NDAWG

National Dose Assessment Working Group

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Short-term Releases to the Atmosphere

NDAWG Short-term Release Sub-group

The views presented in this paper are those of the authors in consultation with members of NDAWG. They represent the views of the majority of members of NDAWG but do not necessarily reflect the views of the organisations from which the members are drawn.

SUMMARY

The NDAWG short-term release sub-group has recommended general guidance for assessing short-term releases to atmosphere 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 atmosphere.

Dose[1] per unit release data, for short-term releases to the atmosphere, have been calculated for some radionuclides using the recommended realistic and cautious assumptions. In addition, doses to members of the public living near to an Advanced Gas-cooled Reactor (AGR) and a cyclotron have been estimated. The dose per unit release results and case studies have shown that where there are limits in place, that are typically an order of magnitude less than the authorised annual discharge limits (eg, monthly limits), estimates of dose using the **realistic** short-term release assessment described here for a **single** release are unlikely to be more than a factor of three greater than those estimated from a continuous release assessment. Where there are only annual limits in place, **and it is cautiously assumed that discharges occur at these limits over a short period of time**, then doses from the assessment of a **single realistic** short-term release are a factor of about 20 greater than doses from the continuous release assessment. In addition, it is possible that multiple short-term releases may occur. In such circumstances, it is recommended that only the additional contribution from external and inhalation doses are included in the overall dose assessment and not the ingestion dose because multiple discharges are unlikely to coincide with multiple harvests. Nevertheless, the total dose may increase significantly as a result of these multiple releases.

[1] In this report the term dose is used to refer to effective dose and is the sum of the annual external effective dose and the committed effective dose for intakes over a year. The exposure pathways included are those of most radiological significance for the radionuclides considered.

CONTENTS

1 INTRODUCTION

1.1 The Radioactive Substances Act 1993 (RSA 93) provides the framework for controlling the generation and disposal of solid, liquid and gaseous radioactive waste so as to protect the public and the environment. In particular, RSA 93 requires prior authorisation for the disposal or discharge of radioactive waste to the environment. RSA 93 will be replaced by new environmental permitting regulations for England and Wales in 2010. Responsibility for granting an authorisation rests with the Environment Agency (in England and Wales), the Scottish Environment Protection Agency (SEPA) and the Northern Ireland Environment Agency.

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 (now Northern Ireland Environment Agency) 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 that 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 The purpose of this paper is to provide guidance on assessing the doses from planned short-term releases to inform the process of proposing or setting short-term limits/notification levels.

2 PATTERN OF DISCHARGES TO THE ATMOSPHERE

2.1 In England and Wales, there are about 300 RSA 93 authorisations with releases to air. The majority of these authorised discharges are from non-nuclear users. In Scotland, there are around 76 premises with authorisations for releases to air.

2.2 Authorisations for radioactive discharges from nuclear sites generally have 12 month rolling limits, with some quarterly notification levels (QNL) and/or weekly advisory levels (WAL). Nearly all non-nuclear discharge authorisations have monthly limits (ML), rather than annual or 12-monthly limits. There are some authorisations with daily limits (DL) and 12-month limits.

2.3 Patterns of discharge for a nuclear power reactor and cyclotron are shown in Figures 1 and 2 for illustrative purposes.

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 that is released. This may result, for example, from the production of different batches of radiopharmaceuticals.

3 GENERAL ASSESSMENT GUIDANCE

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

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

- 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.

- 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 6] 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.

4 ASSESSMENT ASSUMPTIONS

4.1 The assumptions for a realistic or cautious assessment of a short-term release to atmosphere, as recommended by the NDAWG short-term releases subgroup, are given in Table 1. The Principles document [Ref 5] states that assessments should be realistic, hence these are the assumptions that should ideally be used. Cautious assumptions may be used for the purposes of an initial assessment. Pessimistic assumptions should be avoided for the purpose of authorising discharges of radioactive substances.

4.2 The source term used in the short-term release assessment will depend upon the limits or notification levels in place. For releases to the atmosphere these include 12-month rolling limits, QNL, ML, WAL and DL. A single release of all radionuclides at the 12-monthly limits may need to be assumed if there are no shorter term notification levels or limits in place. However, it may be possible to demonstrate that there are only short-term releases of some of the radionuclides.

4.3 Where there are short-term notification levels or limits in place, such as QNL or ML, then it is assumed that for each short-term release all radionuclides are discharged at these levels or limits. Alternatively, a site-specific short-term release scenario may be modelled if data are available.

4.4 The number of short-term releases impacting on a particular group of individuals can be estimated in the following way. Wind direction data are often recorded to the nearest 30 degrees. As a first approximation it is therefore assumed that the area around the site is divided into 12 sectors. If the windrose is assumed to be uniform then, on average, the wind is likely to blow into each sector for 1/12 of the time. Therefore, only 1/12 of the annual number of short-term releases are likely to affect the same group of individuals. Consequently, if ML are in place then only 1 short-term release at these limits should be considered, whereas if DL are in place then some 30 short-term releases might be considered. However, this will also depend on operational experience, whether multiple releases are feasible and may be restricted by longer-term discharge limits. The modelling of multiple short-term releases is somewhat cautious because the assumption is that each release coincides with poor meteorological conditions, high occupancies and the predetermined wind direction. Where regular short-term releases occur (eg, scheduled every Friday) careful consideration may be required as to whether there is the potential for correlation with habits (eg, jogging club meet every Friday). Indeed, planned short-term releases could be scheduled not to coincide with certain events such as poor meteorological conditions however this requirement is not imposed because it could result in undue constraints on operational practice. Multiple discharges are unlikely to coincide with multiple harvests and therefore it is recommended that only the additional contribution from external and inhalation doses are included in the overall dose assessment and not the ingestion dose.

4.5 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.

4.6 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.

4.7 It may be argued that the radiological impact of a short-term planned release of radionuclides to the atmosphere should be assessed in the same way as a short-term accidental release. The radiological impact of an accidental release is typically assessed using a probabilistic approach in which the aim is to determine the likelihood of exceeding a number of health effects in a population. The release is assumed to occur during many different meteorological conditions. Doses and health effects are calculated for each meteorological sequence and plotted against probability of occurrence. These probabilities are combined with the probability that the release will actually occur to estimate a total risk. Whether this release is then acceptable is determined by comparison of the total risk with appropriate risk criterion. While it may be justified in some circumstances to adopt this approach for planned releases it is quite complicated and requires specialist tools. In addition, for a short-term planned release the risk to specific individuals would be of interest and at present legislation does not define what is an acceptable level of individual risk for this type of release. In this paper, a simpler deterministic approach to this problem has been developed.

5 ASSESSMENT METHODOLOGY

5.1 In this report the term dose is used to refer to effective dose and is the sum of the annual external effective dose and the committed effective dose for exposures occurring in the first year following the release. The exposure pathways included are those of most radiological significance for the radionuclides considered. It is acknowledged that for a continuous release assessment the dose in the 50th year from 50 years of discharge is usually assessed to account for accumulation of radionuclides in the environment. However, this assessment methodology suggests that the annual dose from a short-term release is dominated by exposures that occur during the year when the release takes place because there is little subsequent build up in the environment. Consequently, if a single short-term release occurs every year for 50 years there is little difference in the annual dose in the first year compared to the 50th year. Differences do arise in the annual dose received in the first and 50th years when the continuous release methodology is used and the dose is dominated by exposure to material deposited on the ground. For example, using the assumption detailed in Table 1 the annual adult dose (mSv) in the first and fiftieth years of a continuous release of 1GBq y^{-1} is estimated to be 3.9 10^{-4} and 3.27 10^{-3} respectively for ^{60}Co and 1.95 10^{-4} and 1.93 10^{-3} respectively for ^{137}Cs.

5.2 Dose per unit short-term release values have been calculated for a range of radionuclides based on the assumptions listed in Table 1. Both realistic and cautious assessment assumptions have been used. Further details of the methodology are given in Appendix A.

5.3 The methodology used to calculate dose per unit release values from short-term releases is based on the approach described in Reference 7. However, the radionuclides discharged by a cyclotron are not included in some of the models used in Reference 7 and therefore a simplified methodology has been developed to assess the doses arising from these discharges (Appendix A). The methodology for calculating dose per unit release values from continuous releases uses ADMS 4 [Ref 8] and PC CREAM [Ref 9].

5.4 The realistic annual dose to individual members of the public 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 dose per unit short-term release value (Sv per Bq released). However, dose per unit short-term release values are only available for particular release scenarios, ie, a ground level release, specific meteorological conditions, two release durations and receptor points located at 100 m and 500 m downwind of the source. If it is known that the scenario to be modelled differs significantly from these assumptions then it will be necessary to use the models and methods described to calculate more appropriate doses.

5.5 The cautious annual dose to individual members of the public 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 dose per unit short-term release value (Sv per Bq released). However, for the reasons given in paragraph 5.4 it may be necessary to use the models and methods described to calculate doses for the specific scenario being considered.

5.6 The annual dose to individual members of the public for a continuous release of a particular radionuclide may be calculated by multiplying the annual discharge of activity (Bq y^{-1}) by the appropriate dose per unit continuous release value (Sv per Bq y^{-1} released). Doses arising from the residual continuous discharges that occur in addition to a short-term release may be calculated in the same way. However, for the reasons given in paragraph 5.4 it may be necessary to use the models and methods described to calculate doses for the specific scenario being considered.

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 released at 1 TBq (representing 12-month limits) in a short-term release. No further discharges for remainder of year.
    - It should be noted that scenario 1 enables a comparison to be made of the different levels of caution for the situation where radionuclides are released entirely within a short period of time, there is no further continuous release of the radionuclides over the subsequent 12 months. In reality, it may be unrealistic to assume that all the radionuclides are released at the 12-month limit in a short period of time. In Table 1 it is advised that expected or planned short-term discharges be used for realistic assessments where only 12-month limits exist. If information on these expected releases is not available, and no short-term limits have been set, then it is really only possible to carry out a more cautious assessment.
- ***Scenario 2 – QNL***. All radionuclides cautiously released at 0.25 TBq (representing quarterly notification levels) in a single short-term release. Remainder of 12-month limits released continuously over the rest of the year.
- ***Scenario 3 – ML***. All radionuclides cautiously released at 0.083 TBq (representing monthly limits) in a single short-term release. Remainder of 12-month limits released continuously over the rest of the 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 source term (short-term plus remaining continuous release throughout the year) and the continuous release source term during the year equates to a unit release of 1 TBq.

6.3 For all generic release scenarios it is assumed that individuals live 100 m from the discharge point where they receive doses from inhalation and external exposure and that their food is derived from a location 500 m from the source from which they receive an ingestion dose.

6.4 For each scenario 1 to 3 the short-term releases have been assessed for three different sets of assumptions, one realistic and the other two cautious. The meteorological data used are detailed in Table A1. For example, for scenario 1:

- ***Scenario 1a (realistic) – unit release over 12 hours realistic neutral meteorological conditions***. One TBq of each radionuclide discharged in a short-term ground-level release. No further discharges for remainder of year. These meteorological conditions include rainfall.

- ***Scenario 1b (cautious) – unit release over 30 minutes cautious neutral meteorological conditions***. One TBq of each radionuclide discharged in a short-term ground-level release. No further discharges for remainder of year. These meteorological conditions include rainfall.

- ***Scenario 1c (cautious) – unit release over 30 minutes stable meteorological conditions***. One TBq of each radionuclide discharged in a short-term ground-level release. No further discharges for remainder of year. These meteorological conditions do not include rainfall.

6.5 Doses per unit short-term release for scenario 1 are presented in Figures 3 to 5 and Tables A10 to A21 of Appendix A along with the dose per unit continuous release values. Doses per unit short-term release for scenario 2 are presented in Figures 6 to 8 and those for scenario 3 are presented in Figures 9 to 11.

6.6 One of the important considerations when calculating doses for a short-term release is the meteorological conditions at the time of the release. The meteorological conditions defined in Tables 1 and A1 are recommended for the realistic and cautious short-term release assessments. Two sets of conditions are used to scope the potential impact of what would be considered as a cautious assessment. The continuous release assessment uses a range of meteorological conditions with different frequencies of occurrence and a uniform windrose (Table A1).

6.7 Doses assessed for members of the public for the realistic short-term release (scenario 1a) are shown in Tables A10, A14 and A18 of Appendix A. The ratios of short-term to continuous doses for adults, children and infants, as a function of radionuclide, are shown in Figures 3 to 5. These results suggest that the realistic short-term discharge assessment predicts doses that are about an order of magnitude greater than those estimated using the continuous discharge assessment for the same unit release of activity. In general, the ratios do not vary greatly over the age groups considered for a given radionuclide. The variation seen between radionuclides arises as a result of the relative importance of different exposure pathways and the half-life of the radionuclide. The picture is complicated by the fact that it has been necessary in some cases to use different models to predict uptake of radionuclides by plants and animals because the models for continuous releases are not suitable over shorter release durations for ^{3}H and ^{14}C. However, where more direct comparisons can be made, eg for ^{85}Kr and ^{133}Xe, it can be seen that the ratio is about a factor of 12. This is mainly due to the fact that for the continuous release a uniform wind rose is used so that the wind blows into a particular 30º sector for only 1/12 of the time.

6.8 Additional scaling factors need to be taken into account depending on the exposure pathway being considered. When comparing doses for exposures that occur following deposition onto the ground it must be recognised that not all the meteorological conditions used for the continuous release scenario include wet deposition (Table A1). The fraction of time during which wet deposition is assumed to occur for a continuous release is about 8% whereas for the realistic short-term release it assumed to be raining all the time but at a reduced rate. This rate is based on the findings of report NRPB-W54 [Ref 7]. An investigation of the impact of different rainfall rates (including dry periods) and durations would require these events to be modelled independently and a weighted averaged of the results to be taken, however, this has not been done in this report. For a dry deposition velocity of 1 10^{-3} m s^{-1} it is estimated that at 100 m and

500 m from the site the total deposition for the realistic case is about a factor of 2 greater than that for the continuous case. This factor will clearly impact on the doses from exposure pathways related to the deposition of radionuclides ie ingestion of foods, external exposure and inhalation of resuspended material. Differences in assumptions made about habit data (Table 1) will also affect dose estimates. The relative importance of these differences is radionuclide dependent. For example, the exclusion of milk products from the realistic assessment is an important consideration for doses from iodine. Specifically, the dose to adults from ingestion of ^{129}I in milk products at an average intake rate of 20 kg y^{-1} would amount to about 3 10^4 µSv for realistic scenario 1a. The difference in inhalation rates used during the passage of the plume for realistic (1.2 m^3 hr^{-1}) and continuous (0.92 m^3 hr^{-1}) assessments would account for a reduction of about 25% in the estimated inhalation dose if the latter were used in realistic scenario 1a and this may be important for actinides.

6.9 Doses assessed for members of the public for the cautious (neutral met conditions) short-term release (scenario 1b) are shown in Tables A11, A15 and A19 of Appendix A. The ratios of short-term to continuous doses for adults, children and infants, as a function of radionuclide, are shown in Figures 3 to 5. These results suggest that the cautious (neutral met conditions) short-term discharge assessment predicts doses that are between about one and two orders of magnitude greater than those estimated using the continuous discharge assessment depending on the radionuclide under consideration. In general, the ratios do not vary greatly over the age groups considered for a given radionuclide and the variation as a function of radionuclide is similar to that for the realistic scenario. However, the overall increase in this ratio can be explained when differences between the realistic and cautious (neutral met conditions) assessment methodologies are considered. The cautious assessment includes enhanced wet deposition and an increase in the release rate albeit over a shorter period of time. This increases the total deposition by a factor of about 2 at 100 m and 4 at 500 m for a dry deposition velocity of 1 10^{-3} m s^{-1}. In addition, doses from direct inhalation and external exposure to the plume both increase by factors of between 1 and 2. The inclusion of peak activity concentrations in vegetables means that concentrations in green vegetables, where direct deposition is important, are likely to be a factor of 20 greater than the integrated activity concentrations used in the realistic assessment and this results in a factor of 3 increase in total dose for some radionuclides such as ^{131}I. The inclusion of milk products in the cautious dose assessment increases the total dose, in particular the contribution from ^{129}I to the total ^{129}I cautious assessment dose increases by about 25%. The increased inhalation rate for adults during the passage of the plume would increase the inhalation dose by about 40% compared to that estimated for the realistic assessment. The fraction of time spent indoors during the passage of the plume is zero for the cautious assessment and could increase doses from external exposure to the plume by factors of about 2, 3 and 4 for adults, children and infants respectively in comparison to the realistic assessment.

6.10 Doses assessed for members of the public for the cautious (stable met conditions) short-term release (scenario 1c) are shown in Tables A12, A16 and A20 of Appendix A. The ratios of short-term to continuous doses for adults, children and infant, as a function of radionuclide are shown in Figures 3 to 8. These results suggest that the cautious (stable met conditions) short-term discharge assessment predicts doses that are consistently two orders of magnitude greater than those estimated using the continuous discharge assessment. In general, the ratios do not vary greatly over the age groups and distances considered for a given radionuclide and the variation as a function of radionuclide is similar to that for the realistic and cautious (neutral met conditions) scenarios. The further increase in this ratio compared with the cautious (neutral met conditions) scenario is due to the reduced dispersion of the plume in the stable meteorological conditions which, even without the contribution from rainfall, can lead to greater levels of deposition. More specifically, this increases the total deposition by a factor of about 2 at 100 m although there is little difference at 500 m for a dry deposition velocity of $1\ 10^{-3}$ m s^{-1}. In addition, doses from direct inhalation and external exposure to the plume both increase by factors of about 4 and 3 respectively.

6.11 For those radionuclides that might be released from a cyclotron, namely ^{11}C, ^{15}O and ^{18}F, the dose per unit short-term release values have been estimated using different assumptions from those adopted for other radionuclides. Only exposure to gamma radiation from the plume and inhalation of the plume are considered and the dispersion does not include dry or wet deposition. Also because releases from cyclotrons are likely to occur over periods of a few minutes it is assumed that the realistic short-term release has a duration of 30 minutes rather than 12 hours so that no account is taken of any enhanced wind meander. Consequently, differences in the predictions from the realistic and cautious (neutral met conditions) scenarios are due almost entirely to the assumptions made about the length of time individuals spend outdoors. The dose ratio for the cautious (stable met conditions) scenario is significantly greater primarily due to the reduced dispersion and hence increased activity concentration in air and gamma irradiation from the plume. There is little difference between ratios at 100 m and 500 m. Results for scenario 1a are shown in Figures 3 to 5.

6.12 For scenarios 2 and 3 the doses assessed for a short-term release (including the continuously released remainder) expressed as a ratio of the doses from a continuous release assessment are shown in Figures 6 to 11 for adults, children and infants. Figures 6 to 8 show that doses from a short-term realistic release assessment are unlikely to exceed those from a continuous release assessment by a factor of more than a factor of 10 when QNL are in place and by a factor of 3 when monthly notification levels are in place (Figures 9 to 11). These differences show the impact of reducing the levels of discharge used in the short-term release source term. They also demonstrate that where ML are in place and the dose from a continuous release assessment (which uses annual limits that are 12 times the ML) is less than 0.1 mSv in a year then a short-term release assessment is not required.

7 CASE STUDIES

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

- Case Study 1 – An Advanced Gas-cooled Reactor (AGR) using a combination of QNL and WAL, and a 12 hour release.
- Case Study 2 – Cyclotron using DL and a 30 minute release.

7.2 Case Study 1 – An Advanced Gas-cooled Reactor

7.2.1 Discharges at QNL and WAL from an AGR have been used in this case study. The discharge limits are provided in Table 3. Where a WAL has been used, ie for ^{35}S, two short-term releases of this radionuclide at this discharge level have been modelled, but only the contributions to dose from inhalation and external exposure have been included in accordance with guidance given in this report.

7.2.2 Cautious and realistic short-term release doses have been calculated to members of the public for radionuclides discharged at the specified short-term levels (see Figures 12 to 14 and Tables 4 to 6). In all cases a release duration of 12 hours has been assumed as a 30 minute duration is not considered reasonable for this scenario. The figures also show the contribution to dose of the remaining discharge that may be made over the rest of the year following the short-term event, although this contribution is not included in Tables 4 to 6. These remainder doses have been calculated by scaling results for the continuous release, such as those in Table 7 for adults, by the difference between the annual discharge limit and the short-term levels.

7.2.3 The difference in the magnitude of the dose between the short-term assessments and the continuous assessment is within a factor of 2 for adults and 3 for children and infants. These much closer results are due to the lower discharge rates at the short-term levels and the fact that a 12 hour release duration has been used for all short-term scenarios. The short-term levels are between about one fifth and one tenth of the annual discharge limit. It is worth noting that, compared to the realistic meteorological conditions, the cautious neutral conditions give rise to lower air concentrations for depositing radionuclides because of the enhanced wet deposition and plume depletion. The consequences of this are only obvious for the cloud beta doses because for inhalation and cloud gamma changes to other factors, namely inhalation rate and indoor occupancy, mask this reduction.

7.2.4 From Figure 12 it can be seen that the total annual adult dose for the realistic short-term scenario (including remaining discharges in the year) is about 100 μSv. For the cautious (neutral met conditions) and the cautious (stable met conditions) scenarios this dose is about 110 μSv and 150 μSv respectively. The total annual dose for a continuous release assessment is almost 90 μSv.

7.2.5 From Figure 13 it can be seen that the total annual child dose for the realistic short-term scenario (including remaining discharges in the year) is about 90 μSv. For the cautious (neutral met conditions) and the cautious (stable met conditions) scenarios this dose is about 110 μSv and 150 μSv respectively. The total annual dose for a continuous release assessment is about 70 μSv.

7.2.6 From Figure 14 it can be seen that the total annual infant dose for the realistic short-term scenario (including remaining discharges in the year) is about 150 μSv. For the cautious (neutral met conditions) and the cautious (stable met conditions) scenarios this dose is about 220 μSv and 290 μSv respectively. The total annual dose for a continuous release assessment is about 100 μSv. The dose to infants is dominated by ^{14}C in milk products.

7.2.7 It is important to note that a degree of caution has been included in this case study because it has been assumed that all the radionuclides are released together. In practice this is unlikely to be the case and more realistic source terms to be considered might include ^{3}H and ^{14}C during depressurisation, or ^{35}S and ^{41}Ar after depressurisation when a reactor is being brought back up to full power, or ^{60}Co if a filter fails or ^{131}I if a fuel element fails.

7.3 Case Study 2 – Cyclotron

7.3.1 Discharges at the DL for a cyclotron have been used in this case study. The discharge limits are provided in Table 3. It has been assumed that 3 short-term releases at the DL may occur. This number is based on the fact that the DL is 1/40 of the annual limit so 40 short-term releases may occur in a year. However, if a uniform windrose is assumed, as a first order approximation, then only 1/12 of these releases will occur when the wind is blowing into the 30º sector where the individuals of interest are located. It could be argued that the remaining 37 potential short-term releases will not contribute to the dose of the individuals being considered and that the residual discharge which occurs continuously over the rest of the year should exclude the total radioactivity from these 37 short-term releases. However, this report has taken a cautious approach and calculated the residual discharge as the difference between the annual limit and 3 times the DL.

7.3.2 Cautious and realistic short-term release doses have been calculated to members of the public for radionuclides discharged at 3 times the DL (Figures 15 to 17 and Tables 8 to 10). The DL applies to all positron-emitting radionuclides but in these calculations it has been applied to each radionuclide separately. In all cases a release duration of 30 minutes has been assumed because a 12 hour duration is considered unreasonable for this scenario. The contribution to dose of the remaining discharge that may be made over the rest of the year following the short-term event is small in comparison and not included in Tables 8 to 10. These remainder doses have been calculated by scaling results for the continuous release, such as those in Table 11 for adults, by the difference between the annual discharge limit and 3 times the DL.

7.3.3 Variations in dose between age groups and release scenarios (ie short-term realistic, short-term cautious and continuous) are due in a large part to differences in the external dose from the plume which is governed by the amount of time spent indoors. It is assumed that individuals are permanently outdoors in the cautious assessment and therefore these results vary very little across the age groups considered.

7.3.4 It should be noted that for this case study the annual doses estimated using the assumptions for a continuous release assessment are less than 0.02 mSv (see Section 3) and therefore short-term assessments would not be required. However, short-term assessments have been carried out here for illustrative purposes.

7.3.5 The largest adult doses arise from discharges of ^{18}F (Figure 15). For this radionuclide the annual adult dose for the realistic short-term scenario is about 4 μSv. For the cautious (neutral met conditions) and the cautious (stable met conditions) scenarios the corresponding dose is about 5 μSv and 19 μSv, respectively. The total annual dose for a continuous release assessment is 1.9 μSv.

7.3.6 The largest child doses arise from discharges of ^{18}F (Figure 16). For this radionuclide the annual child dose for the realistic short-term scenario is about 3 μSv. For the cautious (neutral met conditions) and the cautious (stable met conditions) scenarios the corresponding dose is about 5 μSv and 19 μSv, respectively. The total annual dose for a continuous release assessment is about 1.4 μSv.

7.3.7 The largest infant doses arise from discharges of ^{18}F (Figure 17). For this radionuclide the annual infant dose for the realistic short-term scenario is 3 μSv. For the cautious (neutral met conditions) and the cautious (stable met conditions) scenarios the corresponding dose is about 5 μSv and 20 μSv, respectively. The total annual dose for a continuous release assessment is about 1.3 μSv.

8 CONCLUSIONS

8.1 The NDAWG short-term release sub-group has recommended general guidance for assessing short-term releases to atmosphere 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 atmosphere.

8.2 Dose per unit short-term release data have been calculated for some radionuclides using the recommended cautious and realistic assumptions. These results can be used to estimate generic short-term doses by scaling to the actual discharge rates. Alternatively, where more site-specific information is available, the methods described can be used to determine doses for specific cases as has been done for the two case studies considered in this report. The dose per unit release results and case studies have shown that where there are limits in place, that are typically an order of magnitude less than the authorised annual discharge limits (eg, monthly limits), estimates of dose for a realistic short-term release assessment may only be a factor of 3 higher than the doses from a continuous release assessment. Where there are only 12-month limits in place, doses for a realistic short-term release assessment may be a factor of 20 higher than the continuous release assessment.

8.3 Quantitative estimates of doses to embryo and fetus have not been considered but guidance [Ref 10] on the calculation of doses to these groups indicates that only for ^{33}P are doses likely to exceed those of any other age group, for an atmospheric routine release, and then by a factor of up to four.

9 RECOMMENDATIONS

9.1 This report will provide input to a guidance note for assessing doses to members of the public from reasonably foreseen or planned operational short-term releases of radioactive substances to air. However, it is noted that in some cases it may be difficult to follow this guidance and the following recommendation is made:

- The dose per unit short-term release values presented in this report may be used to scope the radiological impact of such events. However, where there is a need to carry out site-specific assessments the tools to achieve this are not readily available. The development of such tools should be considered.

10 ACKNOWLEDGEMENTS

10.1 The authors are indebted to the valuable comments provided by members of the NDAWG steering group and in particular to Dr Peter Marsden, Dr Tim Parker and Dr Mike Thorne.

11 REFERENCES

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12 TABLES

Table 1 Assumptions for assessing short-term releases to atmosphere

Parameter	Annual average dose	Realistic short-term dose	Cautious short-term dose
Number of years of discharge	50	1	1
Source term (see Appendix B for example applications)			
Limits – 12-month limits only (including no short-term limits/notification levels set)	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 wind blowing into the 30º sector where exposed individuals are located (ie, 1/12 for a uniform windrose), subject to a minimum of one release per year.	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 that 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 and 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 times monthly limits continuously throughout 12 month period	Separate sets of single short-term releases for the groups of radionuclides that 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 and 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.
Limits – 12-month limits and weekly advisory levels (12-month limits should be less than or equal to 52 weekly advisory levels)	All radionuclides at 12-monthly limits continuously throughout 12 month period	Separate sets of multiple short-term releases for the groups of radionuclides that would be expected to be released together in a short-term release. The radionuclides in each group will be released at their weekly advisory levels. The number of short-term releases should be based on the number of weekly advisory limits that are possible in a year (ie, not exceeding 12-month limit) multiplied by the probability of wind blowing into the 30º sector where exposed individuals are located (ie, 1/12 for a uniform windrose). There should be at least one short-term release per year and a maximum of four. The remaining releases of radionuclides up to the 12-month	Multiple short-term releases for all radionuclides at weekly advisory levels. The number of short-term releases should be based on the number of weekly advisory limits that are possible in a year (ie, not exceeding 12-month limit) multiplied by the probability of wind blowing into the 30o sector where exposed individuals are located (ie, 1/12 for a uniform windrose). There should be at least one short-term release per year and a maximum of four. The remaining releases of radionuclides up to the 12-month limits should be assessed as a

Table 1 Assumptions for assessing short-term releases to atmosphere

Parameter	Annual average dose	Realistic short-term dose	Cautious short-term dose
		limits should be assessed as a continuous release.	continuous release.
Limits – 12 month limits and daily limits	All radionuclides at 12-monthly limits continuously throughout 12 month period	Separate sets of multiple short-term releases for the groups of radionuclides that can be released together in a short-term release. The radionuclides in each group will be released at their daily limits. The number of short-term releases should be based on the number of daily limits that are possible in a year (ie, not exceeding 12-month limit) multiplied by the probability of wind blowing into the 30º sector where exposed individuals are located (ie, 1/12 for a uniform windrose). There should be at least one short-term release per year and a maximum of 30. The remaining releases of radionuclides up to the 12-month limits should be assessed as a continuous release.	Multiple short-term releases for all radionuclides at daily limits. The number of short-term releases should be based on the number of daily limits that are possible in a year (ie, not exceeding 12-month limit) multiplied by the probability of wind blowing into the 30º sector where exposed individuals are located (ie, 1/12 for a uniform windrose). There should be at least one short-term release per year and a maximum of 30. The remaining releases of radionuclides up to the 12-month limits should be assessed as a continuous release.
Release duration	Continuous over year	Actual/12 hours (for ^{11}C, $^{15}0$ and ^{18}F the default is assumed to be 30 min)	Actual/30 min
Release height	Actual/ground level	Actual/ground level	Actual/ground level
Meteorological modelling	Average uniform or actual wind rose	Wind blows towards critical group and food crop. Modified average weather (broadly representative of 75th percentile of annual actual weather).	Wind blows towards critical group and food crop. Cautious actual weather (broadly representative of 95th percentile).
Location of local food source	Actual/500 m from site	Actual/500 m from site on plume centre line	Actual/point of maximum deposition
Location of critical group habitation	Actual/100 m from site	Actual/100 m from site on plume centre line	Actual/point of maximum activity concentration in air
Food concentrations	Value representative of annual average concentrations.	Integrated concentrations assuming instantaneous deposit in summer.	Vegetable peak concentrations to represent storage. Milk, meat integrated concentrations assuming instantaneous deposit. Assume summer release.

Table 1 Assumptions for assessing short-term releases to atmosphere

Parameter	Annual average dose	Realistic short-term dose	Cautious short-term dose
Ingestion rates Food groups: green vegetables, fruit, root vegetables, milk, milk products, grain, cow meat, cow offal, sheep meat, sheep offal.	Two most important foods at 95^{th} percentile of national distribution, the rest at 50^{th} percentile of national distribution. Grain not included. Or site-specific data.	Two most important foods at 95^{th} percentile of national distribution, the rest at 50^{th} percentile of national distribution. Milk products and grain are not included. Or site-specific data.	Two most important foods at 95^{th} percentile of national distribution, the rest at 50^{th} percentile of national distribution. Grain not included. Or site-specific data.
Fraction of food consumption derived locally	1 Or site-specific data.	1 Or site-specific data.	1 Or site-specific data.
Air concentrations for inhalation and external dose from plume.	Use annual average air concentration in plume.	Use average air concentration over release duration.	Use average air concentration over release duration.
Inhalation rate in plume (m^3 h^{-1}) [Ref 11]	Average over the year Adult (0.92) Child (0.64) Infant (0.22)	Adult (1.2 average over working day for light work) Child (0.87) Infant (0.31)	Adult (1.69 average over working day for heavy work) Child (0.87) Infant (0.31)
Exposure time to cloud-shine (h)	Adult 8760 Child 8760 Infant 8760	For entire passage of plume	For entire passage of plume
Fraction of time indoors during passage of plume	Adult 0.5 Child 0.8 Infant 0.9	Adult 0.5 Child 0.8 Infant 0.9	0
Location factor cloud gamma	0.2	0.2	-
Location factor cloud beta	1	1	-
Indoor dose reduction factor for inhalation	1	1	-
Deposition for external dose from ground and resuspension	Use annual average deposition rate and calculate integrated dose.	Use total deposit, assume it is instantaneous and calculate integrated dose.	Use total deposit, assume it is instantaneous and calculate integrated dose.

Table 1 Assumptions for assessing short-term releases to atmosphere

Parameter	Annual average dose	Realistic short-term dose	Cautious short-term dose
Time spent at location for deposited gamma / resuspension (h) and fraction of the year (%)	Adult 8760 (100%) Child 8760 (100%) Infant 8760 (100%)	Adult 8760 (100%) School children 7446 (85%) Infant 8760 (100%)	Adult 8760 (100%) Child 8760 (100%) Infant 8760 (100%)
Fraction of time indoors for deposited gamma and resuspension	Adult 0.5 Child 0.8 Infant 0.9	Adult 0.5 Child 0.8 Infant 0.9	Adult 0.5 Child 0.8 Infant 0.9
Location factor for deposited gamma	0.1	0.1	0.1
Indoor dose reduction factor for resuspension	1	1	1
Inhalation rate of resuspended material (m^3 h^{-1}) [Ref 11]	Average over the year Adult (0.92) Child (0.64) Infant (0.22)	Adult (0.92) Child (0.64) Infant (0.22)	Adult (0.92) Child (0.64) Infant (0.22)

Table 2 Generic release source terms for all radionuclides

Scenario	Short-term release			Continuous release for comparison with short-term scenario (TBq/y)
	Short-term release (TBq)	Continuous release for remainder of year (TBq/y)	Total release (TBq/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 Discharges used for case studies

Case study 1 – An Advanced Gas-cooled Reactor			
Radionuclide	**Continuous Annual Limit (Bq)**	**Short-term Quarterly Notification Level (Bq)**	**Historical monthly peaks (1991 - 2007) (Bq)**
H-3	$1.2\ 10^{13}$	$1.2\ 10^{12}$	$1.8\ 10^{12}$
C-14	$3.7\ 10^{12}$	$6.0\ 10^{11}$	$9.3\ 10^{11}$
S-35	$3.5\ 10^{11}$	$2.5\ 10^{10}$ [a]	$5.7\ 10^{10}$
Ar-41	$1.0\ 10^{14}$	$2.0\ 10^{13}$	$2.4\ 10^{13}$
Co-60	$1.0\ 10^{8}$	$1.5\ 10^{7}$	$6.9\ 10^{5}$
I-131	$1.5\ 10^{9}$	$6.0\ 10^{7}$	$6.0\ 10^{7}$

Case study 2 – A Cyclotron		
Radionuclide	**Continuous Annual Limit – to include all discharges (Bq)**	**Short-term Daily limit – to include all discharges (Bq)**
C-14	$4.0\ 10^{12}$	$1.0\ 10^{11}$ [b]
O-15		
F-18		

[a] Two discharges of ^{35}S are assumed to occur at this **weekly advisory level**

[b] Three discharges of these positron emitters at this daily limit are considered in the short-term assessment (see Section 7.3.1)

Table 4 Case Study 1 – Adult annual doses (Sv) at 1200 m from an AGR for realistic short-term release assessment

Radionuclide	Food	Cloud Beta	Cloud Gamma	Deposited Gamma	Inhalation	Total
H-3	2.02E-07	-	-	-	1.51E-08	2.17E-07
C-14	1.73E-05	9.19E-10	-	-	5.81E-07	1.79E-05
S-35	6.33E-06	2.55E-10	-	-	4.94E-08	6.38E-06
Ar-41	-	-	8.49E-07	-	-	8.49E-07
Co-60	3.99E-10	1.42E-13	1.27E-12	2.28E-09	1.10E-10	2.79E-09
I-131	1.61E-08	1.30E-12	7.87E-13	1.94E-10	2.93E-10	1.65E-08
Total	2.39E-05	1.18E-09	8.49E-07	2.47E-09	6.52E-07	**2.54E-05**

Table 5 Case Study 1 – Adult annual doses (Sv) at 1200 m from an AGR for cautious (neutral conditions) short-term release assessment

Radionuclide	Food	Cloud Beta	Cloud Gamma	Deposited Gamma	Inhalation	Total
H-3	1.45E-06	-	-	-	2.07E-08	1.47E-06
C-14	1.92E-05	9.19E-10	-	-	8.18E-07	2.00E-05
S-35	1.68E-05	2.49E-10	-	-	6.80E-08	1.69E-05
Ar-41	-	-	1.41E-06	-	-	1.41E-06
Co-60	5.18E-09	1.39E-13	2.06E-12	7.10E-09	1.51E-10	1.24E-08
I-131	6.32E-08	1.27E-12	1.28E-12	2.95E-10	4.03E-10	6.39E-08
Total	3.80E-05	1.17E-09	1.41E-06	7.39E-09	9.16E-07	**4.03E-05**

Table 6 Case Study 1 – Adult annual doses (Sv) at 1200 m from an AGR for cautious (stable conditions) short-term release assessment

Radionuclide	Food	Cloud Beta	Cloud Gamma	Dep Gamma	Inhalation	Total
H-3	1.27E-06	-	-	-	4.87E-08	1.32E-06
C-14	5.45E-05	2.60E-09	-	-	2.32E-06	5.68E-05
S-35	1.33E-05	6.08E-10	-	-	1.66E-07	1.35E-05
Ar-41	-	-	2.65E-06	-	-	2.65E-06
Co-60	1.57E-09	3.85E-13	3.98E-12	2.15E-09	4.19E-10	4.15E-09
I-131	6.75E-08	2.52E-12	2.39E-12	3.16E-10	8.04E-10	6.87E-08
Total	6.92E-05	3.23E-09	2.65E-06	2.47E-09	2.56E-06	**7.44E-05**

Table 7 Case Study 1 – Adult annual doses (Sv) at 1200 m from an AGR for continuous release assessment

Radionuclide	Food	Cloud Beta	Cloud Gamma	Dep Gamma	Inhalation	Total
H-3	9.41E-08	-	-	-	3.90E-08	1.33E-07
C-14	5.43E-06	1.00E-11	-	-	4.90E-07	5.92E-06
S-35	1.21E-05	3.00E-12	-	-	4.50E-08	1.21E-05
Ar-41	-	9.30E-09	6.00E-07	-	-	6.09E-07
Co-60	3.31E-10	1.70E-15	1.20E-12	7.10E-10	9.80E-11	1.14E-09
I-131	1.49E-07	5.30E-14	2.90E-12	6.70E-10	9.20E-10	1.51E-07
Total	1.78E-05	9.31E-09	6.00E-07	1.38E-09	5.79E-07	**1.90E-05**

Table 8 Case Study 2 – Annual doses (Sv) from a cyclotron for realistic short-term release assessment

	External dose (Sv)						Inhalation dose (Sv)					
	100 m			500 m			100 m			500 m		
	Adult	Child	Infant	Adult	Child	Infant	Adult	Child	Infant	Adult	Child	Infant
C-11	1.65E-06	9.91E-07	7.71E-07	1.08E-07	6.49E-08	5.05E-08	2.02E-07	2.79E-07	3.32E-07	1.32E-08	1.83E-08	2.17E-08
O-15	1.39E-06	8.36E-07	6.50E-07	4.62E-08	2.77E-08	2.16E-08	7.27E-09	-	-	2.41E-10	-	-
F-18	1.68E-06	1.01E-06	7.83E-07	1.17E-07	7.01E-08	5.45E-08	5.22E-07	7.56E-07	9.15E-07	3.64E-08	5.27E-08	6.37E-08

Table 9 Case Study 2 – Annual doses (Sv) from a cyclotron for cautious (neutral conditions) short-term release assessment

	External dose (Sv)						Inhalation dose (Sv)					
	100 m			500 m			100 m			500 m		
	Adult	Child	Infant	Adult	Child	Infant	Adult	Child	Infant	Adult	Child	Infant
C-11	2.75E-06	2.75E-06	2.75E-06	1.80E-07	1.80E-07	1.80E-07	2.84E-07	2.79E-07	3.32E-07	1.86E-08	1.83E-08	2.17E-08
O-15	2.32E-06	2.32E-06	2.32E-06	7.71E-08	7.71E-08	7.71E-08	1.02E-08	-	-	3.40E-10	-	-
F-18	2.79E-06	2.79E-06	2.79E-06	1.95E-07	1.95E-07	1.95E-07	7.35E-07	7.56E-07	9.15E-07	5.12E-08	5.27E-08	6.37E-08

Table 10 Case Study 2 – Annual doses (Sv) from a cyclotron for cautious (stable conditions) short-term release assessment

	External dose (Sv)						Inhalation dose (Sv)					
	100 m			500 m			100 m			500 m		
	Adult	Child	Infant	Adult	Child	Infant	Adult	Child	Infant	Adult	Child	Infant
C-11	1.37E-05	1.37E-05	1.37E-05	1.11E-06	1.11E-06	1.11E-06	1.41E-06	1.39E-06	1.65E-06	1.14E-07	1.12E-07	1.34E-07
O-15	1.06E-05	1.06E-05	1.06E-05	3.09E-07	3.09E-07	3.09E-07	4.68E-08	-	-	1.36E-09	-	-
F-18	1.40E-05	1.40E-05	1.40E-05	1.24E-06	1.24E-06	1.24E-06	3.68E-06	3.79E-06	4.58E-06	3.27E-07	3.37E-07	4.07E-07

Table 11 Case Study 2 – Annual doses (Sv) from a cyclotron for continuous assessment

	External dose (Sv)						Inhalation dose (Sv)					
	100 m			500 m			100 m			500 m		
	Adult	Child	Infant	Adult	Child	Infant	Adult	Child	Infant	Adult	Child	Infant
C-11	1.52E-06	9.13E-07	7.10E-07	1.10E-07	6.58E-08	5.12E-08	1.43E-07	1.89E-07	2.17E-07	1.03E-08	1.36E-08	1.56E-08
O-15	1.30E-06	7.79E-07	6.06E-07	5.05E-08	3.03E-08	2.36E-08	5.20E-09	-	-	2.02E-10	-	-
F-18	1.54E-06	9.26E-07	7.20E-07	1.18E-07	7.10E-08	5.52E-08	3.68E-07	5.12E-07	5.98E-07	2.82E-08	3.93E-08	4.58E-08

13 FIGURES

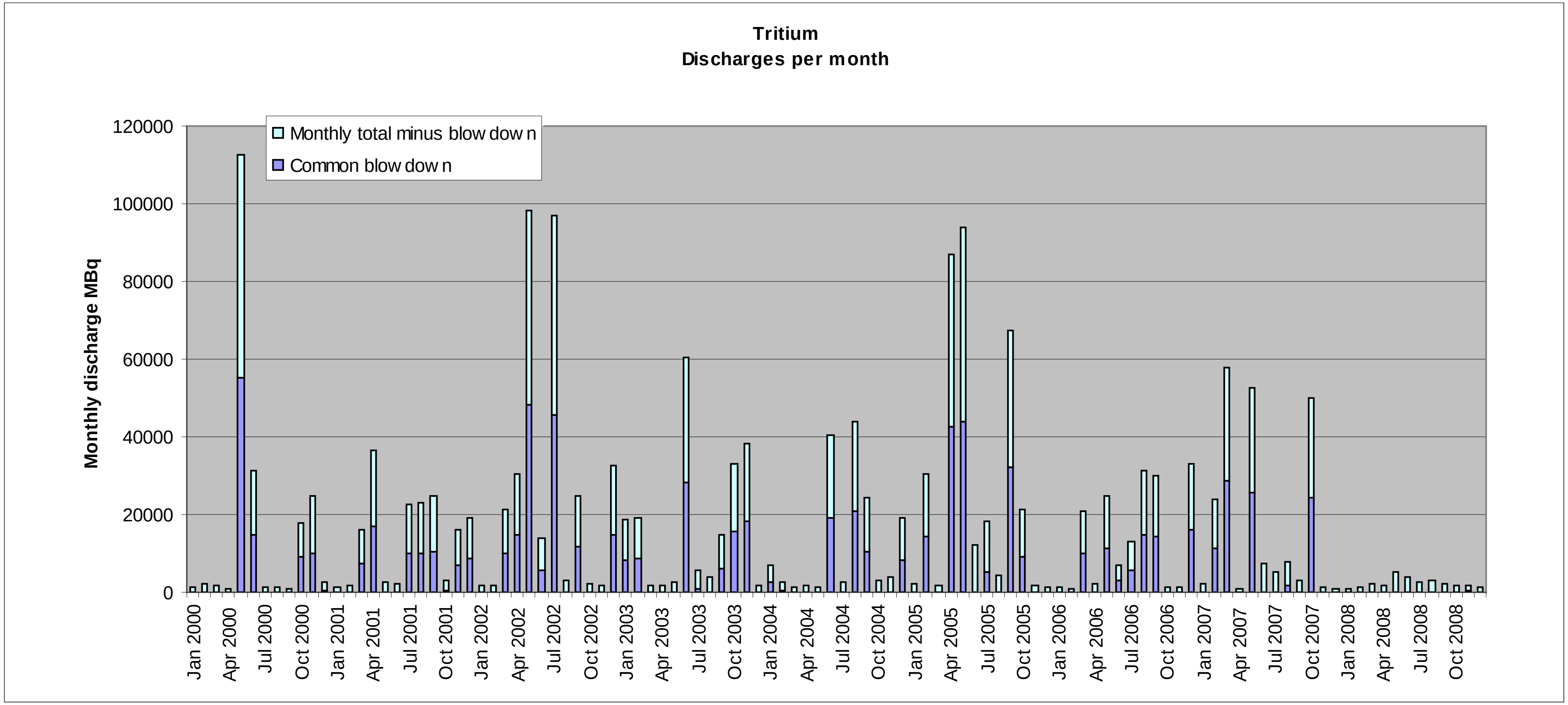

Figure 1a Discharge profile for 3H from an AGR for period 2000 to 2008

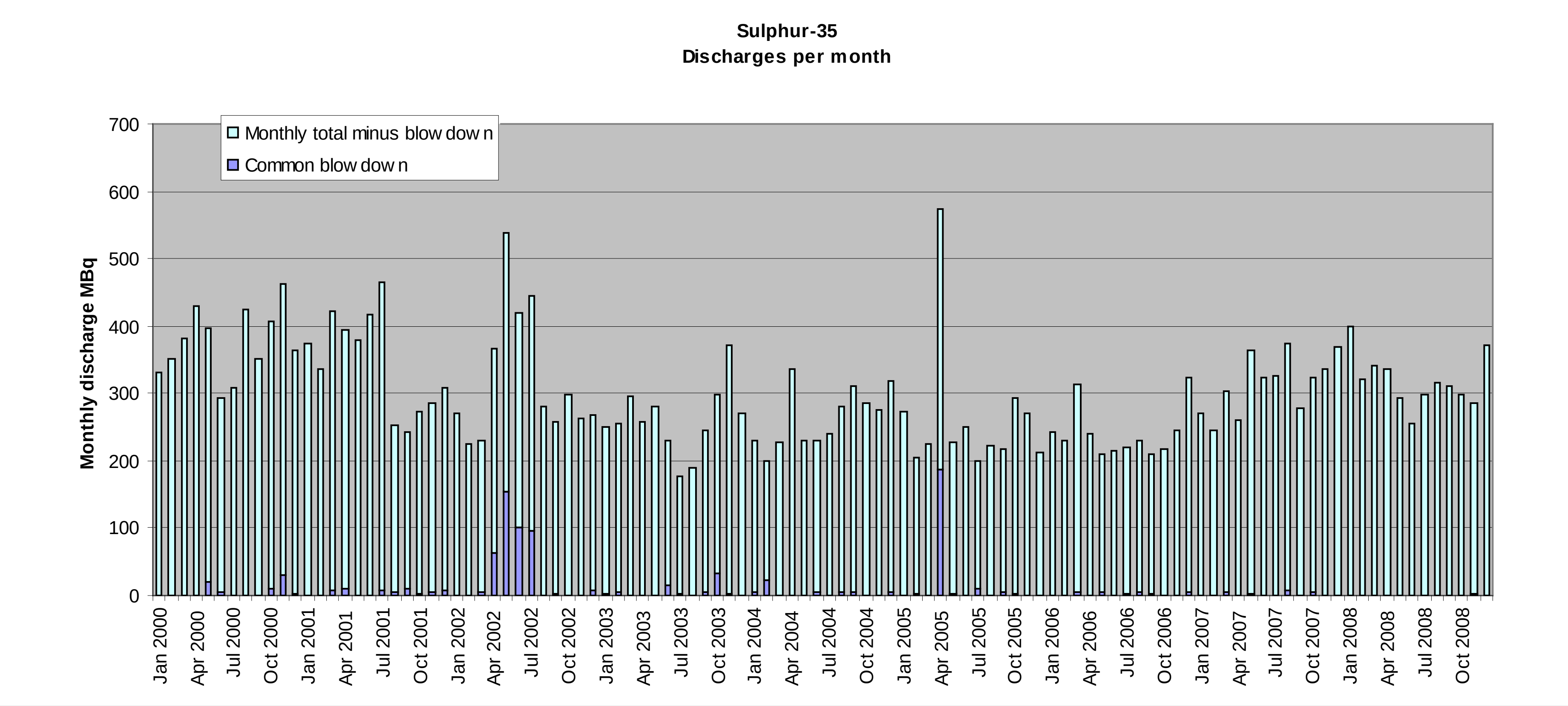

Figure 1b Discharge profile for 35S from an AGR for period 2000 to 2008

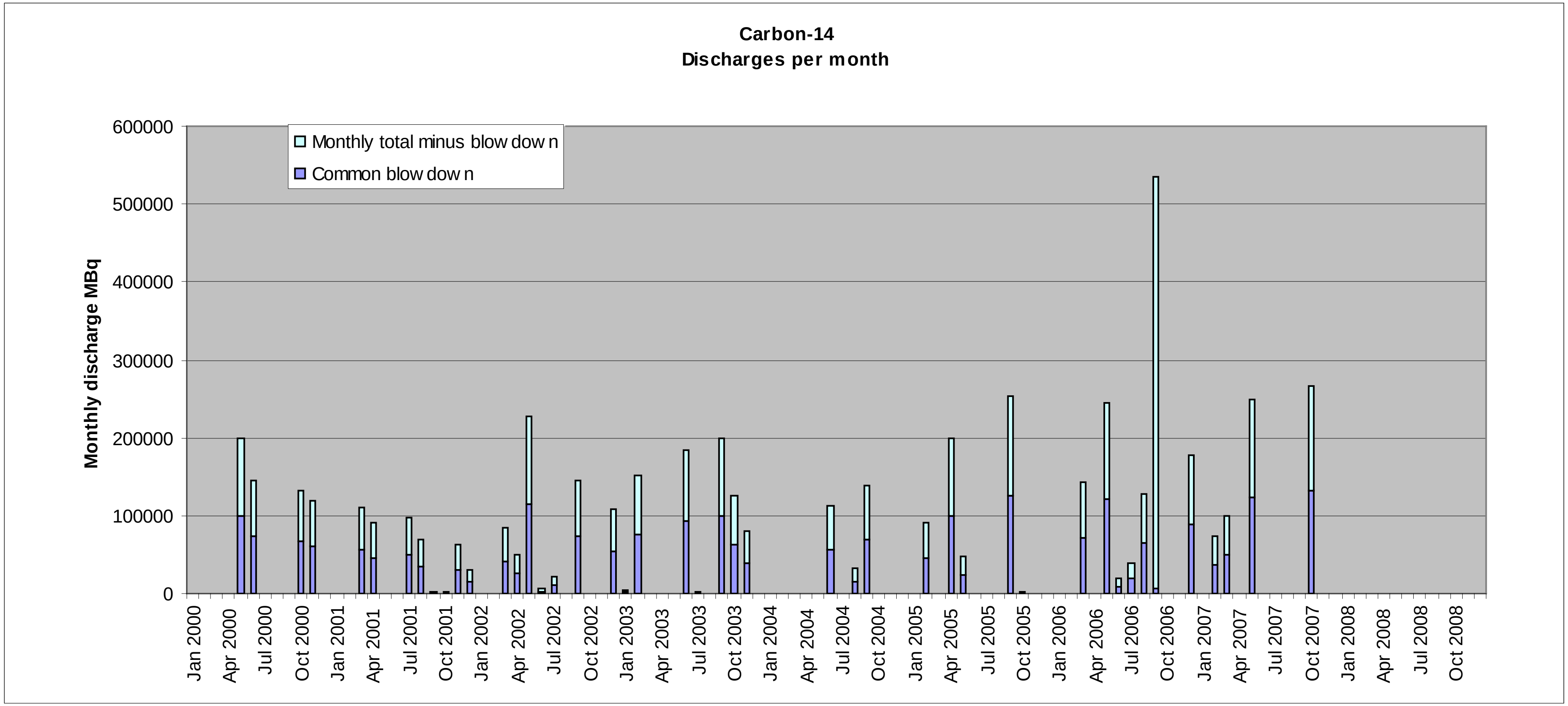

Figure 1c **Discharge profile for 14C from an AGR for period 2000 to 2008**

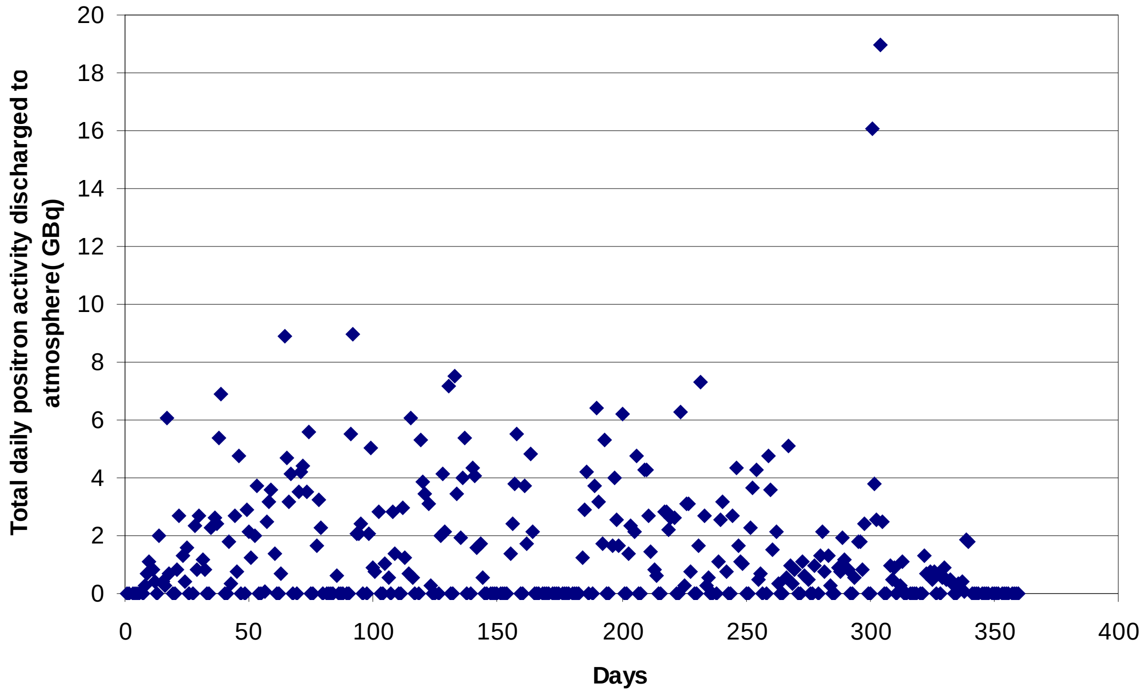

Figure 2 Discharge profile from the Hammersmith Imanet cyclotron. (Outliers exceeding 16 GBq were due to problems occurring with synthesis rigs where a waste trap did not capture all of the waste gases)

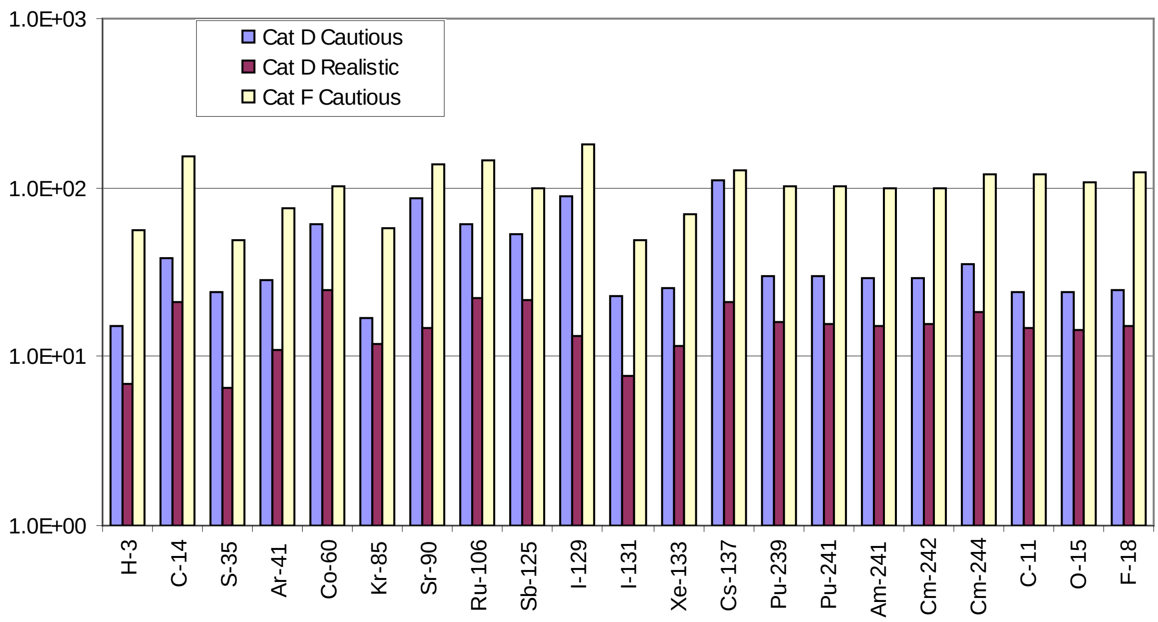

Figure 3 Ratios of adult dose from short-term release scenarios 1a to 1c to continuous release

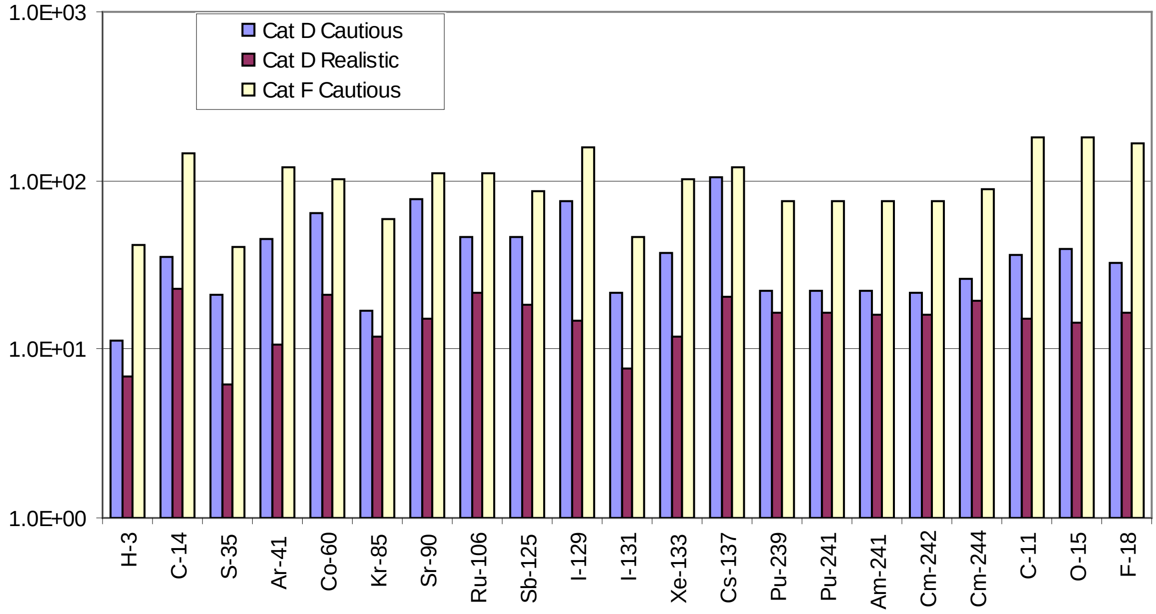

Figure 4 Ratios of child dose from short-term release scenarios 1a to 1c to continuous release

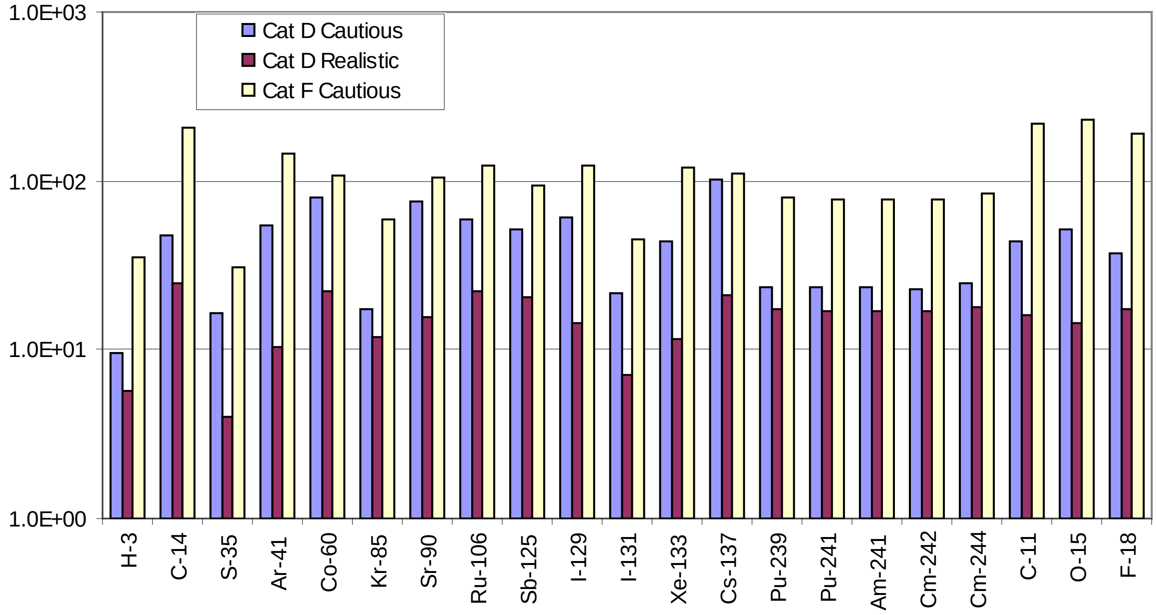

Figure 5 Ratios of infant dose from short-term release scenarios 1a to 1c to continuous release

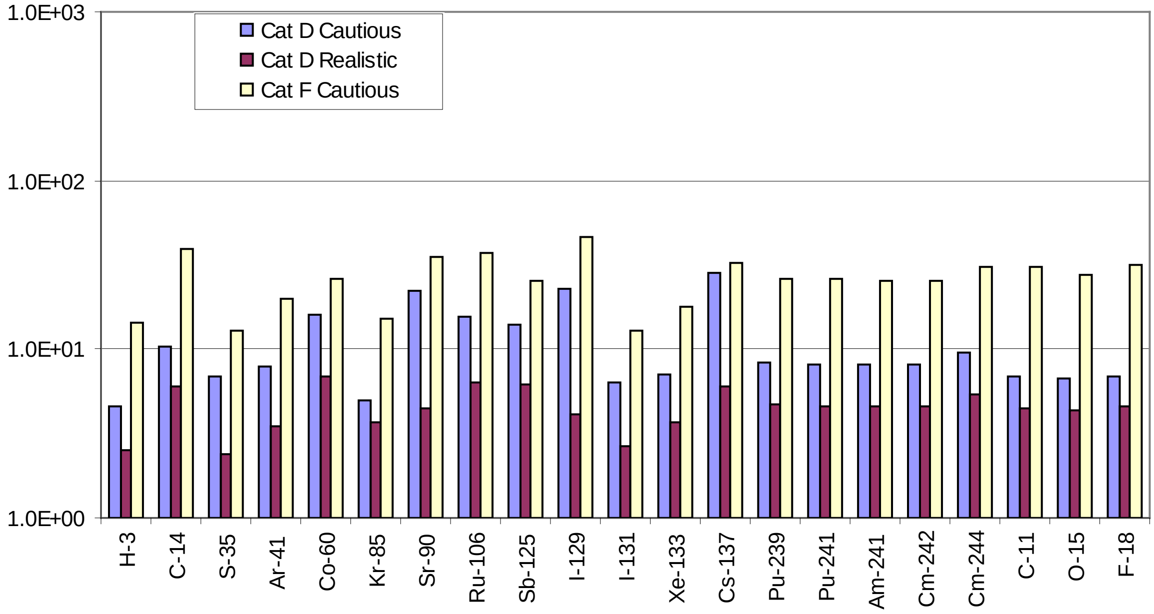

Figure 6 Ratios of adult dose from short-term release scenarios 2a to 2c to continuous release

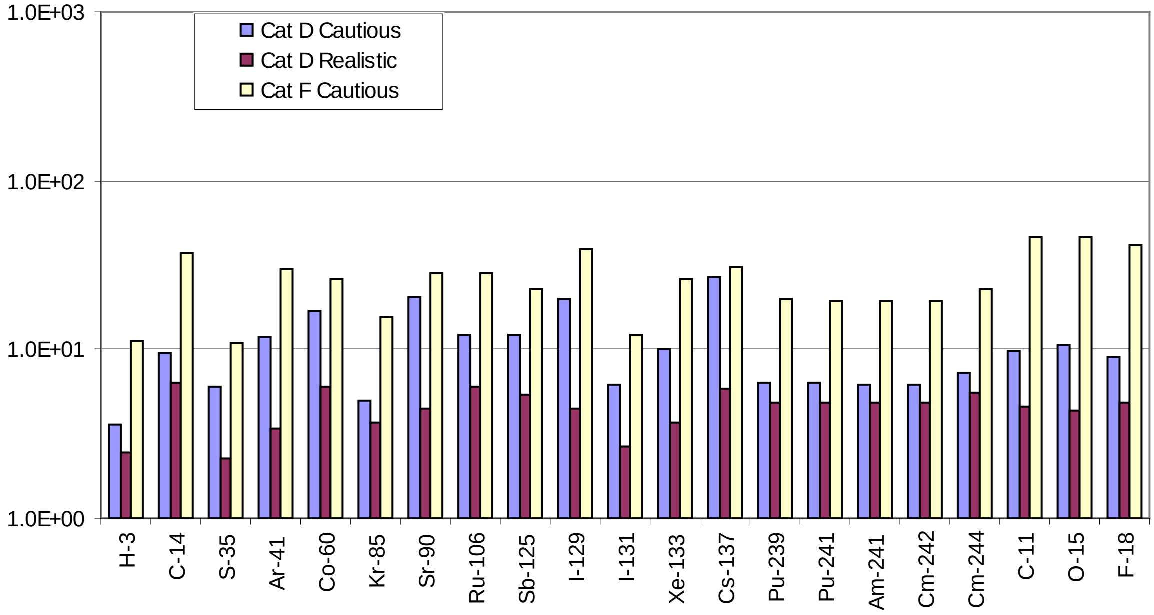

Figure 7 Ratios of child dose from short-term release scenarios 2a to 2c to continuous release

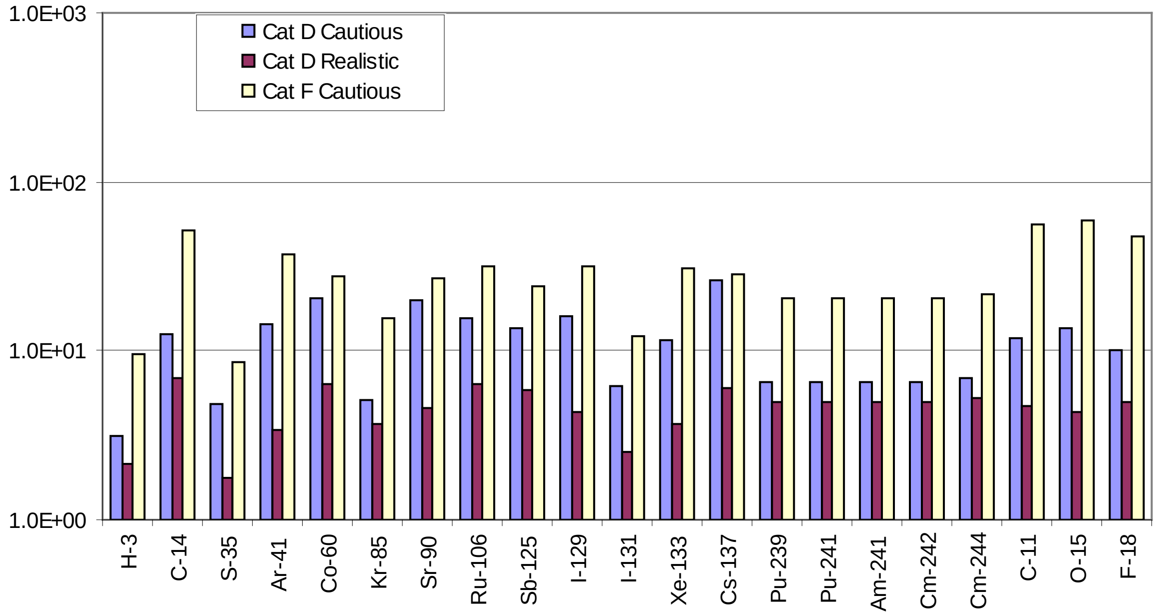

Figure 8 Ratios of infant dose from short-term release scenarios 2a to 2c to continuous release

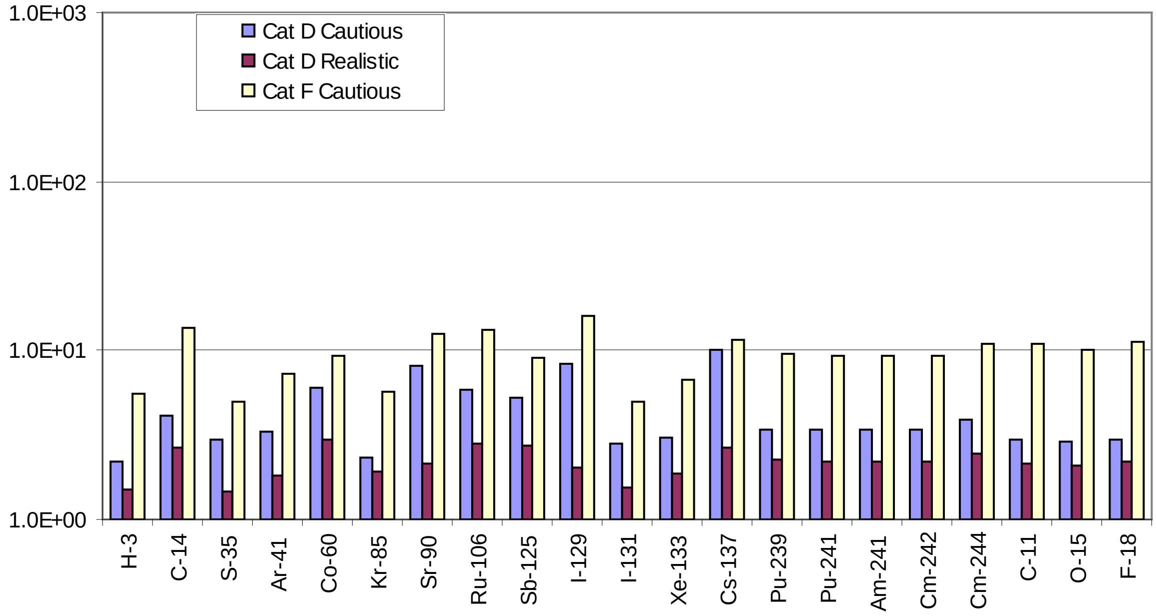

Figure 9 Ratios of adult dose from short-term release scenarios 3a to 3c to continuous release

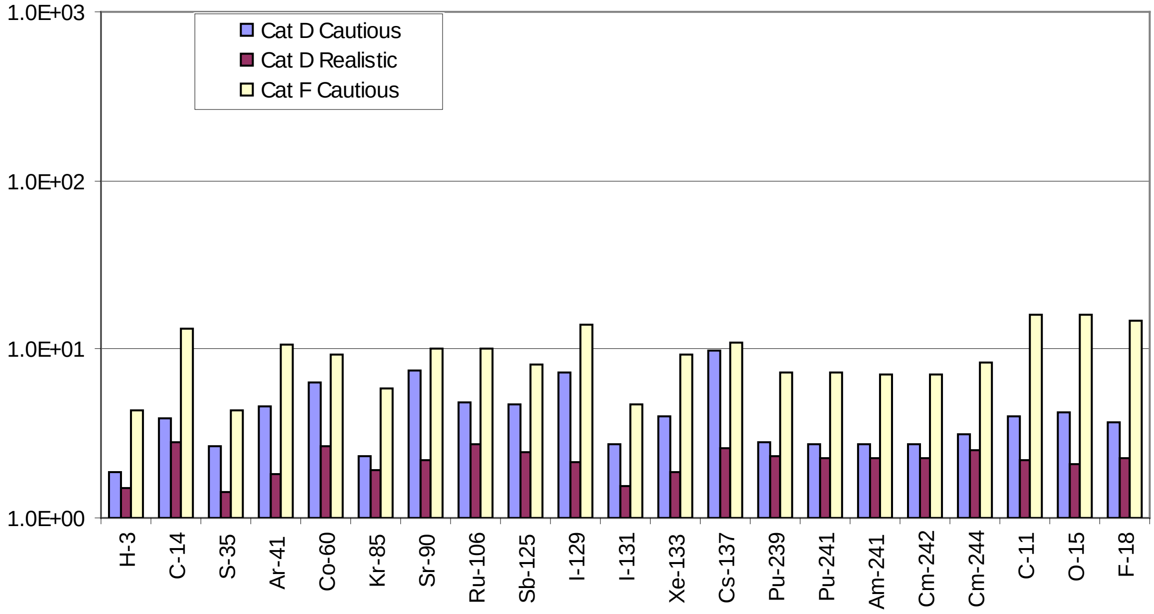

Figure 10 Ratios of child dose from short-term release scenarios 3a to 3c to continuous release

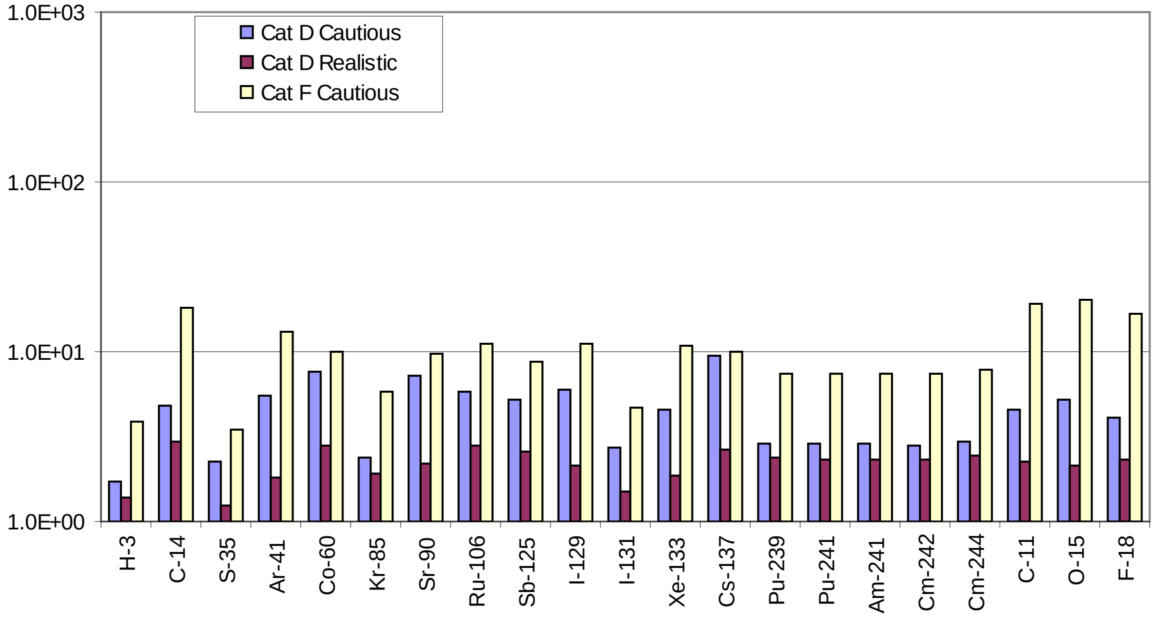

Figure 11 Ratios of infant dose from short-term release scenarios 3a to 3c to continuous release

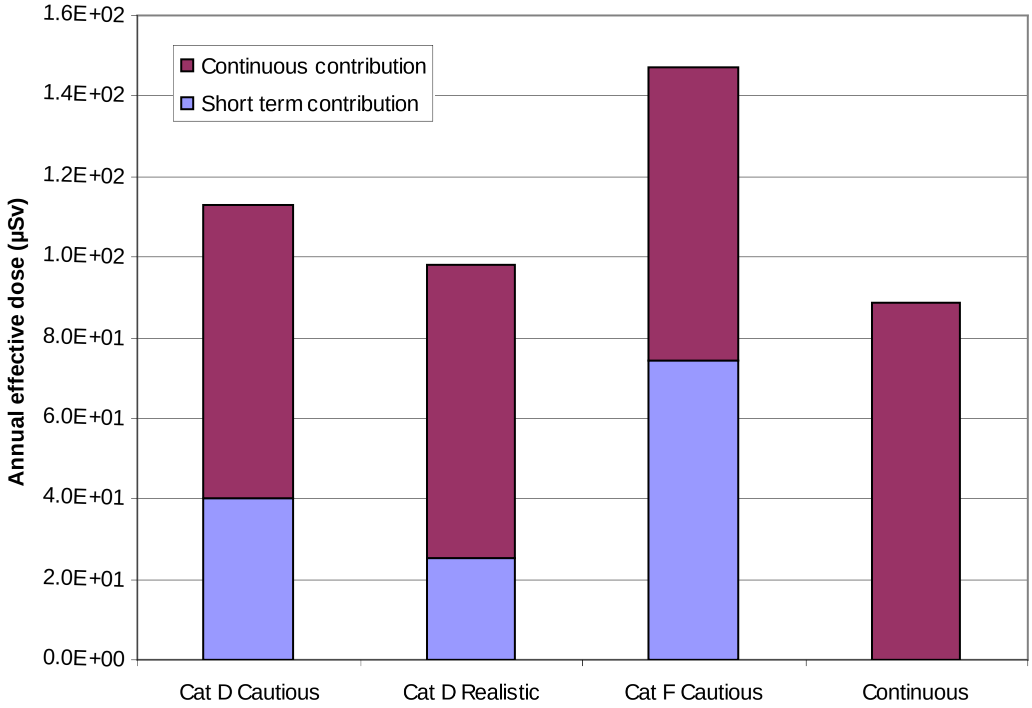

Figure 12 Case study 1 – Adult annual doses (µSv) at 1200 m from an AGR

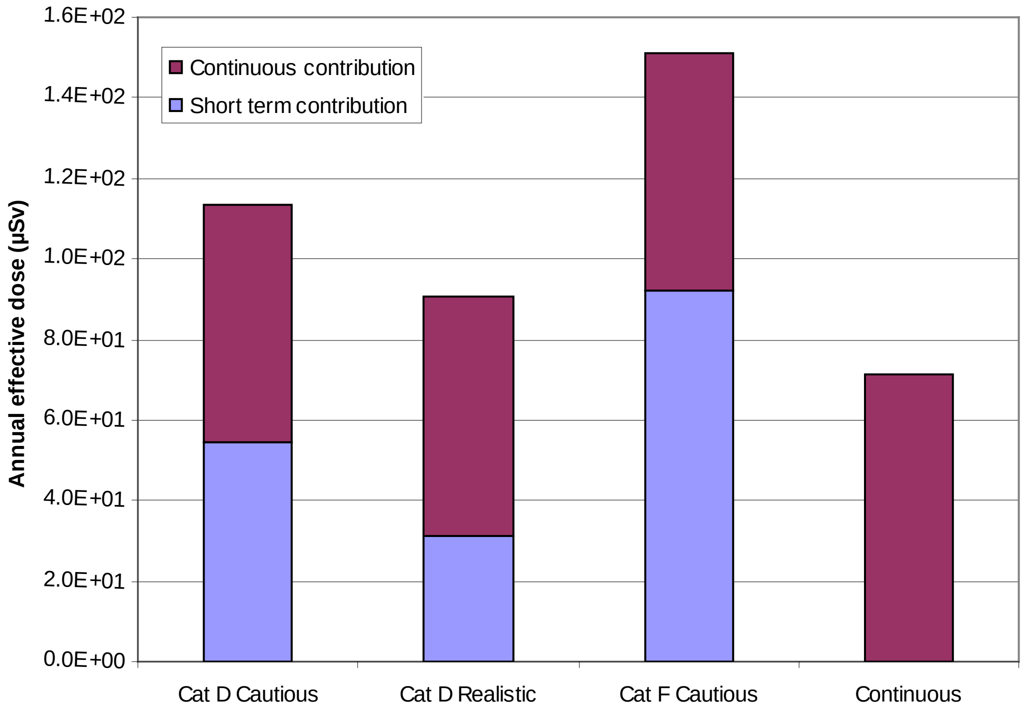

Figure 13 Case study 1 - Child annual doses (µSv) 1200 m from an AGR

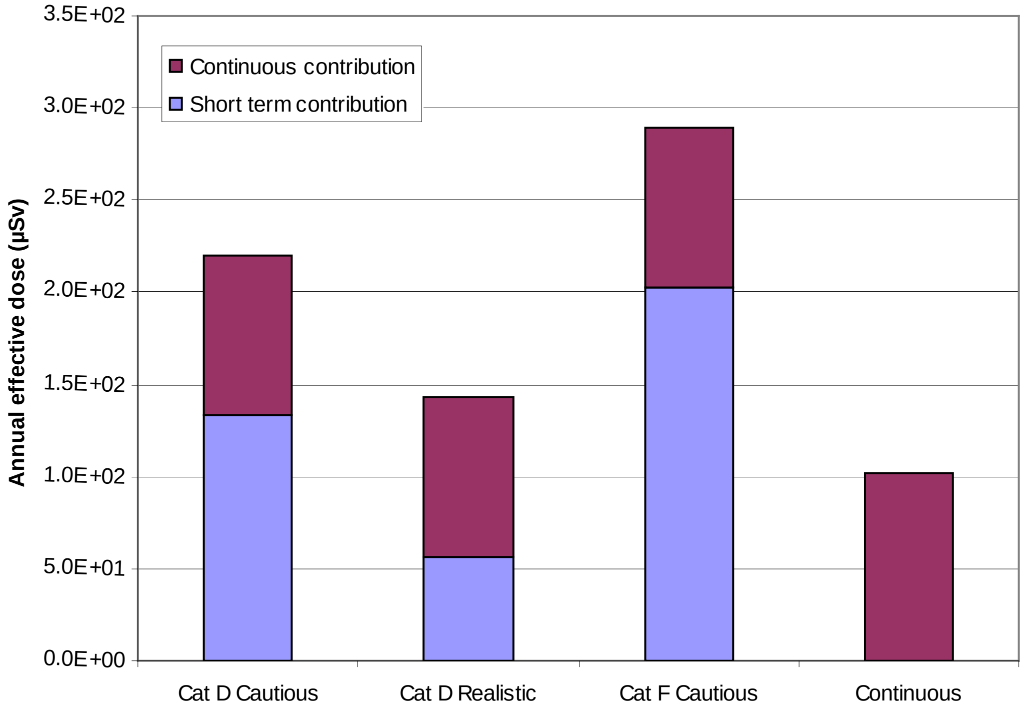

Figure 14 Case study 1 - Infant annual doses (µSv) 1200 m from an AGR

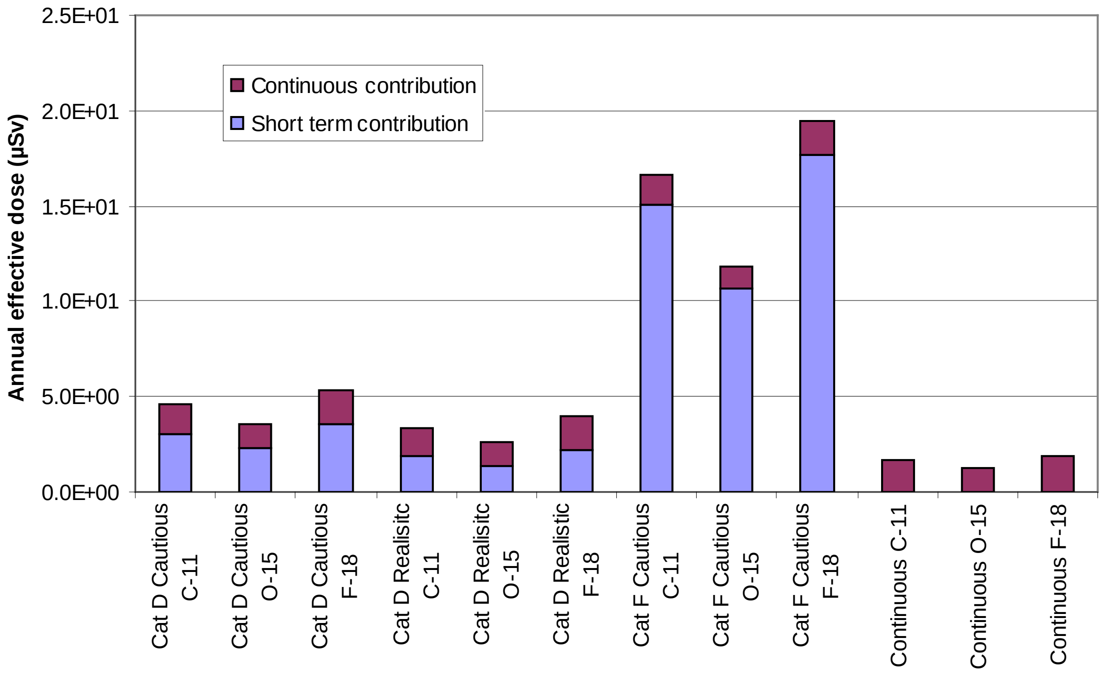

Figure 15 Case study 2 – Adult annual doses (µSv) at 100 m from cyclotron

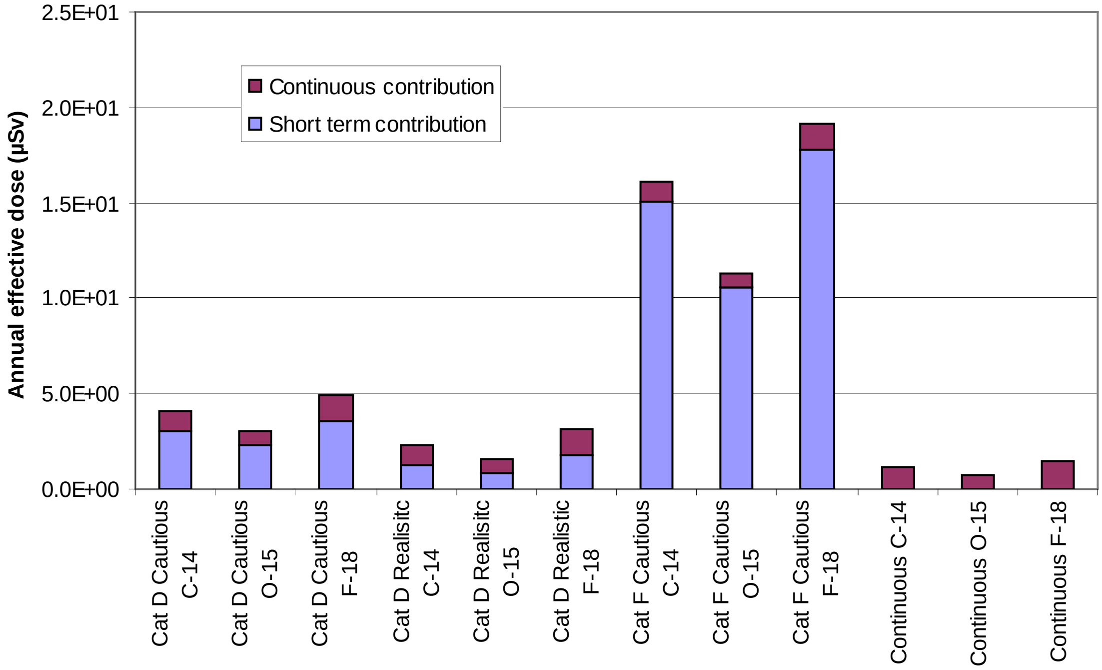

Figure 16 Case study 2 - Child annual doses (µSv) at 100 m from cyclotron

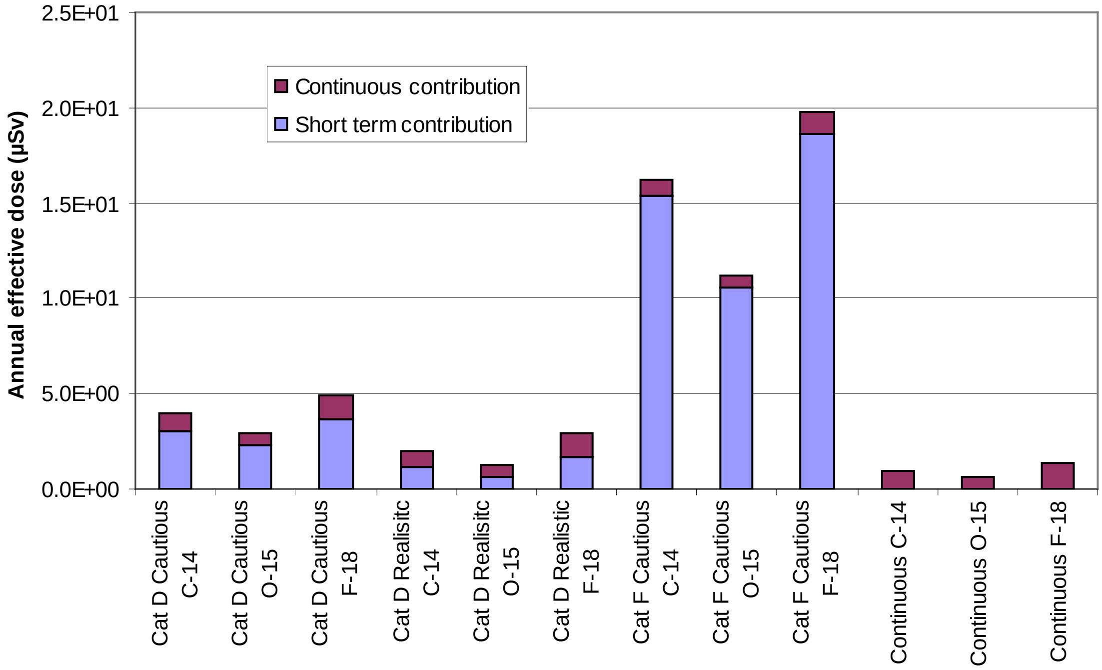

Figure 17 Case study 2 - Infant annual doses (µSv) at 100 m from cyclotron

APPENDIX A Methodologies and data used to assess doses per unit release

A1 INTRODUCTION

Realistic and cautious dose per unit short-term release values have been calculated for releases of radionuclides to atmosphere and compared with dose per unit release values for continuous releases.

A2 METHODOLOGY FOR SHORT-TERM RELEASES

The methodology used to calculate doses from short-term releases follows that described in Reference A1. The atmospheric dispersion model ADMS 4 [Ref A2] has been used to estimate air concentrations, deposition rates and cloud gamma dose rates for each release for selected radionuclides. The meteorological data, source and dispersion parameters used in ADMS 4 are given in Tables A1 and A2. ADMS is designed to model continuous releases but can be used to estimate air concentrations arising from short-term releases if an appropriate release rate is used. In addition, it is sensible to take account of the fluctuation in wind direction during the release and this has been done using the approach adopted in Reference A1. For realistic short-term releases, which are assumed to occur over a 12 hour period, it is estimated that on average the wind will deviate over an angle of about 60 degrees.

ADMS results have been used in a spreadsheet and combined with dose coefficients and habits data to calculate doses to members of the public. Only those exposure pathways of primary importance for the radionuclides being considered have been included. The assumptions made and data used are given in Table 1 of the main text and the tables in this appendix.

Exposures arising from the deposition of radionuclides onto the ground include ingestion of contaminated terrestrial foods, external exposure to gamma radiation and inhalation of resuspended material. Ingestion doses are calculated using estimates of total deposition from ADMS combined with activity concentrations in food (Tables A3 and A4), delay time (Table A5), ingestion rates (Table A6) and ingestion dose coefficients (Table A7). Activity concentrations of ^{14}C and ^{35}S in foods and their time integrals were supplied by Food Standards Agency using the SPADE model [Ref A3] whereas values for other radionuclides were taken from the HPA model FARMLAND [Ref A4]. It is worth noting that equilibrium transfer factors for S-35 in cow meat and cow liver were significantly lower in SPADE than in FARMLAND. The reason for this was not determined. Doses from exposure to gamma rays from deposited radionuclides are calculated using estimates of total deposition from ADMS, occupancy data, shielding factors and dose coefficients [Ref A5]. Doses from inhalation of resuspended material are calculated using estimates of total deposition from ADMS, resuspended activity concentrations in air [Ref A6], occupancy data, inhalation rates and inhalation dose coefficients (Table A8). These calculations can be repeated for any location provided the total deposition and/or the time integrated activity concentrations in air are available from an atmospheric dispersion model.

Exposures arising directly from the radioactive plume include inhalation of the plume, external exposure to beta radiation and external exposure to gamma radiation. Inhalation doses have been calculated using estimates of activity concentrations in air from ADMS combined with inhalation rates, occupancy data and inhalation dose coefficients (Table A8). External exposure to beta radiation from the plume have been calculated using activity concentrations in air from ADMS, occupancy data and dose coefficients from [Ref A7]. External exposure to gamma radiation from the plume are calculated using ADMS.

The dose per unit short-term release values for adults, children and infants are shown in Tables A10 to A12, A14 to A16 and A18 to A20, respectively.

A3 METHODOLOGY FOR CONTINUOUS RELEASES

To calculate doses from continuous releases the model ADMS 4 was used. Output from ADMS 4 has been used as input to the dose assessment software PC CREAM [Ref A7]. The assumptions made are given in Table 1 of the main text. PC CREAM requires information on activity concentrations in air, deposition rates and dose rates from gamma irradiation by the plume as a function of distance from the release point and for specific stability categories. ADMS 4 was run using meteorological data representing the Pasquill-Gifford stability categories (Table A1) and the source and dispersion parameters detailed in Table A2. The ADMS 4 results were then compiled into a file with the format of a PLUME [Ref A7] output file and used in PC CREAM along with long-term statistical meteorological data (Table A1) to estimate annual average doses.

The dose per unit continuous release values for adults, children and infants are shown in Tables A13, A17 and A21, respectively.

A4 METHODOLOGY FOR RELEASES FROM A CYCLOTRON

The radionuclides released from a cyclotron that are of radiological significance are the positron emitters ^{11}C, ^{15}O and ^{18}F. These radionuclides are not available in the dispersion model ADMS 4 and therefore a different approach to the assessment method was developed. The principal exposure pathways are external exposure to gamma rays (two 0.51 MeV rays per Bq) resulting from positron annihilation and inhalation of radionuclides in the plume. It is therefore unnecessary to calculate doses from other pathways such as the ingestion of terrestrial foods. Consequently, a fairly simple assessment approach has been adopted.

ADMS 4 was used to estimate the activity concentration in air of a radionuclide for which radioactive decay over the timescales of interest was negligible. This was done for realistic and a cautious short-term releases. However, the release duration for the realistic scenario was assumed to be 30 minutes, rather than the default 12 hours, because such emissions from cyclotrons occur over short periods of time. The activity concentrations in air for ^{11}C, ^{15}O and ^{18}F were then calculated taking into account the radioactive decay of these radionuclides. Dose rates for submersion in a semi-infinite cloud (Table A1.9) were taken from [Ref A8] which derived the data from [Ref A9]. These results are for effective dose equivalent but provide an adequate estimate of the effective dose. Doses from inhalation of radionuclides in the plume have been estimated using the dose coefficients given in Table A9 and the inhalation rates from Table 1 of the main text.

Estimates of doses arising from continuous releases have also been calculated for comparison purposes. The method adopted is similar to that described for short-term releases except that long term statistical meteorological data are used to represent dispersion over an entire year (Table A1). These data account for the frequency with which different atmospheric conditions occur and can be used to estimate an annual average activity concentration in air from the ongoing release.

Short-term release doses arising from 3 discharges, each of 100 GBq, are given in Tables 8 to 10 of the main text and for a continuous release of 4 TBq per year in Table 11.

A5 DISCUSSION OF METHODOLOGY ASSUMPTIONS

The assessment of doses from the various exposure pathways is likely to be cautious for the reasons identified below. Many of the cautious assumptions listed are equally applicable to continuous release assessments. If necessary, site-specific data should be used to improve the accuracy of the dose assessment.

A5.1 Food dose per unit release data

- It is assumed that the plume blows straight towards the location of agricultural production for the duration of the release.
- All the food consumed by the critical group is assumed to be derived from the same location.
- The "Top Two" approach is adopted, ie, the two foods that make the greatest contribution to dose are assumed to be consumed at the 95th percentile levels and the remaining foods at the 50th percentile levels of a distribution based on national intake rates.

A5.2 Cloud beta dose, cloud gamma dose, inhalation dose

- It is assumed that the plume blows straight towards the location of the critical group for the duration of the release.
- Individuals are assumed to remain at the same location during the passage of the plume.
- The indoor dose reduction factor for inhalation and cloud beta is 1, ie, no reduction.

A5.3 Deposited gamma dose and resuspension

- It is assumed that the plume blows straight towards the location of the critical group for the duration of the release
- Cautious assumptions are made about the number of hours per year spent at the location
- The indoor dose reduction factor for inhalation of resuspended material is 1, ie, no reduction

A6 REFERENCES

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A8 McDonnell C E (2006). Radiological assessment for the GlaxoSmithKline Clinical Imaging Centre, Hammersmith, London. Chilton, RPD-OP-003-2006.

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A10 Clarke RH (1979), The first report of a working group on atmospheric dispersion: A model for short and medium range dispersion of radionuclides released to the atmosphere. Chilton, NRPB-R91.

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A12 ICRP (1996). Age dependent doses to members of the public from intakes of radionuclides: Part 5 compilation of ingestion and inhalation dose coefficients. ICRP Publication 72. *Ann ICRP*, **26** (1).

Table A1 Meteorological data

Stability	Rainfall rate (mm/hr)	Wind speed (m/s)	Mixing layer height (m)
Data for annual average scenarios [a, b]			
Pasquill category A (1/MO length =-0.5)	0	1	1300
Pasquill category B (1/MO length =-0.1)	0	2	900
Pasquill category C (1/MO length =-0.01)	0	5	850
Pasquill category D (1/MO length =0)	0	5	800
Pasquill category E (1/MO length =0.01)	0	3	400
Pasquill category F (1/MO length =0.05)	0	2	100
Pasquill category C (1/MO length =-0.01)	1	5	850
Pasquill category D (1/MO length =0)	1	5	800
Data for short-term release scenarios (realistic neutral conditions)			
Pasquill category D (1/MO length = 0)	0.1	3	800
Data for short-term release scenarios (cautious neutral conditions)			
Pasquill category D (1/MO length = 0)	1	3	800
Data for short-term release scenarios (cautious stable conditions)			
Pasquill category F (1/MO length = 0.05)	0	2	100

[a] Uses a uniform wind rose and stability category frequency of 70% D (as defined in reference A10) or site-specific data from British Energy.
[b] MO is the Monin-Obukhov length (m).

Table A2 Source and Dispersion Parameters for dose per unit release calculations

Parameter	DPUR value	AGR	Cyclotron
Radionuclides	H-3, C-14, S-35, Ar-41, Co-60, Kr-85, Sr-90, Ru-106, I-129, I-131, Xe-133, Cs-137, Pu-239, Am-241, Cm-242, Cm-244, Sb-125, Pu-241	H-3, C-14, S-35, Ar-41, Co-60, Beta particulate (Sr-90) and I-131	I-129 as surrogate for C-11, O-15 and F-18
Source type	Point	Point	Point
Source diameter	1 m	1 m	1 m
Effective Stack Height	0 m	21 m	0 m
Emission velocity	0 m/s	0 m/s	0 m/s
Radioactive decay	yes	yes	No (applied outside dispersion calculation)
Dry deposition included	1e-3 m/s (exceptions: 1e-2 for Iodine; 5e-3 for H-3 and 4e-3 for S-35; 0 for noble gases, C-11, O-15 and F-18)	1e-3 m/s (exceptions: 1e-2 for Iodine; 5e-3 for H-3 and 4e-3 for S-35; 0 for noble gases)	no
Wet deposition included	Dependent on rainfall rate in met file (not included for noble gases, C-11, O-15 and F-18)	Dependent on rainfall rate in met file (not included for noble gases)	no
Cloud gamma included	yes	yes	yes
Release rate	1 TBq y-1 or 1/(release duration in seconds) TBq s-1	AL Bq y-1 or QNL/(release duration in seconds) Bq s-1	1 TBq y-1 or 1/(release duration in seconds) TBq s-1
Release duration	Continuous, 12 hour (realistic) and 30 minutes (cautious) (30 minutes as realistic for positron emitters)	Continuous and 12 hour (12 hour also used for cautious assessment)	Continuous and 30 minutes (30 minutes also used for cautious assessment)
Met data	Uniform wind rose and 70% D, realistic D, cautious D and F (See Table A1)	Uniform wind rose and site-specific met frequencies, realistic D, cautious D and F (See Table 1)	Uniform wind rose and 70% D, realistic D, cautious D and F (See Table 1)
Roughness length	0.3	0.3	1

Table A3 Activity concentrations in foods for realistic short-term assessment integrated to 1 year (Bq y kg^{-1} per Bq m^{-2})

	Green vegetables	Fruit	Root vegetables	Cow milk	Cow meat	Cow liver	Sheep meat	Sheep liver
H-3	1.95E-03	1.95E-03	1.95E-03	9.06E-04	7.83E-04	7.83E-04	1.19E-03	1.19E-03
C-14 [a]	2.63E+00	6.33E+00	6.59E+00	3.30E+00	1.57E+01	1.31E+01	2.01E+01	1.32E+01
S-35	4.12E-02	2.98E-02	7.61E-02	1.46E-02	2.22E-04	2.22E-04	2.28E-03	2.28E-03
Co-60	3.17E-03	1.87E-03	4.05E-05	4.23E-03	1.12E-03	1.12E-01	9.66E-04	9.67E-02
Sr-90	3.80E-03	2.09E-03	1.28E-04	2.26E-03	4.83E-04	4.83E-04	3.63E-04	3.63E-04
Ru-106	2.91E-03	3.45E-04	1.54E-05	1.77E-06	6.63E-04	6.63E-04	6.33E-04	6.33E-04
Sb-125	3.15E-03	1.85E-03	3.81E-05	2.04E-04	1.97E-03	1.97E-01	1.80E-03	1.80E-01
I-129	3.76E-03	3.74E-02	9.65E-03	1.12E-02	7.54E-03	7.54E-03	9.48E-03	9.48E-03
I-131	1.25E-03	2.99E-03	2.73E-04	1.84E-03	7.84E-04	7.84E-04	1.01E-03	1.01E-03
Cs-137	3.73E-03	3.72E-02	9.53E-03	1.10E-02	5.49E-02	5.49E-02	4.60E-02	4.60E-02
Pu-239	3.00E-03	3.35E-04	1.07E-07	8.93E-07	4.90E-05	5.93E-03	5.56E-05	3.94E-03
Pu-241	2.99E-03	3.34E-04	1.05E-07	8.69E-07	4.78E-05	5.77E-03	5.46E-05	3.87E-03
Am-241	3.00E-03	3.35E-04	1.72E-07	8.93E-07	4.90E-05	5.93E-03	5.56E-05	3.94E-03
Cm-242	2.78E-03	3.08E-04	3.22E-08	4.07E-07	2.22E-05	2.66E-03	3.21E-05	2.24E-03
Cm-244	2.99E-03	3.34E-04	6.33E-08	8.75E-07	4.80E-05	5.81E-03	5.48E-05	3.88E-03

[a] Units are Bq y kg^{-1} per Bq d m^{-3}

Table A4 Activity concentrations in foods for cautious short-term assessment integrated to 1 year (Bq y kg^{-1} per Bq m^{-2})[a]

	Green vegetables	Fruit	Root vegetables	Cow milk	Cow meat	Cow liver	Sheep meat	Sheep liver
H-3	1.62E-02	1.62E-02	1.62E-02	9.06E-04	7.83E-04	7.83E-04	1.19E-03	1.19E-03
C-14 [b]	5.00E-01	1.24E+00	1.24E+00	3.30E+00	1.57E+01	1.31E+01	2.01E+01	1.32E+01
S-35	7.98E-02	1.63E-02	5.81E-02	1.46E-02	2.22E-04	2.22E-04	2.28E-03	2.28E-03
Co-60	5.62E-02	2.90E-03	4.46E-05	4.23E-03	1.12E-03	1.12E-01	9.66E-04	9.67E-02
Sr-90	5.93E-02	3.21E-03	1.35E-04	2.26E-03	4.83E-04	4.83E-04	3.63E-04	3.63E-04
Ru-106	4.34E-02	1.66E-03	1.40E-05	1.77E-06	6.63E-04	6.63E-04	6.33E-04	6.33E-04
Sb-125	5.31E-02	2.72E-03	4.09E-05	2.04E-04	1.97E-03	1.97E-01	1.80E-03	1.80E-01
I-129	6.00E-02	8.15E-02	2.27E-02	1.12E-02	7.54E-03	7.54E-03	9.48E-03	9.48E-03
I-131	1.91E-03	5.33E-04	1.26E-04	1.84E-03	7.84E-04	7.84E-04	1.01E-03	1.01E-03
Cs-137	5.93E-02	8.04E-02	2.24E-02	1.10E-02	5.49E-02	5.49E-02	4.60E-02	4.60E-02
Pu-239	6.00E-02	2.29E-03	1.10E-07	8.93E-07	4.90E-05	5.93E-03	5.56E-05	3.94E-03
Pu-241	5.86E-02	2.24E-03	1.07E-07	8.69E-07	4.78E-05	5.77E-03	5.46E-05	3.87E-03
Am-241	6.00E-02	2.29E-03	1.77E-07	8.93E-07	4.90E-05	5.93E-03	5.56E-05	3.94E-03
Cm-242	3.05E-02	1.16E-03	2.71E-08	4.07E-07	2.22E-05	2.66E-03	3.21E-05	2.24E-03
Cm-244	5.89E-02	2.25E-03	6.45E-08	8.75E-07	4.80E-05	5.81E-03	5.48E-05	3.88E-03

[a] Activity concentrations in vegetables are based on peaks which are then integrated taking account of radioactive decay

[b] Units are Bq y kg^{-1} per Bq d m^{-3}

Table A5 Delay times (days)[a]

Foodstuff	Continuous release	Short-term release
Green vegetables	0	0
Soft fruit	0	0
Potatoes	0	0
Carrots	0	0
Milk	0	0
Milk products	2	2
Cow meat	0	3
Cow offal (liver)	2	1
Sheep meat	0	1
Sheep offal (liver)	0	1

[a] Delay times for a continuous release assessment have been taken from PC-CREAM 98 [Ref A7] while those for a short-term release assessment are from NRPB-W54 [Ref A1]. It is noted that there are inconsistencies but these do not have a large effect on the dose results for the radionuclides considered in this report.

Table A6 Ingestion rates (kg yr^{-1}) [a]

	Adult		Child (aged 10-11yrs)		Infant	
	95th percentile	Average	95th percentile	Average	95th percentile	Average
Green vegetables	7.00E+01	3.00E+01	3.00E+01	1.00E+01	1.50E+01	5.00E+00
Soft fruit	6.00E+01	1.50E+01	4.00E+01	1.50E+01	2.50E+01	7.50E+00
Potatoes	1.00E+02	5.00E+01	7.50E+01	4.50E+01	2.50E+01	1.00E+01
Milk	2.10E+02	9.50E+01	2.20E+02	1.10E+02	2.90E+02	1.20E+02
Milk products	5.00E+01	2.00E+01	4.00E+01	1.50E+01	4.00E+01	1.50E+01
Cow meat	4.00E+01	1.50E+01	2.50E+01	1.00E+01	8.00E+00	3.00E+00
Cow offal (liver)	7.50E+00	1.00E+00	4.50E+00	5.00E-01	1.75E+00	2.00E-01
Sheep meat	2.00E+01	3.00E+00	1.00E+01	1.50E+00	2.00E+00	6.00E-01
Sheep offal (liver)	7.50E+00	1.00E+00	4.50E+00	5.00E-01	1.75E+00	2.00E-01

[a] Reference A11

Table A7 Ingestion Dose Coefficients (Sv Bq^{-1}) [a]

Radionuclide	Infant	Child	Adult
H-3 [b]	6.24E-11	2.98E-11	2.28E-11
C-14	1.60E-09	8.00E-10	5.80E-10
S-35 [c]	5.40E-09	1.60E-09	7.70E-10
Co-60	2.70E-08	1.10E-08	3.40E-09
Sr-90	7.30E-08	6.00E-08	2.80E-08
Ru-106	4.90E-08	1.50E-08	7.00E-09
Sb-125	6.10E-09	2.10E-09	1.10E-09
I-129	2.20E-07	1.90E-07	1.10E-07
I-131	1.80E-07	5.20E-08	2.20E-08
Cs-137	1.20E-08	1.00E-08	1.30E-08
Pu-239	4.20E-07	2.70E-07	2.50E-07
Pu-241	5.70E-09	5.10E-09	4.80E-09
Am-241	3.70E-07	2.20E-07	2.00E-07
Cm-242	7.60E-08	2.40E-08	1.20E-08
Cm-244	2.90E-07	1.40E-07	1.20E-07

[a] Reference A12.
[b] For H-3 the dose coefficient is calculated assuming a 20% contribution from OBT and 80% from HTO.
[c] For S-35 the organic form is assumed.

Table A8 Inhalation Dose Coefficients (Sv Bq^{-1}) [a]

Radionuclide	Absorption Type	Infant	Child	Adult
H-3 [b]	-	4.80E-11	2.30E-11	1.80E-11
C-14	'M'	4.10E-09	1.80E-09	1.30E-09
S-35	'M'	4.50E-09	2.00E-09	1.40E-09
Co-60	'M'	3.40E-08	1.50E-08	1.00E-08
Sr-90	'M'	1.10E-07	5.10E-08	3.60E-08
Ru-106	'M'	1.10E-07	4.10E-08	2.80E-08
Sb-125	'M'	1.60E-08	6.80E-09	4.80E-09
I-129	'F'	8.60E-08	6.70E-08	3.60E-08
I-131	'F'	7.20E-08	1.90E-08	7.40E-09
Cs-137	'F'	5.40E-09	3.70E-09	4.60E-09
Pu-239	'M'	7.70E-05	4.80E-05	5.00E-05
Pu-241	'M'	9.70E-07	8.30E-07	9.00E-07
Am-241	'M'	6.90E-05	4.00E-05	4.20E-05
Cm-242	'M'	1.80E-05	7.30E-06	5.20E-06
Cm-244	'M'	5.70E-05	2.70E-05	2.70E-05

[a] Reference A12
[b] Tritium is assumed to be in form of tritiated water

Table A9 Dose Coefficients for positron emitters [a]

Radionuclide	External dose from immersion in plume Sv/h per Bq/m3	Inhalation DPUI (Sv/Bq)		
		Adult	Child	Infant
C-11 {1 micron AMAD aerosol (Type F)}	1.80E-10	1.10E-11	2.10E-11	7.00E-11
O-15 {SR-2 (soluble reactive gas)}	1.80E-10	4.70E-13	[b]	[b]
F-18 {1 micron AMAD aerosol (Type F)}	1.80E-10	2.80E-11	5.60E-11	1.90E-10

[a] Reference A8

[b] Inhalation dose coefficients for ^{15}O could be estimated for children and infants by appropriate scaling however this has not been done in this report.

Table A10 Adult annual doses per unit release (1 TBq) for a realistic short-term release assessment (scenario 1a) (µSv)

Radio-nuclide	Green vegetables	Root vegetables	Cow meat	Cow liver	Sheep meat	Sheep liver	Milk	Milk Products	Fruit	Cloud Beta	Cloud Gamma	Deposited Gamma	Inhalation	Resuspension	Total
H-3	2.12E-02	1.52E-02	1.82E-03	1.21E-04	5.52E-04	1.84E-04	2.95E-02	-	4.55E-03	-	-	-	1.73E+00	-	1.80E+00
C-14	1.70E+01	3.05E+01	2.18E+01	1.21E+00	5.56E+00	1.22E+00	6.49E+01	-	8.78E+00	1.99E-03	-	-	1.26E+02	-	2.77E+02
S-35	1.35E+02	1.78E+02	1.52E-01	1.03E-02	3.18E-01	1.06E-01	1.44E+02	-	2.09E+01	6.52E-03	-	-	1.26E+02	-	6.05E+02
Ar-41	-	-	-	-	-	-	-	-	-	6.98E-02	1.09E+00	-	-	-	1.16E+00
Co-60	1.87E+01	1.70E-01	1.41E+00	9.40E+00	2.44E-01	8.14E+00	7.48E+01	-	2.36E+00	1.23E-02	2.11E+00	8.60E+03	9.50E+02	-	9.66E+03
Kr-85	-	-	-	-	-	-	-	-	-	3.58E-02	2.18E-03	-	-	-	3.80E-02
Sr-90	1.84E+02	4.43E+00	5.02E+00	3.35E-01	7.56E-01	2.52E-01	3.30E+02	-	2.17E+01	2.73E-02	5.62E-11	1.85E-04	3.42E+03	-	3.97E+03
Ru-106	3.53E+01	1.34E-01	1.71E+00	1.15E-01	3.29E-01	1.10E-01	6.45E-02	-	8.96E-01	1.98E-01	1.45E-01	5.67E+02	2.66E+03	1.67E+00	3.27E+03
Sb-125	6.01E+00	5.19E-02	8.03E-01	5.36E+00	1.47E-01	4.89E+00	1.17E+00	-	7.57E-01	1.34E-02	4.15E-01	1.36E+03	4.56E+02	-	1.83E+03
I-129	3.45E+03	6.33E+03	1.48E+03	9.90E+01	3.73E+02	1.24E+02	3.08E+04	-	7.35E+03	1.49E-03	2.03E-02	1.82E+02	2.94E+03	-	5.31E+04
I-131	2.30E+02	3.58E+01	2.38E+01	1.89E+00	7.26E+00	2.42E+00	1.02E+03	-	1.18E+02	2.67E-02	3.40E-01	3.43E+02	6.04E+02	-	2.38E+03
Xe-133	-	-	-	-	-	-	-	-	-	1.49E-02	5.53E-02	-	-	-	7.03E-02
Cs-137	8.41E+01	1.53E+02	2.65E+02	1.77E+01	4.45E+01	1.48E+01	7.44E+02	-	1.80E+02	3.76E-02	1.11E-01	2.12E+03	4.37E+02	3.00E-01	4.06E+03
Pu-239	1.30E+03	3.33E-02	4.55E+00	3.67E+01	1.03E+00	2.44E+01	1.16E+00	-	3.11E+01	7.86E-04	2.38E-04	2.69E-01	4.75E+06	3.26E+03	4.75E+06
Pu-241	2.49E+01	6.23E-04	8.52E-02	6.86E-01	1.95E-02	4.60E-01	2.17E-02	-	5.96E-01	3.34E-08	2.18E-06	4.77E-02	8.55E+04	5.84E+01	8.56E+04
Am-241	1.04E+03	4.26E-02	3.64E+00	2.94E+01	8.27E-01	1.95E+01	9.29E-01	-	2.49E+01	2.87E-05	3.28E-02	5.62E+01	3.99E+06	2.74E+03	3.99E+06
Cm-242	5.78E+01	4.79E-04	9.78E-02	7.87E-01	2.85E-02	6.64E-01	2.54E-02	-	1.38E+00	9.13E-10	5.70E-04	-	4.94E+05	2.85E+02	4.94E+05
Cm-244	6.23E+02	9.41E-03	2.14E+00	1.73E+01	4.88E-01	1.15E+01	5.46E-01	-	1.49E+01	-	6.95E-04	-	2.94E+06	2.01E+03	2.95E+06

Table A11 Adult annual doses per unit release (1 TBq) for a cautious (Cat D) short-term release assessment (scenario 1b) (μSv)

Radio-nuclide	Green vegetables	Root vegetables	Cow meat	Cow liver	Sheep meat	Sheep liver	Milk	Milk Products	Fruit	Cloud Beta	Cloud Gamma	Deposited Gamma	Inhalation	Resuspension	Total
H-3	3.20E-01	2.28E-01	3.30E-03	2.20E-04	1.00E-03	3.34E-04	5.36E-02	2.24E-03	6.85E-02	-	-	-	3.28E+00	-	3.96E+00
C-14	5.87E+00	1.04E+01	3.95E+01	2.20E+00	1.01E+01	2.21E+00	1.18E+02	6.73E+01	3.12E+00	2.68E-03	-	-	2.39E+02	-	4.97E+02
S-35	7.54E+02	3.92E+02	4.39E-01	2.97E-02	9.16E-01	3.05E-01	4.14E+02	4.27E+02	3.30E+01	8.76E-03	-	-	2.39E+02	-	2.26E+03
Ar-41	-	-	-	-	-	-	-	-	-	9.41E-02	2.93E+00	-	-	-	3.02E+00
Co-60	1.53E+03	8.68E-01	6.51E+00	4.34E+01	1.13E+00	3.76E+01	3.45E+02	3.61E+02	1.69E+01	1.65E-02	5.55E+00	1.96E+04	1.80E+03	-	2.38E+04
Kr-85	-	-	-	-	-	-	-	-	-	4.83E-02	4.94E-03	-	-	-	5.32E-02
Sr-90	1.33E+04	2.16E+01	2.32E+01	1.55E+00	3.49E+00	1.16E+00	1.52E+03	1.60E+03	1.54E+02	3.67E-02	1.29E-10	4.23E-04	6.47E+03	-	2.31E+04
Ru-106	2.43E+03	5.62E-01	7.91E+00	5.30E-01	1.52E+00	5.06E-01	2.98E-01	3.11E-01	1.99E+01	2.66E-01	3.12E-01	1.30E+03	5.03E+03	3.82E+00	8.80E+03
Sb-125	4.68E+02	2.57E-01	3.71E+00	2.48E+01	6.78E-01	2.26E+01	5.38E+00	5.63E+00	5.14E+00	1.80E-02	9.30E-01	3.10E+03	8.63E+02	-	4.50E+03
I-129	1.26E+05	3.42E+04	3.40E+03	2.27E+02	8.55E+02	2.85E+02	7.05E+04	7.39E+04	3.68E+04	2.00E-03	4.51E-02	2.66E+02	5.56E+03	-	3.52E+05
I-131	8.03E+02	3.78E+01	5.46E+01	4.32E+00	1.67E+01	5.55E+00	2.33E+03	2.05E+03	4.81E+01	3.59E-02	7.68E-01	5.01E+02	1.14E+03	-	7.00E+03
Xe-133	-	-	-	-	-	-	-	-	-	2.01E-02	1.32E-01	-	-	-	1.52E-01
Cs-137	6.17E+03	1.67E+03	1.22E+03	8.16E+01	2.05E+02	6.84E+01	3.43E+03	1.12E+03	1.79E+03	5.05E-02	2.38E-01	4.84E+03	8.27E+02	6.84E-01	2.14E+04
Pu-239	1.20E+05	1.58E-01	2.10E+01	1.70E+02	4.77E+00	1.13E+02	5.36E+00	5.62E+00	9.82E+02	1.06E-03	5.36E-04	6.15E-01	8.99E+06	7.46E+03	9.11E+06
Pu-241	2.25E+03	2.92E-03	3.93E-01	3.17E+00	8.98E-02	2.12E+00	1.00E-01	1.05E-01	1.84E+01	4.48E-08	5.29E-06	1.09E-01	1.62E+05	1.33E+02	1.64E+05
Am-241	9.60E+04	2.02E-01	1.68E+01	1.36E+02	3.82E+00	9.02E+01	4.29E+00	4.50E+00	7.85E+02	3.85E-05	7.53E-02	1.28E+02	7.55E+06	6.26E+03	7.65E+06
Cm-242	2.93E+03	1.86E-03	4.51E-01	3.63E+00	1.32E-01	3.07E+00	1.17E-01	1.22E-01	2.39E+01	1.23E-09	1.27E-03	-	9.34E+05	6.51E+02	9.38E+05
Cm-244	5.66E+04	4.42E-02	9.88E+00	7.97E+01	2.25E+00	5.33E+01	2.52E+00	2.64E+00	4.63E+02	-	1.54E-03	-	5.57E+06	4.60E+03	5.63E+06

Table A12 Adult annual doses per unit release (1 TBq) for a cautious (Cat F) short-term release assessment (scenario 1c) (µSv)

Radio-nuclide	Green vegetables	Root vegetables	Cow meat	Cow liver	Sheep meat	Sheep liver	Milk	Milk Products	Fruit	Cloud Beta	Cloud Gamma	Deposited Gamma	Inhalation	Resuspension	Total
H-3	1.40E+00	9.98E-01	1.44E-02	9.62E-04	4.37E-03	1.46E-03	2.34E-01	9.80E-03	2.99E-01	-	-	-	1.14E+01	-	1.43E+01
C-14	2.64E+01	4.68E+01	1.78E+02	9.88E+00	4.54E+01	9.95E+00	5.30E+02	3.03E+02	1.40E+01	9.46E-03	-	-	8.42E+02	-	2.00E+03
S-35	1.42E+03	7.39E+02	8.27E-01	5.60E-02	1.73E+00	5.75E-01	7.80E+02	8.04E+02	6.23E+01	2.71E-02	-	-	7.39E+02	-	4.55E+03
Ar-41	-	-	-	-	-	-	-	-	-	3.29E-01	7.71E+00	-	-	-	8.04E+00
Co-60	1.39E+03	7.86E-01	5.89E+00	3.93E+01	1.02E+00	3.40E+01	3.13E+02	3.27E+02	1.53E+01	5.64E-02	1.45E+01	3.15E+04	6.14E+03	-	3.98E+04
Kr-85	-	-	-	-	-	-	-	-	-	1.70E-01	1.29E-02	-	-	-	1.83E-01
Sr-90	1.20E+04	1.96E+01	2.10E+01	1.40E+00	3.16E+00	1.05E+00	1.38E+03	1.45E+03	1.40E+02	1.25E-01	8.53E-10	6.79E-04	2.21E+04	-	3.72E+04
Ru-106	2.20E+03	5.09E-01	7.17E+00	4.80E-01	1.37E+00	4.58E-01	2.70E-01	2.81E-01	1.80E+01	9.09E-01	1.11E+00	2.08E+03	1.72E+04	6.13E+00	2.15E+04
Sb-125	4.23E+02	2.33E-01	3.36E+00	2.24E+01	6.14E-01	2.05E+01	4.88E+00	5.10E+00	4.65E+00	6.14E-02	2.39E+00	4.98E+03	2.95E+03	-	8.42E+03
I-129	2.58E+05	6.99E+04	6.96E+03	4.64E+02	1.75E+03	5.83E+02	1.44E+05	1.51E+05	7.52E+04	5.23E-03	1.05E-01	6.22E+02	1.45E+04	-	7.24E+05
I-131	1.64E+03	7.73E+01	1.12E+02	8.84E+00	3.41E+01	1.14E+01	4.76E+03	4.20E+03	9.83E+01	9.37E-02	1.70E+00	1.17E+03	2.98E+03	-	1.51E+04
Xe-133	-	-	-	-	-	-	-	-	-	7.07E-02	3.45E-01	-	-	-	4.15E-01
Cs-137	5.59E+03	1.51E+03	1.11E+03	7.39E+01	1.86E+02	6.20E+01	3.11E+03	1.01E+03	1.62E+03	1.73E-01	1.16E+00	7.77E+03	2.83E+03	1.10E+00	2.49E+04
Pu-239	1.09E+05	1.43E-01	1.90E+01	1.54E+02	4.32E+00	1.02E+02	4.86E+00	5.09E+00	8.90E+02	3.61E-03	1.58E-03	9.87E-01	3.07E+07	1.20E+04	3.08E+07
Pu-241	2.04E+03	2.65E-03	3.56E-01	2.87E+00	8.14E-02	1.92E+00	9.07E-02	9.50E-02	1.67E+01	1.53E-07	1.37E-05	1.75E-01	5.53E+05	2.14E+02	5.55E+05
Am-241	8.70E+04	1.83E-01	1.52E+01	1.23E+02	3.46E+00	8.17E+01	3.89E+00	4.07E+00	7.11E+02	1.32E-04	1.96E-01	2.06E+02	2.58E+07	1.01E+04	2.59E+07
Cm-242	2.65E+03	1.69E-03	4.09E-01	3.29E+00	1.19E-01	2.78E+00	1.06E-01	1.10E-01	2.17E+01	4.19E-09	3.86E-03	-	3.19E+06	1.04E+03	3.20E+06
Cm-244	5.12E+04	4.01E-02	8.95E+00	7.22E+01	2.04E+00	4.83E+01	2.28E+00	2.39E+00	4.19E+02	-	4.52E-03	-	1.90E+07	7.38E+03	1.91E+07

Table A13 Adult annual doses per unit release (1 TBq y^{-1}) for a continuous release assessment (µSv)

Radio-nuclide	Green vegetables	Root vegetables	Cow meat	Cow liver	Sheep meat	Sheep liver	Milk	Milk Products	Fruit	Cloud Beta	Cloud Gamma	Deposited Gamma	Inhalation	Resuspension	Total
H-3	7.40E-03	5.60E-03	1.20E-03	8.20E-05	2.50E-04	8.20E-05	2.20E-02	9.30E-04	1.40E-03	-	-	-	2.20E-01	-	2.59E-01
C-14	5.80E-01	9.80E-01	3.70E-01	2.50E-02	7.40E-02	2.50E-02	1.70E+00	9.90E-01	2.50E-01	1.70E-04	-	-	8.10E+00	-	1.31E+01
S-35	1.30E+00	8.50E-01	1.30E+01	9.10E-01	6.50E+00	8.70E-01	3.00E+01	3.10E+01	1.50E-01	5.40E-04	-	-	8.00E+00	1.40E-02	9.26E+01
Ar-41	-	-	-	-	-	-	-	-	-	5.90E-03	1.00E-01	-	-	-	1.06E-01
Co-60	1.70E+00	4.90E-03	6.20E-02	4.10E-01	2.00E-02	6.60E-01	2.70E+00	2.80E+00	5.90E-02	1.00E-03	2.00E-01	3.20E+02	6.10E+01	3.90E-02	3.90E+02
Kr-85	-	-	-	-	-	-	-	-	-	3.00E-03	1.80E-04	-	-	-	3.18E-03
Sr-90	1.40E+01	1.30E-01	2.40E-01	1.60E-02	6.00E-02	2.00E-02	1.60E+01	1.70E+01	4.90E-01	2.30E-03	-	7.30E-06	2.20E+02	1.40E-01	2.68E+02
Ru-106	3.10E+00	5.10E-03	8.30E-02	5.60E-03	2.70E-02	8.90E-03	2.70E-03	2.80E-03	5.90E-02	1.20E-02	9.90E-03	2.30E+01	1.20E+02	1.00E-01	1.46E+02
Sb-125	5.30E-01	1.50E-03	3.00E-02	2.00E-01	1.20E-02	3.90E-01	4.30E-02	4.50E-02	1.90E-02	1.10E-03	3.30E-02	5.50E+01	2.90E+01	1.80E-02	8.53E+01
I-129	4.10E+02	3.30E+02	7.00E+01	4.60E+00	4.00E+01	1.30E+01	1.40E+03	1.50E+03	4.90E+01	1.20E-04	1.60E-03	7.60E+00	1.80E+02	1.10E+00	4.01E+03
I-131	2.60E+01	4.60E+00	2.80E+00	2.20E-01	8.50E-01	2.80E-01	1.10E+02	9.60E+01	4.10E+00	2.20E-03	2.70E-02	2.70E+01	3.80E+01	7.70E-02	3.10E+02
Xe-133	-	-	-	-	-	-	-	-	-	1.30E-03	4.70E-03	-	-	-	6.00E-03
Cs-137	7.60E+00	6.00E+00	9.60E+00	6.40E-01	3.60E+00	1.20E+00	2.70E+01	2.80E+01	9.00E-01	3.10E-03	7.80E-03	8.20E+01	2.80E+01	1.80E-02	1.95E+02
Pu-239	1.20E+02	1.00E-03	2.10E-01	1.70E+00	8.30E-02	2.00E+00	5.30E-02	5.60E-02	2.20E+00	6.60E-05	1.90E-05	1.00E-02	3.00E+05	2.00E+02	3.00E+05
Pu-241	2.20E+00	1.90E-05	3.90E-03	3.20E-02	1.60E-03	3.70E-02	1.00E-03	1.00E-03	4.20E-02	2.80E-09	1.90E-07	1.30E-03	5.50E+03	3.60E+00	5.51E+03
Am-241	9.30E+01	1.30E-03	1.70E-01	1.40E+00	6.70E-02	1.60E+00	4.40E-02	4.60E-02	1.70E+00	2.40E-06	2.70E-03	2.10E+00	2.60E+05	1.70E+02	2.60E+05
Cm-242	5.10E+00	2.30E-05	5.40E-03	4.40E-02	2.30E-03	5.40E-02	1.40E-03	1.50E-03	9.80E-02	7.60E-11	4.60E-05	9.90E-03	3.20E+04	1.70E+01	3.20E+04
Cm-244	5.50E+01	2.90E-04	9.90E-02	8.00E-01	3.90E-02	9.30E-01	2.50E-02	2.60E-02	1.00E+00	-	5.60E-05	3.50E-02	1.60E+05	1.10E+02	1.60E+05

Table A14 Child annual doses per unit release (1 TBq) for a realistic short-term release assessment (scenario 1a) (µSv)

Radio-nuclide	Green vegetables	Root vegetables	Cow meat	Cow liver	Sheep meat	Sheep liver	Milk	Milk Products	Fruit	Cloud Beta	Cloud Gamma	Deposited Gamma	Inhalation	Resuspension	Total
H-3	1.19E-02	1.78E-02	1.59E-03	7.94E-05	3.61E-04	1.20E-04	4.05E-02	-	5.94E-03	-	-	-	1.60E+00	-	1.68E+00
C-14	1.01E+01	3.78E+01	2.00E+01	8.35E-01	3.84E+00	8.41E-01	9.38E+01	-	1.21E+01	1.99E-03	-	-	1.26E+02	-	3.06E+02
S-35	1.20E+02	3.33E+02	2.11E-01	1.07E-02	3.30E-01	1.10E-01	3.13E+02	-	4.35E+01	6.52E-03	-	-	1.31E+02	-	9.41E+02
Ar-41	-	-	-	-	-	-	-	-	-	6.98E-02	6.52E-01	-	-	-	7.21E-01
Co-60	2.59E+01	4.96E-01	3.04E+00	1.52E+01	3.95E-01	1.32E+01	2.53E+02	-	7.64E+00	1.23E-02	1.27E+00	3.72E+03	1.03E+03	-	3.54E+03
Kr-85	-	-	-	-	-	-	-	-	-	3.58E-02	1.31E-03	-	-	-	3.71E-02
Sr-90	1.69E+02	8.54E+00	7.17E+00	3.59E-01	8.10E-01	2.70E-01	7.41E+02	-	4.65E+01	2.73E-02	3.37E-11	8.01E-05	3.51E+03	-	4.49E+03
Ru-106	3.25E+01	2.58E-01	2.45E+00	1.23E-01	3.52E-01	1.17E-01	1.45E-01	-	1.92E+00	1.98E-01	8.69E-02	2.45E+02	2.82E+03	1.45E+00	3.01E+03
Sb-125	4.91E+00	8.92E-02	1.02E+00	5.12E+00	1.40E-01	4.67E+00	2.33E+00	-	1.44E+00	1.34E-02	2.49E-01	5.88E+02	4.68E+02	-	8.34E+02
I-129	2.56E+03	9.84E+03	1.71E+03	8.55E+01	3.22E+02	1.07E+02	5.56E+04	-	1.27E+04	1.49E-03	1.22E-02	7.88E+01	3.97E+03	-	8.70E+04
I-131	2.33E+02	7.61E+01	3.75E+01	2.23E+00	8.58E+00	2.86E+00	2.51E+03	-	2.78E+02	2.67E-02	2.04E-01	1.48E+02	1.12E+03	-	4.37E+03
Xe-133	-	-	-	-	-	-	-	-	-	1.49E-02	3.32E-02	-	-	-	4.81E-02
Cs-137	2.77E+01	1.06E+02	1.36E+02	6.80E+00	1.71E+01	5.70E+00	5.99E+02	-	1.38E+02	3.76E-02	6.64E-02	9.17E+02	2.55E+02	1.42E-01	1.83E+03
Pu-239	6.01E+02	3.23E-02	3.28E+00	1.98E+01	5.58E-01	1.32E+01	1.31E+00	-	3.36E+01	7.86E-04	1.43E-04	1.17E-01	3.31E+06	1.85E+03	3.31E+06
Pu-241	1.13E+01	5.96E-04	6.04E-02	3.64E-01	1.03E-02	2.44E-01	2.42E-02	-	6.34E-01	3.34E-08	1.31E-06	2.06E-02	5.72E+04	3.18E+01	5.72E+04
Am-241	4.90E+02	4.21E-02	2.67E+00	1.62E+01	4.55E-01	1.07E+01	1.07E+00	-	2.74E+01	2.87E-05	1.97E-02	2.43E+01	2.75E+06	1.54E+03	2.76E+06
Cm-242	4.96E+01	8.62E-04	1.30E-01	7.87E-01	2.85E-02	6.64E-01	5.32E-02	-	2.75E+00	9.13E-10	3.42E-04	-	5.03E+05	2.37E+02	5.03E+05
Cm-244	3.11E+02	9.88E-03	1.66E+00	1.01E+01	2.85E-01	6.73E+00	6.68E-01	-	1.74E+01	-	4.17E-04	-	2.13E+06	1.19E+03	2.14E+06

Table A15 Child annual doses per unit release (1 TBq) for a cautious (Cat D) short-term release assessment (scenario 1b) (µSv)

Radio-nuclide	Green vegetables	Root vegetables	Cow meat	Cow liver	Sheep meat	Sheep liver	Milk	Milk Products	Fruit	Cloud Beta	Cloud Gamma	Deposited Gamma	Inhalation	Resuspension	Total
H-3	1.79E-01	2.69E-01	2.88E-03	1.44E-04	6.54E-04	2.18E-04	7.33E-02	2.20E-03	8.96E-02	-	-	-	2.16E+00	-	2.77E+00
C-14	3.47E+00	1.29E+01	3.63E+01	1.51E+00	6.96E+00	1.52E+00	1.70E+02	6.96E+01	4.30E+00	2.68E-03	-	-	1.70E+02	-	4.77E+02
S-35	6.71E+02	7.33E+02	6.08E-01	3.09E-02	9.52E-01	3.17E-01	9.01E+02	6.65E+02	6.87E+01	8.76E-03	-	-	1.76E+02	-	3.22E+03
Ar-41	-	-	-	-	-	-	-	-	-	9.41E-02	2.93E+00	-	-	-	3.02E+00
Co-60	2.12E+03	2.53E+00	1.40E+01	7.02E+01	1.82E+00	6.08E+01	1.17E+03	8.77E+02	5.48E+01	1.65E-02	5.55E+00	1.00E+04	1.39E+03	-	1.58E+04
Kr-85	-	-	-	-	-	-	-	-	-	4.83E-02	4.94E-03	-	-	-	5.32E-02
Sr-90	1.22E+04	4.17E+01	3.31E+01	1.66E+00	3.74E+00	1.25E+00	3.42E+03	2.56E+03	3.30E+02	3.67E-02	1.29E-10	2.15E-04	4.72E+03	-	2.33E+04
Ru-106	2.23E+03	1.08E+00	1.13E+01	5.68E-01	1.63E+00	5.42E-01	6.68E-01	4.99E-01	4.26E+01	2.66E-01	3.12E-01	6.60E+02	3.79E+03	3.89E+00	6.75E+03
Sb-125	3.83E+02	4.42E-01	4.72E+00	2.36E+01	6.47E-01	2.16E+01	1.08E+01	8.06E+00	9.81E+00	1.80E-02	9.30E-01	1.58E+03	6.29E+02	-	2.67E+03
I-129	9.35E+04	5.31E+04	3.92E+03	1.96E+02	7.38E+02	2.46E+02	1.28E+05	9.57E+04	6.35E+04	2.00E-03	4.51E-02	1.36E+02	5.32E+03	-	4.44E+05
I-131	8.13E+02	8.04E+01	8.60E+01	5.11E+00	1.97E+01	6.56E+00	5.77E+03	3.64E+03	1.14E+02	3.59E-02	7.68E-01	2.55E+02	1.51E+03	-	1.23E+04
Xe-133	-	-	-	-	-	-	-	-	-	2.01E-02	1.32E-01	-	-	-	1.52E-01
Cs-137	2.04E+03	1.15E+03	6.27E+02	3.14E+01	7.90E+01	2.63E+01	2.77E+03	6.44E+02	1.38E+03	5.05E-02	2.38E-01	2.46E+03	3.42E+02	3.83E-01	1.15E+04
Pu-239	5.56E+04	1.53E-01	1.51E+01	9.15E+01	2.57E+00	6.08E+01	6.07E+00	4.55E+00	1.06E+03	1.06E-03	5.36E-04	3.13E-01	4.44E+06	4.98E+03	4.50E+06
Pu-241	1.03E+03	2.80E-03	2.79E-01	1.68E+00	4.77E-02	1.13E+00	1.11E-01	8.36E-02	1.96E+01	4.48E-08	5.29E-06	5.55E-02	7.68E+04	8.55E+01	7.79E+04
Am-241	4.53E+04	2.00E-01	1.23E+01	7.46E+01	2.10E+00	4.96E+01	4.94E+00	3.71E+00	8.64E+02	3.85E-05	7.53E-02	6.53E+01	3.70E+06	4.15E+03	3.75E+06
Cm-242	2.51E+03	3.35E-03	6.02E-01	3.63E+00	1.32E-01	3.07E+00	2.46E-01	1.83E-01	4.79E+01	1.23E-09	1.27E-03	-	6.75E+05	6.36E+02	6.79E+05
Cm-244	2.83E+04	4.64E-02	7.68E+00	4.65E+01	1.32E+00	3.11E+01	3.08E+00	2.31E+00	5.40E+02	-	1.54E-03	-	2.87E+06	3.20E+03	2.90E+06

Table A16 Child annual doses per unit release (1 TBq) for a cautious (Cat F) short-term release assessment (scenario 1c) (µSv)

Radio-nuclide	Green vegetables	Root vegetables	Cow meat	Cow liver	Sheep meat	Sheep liver	Milk	Milk Products	Fruit	Cloud Beta	Cloud Gamma	Deposited Gamma	Inhalation	Resuspension	Total
H-3	7.82E-01	1.17E+00	1.26E-02	6.29E-04	2.86E-03	9.52E-04	3.20E-01	9.61E-03	3.91E-01	-	-	-	7.47E+00	-	1.02E+01
C-14	1.56E+01	5.81E+01	1.63E+02	6.81E+00	3.13E+01	6.86E+00	7.65E+02	3.13E+02	1.94E+01	9.46E-03	-	-	6.00E+02	-	1.98E+03
S-35	1.26E+03	1.38E+03	1.15E+00	5.82E-02	1.79E+00	5.98E-01	1.70E+03	1.25E+03	1.29E+02	2.71E-02	-	-	5.43E+02	-	6.27E+03
Ar-41	-	-	-	-	-	-	-	-	-	3.29E-01	7.71E+00	-	-	-	8.04E+00
Co-60	1.92E+03	2.29E+00	1.27E+01	6.36E+01	1.65E+00	5.51E+01	1.06E+03	7.94E+02	4.96E+01	5.64E-02	1.45E+01	1.60E+04	4.74E+03	-	2.48E+04
Kr-85	-	-	-	-	-	-	-	-	-	1.70E-01	1.29E-02	-	-	-	1.83E-01
Sr-90	1.11E+04	3.78E+01	3.00E+01	1.50E+00	3.39E+00	1.13E+00	3.10E+03	2.32E+03	2.99E+02	1.25E-01	8.53E-10	3.45E-04	1.61E+04	-	3.30E+04
Ru-106	2.02E+03	9.83E-01	1.02E+01	5.14E-01	1.47E+00	4.91E-01	6.05E-01	4.52E-01	3.86E+01	9.09E-01	1.11E+00	1.06E+03	1.30E+04	6.25E+00	1.61E+04
Sb-125	3.46E+02	4.01E-01	4.27E+00	2.14E+01	5.86E-01	1.95E+01	9.75E+00	7.30E+00	8.89E+00	6.14E-02	2.39E+00	2.54E+03	2.15E+03	-	5.11E+03
I-129	1.91E+05	1.09E+05	8.01E+03	4.01E+02	1.51E+03	5.03E+02	2.61E+05	1.96E+05	1.30E+05	5.23E-03	1.05E-01	3.17E+02	1.39E+04	-	9.11E+05
I-131	1.66E+03	1.64E+02	1.76E+02	1.04E+01	4.02E+01	1.34E+01	1.18E+04	7.44E+03	2.32E+02	9.37E-02	1.70E+00	5.96E+02	3.94E+03	-	2.61E+04
Xe-133	-	-	-	-	-	-	-	-	-	7.07E-02	3.45E-01	-	-	-	4.15E-01
Cs-137	1.84E+03	1.04E+03	5.68E+02	2.84E+01	7.15E+01	2.38E+01	2.51E+03	5.83E+02	1.25E+03	1.73E-01	1.16E+00	3.96E+03	1.17E+03	6.14E-01	1.30E+04
Pu-239	5.03E+04	1.39E-01	1.37E+01	8.29E+01	2.33E+00	5.51E+01	5.50E+00	4.12E+00	9.61E+02	3.61E-03	1.58E-03	5.03E-01	1.52E+07	7.99E+03	1.52E+07
Pu-241	9.29E+02	2.53E-03	2.52E-01	1.52E+00	4.32E-02	1.02E+00	1.01E-01	7.57E-02	1.77E+01	1.53E-07	1.37E-05	8.90E-02	2.62E+05	1.37E+02	2.64E+05
Am-241	4.10E+04	1.81E-01	1.12E+01	6.76E+01	1.90E+00	4.49E+01	4.48E+00	3.36E+00	7.82E+02	1.32E-04	1.96E-01	1.05E+02	1.26E+07	6.66E+03	1.27E+07
Cm-242	2.27E+03	3.03E-03	5.45E-01	3.29E+00	1.19E-01	2.78E+00	2.22E-01	1.65E-01	4.34E+01	4.19E-09	3.86E-03	-	2.31E+06	1.02E+03	2.31E+06
Cm-244	2.56E+04	4.21E-02	6.96E+00	4.21E+01	1.19E+00	2.82E+01	2.79E+00	2.09E+00	4.89E+02	-	4.52E-03	-	9.80E+06	5.13E+03	9.83E+06

Table A17 Child annual doses per unit release (1 TBq y^{-1}) for a continuous release assessment (µSv)

Radio-nuclide	Green vegetables	Root vegetables	Cow meat	Cow liver	Sheep meat	Sheep liver	Milk	Milk Products	Fruit	Cloud Beta	Cloud Gamma	Deposited Gamma	Inhalation	Resuspension	Total
H-3	4.00E-03	6.00E-03	1.00E-03	5.20E-05	1.60E-04	5.20E-05	3.00E-02	8.90E-04	1.80E-03	-	-	-	2.00E-01	-	2.44E-01
C-14	3.40E-01	1.10E+00	3.40E-01	1.70E-02	5.10E-02	1.70E-02	2.50E+00	1.00E+00	3.40E-01	1.70E-04	-	-	7.80E+00	-	1.35E+01
S-35	1.10E+00	1.50E+00	1.90E+01	9.40E-01	6.80E+00	9.10E-01	6.60E+01	4.90E+01	3.10E-01	5.40E-04	-	-	7.90E+00	1.40E-02	1.53E+02
Ar-41	-	-	-	-	-	-	-	-	-	5.90E-03	6.20E-02	-	-	-	6.79E-02
Co-60	2.30E+00	1.30E-02	1.30E-01	6.70E-01	3.20E-02	1.10E+00	9.10E+00	6.80E+00	1.90E-01	1.00E-03	1.20E-01	1.60E+02	6.30E+01	4.10E-02	2.43E+02
Kr-85	-	-	-	-	-	-	-	-	-	3.00E-03	1.10E-04	-	-	-	3.11E-03
Sr-90	1.30E+01	2.40E-01	3.50E-01	1.70E-02	6.50E-02	2.20E-02	3.60E+01	2.70E+01	1.00E+00	2.30E-03	-	3.70E-06	2.20E+02	1.40E-01	2.98E+02
Ru-106	2.90E+00	9.10E-03	1.20E-01	6.00E-03	2.80E-02	9.50E-03	6.00E-03	4.50E-03	1.30E-01	1.20E-02	6.00E-03	1.20E+01	1.30E+02	1.00E-01	1.45E+02
Sb-125	4.40E-01	2.50E-03	3.80E-02	1.90E-01	1.10E-02	3.80E-01	8.60E-02	6.50E-02	3.60E-02	1.10E-03	2.00E-02	2.80E+01	2.90E+01	1.80E-02	5.83E+01
I-129	3.10E+02	4.80E+02	8.00E+01	4.00E+00	3.40E+01	1.10E+01	2.60E+03	2.00E+03	8.40E+01	1.20E-04	9.70E-04	3.90E+00	2.40E+02	1.50E+00	5.85E+03
I-131	2.60E+01	9.20E+00	4.40E+00	2.60E-01	1.00E+00	3.30E-01	2.70E+02	1.70E+02	9.70E+00	2.20E-03	1.60E-02	1.30E+01	6.70E+01	1.40E-01	5.71E+02
Xe-133	-	-	-	-	-	-	-	-	-	1.30E-03	2.80E-03	-	-	-	4.10E-03
Cs-137	2.50E+00	3.90E+00	4.90E+00	2.50E-01	1.40E+00	4.60E-01	2.10E+01	1.60E+01	6.90E-01	3.10E-03	4.70E-03	4.20E+01	1.60E+01	1.00E-02	1.09E+02
Pu-239	5.40E+01	9.20E-04	1.50E-01	9.10E-01	4.50E-02	1.10E+00	6.00E-02	4.50E-02	2.30E+00	6.60E-05	1.20E-05	5.20E-03	2.00E+05	1.30E+02	2.00E+05
Pu-241	1.00E+00	1.70E-05	2.80E-03	1.70E-02	8.30E-04	2.00E-02	1.10E-03	8.30E-04	4.40E-02	2.80E-09	1.10E-07	6.50E-04	3.50E+03	2.30E+00	3.50E+03
Am-241	4.40E+01	1.20E-03	1.30E-01	7.60E-01	3.70E-02	8.70E-01	5.00E-02	3.80E-02	1.90E+00	2.40E-06	1.60E-03	1.10E+00	1.70E+05	1.10E+02	1.70E+05
Cm-242	4.40E+00	3.80E-05	7.30E-03	4.40E-02	2.30E-03	5.40E-02	2.90E-03	2.20E-03	2.00E-01	7.60E-11	2.80E-05	5.10E-03	3.10E+04	1.70E+01	3.10E+04
Cm-244	2.80E+01	2.90E-04	7.70E-02	4.70E-01	2.30E-02	5.40E-01	3.10E-02	2.30E-02	1.20E+00	-	3.40E-05	1.80E-02	1.10E+05	7.50E+01	1.10E+05

Table A18 Infant annual doses per unit release (1 TBq) for a realistic short-term release assessment (scenario 1a) (µSv)

Radio-nuclide	Green vegetables	Root vegetables	Cow meat	Cow liver	Sheep meat	Sheep liver	Milk	Milk Products	Fruit	Cloud Beta	Cloud Gamma	Deposited Gamma	Inhalation	Resuspension	Total
H-3	1.24E-02	8.30E-03	9.97E-04	6.65E-05	3.02E-04	1.01E-04	1.12E-01	-	6.22E-03	-	-	-	1.19E+00	-	1.33E+00
C-14	1.01E+01	1.68E+01	1.20E+01	6.68E-01	3.07E+00	6.73E-01	2.47E+02	-	1.21E+01	1.99E-03	-	-	1.02E+02	-	4.05E+02
S-35	2.03E+02	2.50E+02	2.14E-01	1.45E-02	4.46E-01	1.49E-01	1.39E+03	-	7.34E+01	6.52E-03	-	-	1.05E+02	-	2.02E+03
Ar-41	-	-	-	-	-	-	-	-	-	6.98E-02	5.07E-01	-	-	-	5.77E-01
Co-60	3.18E+01	2.71E-01	2.24E+00	1.49E+01	3.88E-01	1.29E+01	8.20E+02	-	9.37E+00	1.23E-02	9.86E-01	2.97E+03	8.34E+02	-	4.70E+03
Kr-85	-	-	-	-	-	-	-	-	-	3.58E-02	1.02E-03	-	-	-	3.68E-02
Sr-90	1.03E+02	2.31E+00	2.62E+00	1.75E-01	3.94E-01	1.31E-01	1.19E+03	-	2.83E+01	2.73E-02	2.62E-11	6.39E-05	2.70E+03	-	4.02E+03
Ru-106	5.30E+01	1.87E-01	2.40E+00	1.61E-01	4.60E-01	1.53E-01	6.23E-01	-	3.14E+00	1.98E-01	6.76E-02	1.96E+02	2.70E+03	1.57E+00	2.96E+03
Sb-125	7.14E+00	5.76E-02	8.90E-01	5.95E+00	1.63E-01	5.42E+00	8.93E+00	-	2.10E+00	1.34E-02	1.94E-01	4.70E+02	3.93E+02	-	8.93E+02
I-129	1.48E+03	2.53E+03	5.94E+02	3.96E+01	1.49E+02	4.97E+01	8.49E+04	-	7.35E+03	1.49E-03	9.47E-03	6.29E+01	1.81E+03	-	9.90E+04
I-131	4.03E+02	5.85E+01	3.90E+01	3.09E+00	1.19E+01	3.96E+00	1.15E+04	-	4.81E+02	2.67E-02	1.59E-01	1.18E+02	1.52E+03	-	1.41E+04
Xe-133	-	-	-	-	-	-	-	-	-	1.49E-02	2.58E-02	-	-	-	4.07E-02
Cs-137	1.66E+01	2.83E+01	4.89E+01	3.26E+00	8.21E+00	2.74E+00	9.48E+02	-	8.30E+01	3.76E-02	5.16E-02	7.32E+02	1.33E+02	8.41E-02	2.00E+03
Pu-239	4.68E+02	1.12E-02	1.53E+00	1.23E+01	3.47E-01	8.20E+00	2.70E+00	-	2.62E+01	7.86E-04	1.11E-04	9.30E-02	1.89E+06	1.20E+03	1.89E+06
Pu-241	6.33E+00	1.48E-04	2.02E-02	1.63E-01	4.62E-03	1.09E-01	3.56E-02	-	3.54E-01	3.34E-08	1.02E-06	1.65E-02	2.38E+04	1.50E+01	2.38E+04
Am-241	4.12E+02	1.58E-02	1.35E+00	1.09E+01	3.06E-01	7.23E+00	2.37E+00	-	2.30E+01	2.87E-05	1.53E-02	1.94E+01	1.69E+06	1.08E+03	1.69E+06
Cm-242	7.85E+01	6.07E-04	1.24E-01	9.97E-01	3.61E-02	8.41E-01	2.22E-01	-	4.36E+00	9.13E-10	2.66E-04	-	4.42E+05	2.36E+02	4.42E+05
Cm-244	3.22E+02	4.55E-03	1.03E+00	8.34E+00	2.36E-01	5.58E+00	1.82E+00	-	1.80E+01	-	3.24E-04	-	1.50E+06	9.47E+02	1.50E+06

Table A19 Infant annual doses per unit release (1 TBq) for a cautious (Cat D) short-term release assessment (scenario 1b) (µSv)

Radio-nuclide	Green vegetables	Root vegetables	Cow meat	Cow liver	Sheep meat	Sheep liver	Milk	Milk Products	Fruit	Cloud Beta	Cloud Gamma	Deposited Gamma	Inhalation	Resuspension	Total
H-3	1.88E-01	1.25E-01	1.81E-03	1.21E-04	5.48E-04	1.83E-04	2.02E-01	4.61E-03	9.38E-02	-	-	-	1.60E+00	-	2.22E+00
C-14	3.47E+00	5.74E+00	2.18E+01	1.21E+00	5.57E+00	1.22E+00	4.49E+02	1.39E+02	4.30E+00	2.68E-03	-	-	1.38E+02	-	7.69E+02
S-35	1.13E+03	5.50E+02	6.16E-01	4.17E-02	1.28E+00	4.28E-01	4.01E+03	2.24E+03	1.16E+02	8.76E-03	-	-	1.41E+02	-	8.20E+03
Ar-41	-	-	-	-	-	-	-	-	-	9.41E-02	2.93E+00	-	-	-	3.02E+00
Co-60	2.60E+03	1.38E+00	1.03E+01	6.89E+01	1.79E+00	5.97E+01	3.78E+03	2.15E+03	6.72E+01	1.65E-02	5.55E+00	6.78E+03	1.12E+03	-	1.67E+04
Kr-85	-	-	-	-	-	-	-	-	-	4.83E-02	4.94E-03	-	-	-	5.32E-02
Sr-90	7.43E+03	1.13E+01	1.21E+01	8.06E-01	1.82E+00	6.07E-01	5.48E+03	3.12E+03	2.01E+02	3.67E-02	1.29E-10	1.46E-04	3.63E+03	-	1.99E+04
Ru-106	3.65E+03	7.87E-01	1.11E+01	7.42E-01	2.12E+00	7.08E-01	2.88E+00	1.63E+00	6.97E+01	2.66E-01	3.12E-01	4.48E+02	3.63E+03	3.59E+00	7.82E+03
Sb-125	5.56E+02	2.86E-01	4.11E+00	2.75E+01	7.52E-01	2.50E+01	4.12E+01	2.34E+01	1.42E+01	1.80E-02	9.30E-01	1.07E+03	5.27E+02	-	2.29E+03
I-129	5.41E+04	1.37E+04	1.36E+03	9.08E+01	3.42E+02	1.14E+02	1.95E+05	1.11E+05	3.68E+04	2.00E-03	4.51E-02	9.20E+01	2.43E+03	-	4.15E+05
I-131	1.41E+03	6.18E+01	8.93E+01	7.08E+00	2.73E+01	9.08E+00	2.63E+04	1.26E+04	1.97E+02	3.59E-02	7.68E-01	1.73E+02	2.04E+03	-	4.29E+04
Xe-133	-	-	-	-	-	-	-	-	-	2.01E-02	1.32E-01	-	-	-	1.52E-01
Cs-137	1.22E+03	3.07E+02	2.26E+02	1.51E+01	3.79E+01	1.26E+01	4.38E+03	7.72E+02	8.27E+02	5.05E-02	2.38E-01	1.67E+03	1.78E+02	1.92E-01	9.65E+03
Pu-239	4.32E+04	5.29E-02	7.06E+00	5.70E+01	1.60E+00	3.79E+01	1.24E+01	7.08E+00	8.25E+02	1.06E-03	5.36E-04	2.12E-01	2.54E+06	2.75E+03	2.59E+06
Pu-241	5.73E+02	6.94E-04	9.34E-02	7.52E-01	2.13E-02	5.04E-01	1.64E-01	9.34E-02	1.09E+01	4.48E-08	5.29E-06	3.76E-02	3.20E+04	3.44E+01	3.26E+04
Am-241	3.81E+04	7.47E-02	6.22E+00	5.02E+01	1.41E+00	3.34E+01	1.10E+01	6.24E+00	7.26E+02	3.85E-05	7.53E-02	4.43E+01	2.27E+06	2.46E+03	2.32E+06
Cm-242	3.97E+03	2.36E-03	5.72E-01	4.60E+00	1.67E-01	3.88E+00	1.03E+00	5.78E-01	7.58E+01	1.23E-09	1.27E-03	-	5.93E+05	5.39E+02	5.98E+05
Cm-244	2.93E+04	2.14E-02	4.78E+00	3.85E+01	1.09E+00	2.58E+01	8.41E+00	4.79E+00	5.59E+02	-	1.54E-03	-	2.01E+06	2.16E+03	2.04E+06

Table A20 Infant annual doses per unit release (1 TBq) for a cautious (Cat F) short-term release assessment (scenario 1c) (μSv)

Radio-nuclide	Green vegetables	Root vegetables	Cow meat	Cow liver	Sheep meat	Sheep liver	Milk	Milk Products	Fruit	Cloud Beta	Cloud Gamma	Deposited Gamma	Inhalation	Resuspension	Total
H-3	8.19E-01	5.46E-01	7.90E-03	5.27E-04	2.39E-03	7.98E-04	8.84E-01	2.01E-02	4.10E-01	-	-	-	5.55E+00	-	8.24E+00
C-14	1.56E+01	2.58E+01	9.81E+01	5.45E+00	2.50E+01	5.49E+00	2.02E+03	6.26E+02	1.94E+01	9.46E-03	-	-	4.87E+02	-	3.33E+03
S-35	2.13E+03	1.04E+03	1.16E+00	7.86E-02	2.42E+00	8.07E-01	7.55E+03	4.23E+03	2.18E+02	2.71E-02	-	-	4.36E+02	-	1.56E+04
Ar-41	-	-	-	-	-	-	-	-	-	3.29E-01	7.71E+00	-	-	-	8.04E+00
Co-60	2.36E+03	1.25E+00	9.36E+00	6.24E+01	1.62E+00	5.41E+01	3.43E+03	1.95E+03	6.09E+01	5.64E-02	1.45E+01	1.09E+04	3.83E+03	-	2.27E+04
Kr-85	-	-	-	-	-	-	-	-	-	1.70E-01	1.29E-02	-	-	-	1.83E-01
Sr-90	6.73E+03	1.02E+01	1.09E+01	7.30E-01	1.65E+00	5.50E-01	4.97E+03	2.83E+03	1.82E+02	1.25E-01	8.53E-10	2.34E-04	1.24E+04	-	2.71E+04
Ru-106	3.31E+03	7.13E-01	1.00E+01	6.72E-01	1.92E+00	6.42E-01	2.61E+00	1.48E+00	6.31E+01	9.09E-01	1.11E+00	7.18E+02	1.24E+04	5.76E+00	1.65E+04
Sb-125	5.03E+02	2.59E-01	3.72E+00	2.49E+01	6.81E-01	2.27E+01	3.73E+01	2.12E+01	1.29E+01	6.14E-02	2.39E+00	1.72E+03	1.80E+03	-	4.15E+03
I-129	1.11E+05	2.80E+04	2.78E+03	1.86E+02	6.99E+02	2.33E+02	3.98E+05	2.27E+05	7.52E+04	5.23E-03	1.05E-01	2.15E+02	6.36E+03	-	8.49E+05
I-131	2.88E+03	1.26E+02	1.83E+02	1.45E+01	5.57E+01	1.86E+01	5.38E+04	2.58E+04	4.02E+02	9.37E-02	1.70E+00	4.05E+02	5.32E+03	-	8.90E+04
Xe-133	-	-	-	-	-	-	-	-	-	7.07E-02	3.45E-01	-	-	-	4.15E-01
Cs-137	1.11E+03	2.78E+02	2.05E+02	1.36E+01	3.43E+01	1.14E+01	3.96E+03	7.00E+02	7.49E+02	1.73E-01	1.16E+00	2.68E+03	6.08E+02	3.08E-01	1.04E+04
Pu-239	3.92E+04	4.79E-02	6.40E+00	5.16E+01	1.45E+00	3.43E+01	1.13E+01	6.41E+00	7.47E+02	3.61E-03	1.58E-03	3.41E-01	8.67E+06	4.41E+03	8.72E+06
Pu-241	5.19E+02	6.29E-04	8.46E-02	6.81E-01	1.93E-02	4.57E-01	1.49E-01	8.46E-02	9.90E+00	1.53E-07	1.37E-05	6.04E-02	1.09E+05	5.51E+01	1.10E+05
Am-241	3.45E+04	6.77E-02	5.64E+00	4.55E+01	1.28E+00	3.02E+01	9.93E+00	5.65E+00	6.58E+02	1.32E-04	1.96E-01	7.11E+01	7.77E+06	3.95E+03	7.81E+06
Cm-242	3.60E+03	2.14E-03	5.18E-01	4.17E+00	1.51E-01	3.52E+00	9.28E-01	5.24E-01	6.87E+01	4.19E-09	3.86E-03	-	2.03E+06	8.65E+02	2.03E+06
Cm-244	2.65E+04	1.94E-02	4.33E+00	3.49E+01	9.87E-01	2.33E+01	7.62E+00	4.34E+00	5.06E+02	-	4.52E-03	-	6.87E+06	3.47E+03	6.90E+06

Table A21 Infant annual doses per unit release (1 TBq y^{-1}) for a continuous release assessment (μSv)

Radio-nuclide	Green vegetables	Root vegetables	Cow meat	Cow liver	Sheep meat	Sheep liver	Milk	Milk Products	Fruit	Cloud Beta	Cloud Gamma	Deposited Gamma	Inhalation	Resuspension	Total
H-3	4.20E-03	3.60E-03	6.60E-04	4.40E-05	1.30E-04	4.40E-05	8.20E-02	1.90E-03	1.90E-03	-	-	-	1.40E-01	-	2.34E-01
C-14	3.40E-01	6.60E-01	2.00E-01	1.40E-02	4.10E-02	1.40E-02	6.60E+00	2.00E+00	3.40E-01	1.70E-04	-	-	6.10E+00	-	1.63E+01
S-35	1.90E+00	1.40E+00	1.90E+01	1.30E+00	9.20E+00	1.20E+00	2.90E+02	1.70E+02	5.20E-01	5.40E-04	-	-	6.10E+00	1.10E-02	5.01E+02
Ar-41	-	-	-	-	-	-	-	-	-	5.90E-03	4.90E-02	-	-	-	5.49E-02
Co-60	2.80E+00	9.40E-03	9.80E-02	6.60E-01	3.10E-02	1.00E+00	2.90E+01	1.70E+01	2.30E-01	1.00E-03	9.20E-02	1.10E+02	4.90E+01	3.20E-02	2.10E+02
Kr-85	-	-	-	-	-	-	-	-	-	3.00E-03	8.20E-05	-	-	-	3.08E-03
Sr-90	8.10E+00	8.30E-02	1.30E-01	8.50E-03	3.20E-02	1.10E-02	5.80E+01	3.30E+01	6.30E-01	2.30E-03	-	2.50E-06	1.60E+02	1.00E-01	2.60E+02
Ru-106	4.70E+00	8.60E-03	1.20E-01	7.90E-03	3.70E-02	1.20E-02	2.60E-02	1.50E-02	2.10E-01	1.20E-02	4.60E-03	8.00E+00	1.20E+02	9.50E-02	1.33E+02
Sb-125	6.40E-01	2.10E-03	3.30E-02	2.20E-01	1.30E-02	4.40E-01	3.30E-01	1.90E-01	5.20E-02	1.10E-03	1.50E-02	1.90E+01	2.30E+01	1.50E-02	4.40E+01
I-129	1.80E+02	1.60E+02	2.80E+01	1.90E+00	1.60E+01	5.30E+00	4.00E+03	2.30E+03	4.90E+01	1.20E-04	7.50E-04	2.60E+00	1.00E+02	6.50E-01	6.84E+03
I-131	4.50E+01	9.10E+00	4.50E+00	3.60E-01	1.40E+00	4.60E-01	1.20E+03	5.90E+02	1.70E+01	2.20E-03	1.30E-02	9.20E+00	8.80E+01	1.80E-01	1.97E+03
Xe-133	-	-	-	-	-	-	-	-	-	1.30E-03	2.20E-03	-	-	-	3.50E-03
Cs-137	1.50E+00	1.30E+00	1.80E+00	1.20E-01	6.60E-01	2.20E-01	3.40E+01	1.90E+01	4.20E-01	3.10E-03	3.60E-03	2.80E+01	7.90E+00	5.10E-03	9.49E+01
Pu-239	4.20E+01	4.10E-04	7.10E-02	5.70E-01	2.80E-02	6.60E-01	1.20E-01	7.10E-02	1.80E+00	6.60E-05	9.10E-06	3.50E-03	1.10E+05	7.40E+01	1.10E+05
Pu-241	5.60E-01	5.60E-06	9.40E-04	7.60E-03	3.70E-04	8.80E-03	1.60E-03	9.30E-04	2.50E-02	2.80E-09	8.80E-08	4.40E-04	1.40E+03	9.20E-01	1.40E+03
Am-241	3.70E+01	5.80E-04	6.40E-02	5.10E-01	2.50E-02	5.80E-01	1.10E-01	6.40E-02	1.60E+00	2.40E-06	1.30E-03	7.30E-01	1.00E+05	6.60E+01	1.00E+05
Cm-242	6.90E+00	3.50E-05	6.90E-03	5.50E-02	2.90E-03	6.80E-02	1.20E-02	6.90E-03	3.10E-01	7.60E-11	2.20E-05	3.40E-03	2.60E+04	1.40E+01	2.60E+04
Cm-244	2.90E+01	1.70E-04	4.80E-02	3.90E-01	1.90E-02	4.50E-01	8.40E-02	4.80E-02	1.30E+00	-	2.60E-05	1.20E-02	8.30E+04	5.40E+01	8.31E+04

APPENDIX B Example derivation of source terms

B1 INTRODUCTION

Tables 1 and 2 describe 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 Tables 1 and 2). 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 wind blowing into a sector (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 be 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 radionuclides 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 Tables 1 and 2). 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 radionuclides 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 Tables 1 and 2). 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.

B5 TWELVE-MONTH LIMITS AND WEEKLY ADVISORY LEVELS

Table B7 provides example 12 month limits and weekly advisory levels for discharges from a site. Also shown are the radionuclides which might be released together in short-term releases, resulting in four example 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 Tables 1 and 2). Hence, four release scenarios should be assessed as shown in Table B8. In this case there may be four occasions in the year when each of the short-term releases impacts on the individuals of interest, with each short-term discharge occurring at the weekly advisory levels for each radionuclide. Also shown in Table B8 is the continuous discharge for the remainder of the year.

For a cautious assessment, it is assumed that there are four releases of all radionuclides at the weekly advisory levels (see Table B8). Continuous releases for the remainder of the year are also shown in Table B8.

B6 DAILY LIMITS

Table B9 provides example daily limits for discharges from a site. Also shown are the radionuclides which might be released together in short-term releases, resulting in four example 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 Tables 1 and 2). Hence, four release scenarios should be assessed as shown in Table B10. In this case there may be 30 occasions in the year when each of the short-term releases impacts on the individuals of interest, with each short-term discharge occurring at the daily limit for each radionuclide. Also shown in Table B10 is the continuous discharge for the remainder of the year.

For a cautious assessment, it is assumed that there are 30 releases of all radionuclides at the weekly advisory levels (see Table B10). Continuous releases for the remainder of the year are also shown in Table B10.

It should be noted that if 12 month limits exist in addition to daily limits then the number of short-term releases may be further constrained by the 12 month limits.

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 of probability of wind blowing into a sector (1/12), subject to a minimum of 1 release per year.		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				✓
Number of possible releases per year			4	4	4	4
Number of releases per year taking account of probability of wind blowing into a sector (1/12), subject to a minimum of 1 release per year.			1	1	1	1

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				✓
Number of possible releases per year		12	12	12	12
Number of releases per year taking account of probability of wind blowing into a sector (1/12), subject to a minimum of 1 release per year.		1	1	1	1

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

Table B7 12 month limits and weekly advisory levels - Example limits and typical short-term release scenarios

Radionuclide	12 month limits (Bq)	Weekly advisory levels (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	2.0E+10	✓			
Carbon-14	1.0E+10	2.0E+08	✓			
Phosphorus-32	1.0E+09	2.0E+07		✓		
Strontium-89	1.0E+06	2.0E+04			✓	
Strontium-90	1.0E+07	2.0E+05			✓	
Iodine-125	1.0E+10	2.0E+08				✓
Iodine-131	1.0E+12	2.0E+10				✓
Number of possible releases per year			50	50	50	50
Number of releases per year taking account of probability of wind blowing into a sector (1/12), subject to a minimum of 1 release per year.			4	4	4	4

Table B8 12 month limits and weekly advisory 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	8.0E+10	9.2E+11		1.0E+12		1.0E+12		1.0E+12	8.0E+10	9.2E+11
Carbon-14	8.0E+08	9.2E+09		1.0E+10		1.0E+10		1.0E+10	8.0E+08	9.2E+09
Phosphorus-32		1.0E+09	8.0E+07	9.2E+08		1.0E+09		1.0E+09	8.0E+07	9.2E+08
Strontium-89		1.0E+06		1.0E+06	8.0E+04	9.2E+05		1.0E+06	8.0E+04	9.2E+05
Strontium-90		1.0E+07		1.0E+07	8.0E+05	9.2E+06		1.0E+07	8.0E+05	9.2E+06
Iodine-125		1.0E+10		1.0E+10		1.0E+10	8.0E+08	9.2E+09	8.0E+08	9.2E+09
Iodine-131		1.0E+12		1.0E+12		1.0E+12	8.0E+10	9.2E+11	8.0E+10	9.2E+11

Table B9 Daily limits - Example limits and typical short-term release scenarios

Radionuclide	Daily 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+10	✓			
Carbon-14	1.0E+08	✓			
Phosphorus-32	1.0E+07		✓		
Strontium-89	1.0E+04			✓	
Strontium-90	1.0E+05			✓	
Iodine-125	1.0E+08				✓
Iodine-131	1.0E+10				✓
Number of possible releases per year (**but may also be constrained by 12 month limits if these exist**)		365	365	365	365
Number of releases per year taking account of probability of wind blowing into a sector (1/12), subject to a minimum of 1 release per year.		30	30	30	30

Table B10 Daily 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	3.0E+11	3.4E+12		3.7E+12		3.7E+12		3.7E+12	3.0E+11	3.4E+12
Carbon-14	3.0E+09	3.4E+10		3.7E+10		3.7E+10		3.7E+10	3.0E+09	3.4E+10
Phosphorus-32		3.7E+09	3.0E+08	3.4E+09		3.7E+09		3.7E+09	3.0E+08	3.4E+09
Strontium-89		3.7E+06		3.7E+06	3.0E+05	3.4E+06		3.7E+06	3.0E+05	3.4E+06
Strontium-90		3.7E+07		3.7E+07	3.0E+06	3.4E+07		3.7E+07	3.0E+06	3.4E+07
Iodine-125		3.7E+10		3.7E+10		3.7E+10	3.0E+09	3.4E+10	3.0E+09	3.4E+10
Iodine-131		3.7E+12		3.7E+12		3.7E+12	3.0E+11	3.4E+12	3.0E+11	3.4E+12