x integrated root veg conc per unit deposition (Bq s/kg per Bq/m^2) x critical consumption rate (kg/d) x dose coefficient (Sv/Bq)

Fruit dpur (Sv/Bq) = integrated water conc (Bq d/l per Bq) x irrigation rate (l/m^2/s) x integrated fruit conc per unit deposition (Bq s/kg per Bq/m^2) x critical consumption rate (kg/d) x dose coefficient (Sv/Bq)

The realistic and cautious dose per unit short term release values for a particular radionuclide have been calculated as the maximum of those for each age group. This will make the assessment cautious, but it does simplify the assessment process.

The realistic dose per unit short term release values for the angling family and irrigated food consuming family are shown in Tables A10 and A11. The cautious dose per unit short term release values for the angling family are shown in Table A12.

A3 Discussion of methodology assumptions

A3.1 Water dose per unit release data

The assessment of doses from drinking water is likely to be cautious for the following reasons:

- Although there may be direct extraction of river water for occasional use by some population groups (eg, campers), the likelihood of water extraction coinciding with a short term release is low.
- Water may be sourced from wells dug near the river and hence containing a proportion of river water. However, there will be some filtering of this groundwater through bed sediment and soil and time delay before abstraction (allowing time for decay for the short lived radionuclides).
- River water abstracted for drinking water will be filtered and probably mixed with other sources of water prior to being delivered to the tap. The time taken for these water treatment operations and distribution will also allow time for decay of the short lived radionuclides.
- Many of these cautious assumptions are equally applicable to continuous release assessments. It is possible to take account of these areas of caution in a more detailed and realistic radiological assessment.

A3.2 Fish dose per unit release data

A kinetic model [Ref A1] has been used to derive maximum and integrated fish concentrations. This model provides a more realistic estimate of the fish concentrations than would be the case if instantaneous equilibrium was assumed. For example, the maximum concentration of carbon-14 in fish using the kinetic model is 8.0 10^{-7} Bq/kg per Bq released (Table A3), compared to a value of 2.6 10^{-4} Bq/kg per Bq released assuming instantaneous equilibrium (max water concentration of 1.2 10^{-8} Bq/l per Bq released from Table A1 multiplied by concentration factor of 2.2 10^{4} Bg/kg per Bq/l [Ref A1]). However, it is important to note that the kinetic model used is relatively simple single compartment model which does not take account of the multiple components of uptake and retention in fish. For this reason, elements of caution are retained in the assessment (eg, critical fish consumption rates) to ensure that doses are not under-predicted.

The effects of higher rates of metabolism of fish at higher temperatures in summer are taken into account by assuming higher consumption rates at higher temperatures [Ref A1]. This is achieved in the kinetic fish model by changing both the uptake (k_f) and clearance (k_b) rates for different radionuclides. This will only affect the rate at which equilibrium is approached and will not affect the magnitude of the equilibrium. In practice, changing the water temperature will have complex effects on feeding rate, assimilation efficiency and turnover rate.

A3.3 Sediment dose per unit release data

The kinetic sediment model in Reference A1 does not take account of any losses of radionuclides from river bed sediment, other than radioactive decay. This will be a cautious assumption over a long-period of time, leading to much higher sediment partitioning coefficients than equilibrium values. It is possible that over shorter timescales, sediment will accumulate during periods of lower flow (eg, summer) and then be scoured away during periods of higher flow. However, given the existing cautious assumption that there is occupancy over the river bed sediments, rather than bank sediments, the sediment model in Reference A1 has been modified to take account of these losses.

A sediment clearance rate (k) has been defined to ensure that the sediment mass in the river bed mixing zone (to a depth of 2 cm) remains constant. Hence the addition of deposited suspended sediment is balanced by a loss of the same mass of sediment.

A4 References

A1 Smith JT and Bowes M (2002). Aquatic Dispersion Models for Short Duration Radionuclide Releases. Environment Agency R&D Technical Report P3-074.

A2 Science Report SC030162 Initial Radiological Assessment Methodology – Part 2 Methods and Input Data ISBN Number 1844325431 April 2006. (http://publications.environment-agency.gov.uk/epages/eapublications.storefront/450967d1001ab534273fc0a802960648/Product/View/SCHO0106BKDV&2DE&2DE).

A3 US EPA Office of Water. Estimated Per Capita Water Ingestion and Body Weight in the United States. An Update Based on Data Collected by the United States Department of Agriculture's 1994–1996 and 1998 Continuing Survey of Food Intakes by Individuals.

A4 Drinking Water Inspectorate (2008). National Tap Water Consumption Study. Phase Two. Final Report. DWI 70/2/217.

A5 British Marine Federation, Maritime & Coastguard Agency, Royal National Lifeboat Institution, Royal Yachting Association, Sunsail (First Choice Marine) Ltd. Watersports and Leisure Participation Survey 2007.

A6 IAEA (1994). Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments. Technical Report 364.

Table A1 Data used for calculation of realistic and cautious dose per unit short term release values

Key assessment parameter	Realistic short term release	Cautious short term release
Source term	Unit limits (1 Bq)	Unit limits (1 Bq)
Release duration	1 day	30 min
River flow	Unit flow = 1 m^3/s	Unit flow = 1 m^3/s
Water concentration for consumption	Integrated filtered water concentrations per unit release – See Table A2.	Maximum dose for: (1) Integrated filtered water concentrations per unit release – See Table A2. or (2) Average unfiltered first day water concentration = 1.2 10^{-8} Bq/l per Bq released Derived from simple dilution model of 1Bq into 1000 l/s over 24 hours.
Water consumption rate	Summer critical group consumption rate – assumes 30%[a] of annual consumption rate [Ref A2] consumed over summer: Offspring[b] 2.0 l/d Infants 0.85 l/d Children 1.2 l/d Adults 2.0 l/d Remaining 9 months – assumes 70% of annual consumption rate [Ref A2] consumed over 9 months: Offspring[b] 1.5 l/d Infants 0.66 l/d Children 0.89 l/d Adults 1.5 l/d	Maximum dose for: (1) Realistic short term release assessment assumptions or (2) Daily critical (95^{th} percentile) consumption [Ref A3]: Offspring[b] 2.8 l Infants 1.0 l Children 1.9 l Adults 2.8 l

[a]Slightly higher water consumption assumed than average due to warmer summer months. A survey by the Drinking Water Inspectorate has shown a small, although not statistically significant, increase in tap water consumption of about 4% from spring to summer [Ref A4].

[b]This is for the mother and used in the calculation of dose to the fetus.

Table A1 Continued

Key assessment parameter	Realistic short term release	Cautious short term release
Fish concentrations	Integrated fish concentrations per unit release for summer months and following 9 months - See Tables A3 and A4. These are based on filtered integrated water concentrations and hence take account of loss of activity to suspended sediment.	Maximum dose for: (1) Realistic short term release assessment assumptions or (2) Max fish concentration - See Table A5. Max fish concentrations are calculated from unfiltered water concentrations.
Fish consumption rate	Summer critical group consumption rate – assumes 40%[a] of annual consumption rate [Ref A2] consumed over summer: Offspring[b] 0.088 kg/d Infants 0.004 kg/d Children 0.022 kg/d Adults 0.088 kg/d Remaining 9 months – assumes 60% of annual consumption rate [Ref A2] consumed over 9 months: Offspring[b] 0.044 kg/d Infants 0.002 kg/d Children 0.011 kg/d Adults 0.044 kg/d	Maximum dose for: (1) Realistic short term release assessment assumptions Or (2) Critical daily catch of edible fraction of fish (cautious judgement): Offspring[b] 2 kg Infants 1 kg Children 2 kg Adults 2 kg
Sediment concentrations	Integrated sediment concentration for summer months and remaining 9 months - See Table A6.	Maximum dose for: (1) Realistic short term release assessment assumptions or (2) Max sediment concentration - See Table A7.

[a] 41% of angling activities occur in summer months [Ref A5].

[b] This is for the mother and used in the calculation of dose to the fetus.

Table A1 Continued

Key assessment parameter	Realistic short term release	Cautious short term release
Sediment exposure	Summer critical group occupancy rate - assumes 40%[a] of annual occupancy rate [Ref A2] occurs over summer: Offspring[b] 4.4 h/d Infants 0.13 h/d Children 2.2 h/d Adults 4.4 h/d Remaining 9 months - assumes 60% of annual occupancy rate [Ref A2] occurs over remainder of year: Offspring[b] 2.2 h/d Infants 0.07 h/d Children 1.1 h/d Adults 2.2 h/d	Maximum dose for: (1) Realistic short term release assessment assumptions or (2) Critical daily occupancy (cautious judgement): Offspring[b] 10 h Infants 10 h Children 10 h Adults 10 h
Water concentration for irrigated foods	Integrated filtered water concentrations per unit release – See Table A2.	Not assessed.
Irrigation rate	Irrigation rate for summer = 1.3 10^{-5} $l/m^2/s$ Derived from assuming annual irrigation rate of 0.1 $m^3/m^2/y$ [Ref A2] occurs just in the summer.	Not assessed.
Irrigated food concentrations	Integrated food concentrations over summer - See Table A8.	Not assessed.

[a]41% of angling activities occur in summer months [Ref A5].

[b]This is for the mother and used in the calculation of dose to the fetus.

Table A1 Continued

Key assessment parameter	Realistic short term release	Cautious short term release
Irrigated food consumption rates	Summer critical group consumption rate – assumes 30%[a] of annual consumption rate [Ref A2] consumed over summer: Green vegetables: Offspring[b] 0.26 kg/d Infants 0.05 kg/d Children 0.11 kg/d Adults 0.26 kg/d Root vegetables: Offspring[b] 0.43 kg/d Infants 0.15 kg/d Children 0.31 kg/d Adults 0.43 kg/d Fruit: Offspring[b] 0.25 kg/d Infants 0.11 kg/d Children 0.16 kg/d Adults 0.25 kg/d	Not assessed.
Dose coefficients	See Table A9	See Table A9

[a]Slightly higher water consumption assumed than average due to greater availability of local produce.

[b]This is for the mother and used in the calculation of dose to the fetus

Table A2 Integrated water concentrations

Radionuclide	Integrated unfiltered water concentration for unit flow[a] (1 m^3/s) (Bq d/l per Bq)	Sediment partitioning coefficient (Bq/kg per Bq/l)[b]	Filtered fraction[c]	Integrated filtered water concentration for unit flow (1 m^3/s) (Bq d/l per Bq)
Tritium	1.2E-08	0.03	1.00	1.2E-08
Carbon-14	1.2E-08	2000	0.97	1.2E-08
Phosphorus-32	1.2E-08	1000	0.99	1.2E-08
Cobalt-60	1.2E-08	20000	0.79	9.5E-09
Zinc-65	1.2E-08	1000	0.99	1.2E-08
Strontium-89	1.2E-08	2000	0.97	1.2E-08
Strontium-90	1.2E-08	2000	0.97	1.2E-08
Iodine-125	1.2E-08	300	1.00	1.2E-08
Iodine-131	1.2E-08	300	1.00	1.2E-08
Caesium-134	1.2E-08	2000	0.97	1.2E-08
Caesium-137	1.2E-08	2000	0.97	1.2E-08
Uranium-234	1.2E-08	50	1.00	1.2E-08
Uranium-235	1.2E-08	50	1.00	1.2E-08
Uranium-238	1.2E-08	50	1.00	1.2E-08
Plutonium-238	1.2E-08	100000	0.43	5.2E-09
Plutonium-239	1.2E-08	100000	0.43	5.2E-09
Plutonium-240	1.2E-08	100000	0.43	5.2E-09
Americium-241	1.2E-08	5000	0.94	1.1E-08

[a]Derived from integrated flow rate of 1.2 10^{-2} Bq d/l per MBq released per unit flow (1 m^3/s) [Ref A1].

[b]From Reference A2, except for americium-241 which is from Reference A6.

[c]Calculated from 1 / (1 + k_d SSL) [Ref A2]; where k_d is the sediment partitioning coefficient and SSL is the freshwater suspended solid load (1.3 10^{-5} kg/l, [Ref A1]).

Table A3 Integrated fish concentrations – Summer months

Radionuclide	Uptake rate[a] (k_f) (17^oC) (l/(kg d))	Clearance rate[a] (k_b) (17^oC) (d^{-1})	Radioactive decay constant[b] (λ) (d^{-1})	Integrated fish conc[c] (Bq d/kg per Bq for 1 m^3/s)
Tritium	0.69	0.69	1.5E-04	1.2E-08
Carbon-14	147	0.0067	3.3E-07	1.2E-04
Phosphorus-32	476	0.048	4.8E-02	5.8E-05
Cobalt-60	1.43	0.0048	3.6E-04	9.9E-07
Zinc-65	238	0.048	2.8E-03	5.5E-05
Strontium-89	0.68	0.011	1.4E-02	2.9E-07
Strontium-90	0.68	0.011	6.5E-05	4.6E-07
Iodine-125	1.9	0.048	1.2E-02	3.8E-07
Iodine-131	1.9	0.048	8.6E-02	1.7E-07
Caesium-134	20.9	0.01	9.2E-04	1.4E-05
Caesium-137	20.9	0.01	6.3E-05	1.5E-05
Uranium-234	2.38	0.048	7.8E-09	5.9E-07
Uranium-235	2.38	0.048	2.7E-12	5.9E-07
Uranium-238	2.38	0.048	4.3E-13	5.9E-07
Plutonium-238	2.38	0.048	2.2E-05	2.6E-07
Plutonium-239	2.38	0.048	7.9E-08	2.6E-07
Plutonium-240	2.38	0.048	2.9E-07	2.6E-07
Americium-241	47.6	0.048	4.4E-06	1.1E-05

[a]Reference A1.

[b]Calculated from radioactive half-lives in Reference A2.

[c]Calculated from following equation [Ref A1]:

Int fish conc = c_w(filt) k_f [exp(-(k_b+ λ) τ_1) – exp(-(k_b+ λ) τ_2)]/ (k_b+ λ)

Where c_w (filt) is the integrated filtered water concentration per unit release (Table A2); τ_1 is the integration time period to the start time (0 months); and τ_2 is the integration time period to the end time (3 months).

Table A4 Integrated fish concentrations – Remaining 9 months

Radionuclide	Uptake rate[a] (k_f) (12°C) (l/(kg d))	Clearance rate[a] (k_b) (12°C) (d^{-1})	Radioactive decay constant[b] (λ) (d^{-1})	Integrated fish conc[c] (Bq d/kg per Bq for 1 m^3/s)
Tritium	0.69	0.69	1.5E-04	0.0E+00
Carbon-14	72.7	0.0033	3.3E-07	1.1E-04
Phosphorus-32	236	0.024	4.8E-02	5.2E-08
Cobalt-60	0.71	0.0024	3.6E-04	1.0E-06
Zinc-65	118	0.024	2.8E-03	4.5E-06
Strontium-89	0.68	0.011	1.4E-02	3.4E-08
Strontium-90	0.68	0.011	6.5E-05	2.5E-07
Iodine-125	0.94	0.024	1.2E-02	1.2E-08
Iodine-131	0.94	0.024	8.6E-02	4.4E-12
Caesium-134	10.4	0.0052	9.2E-04	9.2E-06
Caesium-137	10.4	0.0052	6.3E-05	1.1E-05
Uranium-234	1.18	0.024	7.8E-09	6.6E-08
Uranium-235	1.18	0.024	2.7E-12	6.6E-08
Uranium-238	1.18	0.024	4.3E-13	6.6E-08
Plutonium-238	1.18	0.024	2.2E-05	2.9E-08
Plutonium-239	1.18	0.024	7.9E-08	2.9E-08
Plutonium-240	1.18	0.024	2.9E-07	2.9E-08
Americium-241	23.6	0.024	4.4E-06	1.2E-06

[a]Reference A1.

[b]Calculated from radioactive half-lives in Reference A2.

[c]Calculated from following equation [Ref A1]:

Int fish conc = c_w(filt) k_f [exp(-(k_b+ λ) τ_1) – exp(-(k_b+ λ) τ_2)]/ (k_b+ λ)

Where c_w (filt) is the integrated filtered water concentration per unit release (Table A2); τ_1 is the integration time period to the start time (3 months); and τ_2 is the integration time period to the end time (12 months)

Table A5 Maximum fish concentrations

Radionuclide	Max fish conc[a] (Bq/kg per MBq for 1 m^3/s)	Max fish conc (Bq/kg per Bq for 1 m^3/s)	Fish conc scaling factor for 17^oC[a]	Max fish conc in summer (Bq/kg per Bq for 1 m^3/s)
Tritium	-	1.2E-08[b]	2	2.3E-08
Carbon-14	8.0E-01	8.0E-07	2	1.6E-06
Phosphorus-32	3.0E+00	3.0E-06	2	6.0E-06
Cobalt-60	1.2E-02	1.2E-08	2	2.4E-08
Zinc-65	1.4E+00	1.4E-06	2	2.8E-06
Strontium-89	7.0E-03	7.0E-09	1	7.0E-09
Strontium-90	7.0E-03	7.0E-09	1	7.0E-09
Iodine-125	1.2E-02	1.2E-08	2	2.4E-08
Iodine-131	1.2E-02	1.2E-08	2	2.4E-08
Caesium-134	1.2E-01	1.2E-07	2	2.4E-07
Caesium-137	1.2E-01	1.2E-07	2	2.4E-07
Uranium-234	1.2E-02	1.2E-08	2	2.4E-08
Uranium-235	1.2E-02	1.2E-08	2	2.4E-08
Uranium-238	1.2E-02	1.2E-08	2	2.4E-08
Plutonium-238	1.2E-02	1.2E-08	2	2.4E-08
Plutonium-239	1.2E-02	1.2E-08	2	2.4E-08
Plutonium-240	1.2E-02	1.2E-08	2	2.4E-08
Americium-241	3.0E-01	3.0E-07	2	6.0E-07

[a]Reference A1(based on unfiltered water concentrations, ie, assuming no loss of radionuclides to suspended sediment).

[b]Tritium concentration in fish assumed to be the same as average daily water concentration (simple dilution model of 1 Bq into 1000 l/s over 24 hours) in accordance with guidance in Reference A1.

Table A6 Integrated sediment concentrations – Summer months and remaining 9 months

Radionuclide	Fraction of activity with suspended solid[a] (f_s)	Radioactive decay constant[b] (λ) (d^{-1})	Integrated sediment conc[c] (Bq d/kg per Bq for 1 m^3/s flow)	Integrated sediment conc (remaining 9 months)[d] (Bq d/kg per Bq for 1 m^3/s flow)
Tritium	3.9E-07	1.5E-04	4.0E-11	3.5E-11
Carbon-14	2.5E-02	3.3E-07	2.6E-06	2.3E-06
Phosphorus-32	1.3E-02	4.8E-02	3.1E-07	3.3E-09
Cobalt-60	2.1E-01	3.6E-04	2.1E-05	1.8E-05
Zinc-65	1.3E-02	2.8E-03	1.2E-06	8.0E-07
Strontium-89	2.5E-02	1.4E-02	1.5E-06	3.8E-07
Strontium-90	2.5E-02	6.5E-05	2.6E-06	2.3E-06
Iodine-125	3.9E-03	1.2E-02	2.5E-07	7.8E-08
Iodine-131	3.9E-03	8.6E-02	5.3E-08	1.8E-11
Caesium-134	2.5E-02	9.2E-04	2.5E-06	2.1E-06
Caesium-137	2.5E-02	6.3E-05	2.6E-06	2.3E-06
Uranium-234	6.5E-04	7.8E-09	6.7E-08	6.0E-08
Uranium-235	6.5E-04	2.7E-12	6.7E-08	6.0E-08
Uranium-238	6.5E-04	4.3E-13	6.7E-08	6.0E-08
Plutonium-238	5.7E-01	2.2E-05	5.8E-05	5.2E-05
Plutonium-239	5.7E-01	7.9E-08	5.8E-05	5.2E-05
Plutonium-240	5.7E-01	2.9E-07	5.8E-05	5.2E-05
Americium-241	6.1E-02	4.4E-06	6.3E-06	5.6E-06

[a]Calculated as (1 – filtered fraction) (see Table A2 for filtered fractions).

[b]Calculated from radioactive half-lives in Reference A2.

[c]Calculated from following equation [Ref A1]:

$$\text{Int sed conc} = 1000\, f_s\, v_s\, c_w(\text{total})\, [\exp(-(k+\lambda)\, \tau_1) - \exp(-(k+\lambda)\, \tau_2)] / (\rho_s\, d_s\, (k+\lambda))$$

$$k = 1000\, v_s\, SSL / (\rho_s\, d_s)$$

Where v_s is the sedimentation velocity (1 m/d, Ref A1); c_w (total) is the integrated unfiltered water concentration per unit release (Table A2); k is the sediment clearance rate (d^{-1}); τ_1 is the integration time period to the start time (0 months); τ_2 is the integration time period to the end time (3 months); ρ_s is the bed sediment density (500 kg/m^3, Ref A1), d_s is the mixing depth for the bed sediment (0.02m, Ref A1) and SSL is the freshwater suspended solid load (1.3 10^{-5} kg/l [Ref A1]).

[d]Same as footnote [c], with the exceptions that τ_1 is 3 months and τ_2 is 12 months.

Table A7 Maximum sediment concentrations

Radionuclide	Fraction of activity with suspended solid[a] (f_s)	Activity associated with suspended sediment per unit volume of river water per unit release[b] (A) (Bq/m^3 per Bq)	Activity associated with suspended sediment per unit area of river per unit release[c] (B) (Bq/m^2 per Bq)	Max sediment conc[d] (Bq/kg per Bq for unit flow 1 m^3/s)
Tritium	3.9E-07	4.5E-12	4.5E-12	4.5E-13
Carbon-14	2.5E-02	2.9E-07	2.9E-07	2.9E-08
Phosphorus-32	1.3E-02	1.5E-07	1.5E-07	1.5E-08
Cobalt-60	2.1E-01	2.4E-06	2.4E-06	2.4E-07
Zinc-65	1.3E-02	1.5E-07	1.5E-07	1.5E-08
Strontium-89	2.5E-02	2.9E-07	2.9E-07	2.9E-08
Strontium-90	2.5E-02	2.9E-07	2.9E-07	2.9E-08
Iodine-125	3.9E-03	4.5E-08	4.5E-08	4.5E-09
Iodine-131	3.9E-03	4.5E-08	4.5E-08	4.5E-09
Caesium-134	2.5E-02	2.9E-07	2.9E-07	2.9E-08
Caesium-137	2.5E-02	2.9E-07	2.9E-07	2.9E-08
Uranium-234	6.5E-04	7.5E-09	7.5E-09	7.5E-10
Uranium-235	6.5E-04	7.5E-09	7.5E-09	7.5E-10
Uranium-238	6.5E-04	7.5E-09	7.5E-09	7.5E-10
Plutonium-238	5.7E-01	6.5E-06	6.5E-06	6.5E-07
Plutonium-239	5.7E-01	6.5E-06	6.5E-06	6.5E-07
Plutonium-240	5.7E-01	6.5E-06	6.5E-06	6.5E-07
Americium-241	6.1E-02	7.1E-07	7.1E-07	7.1E-08

[a]Calculated as (1 – filtered fraction) (see Table A2 for filtered fractions).

[b]Calculated from 1000 f_s c_w (total); where c_w (total) is the maximum unfiltered water concentration per unit release (Bq/l per Bq) (see Table A1).

[c]Calculated from A / h_w; where h_w is the height of the river water, assumed to be 1 m.

[d]Calculated from B / (ρ_s d_s); where ρ_s is the bed sediment density (500 kg/m^3, Ref A1) and d_s is the mixing depth for the bed sediment (0.02 m, Ref A1).

Table A8 Integrated irrigated food concentrations

Radionuclide	Integrated food conc[a] per unit application (Bq s/kg per Bq/m^2)		
	Green veg	Root veg	Fruit
Tritium	5.1E+04	5.1E+04	5.1E+04
Carbon-14	2.3E+06	1.8E+06	2.3E+06
Phosphorus-32	6.3E+04	5.1E+05	4.1E+04
Cobalt-60	1.2E+05	5.1E+03	4.4E+04
Zinc-65	1.6E+05	3.0E+04	3.6E+04
Strontium-89	8.9E+04	7.0E+02	1.5E+04
Strontium-90	6.2E+05	8.8E+04	1.3E+05
Technetium-99m	2.1E+03	2.1E+02	1.6E+03
Iodine-125	1.0E+05	7.4E+04	6.2E+04
Iodine-131	4.1E+04	8.6E+03	3.1E+04
Caesium-134	1.3E+05	1.2E+05	7.2E+04
Caesium-137	1.5E+05	1.4E+05	7.5E+04
Uranium-234	1.1E+05	2.9E+03	4.5E+04
Uranium-235	1.1E+05	2.9E+03	4.5E+04
Uranium-238	1.1E+05	2.9E+03	4.5E+04
Plutonium-238	1.1E+05	1.2E+02	1.0E+04
Plutonium-239	1.1E+05	1.5E+02	1.1E+04
Plutonium-240	1.1E+05	1.5E+02	1.1E+04
Americium-241	1.1E+05	2.3E+02	1.3E+04

[a] Reference A2. Assumed to be the same as 50th year activity concentrations in foods per unit deposition rate.

Table A9 Dose coefficients[a]

Radionuclide	Ingestion dose coeff (Sv/Bq)				Dose rate factor for sediment (Sv/h per Bq/kg)
	Offspring	Infant	Child	Adult	
Tritium	3.1E-11	4.8E-11	2.3E-11	1.8E-11	0.0E+00
Carbon-14	8.1E-10	1.6E-09	8.0E-10	5.8E-10	6.8E-17
Phosphorus-32	2.4E-08	1.9E-08	5.3E-09	2.4E-09	1.3E-13
Cobalt-60	-	2.7E-08	1.1E-08	3.4E-09	9.5E-11
Zinc-65	-	1.6E-08	6.4E-09	3.9E-09	2.2E-11
Strontium-89	1.2E-08	1.8E-08	5.8E-09	2.6E-09	9.3E-14
Strontium-90	4.2E-08	7.3E-08	6.0E-08	2.8E-08	2.5E-13
Technetium-99m	-	1.3E-10	4.3E-11	2.2E-11	8.3E-13
Iodine-125	-	5.7E-08	3.1E-08	1.5E-08	7.3E-14
Iodine-131	-	1.8E-07	5.2E-08	2.2E-08	2.7E-12
Caesium-134	-	1.6E-08	1.4E-08	1.9E-08	5.5E-11
Caesium-137	-	1.2E-08	1.0E-08	1.3E-08	2.0E-11
Uranium-234	-	1.3E-07	7.4E-08	4.9E-08	2.1E-15
Uranium-235	-	1.3E-07	7.1E-08	4.7E-08	4.3E-12
Uranium-238	-	1.2E-07	6.8E-08	4.5E-08	8.7E-13
Plutonium-238	-	4.0E-07	2.4E-07	2.3E-07	7.2E-16
Plutonium-239	-	4.2E-07	2.7E-07	2.5E-07	1.6E-15
Plutonium-240	-	4.2E-07	2.7E-07	2.5E-07	6.9E-16
Americium-241	-	3.7E-07	2.2E-07	2.0E-07	2.3E-13

[a] Reference A2.

Table A10 Realistic short term dose per unit release – Angling Family (unit flow rate of 1 m^3/s)

Radionuclide	Fish consumption dose per unit release (integrated) (μSv/Bq)				External dose per unit release (integrated summer) (μSv/Bq)			
	Offspring	Infant	Child	Adult	Offspring	Infant	Child	Adult
Tritium	3.2E-14	2.5E-15	6.0E-15	1.9E-14	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Carbon-14	1.2E-08	1.2E-09	3.1E-09	8.8E-09	1.1E-15	3.4E-17	5.6E-16	1.1E-15
Phosphorus-32	1.2E-07	4.9E-09	6.8E-09	1.2E-08	1.7E-13	5.1E-15	8.5E-14	1.7E-13
Cobalt-60	0.0E+00	1.8E-10	3.6E-10	4.5E-10	1.2E-08	3.7E-10	6.2E-09	1.2E-08
Zinc-65	0.0E+00	4.0E-09	8.0E-09	2.0E-08	1.5E-10	4.5E-12	7.5E-11	1.5E-10
Strontium-89	3.2E-10	2.4E-11	3.9E-11	6.9E-11	6.9E-13	2.1E-14	3.5E-13	6.9E-13
Strontium-90	2.1E-09	1.9E-10	7.6E-10	1.4E-09	4.1E-12	1.2E-13	2.1E-12	4.1E-12
Iodine-125	0.0E+00	9.6E-11	2.6E-10	5.1E-10	9.3E-14	2.8E-15	4.6E-14	9.3E-14
Iodine-131	0.0E+00	1.3E-10	1.9E-10	3.3E-10	6.2E-13	1.9E-14	3.1E-13	6.2E-13
Caesium-134	0.0E+00	1.3E-09	5.7E-09	3.1E-08	8.5E-10	2.6E-11	4.3E-10	8.5E-10
Caesium-137	0.0E+00	1.1E-09	4.4E-09	2.3E-08	3.3E-10	9.8E-12	1.6E-10	3.3E-10
Uranium-234	0.0E+00	3.5E-10	1.0E-09	2.7E-09	9.0E-16	2.7E-17	4.5E-16	9.0E-16
Uranium-235	0.0E+00	3.5E-10	9.6E-10	2.6E-09	1.8E-12	5.4E-14	9.0E-13	1.8E-12
Uranium-238	0.0E+00	3.3E-10	9.2E-10	2.4E-09	3.7E-13	1.1E-14	1.9E-13	3.7E-13
Plutonium-238	0.0E+00	4.7E-10	1.4E-09	5.4E-09	2.6E-13	7.9E-15	1.3E-13	2.6E-13
Plutonium-239	0.0E+00	5.0E-10	1.6E-09	5.9E-09	6.0E-13	1.8E-14	3.0E-13	6.0E-13
Plutonium-240	0.0E+00	5.0E-10	1.6E-09	5.9E-09	2.6E-13	7.7E-15	1.3E-13	2.6E-13
Americium-241	0.0E+00	1.9E-08	5.6E-08	2.0E-07	9.1E-12	2.7E-13	4.6E-12	9.1E-12

Table A10 Continued

Radionuclide	Water consumption dose per unit release (μSv/Bq)				Total dose per unit release (μSv/Bq)					
	Offspring	Infant	Child	Adult	Offspring	Infant	Child	Adult	Maximum	Age Group
Tritium	7.2E-13	4.9E-13	3.2E-13	4.3E-13	7.6E-13	4.9E-13	3.2E-13	4.4E-13	7.6E-13	Offspring
Carbon-14	1.9E-11	1.6E-11	1.1E-11	1.3E-11	1.2E-08	1.2E-09	3.1E-09	8.9E-09	1.2E-08	Offspring
Phosphorus-32	5.6E-10	1.9E-10	7.2E-11	5.6E-11	1.2E-07	5.1E-09	6.9E-09	1.2E-08	1.2E-07	Offspring
Cobalt-60	0.0E+00	2.2E-10	1.2E-10	6.4E-11	1.2E-08	7.7E-10	6.7E-09	1.3E-08	1.3E-08	Adult
Zinc-65	0.0E+00	1.6E-10	8.7E-11	9.1E-11	1.5E-10	4.2E-09	8.2E-09	2.0E-08	2.0E-08	Adult
Strontium-89	2.8E-10	1.8E-10	7.8E-11	6.0E-11	6.0E-10	2.0E-10	1.2E-10	1.3E-10	6.0E-10	Offspring
Strontium-90	9.7E-10	7.3E-10	8.1E-10	6.5E-10	3.1E-09	9.2E-10	1.6E-09	2.1E-09	3.1E-09	Offspring
Iodine-125	0.0E+00	5.8E-10	4.3E-10	3.5E-10	9.3E-14	6.8E-10	6.9E-10	8.6E-10	8.6E-10	Adult
Iodine-131	0.0E+00	1.8E-09	7.1E-10	5.2E-10	6.2E-13	2.0E-09	9.1E-10	8.5E-10	2.0E-09	Infant
Caesium-134	0.0E+00	1.6E-10	1.9E-10	4.4E-10	8.5E-10	1.5E-09	6.4E-09	3.2E-08	3.2E-08	Adult
Caesium-137	0.0E+00	1.2E-10	1.3E-10	3.0E-10	3.3E-10	1.2E-09	4.7E-09	2.3E-08	2.3E-08	Adult
Uranium-234	0.0E+00	1.3E-09	1.0E-09	1.2E-09	9.0E-16	1.7E-09	2.0E-09	3.8E-09	3.8E-09	Adult
Uranium-235	0.0E+00	1.3E-09	9.8E-10	1.1E-09	1.8E-12	1.7E-09	1.9E-09	3.7E-09	3.7E-09	Adult
Uranium-238	0.0E+00	1.2E-09	9.4E-10	1.1E-09	3.7E-13	1.6E-09	1.9E-09	3.5E-09	3.5E-09	Adult
Plutonium-238	0.0E+00	1.8E-09	1.4E-09	2.4E-09	2.6E-13	2.3E-09	2.9E-09	7.8E-09	7.8E-09	Adult
Plutonium-239	0.0E+00	1.9E-09	1.6E-09	2.6E-09	6.0E-13	2.4E-09	3.2E-09	8.5E-09	8.5E-09	Adult
Plutonium-240	0.0E+00	1.9E-09	1.6E-09	2.6E-09	2.6E-13	2.4E-09	3.2E-09	8.5E-09	8.5E-09	Adult
Americium-241	0.0E+00	3.6E-09	2.9E-09	4.4E-09	9.1E-12	2.2E-08	5.9E-08	2.1E-07	2.1E-07	Adult

Table A11 Realistic short term dose per unit release – Irrigated food consuming family (unit flow rate of 1 m^3/s)

Radionuclide	Green veg consumption dose per unit release (μSv/Bq)				Root veg consumption dose per unit release (μSv/Bq)			
	Offspring	Infant	Child	Adult	Offspring	Infant	Child	Adult
Tritium	6.2E-14	1.8E-14	2.1E-14	3.7E-14	1.0E-13	5.5E-14	5.6E-14	6.0E-14
Carbon-14	7.3E-11	2.7E-11	3.1E-11	5.2E-11	9.3E-11	6.3E-11	6.7E-11	6.6E-11
Phosphorus-32	6.0E-11	8.9E-12	5.8E-12	6.0E-12	7.8E-10	2.2E-10	1.3E-10	7.8E-11
Cobalt-60	0.0E+00	1.9E-11	1.8E-11	1.3E-11	0.0E+00	2.5E-12	2.1E-12	8.9E-13
Zinc-65	0.0E+00	1.9E-11	1.8E-11	2.5E-11	0.0E+00	1.1E-11	9.0E-12	7.5E-12
Strontium-89	4.1E-11	1.2E-11	8.8E-12	9.0E-12	5.3E-13	2.8E-13	1.9E-13	1.2E-13
Strontium-90	1.0E-09	3.3E-10	6.3E-10	6.8E-10	2.3E-10	1.4E-10	2.4E-10	1.6E-10
Iodine-125	0.0E+00	4.3E-11	5.4E-11	6.0E-11	0.0E+00	9.4E-11	1.1E-10	7.2E-11
Iodine-131	0.0E+00	5.5E-11	3.7E-11	3.6E-11	0.0E+00	3.5E-11	2.1E-11	1.2E-11
Caesium-134	0.0E+00	1.5E-11	3.1E-11	9.6E-11	0.0E+00	4.2E-11	7.8E-11	1.4E-10
Caesium-137	0.0E+00	1.3E-11	2.6E-11	7.6E-11	0.0E+00	3.7E-11	6.5E-11	1.2E-10
Uranium-234	0.0E+00	1.1E-10	1.4E-10	2.2E-10	0.0E+00	8.5E-12	1.0E-11	9.2E-12
Uranium-235	0.0E+00	1.1E-10	1.4E-10	2.1E-10	0.0E+00	8.5E-12	9.8E-12	8.8E-12
Uranium-238	0.0E+00	9.9E-11	1.3E-10	2.0E-10	0.0E+00	7.8E-12	9.4E-12	8.5E-12
Plutonium-238	0.0E+00	1.4E-10	2.0E-10	4.4E-10	0.0E+00	4.7E-13	5.9E-13	7.8E-13
Plutonium-239	0.0E+00	1.5E-10	2.3E-10	4.8E-10	0.0E+00	6.2E-13	8.4E-13	1.1E-12
Plutonium-240	0.0E+00	1.5E-10	2.3E-10	4.8E-10	0.0E+00	6.2E-13	8.4E-13	1.1E-12
Americium-241	0.0E+00	2.9E-10	4.0E-10	8.3E-10	0.0E+00	1.8E-12	2.3E-12	2.8E-12

Table A11 Continued

Radionuclide	Fruit consumption dose per unit release (μSv/Bq)				Total dose per unit release (μSv/Bq)					
	Offspring	Infant	Child	Adult	Offspring	Infant	Child	Adult	Maximum	Age Group
Tritium	5.8E-14	4.3E-14	2.9E-14	3.4E-14	2.2E-13	1.2E-13	1.1E-13	1.3E-13	2.2E-13	Offspring
Carbon-14	6.8E-11	6.3E-11	4.5E-11	4.9E-11	2.3E-10	1.5E-10	1.4E-10	1.7E-10	2.3E-10	Offspring
Phosphorus-32	3.6E-11	1.3E-11	5.4E-12	3.6E-12	8.8E-10	2.4E-10	1.4E-10	8.8E-11	8.8E-10	Offspring
Cobalt-60	0.0E+00	1.6E-11	9.6E-12	4.4E-12	0.0E+00	3.8E-11	3.0E-11	1.8E-11	3.8E-11	Infant
Zinc-65	0.0E+00	9.9E-12	5.7E-12	5.2E-12	0.0E+00	4.0E-11	3.2E-11	3.7E-11	4.0E-11	Infant
Strontium-89	6.6E-12	4.6E-12	2.1E-12	1.4E-12	4.9E-11	1.7E-11	1.1E-11	1.1E-11	4.9E-11	Offspring
Strontium-90	2.0E-10	1.6E-10	1.9E-10	1.3E-10	1.4E-09	6.3E-10	1.1E-09	9.7E-10	1.4E-09	Offspring
Iodine-125	0.0E+00	6.2E-11	4.8E-11	3.5E-11	0.0E+00	2.0E-10	2.1E-10	1.7E-10	2.1E-10	Child
Iodine-131	0.0E+00	9.7E-11	4.0E-11	2.5E-11	0.0E+00	1.9E-10	9.8E-11	7.4E-11	1.9E-10	Infant
Caesium-134	0.0E+00	2.0E-11	2.5E-11	5.0E-11	0.0E+00	7.7E-11	1.3E-10	2.9E-10	2.9E-10	Adult
Caesium-137	0.0E+00	1.5E-11	1.8E-11	3.6E-11	0.0E+00	6.5E-11	1.1E-10	2.3E-10	2.3E-10	Adult
Uranium-234	0.0E+00	1.0E-10	8.3E-11	8.3E-11	0.0E+00	2.2E-10	2.4E-10	3.1E-10	3.1E-10	Adult
Uranium-235	0.0E+00	1.0E-10	8.0E-11	7.9E-11	0.0E+00	2.2E-10	2.3E-10	2.9E-10	2.9E-10	Adult
Uranium-238	0.0E+00	9.4E-11	7.6E-11	7.6E-11	0.0E+00	2.0E-10	2.2E-10	2.8E-10	2.8E-10	Adult
Plutonium-238	0.0E+00	3.0E-11	2.6E-11	3.7E-11	0.0E+00	1.7E-10	2.3E-10	4.8E-10	4.8E-10	Adult
Plutonium-239	0.0E+00	3.5E-11	3.2E-11	4.5E-11	0.0E+00	1.9E-10	2.6E-10	5.2E-10	5.2E-10	Adult
Plutonium-240	0.0E+00	3.5E-11	3.2E-11	4.5E-11	0.0E+00	1.9E-10	2.6E-10	5.2E-10	5.2E-10	Adult
Americium-241	0.0E+00	7.9E-11	6.7E-11	9.1E-11	0.0E+00	3.7E-10	4.7E-10	9.2E-10	9.2E-10	Adult

Table A12 Cautious short term dose per unit release – Angling Family (unit flow rate of 1 m^3/s)

Radionuclide	Fish consumption dose per unit release (μSv/Bq)				Integrated fish dpur or max fish dpur			
	Offspring	Infant	Child	Adult	Offspring	Infant	Child	Adult
Tritium	1.4E-12	1.1E-12	1.1E-12	8.3E-13	Max	Max	Max	Max
Carbon-14	1.2E-08	2.6E-09	3.1E-09	8.8E-09	Integrated	Max	Integrated	Integrated
Phosphorus-32	2.9E-07	1.1E-07	6.4E-08	2.9E-08	Max	Max	Max	Max
Cobalt-60	0.0E+00	6.5E-10	5.3E-10	4.5E-10	Max	Max	Max	Integrated
Zinc-65	0.0E+00	4.5E-08	3.6E-08	2.2E-08	Max	Max	Max	Max
Strontium-89	3.2E-10	1.3E-10	8.1E-11	6.9E-11	Integrated	Max	Max	Integrated
Strontium-90	2.1E-09	5.1E-10	8.4E-10	1.4E-09	Integrated	Max	Max	Integrated
Iodine-125	0.0E+00	1.4E-09	1.5E-09	7.2E-10	Max	Max	Max	Max
Iodine-131	0.0E+00	4.3E-09	2.5E-09	1.1E-09	Max	Max	Max	Max
Caesium-134	0.0E+00	3.8E-09	6.7E-09	3.1E-08	Max	Max	Max	Integrated
Caesium-137	0.0E+00	2.9E-09	4.8E-09	2.3E-08	Max	Max	Max	Integrated
Uranium-234	0.0E+00	3.1E-09	3.6E-09	2.7E-09	Max	Max	Max	Integrated
Uranium-235	0.0E+00	3.1E-09	3.4E-09	2.6E-09	Max	Max	Max	Integrated
Uranium-238	0.0E+00	2.9E-09	3.3E-09	2.4E-09	Max	Max	Max	Integrated
Plutonium-238	0.0E+00	9.6E-09	1.2E-08	1.1E-08	Max	Max	Max	Max
Plutonium-239	0.0E+00	1.0E-08	1.3E-08	1.2E-08	Max	Max	Max	Max
Plutonium-240	0.0E+00	1.0E-08	1.3E-08	1.2E-08	Max	Max	Max	Max
Americium-241	0.0E+00	2.2E-07	2.6E-07	2.4E-07	Max	Max	Max	Max

Table A12 Continued

Radionuclide	External dose per unit release (μSv/Bq)				Integrated sediment dpur or max sediment dpur			
	Offspring	Infant	Child	Adult	Offspring	Infant	Child	Adult
Tritium	0.0E+00	0.0E+00	0.0E+00	0.0E+00	Max	Max	Max	Max
Carbon-14	1.1E-15	3.4E-17	5.6E-16	1.1E-15	Integrated	Integrated	Integrated	Integrated
Phosphorus-32	1.7E-13	1.9E-14	8.5E-14	1.7E-13	Integrated	Max	Integrated	Integrated
Cobalt-60	1.2E-08	3.7E-10	6.2E-09	1.2E-08	Integrated	Integrated	Integrated	Integrated
Zinc-65	1.5E-10	4.5E-12	7.5E-11	1.5E-10	Integrated	Integrated	Integrated	Integrated
Strontium-89	6.9E-13	2.7E-14	3.5E-13	6.9E-13	Integrated	Max	Integrated	Integrated
Strontium-90	4.1E-12	1.2E-13	2.1E-12	4.1E-12	Integrated	Integrated	Integrated	Integrated
Iodine-125	9.3E-14	3.3E-15	4.6E-14	9.3E-14	Integrated	Max	Integrated	Integrated
Iodine-131	6.2E-13	1.2E-13	3.1E-13	6.2E-13	Integrated	Max	Integrated	Integrated
Caesium-134	8.5E-10	2.6E-11	4.3E-10	8.5E-10	Integrated	Integrated	Integrated	Integrated
Caesium-137	3.3E-10	9.8E-12	1.6E-10	3.3E-10	Integrated	Integrated	Integrated	Integrated
Uranium-234	9.0E-16	2.7E-17	4.5E-16	9.0E-16	Integrated	Integrated	Integrated	Integrated
Uranium-235	1.8E-12	5.4E-14	9.0E-13	1.8E-12	Integrated	Integrated	Integrated	Integrated
Uranium-238	3.7E-13	1.1E-14	1.9E-13	3.7E-13	Integrated	Integrated	Integrated	Integrated
Plutonium-238	2.6E-13	7.9E-15	1.3E-13	2.6E-13	Integrated	Integrated	Integrated	Integrated
Plutonium-239	6.0E-13	1.8E-14	3.0E-13	6.0E-13	Integrated	Integrated	Integrated	Integrated
Plutonium-240	2.6E-13	7.7E-15	1.3E-13	2.6E-13	Integrated	Integrated	Integrated	Integrated
Americium-241	9.1E-12	2.7E-13	4.6E-12	9.1E-12	Integrated	Integrated	Integrated	Integrated

Table A12 Continued

Radionuclide	Water dose per unit release (μSv/Bq)				Integrated water dpur or max water dpur			
	Offspring	Infant	Child	Adult	Offspring	Infant	Child	Adult
Tritium	9.9E-13	5.6E-13	5.1E-13	5.8E-13	Max	Max	Max	Max
Carbon-14	2.6E-11	1.9E-11	1.8E-11	1.9E-11	Max	Max	Max	Max
Phosphorus-32	7.8E-10	2.2E-10	1.2E-10	7.8E-11	Max	Max	Max	Max
Cobalt-60	0.0E+00	3.1E-10	2.4E-10	1.1E-10	Max	Max	Max	Max
Zinc-65	0.0E+00	1.9E-10	1.4E-10	1.3E-10	Max	Max	Max	Max
Strontium-89	3.9E-10	2.1E-10	1.3E-10	8.4E-11	Max	Max	Max	Max
Strontium-90	1.4E-09	8.4E-10	1.3E-09	9.1E-10	Max	Max	Max	Max
Iodine-125	0.0E+00	6.6E-10	6.8E-10	4.9E-10	Max	Max	Max	Max
Iodine-131	0.0E+00	2.1E-09	1.1E-09	7.1E-10	Max	Max	Max	Max
Caesium-134	0.0E+00	1.9E-10	3.1E-10	6.2E-10	Max	Max	Max	Max
Caesium-137	0.0E+00	1.4E-10	2.2E-10	4.2E-10	Max	Max	Max	Max
Uranium-234	0.0E+00	1.5E-09	1.6E-09	1.6E-09	Max	Max	Max	Max
Uranium-235	0.0E+00	1.5E-09	1.6E-09	1.5E-09	Max	Max	Max	Max
Uranium-238	0.0E+00	1.4E-09	1.5E-09	1.5E-09	Max	Max	Max	Max
Plutonium-238	0.0E+00	4.6E-09	5.3E-09	7.5E-09	Max	Max	Max	Max
Plutonium-239	0.0E+00	4.9E-09	5.9E-09	8.1E-09	Max	Max	Max	Max
Plutonium-240	0.0E+00	4.9E-09	5.9E-09	8.1E-09	Max	Max	Max	Max
Americium-241	0.0E+00	4.3E-09	4.8E-09	6.5E-09	Max	Max	Max	Max

Table A12 Continued

Radionuclide	Total dose per unit release (μSv/Bq)					
	Offspring	Infant	Child	Adult	Maximum	Age Group
Tritium	2.4E-12	1.7E-12	1.6E-12	1.4E-12	2.4E-12	Offspring
Carbon-14	1.2E-08	2.6E-09	3.1E-09	8.9E-09	1.2E-08	Offspring
Phosphorus-32	2.9E-07	1.1E-07	6.4E-08	2.9E-08	2.9E-07	Offspring
Cobalt-60	1.2E-08	1.3E-09	7.0E-09	1.3E-08	1.3E-08	Adult
Zinc-65	1.5E-10	4.5E-08	3.6E-08	2.2E-08	4.5E-08	Infant
Strontium-89	7.1E-10	3.3E-10	2.1E-10	1.5E-10	7.1E-10	Offspring
Strontium-90	3.5E-09	1.4E-09	2.2E-09	2.3E-09	3.5E-09	Offspring
Iodine-125	9.3E-14	2.0E-09	2.2E-09	1.2E-09	2.2E-09	Child
Iodine-131	6.2E-13	6.4E-09	3.6E-09	1.8E-09	6.4E-09	Infant
Caesium-134	8.5E-10	4.1E-09	7.5E-09	3.3E-08	3.3E-08	Adult
Caesium-137	3.3E-10	3.0E-09	5.2E-09	2.4E-08	2.4E-08	Adult
Uranium-234	9.0E-16	4.6E-09	5.2E-09	4.3E-09	5.2E-09	Child
Uranium-235	1.8E-12	4.6E-09	5.0E-09	4.1E-09	5.0E-09	Child
Uranium-238	3.7E-13	4.3E-09	4.8E-09	3.9E-09	4.8E-09	Child
Plutonium-238	2.6E-13	1.4E-08	1.7E-08	1.8E-08	1.8E-08	Adult
Plutonium-239	6.0E-13	1.5E-08	1.9E-08	2.0E-08	2.0E-08	Adult
Plutonium-240	2.6E-13	1.5E-08	1.9E-08	2.0E-08	2.0E-08	Adult
Americium-241	9.1E-12	2.3E-07	2.7E-07	2.5E-07	2.7E-07	Child

APPENDIX B EXAMPLE DERIVATION OF SOURCE TERMS

B1 Introduction

Table 1 describes the realistic and cautious assumptions for defining the source term for short term releases assessments. Examples of the application of this guidance are provided in this appendix.

B2 Twelve month limits only

Table B1 provides example 12 month limits for different radionuclides discharged from a site. It also shows an example of four short term release scenarios for the site. Release scenario 1 is a short term release of tritium and carbon-14 only. This type of release typically occurs 18 times per year. Release scenario 2 is a short term release of phosphorus-32 which occurs four times per year. Release scenario 3 is a short term release of strontium-89 and strontium-90 which typically occur 8 times per year. Finally, release scenario 4 is a short term release of iodine-125 and iodine-131 and occurs about twice per year.

For a realistic assessment, the release scenarios should be used to define short term releases (see Table 1). Hence, in this example, four short term release scenarios should be assessed as shown in Table B2. These release scenarios are modified by the probability of the releases occurring during a one month period of both low flow and high occupancy. In this case, it is assumed that the releases could occur at any time of the year and hence the number of releases per year can be modified by 1/12, subject to a minimum of 1 release per year. Also shown in Table B2 is the continuous discharge for the remainder of the year.

For a cautious assessment, it is simply assumed that the 12 month limits are released in a single short term release, as shown in Table B2. Clearly there will no continuous release for the remainder of the year in this case.

B3 Twelve month limits and quarterly notification levels

Table B3 provides example 12 month limits and quarterly notification levels for discharges from a site. Also shown are the nuclides which are typically released together in short term releases, resulting in four typical release scenarios.

For a realistic assessment, separate sets of releases should be defined based on the radionuclides which are likely to be released together (see Table 1). Hence, four release scenarios should be assessed as shown in Table B4. In this case the short term releases are at the quarterly notification levels for each radionuclide. Also shown in Table B4 is the continuous discharge for the remainder of the year.

For a cautious assessment, it is assumed that there is a single release of all radionuclides at the quarterly notification levels (see Table B4). Continuous releases for the remainder of the year are also shown in Table B4.

B4 Monthly limits

Table B5 provides example monthly limits for discharges from a site. Also shown are the nuclides which are typically released together in short term releases, resulting in four typical release scenarios.

For a realistic assessment, separate sets of releases should be defined based on the radionuclides which are likely to be released together (see Table 1). Hence, four release scenarios should be assessed as shown in Table B6. In this case the short term releases are at the monthly limits for each radionuclide. Also shown in Table B6 is the continuous discharge for the remainder of the year for each radionuclide. This is calculated by subtracting the short term release from 12 times the monthly limit.

For a cautious assessment, it is assumed that there is a single release of all radionuclides at the monthly limits (see Table B6). Continuous releases for the remainder of the year are also shown in Table B6, calculated in the same way as the realistic assessment.

Table B1 12 month limits only - Example limits and typical short term release scenarios

Radionuclide	12 month limits (Bq)	Typical release scenario 1 (Bq)	Typical release scenario 2 (Bq)	Typical release scenario 3 (Bq)	Typical release scenario 4 (Bq)
Tritium	1.0E+12	5.0E+10			
Carbon-14	1.0E+10	5.0E+08			
Phosphorus-32	1.0E+09		1.0E+08		
Strontium-89	1.0E+06			1.0E+05	
Strontium-90	1.0E+07			1.0E+06	
Iodine-125	1.0E+10				1.0E+09
Iodine-131	1.0E+12				1.0E+11
Typical number of releases per year		18	4	8	2
Number of releases per year taking account probability of coinciding with 1 month low flow (1/12), subject to a minimum of 1 release/y		1.5	1	1	1

Table B2 12 month limits only - Short term release assessment scenarios for realistic and cautious assumptions

Radionuclide	Realistic assumptions (Bq)								Cautious assumptions (Bq)	
	Release scenario 1		Release scenario 2		Release scenario 3		Release scenario 4			
	Short term release	Continuous release for remainder of year	Short term release	Continuous release for remainder of year	Short term release	Continuous release for remainder of year	Short term release	Continuous release for remainder of year	Short term release	Continuous release for remainder of year
Tritium	7.5E+10	9.3E+11		1.0E+12		1.0E+12		1.0E+12	1.0E+12	0.0E+00
Carbon-14	7.5E+08	9.3E+09		1.0E+10		1.0E+10		1.0E+10	1.0E+10	0.0E+00
Phosphorus-32		1.0E+09	1.0E+08	9.0E+08		1.0E+09		1.0E+09	1.0E+09	0.0E+00
Strontium-89		1.0E+06		1.0E+06	1.0E+05	9.0E+05		1.0E+06	1.0E+06	0.0E+00
Strontium-90		1.0E+07		1.0E+07	1.0E+06	9.0E+06		1.0E+07	1.0E+07	0.0E+00
Iodine-125		1.0E+10		1.0E+10		1.0E+10	1.0E+09	9.0E+09	1.0E+10	0.0E+00
Iodine-131		1.0E+12		1.0E+12		1.0E+12	1.0E+11	9.0E+11	1.0E+12	0.0E+00

Table B3 12 month limits and quarterly notification levels - Example limits / notification levels and typical short term release scenarios

Radionuclide	12 month limits (Bq)	Quarterly notification (Bq)	Typical release scenario 1 (Bq)	Typical release scenario 2 (Bq)	Typical release scenario 3 (Bq)	Typical release scenario 4 (Bq)
Tritium	1.0E+12	3.0E+11	✓			
Carbon-14	1.0E+10	3.0E+09	✓			
Phosphorus-32	1.0E+09	3.0E+08		✓		
Strontium-89	1.0E+06	3.0E+05			✓	
Strontium-90	1.0E+07	3.0E+06			✓	
Iodine-125	1.0E+10	3.0E+09				✓
Iodine-131	1.0E+12	3.0E+11				✓

Table B4 12 month limits and quarterly notification levels - Short term release assessment scenarios for realistic and cautious assumptions

Radionuclide	Realistic assumptions (Bq)								Cautious assumptions (Bq)	
	Release scenario 1		Release scenario 2		Release scenario 3		Release scenario 4			
	Short term release	Continuous release for remainder of year	Short term release	Continuous release for remainder of year	Short term release	Continuous release for remainder of year	Short term release	Continuous release for remainder of year	Short term release	Continuous release for remainder of year
Tritium	3.0E+11	7.0E+11		1.0E+12		1.0E+12		1.0E+12	3.0E+11	7.0E+11
Carbon-14	3.0E+09	7.0E+09		1.0E+10		1.0E+10		1.0E+10	3.0E+09	7.0E+09
Phosphorus-32		1.0E+09	3.0E+08	7.0E+08		1.0E+09		1.0E+09	3.0E+08	7.0E+08
Strontium-89		1.0E+06		1.0E+06	3.0E+05	7.0E+05		1.0E+06	3.0E+05	7.0E+05
Strontium-90		1.0E+07		1.0E+07	3.0E+06	7.0E+06		1.0E+07	3.0E+06	7.0E+06
Iodine-125		1.0E+10		1.0E+10		1.0E+10	3.0E+09	7.0E+09	3.0E+09	7.0E+09
Iodine-131		1.0E+12		1.0E+12		1.0E+12	3.0E+11	7.0E+11	3.0E+11	7.0E+11

Table B5 Monthly limits - Example limits and typical short term release scenarios

Radionuclide	Monthly limits (Bq)	Typical release scenario 1 (Bq)	Typical release scenario 2 (Bq)	Typical release scenario 3 (Bq)	Typical release scenario 4 (Bq)
Tritium	1.0E+11	✓			
Carbon-14	1.0E+09	✓			
Phosphorus-32	1.0E+08		✓		
Strontium-89	1.0E+05			✓	
Strontium-90	1.0E+06			✓	
Iodine-125	1.0E+09				✓
Iodine-131	1.0E+11				✓

Table B6 Monthly limits - Short term release assessment scenarios for realistic and cautious assumptions

Radionuclide	Realistic assumptions (Bq)								Cautious assumptions (Bq)	
	Release scenario 1		Release scenario 2		Release scenario 3		Release scenario 4			
	Short term release	Continuous release for remainder of year	Short term release	Continuous release for remainder of year	Short term release	Continuous release for remainder of year	Short term release	Continuous release for remainder of year	Short term release	Continuous release for remainder of year
Tritium	1.0E+11	1.1E+12		1.2E+12		1.2E+12		1.2E+12	1.0E+11	1.1E+12
Carbon-14	1.0E+09	1.1E+10		1.2E+10		1.2E+10		1.2E+10	1.0E+09	1.1E+10
Phosphorus-32		1.2E+09	1.0E+08	1.1E+09		1.2E+09		1.2E+09	1.0E+08	1.1E+09
Strontium-89		1.2E+06		1.2E+06	1.0E+05	1.1E+06		1.2E+06	1.0E+05	1.1E+06
Strontium-90		1.2E+07		1.2E+07	1.0E+06	1.1E+07		1.2E+07	1.0E+06	1.1E+07
Iodine-125		1.2E+10		1.2E+10		1.2E+10	1.0E+09	1.1E+10	1.0E+09	1.1E+10
Iodine-131		1.2E+12		1.2E+12		1.2E+12	1.0E+11	1.1E+12	1.0E+11	1.1E+12