NDAWG
National Dose Assessment Working Group

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Paper 10.04: Guidance on Simple Dose Assessment Tools

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1 Introduction

The National Dose Assessment Working Group (NDAWG) considered simple dose assessment tools at a meeting in April 2005 on radiological assessment issues for non-nuclear users of radioactive substances.

Simple dose assessment tools are as follows:

- Environment Agency's initial radiological assessment methodology [Refs 1, 2]. Available as 'pdf' files from the Environment Agency's publication web site.
- National Radiological Protection Board (NRPB) (now Health Protection Agency - HPA) radiological assessments for small users (NRPB-W63) [Ref 3]. Available as a printed report and as a 'pdf' file from the HPA web site.
- National Radiological Protection Board (NRPB) (now HPA) Generalised Derived Limits [Refs 4, 5, 6] and Generalised Derived Constraints [Refs 7, 8].

In addition, the International Atomic Energy Agency (IAEA) has published Safety Reports Series No 19 entitled Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment [Ref 9]. This report describes relatively simple models and methods that can be used to assess the radiological impact of radioactive discharges to the environment. The models and data in this report are intended for use as screening tools and contain cautious assumptions. It is possible to implement the models using a calculator or by setting up simple spreadsheets and such an approach could be used instead of the other simple tools described in this paper.

This paper provides a description of these tools; compares the scope of the tools and their limitations; and provides guidance on when it is most appropriate to use each assessment tool.

2 Initial radiological assessment methodology

The Environment Agency has developed an initial radiological assessment methodology to assess the impact of discharges of radioactive waste to the environment which are authorised under the Radioactive Substances Act 1993 (RSA 93). This methodology was originally developed for internal use by Environment Agency officers, but has now been improved and enhanced by Serco Assurance and is published as two Environment Agency science reports [Refs 1, 2]. The first report is a user report which describes and provides guidance on the assessment methodology. The second part of the report describes the underlying data and assumptions used in the methodology.

The Environment Agency, Scottish Environment Protection Agency and the Department of Environment in Northern Ireland in collaboration with the Food Standards Agency and NRPB (now HPA) have developed and published principles and guidance for the prospective assessment of public doses [Ref 10]. A staged approach to the assessment of critical group doses for authorisation purposes is recommended, as shown in Figure 1. The first stage consists of a simple and cautious assessment of the critical group dose rate (initial radiological assessment). If the resulting effective dose rate is less than 20 µSv/y then no further assessment would be warranted for the purpose of authorising the discharge of radioactive waste to the environment. Further investigation using more realistic data should be undertaken when effective dose rates exceed 20 µSv/y, in particular if a regulatory decision is dependent on the outcome of the assessment.

The initial radiological assessment methodology has been developed to be help the Environment Agencies and applicants for RSA 93 authorisations to make decisions on when a more detailed assessment is required as shown in Figure 1 (ie, including detailed source and site assessment; short-term release assessment, collective dose assessment and variability and uncertainty assessments).

2.1 Purpose and scope of initial radiological assessment methodology

The purpose of the initial radiological assessment methodology is to:

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

The methodology can be applied to all premises (including nuclear sites) which are authorised by the Environment Agency under RSA 93 to discharge radioactive waste to the environment to air, estuary/coastal water, river and public sewer (and then on to river and estuary). The methodology does not apply to the disposal of radioactive waste to land or discharges to lakes.

2.2 Overview of initial radiological assessment methodology

The methodology is based on the simple use of dose per unit release (DPUR) values for different radionuclides, release routes (eg, to air, water, sewer) and exposure pathways (eg, external dose from deposited radionuclides). DPUR factors have been derived for four discharge scenarios (discharges to air, estuary/coastal water, river and sewer), 100 radionuclides and seven exposure groups, including a total of 41 exposure pathways. The exposure group for the difference releases routes and the relevant exposure pathways are shown in Table 1.

Four age groups have been considered, including the fetus. The term offspring has been used to collectively denote the embryo, fetus and newborn child [Ref 11]. The doses assessed by this methodology are the doses for the worst age group of offspring, infant, child or adult. The DPUR values are then multiplied by the actual or proposed authorised limits to calculate the initial dose.

The assumptions which have been used to calculate DPUR factors for the initial radiological assessment methodology are generally cautious and have followed a conventional critical group approach as described in EC guidance [Ref 12]. The approach is similar to the calculations used to define Generalised Derived Constraints [Refs 7, 8]. It should be noted that the endpoint for GDCs is different, being the annual release that would give rise to a dose of 300 µSv/y.

The methodology does require that significant direct external radiation doses from a site using radioactive substances are included. However, DPUR factors are not appropriate for this exposure pathway. Rather, direct radiation doses would be determined by measurement.

2.3 Guidance on the application of the initial radiological assessment methodology

Guidance in the initial radiological assessment user report recommends that a three stage approach is adopted for initial radiological assessment:

- **Stage 1 – Initial radiological assessment using default data**. The default DPUR values are multiplied by the actual or proposed authorised limits, choosing surrogate radionuclides if DPUR data is not available for the radionuclide limit category in the authorisation. Direct radiation doses are assessed if these are above background at the site fence. The total dose is then calculated. If the assessed dose is >20 μSv/y, then proceed to Stage 2.
- **Stage 2 – Initial radiological assessment using refined data**. Some scaling can be applied to take account of site-specific dispersion conditions arising during releases to air (different effective release heights), releases to river (river flow), releases to estuary (water exchange rate) and releases to sewer (raw sewage input rate). These data are used to modify the assessed initial dose. In addition, guidance is given on deciding which doses should be added together to give a more realistic total dose. For example, if a discharge to water is a long way from the site, then it is unlikely to be realistic that the persons exposed to the releases to water will also be exposed to releases to air. If the assessed dose is >20 μSv/y, then proceed to Stage 3.
- **Stage 3 – Determine need for separate site-specific assessment**. Guidance is given on reviewing how realistic the assessment has been using the initial radiological assessment methodology. For example, sewage sludge may be incinerated rather than spread on to land. There may be no physical access to a brook below a sewage treatment works before it enters a river with a higher flow.

2.4 Worked examples

Worked examples using proformas are provided in the initial radiological assessment methodology user report [Ref 1].

3 Radiological assessments for small users (NRPB-W63)

The National Radiological Protection Board (now the Health Protection Agency) has published guidance on radiological assessment for non-nuclear users (NRPB-W63) [Ref 3]. This is an update of previous guidance [Ref 13]. Although spreadsheets were used to produce the figures in this report it was not possible to publish the spreadsheets as this would have involved substantial resources for QA and user support.

It should be noted that NRPB-W63 has not been designed to be used for assessing discharges of actinides, transuranics and fission isotopes, nor the combinations of radionuclides in NORM discharges.

3.1 Purpose and scope of NRPB-W63 methodology

The declared main purpose of NRPB-W63 is to help Radiation Protection Advisers within HPA (and previously NRPB) to prepare radiological assessments on a commercial basis for clients. This is almost always done where the assessment is being requested for the purposes of an application for authorisation under RSA 93. It provides a methodology that can be referenced and used for individual assessments that ensures a common approach and avoids "re-inventing the wheel" each time.

However, a secondary purpose is to provide a way for non-nuclear users themselves to undertake assessments to a certain standard, recognising that many of the individuals faced with this task do not appear to have access to the budgets that would be needed to fund specialist commercial consultants to do the work. In meeting this second objective, one of the intended benefits of NRPB-W63 is that it brings together in one document all the basic (non-site specific) input data that a user is likely to need. The alternative can be a laborious review of a large number of documents (eg, ICRP, NRPB, etc, publications).

3.2 Overview of NRPB-W63 methodology

An important point is that NRPB-W63 does not seek to provide anything that is not already published in one form or another. It merely brings together data and methodologies that appear in other HPA (NRPB) reports some of which were prepared in collaboration with other organisations. Two key reports are the NRPB contract report for the Environment Agency on discharges to sewage systems [Ref 14] which describes the SMART model and the more recent Centre for Ecology and Hydrology (CEH)/NRPB rivers discharge report [Ref 15]. The remaining modelling is of a basic dilution/concentration calculation type designed for what would normally be described as "screening calculations".

The methodology does insist that the user should provide site-specific input to the assessment including finding out something about their sewage works and river environment, and local agriculture (for aerial discharges). This effort to look at the actual routes is an important part of an assessment even for a fairly trivial source term. However there are limits to how far it is hoped users would be expected to go in 'exploring' site specific details. Many users are naturally reluctant to press sewage companies and others on radioactive discharges as this in itself can raise concerns that may develop into considerable public relations issues for them.

NRPB-W63 provides an indication of the implications of considering age groups other than adults in assessments and highlights the possibility that infant and child doses could be higher than adult doses for some common non-nuclear user radionuclides. It deliberately avoids suggesting that users need to perform more than one set of calculations for routine "regulatory" assessments since this would further add complexity and effort involved. Nevertheless, where assessed doses are significant then consideration of other age groups may be unavoidable, although this has rarely if ever been done in the past. NRPB-W63 allows doses for only a limited sub-set of radionuclides to be calculated without reference to other published data sets.

3.2.1 Releases to air

Aerial dispersion is dealt with using a simple Gaussian plume model. There is some discussion of building effects. The methodology assumes releases are relatively well spread over the calendar year and, despite some illustrative calculations for a one off-release, this treatment is not 'theoretically' applicable to small numbers of short releases. More complex modelling systems such as ADMS [Ref 16] may be required.

Food doses are dealt with by looking at the local situation, but recognising that this may fluctuate and that users will not want to undertake intrusive inquiries. The suggestion is to consider a reasonably cautious set of calculations admitting that the assessed doses are hypothetical. The implied default is a vegetable garden at five hundred metres and a dairy/beef/sheep farm at a nominal one kilometre, if relevant. This it is felt is reasonable and avoids excessive pessimism (eg, the effect of modelling a dairy cow at only one hundred metres). The report does enable doses to be calculated for shorter distances if there is evidence of local food production nearer to the site.

Experience has shown that the doses from aerial releases are less than 20 μSv/y for the majority of non-nuclear users. The main challenge has been over the effect of buildings on dispersion.

3.2.2 Releases to sewer and river

The methodologies in NRPB-W63 for releases to sewer and river have almost completely replaced those in the previous guidance in radiological assessment for non-nuclear users (NRPB-M744) [Ref 13].

To assess doses to sewer workers, NRPB-W63 includes simplified output from the SMART model [Ref 14]. NRPB-W63 includes some suggested 'sludge transfer' factors that are based in part on NRPB-W32 [Ref 17]. There is some flexibility to allow the user to set their own factors to the particular type of sewage treatment process in use and allow the effect of short half-lives (especially that of fluorine-18 and technetium-99m) to be taken into account.

NRPB-W63 describes how screening calculations can be done using a simple dilution model and sediment and fish concentration factors for discharges to inland rivers, whether or not via a sewage treatment works. However, NRPB-W63 recommends dose results derived from the CEH/NRPB rivers discharge report [Ref 15] are used and these can be scaled for site-specific conditions.

Included in NRPB-W63 is an indication of how doses for irrigation of crops using river water and doses consequent on disposal of sewage sludge to agricultural land may be estimated, but only for a limited selection of radionuclides.

3.3 Worked examples

NRPB-W63 provides worked examples of assessed doses for a reference source term.

4 Generalised derived limits and generalised derived constraints

4.1 Generalised derived limits

Generalised derived limits (GDLs) are intended for use as convenient reference levels against which the results of environmental monitoring can be compared. Therefore, they are used for retrospective assessments. GDLs have been calculated in various environmental materials for the radiologically significant isotopes of the following groups of elements:

- Strontium, iodine, caesium, plutonium, americium and curium [Ref 4].
- Polonium, lead, radium and uranium [Ref 5].
- Hydrogen, carbon, phosphorus, sulphur, chromium, manganese, cobalt, zinc, selenium, technetium, antimony, thorium and neptunium [Ref 6].

GDLs have been derived from the annual effective dose limit of 1 mSv. They have been calculated using deliberately cautions assumptions and are based on the assumption that the level of environmental contamination is uniform over a year. Fetal doses have been taken into account for the latest group of radioisotopes for which GDLs have been calculated [Ref 6].

If a measured environmental concentration exceeds about 10% of the GDL then the doses should be examined more closely, taking account of site specific factors and the length of time for which the measured level is likely to be maintained.

4.2 Generalised derived constraints

Generalised derived constraints (GDCs) are intended as convenient reference levels against which proposed discharges can be assessed. They are used for prospective assessments. GDCs have been calculated for discharges to atmosphere, rivers and sewers for the radiologically significant isotopes of the following groups of elements:

- Strontium, ruthenium, iodine, caesium, plutonium, americium and curium [Ref 7].
- Polonium, lead, radium and uranium [Ref 8].
- Hydrogen, carbon, phosphorus, sulphur, chromium, manganese, cobalt, zinc, selenium, technetium, antimony, thorium and neptunium (to be published).

GDCs apply to discharges of radionuclides to the environment and are based on the upper value of constraint on effective dose for members of the public of 0.3 mSv/y. They have been calculated using deliberately cautious assumptions and assume that releases to the environment are continuous over a year.

If a proposed discharge is greater than about 30% of the GDC then the doses should be examined more closely, taking account of site specific factors.

5 Comparison of scope and limitations of the assessment tools

One of the methodologies, generalised derived limits, is only applicable to retrospective assessments. The others are used for prospective assessments. The different tools which can be used for prospective assessments have been compared in Tables 1 - 6. The main aspects of the scope and limitations of the prospective assessment tools are as follows:

- ***Environment Agency Initial Radiological Assessment Methodology:***
  - Considers releases to air, river, estuary/coastal waters and sewer.
  - Provides assessment data for 100 radionuclides.
  - Includes a large number of exposure pathways, but does not include sewer maintenance workers.
  - Doses to adults, children, infants and offspring (fetus) are included in the assessment.
  - User is required to make some calculations, multiplying radionuclide limits by dose per unit release data and scaling the result for different effective release heights, river flow rates etc.

- ***Radiological assessment for small users (NRPB-W63):***
  - Considers releases to air, river, estuary/coastal waters and sewer.
  - Provides an assessment methodology for the key radionuclides which will be important for non-nuclear users.
  - Methodology includes all major exposure pathways, except for external radiation from deposited radionuclides which have been released to air. However, data is limited for some radionuclides.
  - Methodology is designed for assessing adult doses only, although some indication is given on doses for other age groups.
  - Detailed calculations are required to assess doses, requiring several parameters to be multiplies together for each radionuclide and exposure pathway.

- ***NRPB Generalised derived constraints:***
  - Considers releases to air, river and sewer, but not estuary/coastal waters.
  - GDCs are currently provided for 31 radionuclides, most of which are important for nuclear discharges. Calculations have also been carried out for a further 19 radionuclides, many of which are relevant to non-nuclear users and a report on these results is in preparation.
  - Methodology includes most exposure pathways, but does not include doses to sewer maintenance workers or fishermen exposed to discharges to the coast/estuary.
  - Adults, children and infants are covered by the methodology, but not offspring (fetus), except for the latest set of radionuclides to be published.
  - Calculations may not be required as the radionuclide discharge limits are compared to the GDCs.

The key differences in assumptions in the assessment tools which may affect the results of assessments are as follows:

- ***Releases to air*** – All assessment tools are broadly equivalent for a ground-level release, so long as the same assumptions are selected, in particular the distance to the location of food. The GDCs cannot be modified for different effective release heights.

- ***Releases to river*** – The initial radiological assessment methodology uses a cautious model for assessing river bed sediment concentrations and hence external dose rates, leading to higher doses. It also tends to use more cautious concentration factors for assessing transfer of radionuclides to fish. The GDCs and NRPB-W63 use an empirical dispersion and sedimentation model which may give more realistic river bed concentrations. However, there is limited radionuclide data available and the results do not always match observations. For example, the model assumes that radioiodine does not deposit in river bed sediments, but radioiodine has been found in sediments in the

River Thames. The GDCs cannot be modified for different river flow rates. Offspring (fetal) doses can become important for phosphorus-32/33 in fish and assessment of these doses is not included in the GDCs and NRPB-W63. Offspring doses have been included in the as yet unpublished GDCs for phosphorus isotopes.

- ***Releases to estuary/coastal waters*** – NRPB-W63 does not take account of radioactive decay for releases to estuary/coastal waters, leading to higher doses than the initial radiological assessment methodology.

- ***Releases to sewer*** - The initial radiological assessment methodology uses a lower occupancy for workers adjacent to sludge tanks than the other methodologies, leading to lower doses. The initial radiological assessment methodology and NRPB-W63 have nearly identical assumptions for disposal of sludge to land, leading to similar doses. The GDCs do not take account of partitioning of radionuclides or radioactive decay during transport and storage of sludge, so generally are more cautious.

6 Guidance on when to use assessment tools

Generalised derived limits are intended as reference levels against which the results of environmental monitoring can be compared. If a measured environmental concentration exceeds about 10% of the GDL then a more detailed site specific dose assessment may be required. The retrospective dose assessment principles [Ref 18] provides some guidance on retrospective assessments.

The prospective dose assessment principles [Ref 10] provides guidance on assessing prospective doses to members of the public. It recommends a cautious initial assessment which should then be followed by a more detailed site specific assessment if the dose exceeds 20 μSv/y. The assessment tools may be used in the following way to be consistent with this framework. Please note that it is not necessary to follow through each step in turn; it may be more appropriate to start at a later step.

- ***Step 1 – Check limits against NRPB Generalised derived constraints***:

  Radionuclide discharge limits may be compared to the appropriate GDCs, where these are available. The GDCs are based on the dose constraint of 0.3 mSv/y. There is no need to undertake a more detailed site specific prospective assessment, if the discharge limits are a small fraction of the GDCs.

  The prospective dose assessment principles state that a more detailed site specific assessment should be undertaken, if the total dose for all radionuclides is greater than 20 μSv/y. To ensure that the GDCs are used in a way which is consistent with these principles, the total dose from the different radionuclide discharge limits should be compared to the dose threshold of 20 μSv/y.

  Hence, the ratio of each radionuclide discharge limit to the appropriate GDC should be calculated and summed for all radionuclides released via a particular discharge route (eg, air, sewer). These summed ratios for a particular discharge route should be totalled, unless it is clear that one population group cannot be exposed to discharges from different discharge routes. A detailed site specific assessment should be considered, if the summed ratio(s) exceeds 0.07 (ie, 20 μSv/y divided by 300 μSv/y).

  There is no need to proceed further, if no detailed site specific assessment is required. Otherwise, proceed to step 2a.

- ***Step 2a – Initial radiological assessment***:

  Use Environment Agency's initial radiological assessment methodology [Ref 1]. The assessment can be refined to take account of different effective release heights, river

flows, estuary/coastal water exchange rates and raw sewage flow rates. Guidance is also provided on when a more realistic assessment is required. Proceed to step 2b, if a more realistic assessment is required.

- ***Step 2b – More realistic site specific assessment (NRPB-W63)***:

  Use NRPB-W63 to undertake a more realistic site specific assessment, where the initial radiological assessment methodology is not sufficiently flexible to be used. The relevant exposure pathways and site specific data can be selected and used in the assessment. Some data may be sourced from the supporting report to the initial radiological assessment methodology [Ref 2], where it is not available in NRPB-W63.

- ***Step 3 – Detailed site specific assessment using an expert:***

  For complex release routes and exposure pathways, it may be necessary to seek the services of a radiological assessment expert, perhaps from a consulting organisation. NDAWG is considering whether there is merit in having a certification scheme for radiological assessors.

7 Way forward for NDAWG

NDAWG and its sub-groups are proposing future developments in the following key areas:

- NDAWG plans to prepare a web page providing guidance on radiological assessments for non-nuclear users.

- Releases, particularly short term releases, into a built-up environment where hospitals are generally located are difficult to model accurately. This has become more important as the use of cyclotrons increases with the release of short-lived radionuclides. NDAWG has established a sub-group to help provide guidance on short-term releases.

- Release of phosphorus-32/phosphorus-33 into rivers with subsequent uptake into fish and consumption by pregnant mothers has become recognised as a potentially significant exposure pathway for offspring. NDAWG has taken an interest in this and the Environment Agency has commissioned some water and fish monitoring in the River Cam which receives some of the highest combined discharges of phosphorus isotopes in England and Wales.

- The simple river dispersion model used for the initial radiological assessment methodology probably over-estimates the river bed sediment concentrations which are used to calculate external radiation doses. The NDAWG modelling sub-group has recommended more research in this area. However, there is limited radionuclide data available and the results do not always match observations

- There is limited realistic sewage sludge partitioning data available for the different radio-elements released to sewer. The Environment Agency and Food Standards Agency have funded research in this area and this has been supported by the NDAWG modelling sub-group.

- NDAWG to consider the merit of a certification scheme for radiological assessors.

8 Conclusions

The Environment Agency has published an initial radiological assessment methodology which uses dose per unit release factors to enable prospective doses to be calculated for a large range of radionuclides released to air, river, coast/estuary and sewer. The dose per unit

release factors are scalable by some simple environmental dispersion factors, for example, river flows rate.

The NRPB, now HPA Radiation Protection Division, has published guidance for non-nuclear users (NRPB-W63) which is designed for used for prospective radiological assessments. Data and example doses are provided for key radionuclides released by non-nuclear users. NRPB also published Generalised Derived Limits and Generalised Derived Constraints. GDLs can be used to assess the significance of environmental monitoring results and are hence used retrospectively (ie, after releases to the environment). The GDCs can be used as a screening assessment of planned releases.

The scope and limitations of the three prospective assessment tools have been examined and guidance provided on when it is most appropriate to use each assessment tool.

NDAWG is planning to provide a web page with guidance on radiological assessment for non-nuclear users. NDAWG is also investigating areas of significant uncertainty in radiological assessments, including short term releases in built up areas (eg, from cyclotrons), releases of phosphorus isotopes to rivers which could give significant doses to the offspring, improvements in modelling river bed sediment concentrations and research into more realistic sewage sludge partitioning data for radio-elements released to sewer.

9 References

1 Science Report SC030162 Initial Radiological Assessment Methodology – Part 1 User Report ISBN Number 1844325423 April 2006 (http://publications.environment-agency.gov.uk/epages/eapublications.storefront/450967d1001ab534273fc0a802960648/Product/View/SCHO0106BKDT&2DE&2DE).

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

3 McDonnell CE (2004). Radiological Assessments for Small Users. Chilton, NRPB W-63.

4 NRPB (1998). Revised generalised derived limits for radioisotopes of strontium, iodine, caesium, plutonium, americium and curium. *Doc NRPB*, **9** (1), 1-34.

5 NRPB (2000). Generalised derived limits for radioisotopes of polonium, lead, radium and uranium. *Doc NRPB*, **11** (2), 43-71.

6 NRPB (2005). Generalised derived limits for radioisotopes of hydrogen, carbon, phosphorus, sulphur, chromium, manganese, cobalt, zinc, selenium, technetium, antimony, thorium and neptunium. *Doc NRPB*, **16** (3), 1-45.

7 Titley JG, Attwood CA and Simmonds JR (2000). Generalised Derived Constraints for Radioisotopes of Strontium, Ruthenium, Iodine, Caesium, Plutonium, Americium and Curium. *Doc NRPB*, **11** (2), 1–41.

8 Harvey MP and Simmonds JR (2002). Generalised Derived Constraints for Radio-isotopes of Polonium, Lead, Radium and Uranium. *Doc NRPB*, **13** (2), 1–38.

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

10 Environment Agency, Scottish Environment Protection Agency, Northern Ireland Department of Environment, National Radiological Protection Board and Food Standards

Agency (2002). Authorisation of Discharges of Radioactive Waste to the Environment. Principles for the Assessment of Prospective Public Doses. http://publications.environment-agency.gov.uk/pdf/PMHO1202BKLH-e-e.pdf.

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

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

13 McDonnell CE (1996) Assessment of the Radiological Consequences of Accumulation and Disposal of Radioactive Wastes by Small Users of Radioactive Materials. Chilton, NRPB-M744.

14 Titley JG, Carey AD, Crockett GM, Ham GJ, Harvey MP, Mobbs SF, Tournette C, Penfold JSS, Wilkins BT (2000) Investigation of the sources and fate of radioactive discharges to public sewers. Environment Agency R&D Technical Report P288, ISBN 1 85705 1114.

15 Hilton J, Small S, Hornby D, Scarlett, Harvey M, Simmonds J, Bexon A and Jones JA (2003). Modelling the Combined Impact of Radionuclide Discharges Reaching Rivers. R&D Technical Report P3-068/TR prepared for the Environment Agency by the Centre for Ecology and Hydrology and NRPB.

16 Carruthers DJ, Holroyd RJ, Hunt JCR, Weng WS, Robins AG, Apsley DD, Thompson DJ and Smith FB (1994). UK-ADMS: A new approach to modelling dispersion in the Earth's atmospheric boundary layer. *J Wind Engineering and Industrial Aerodynamics*, **52**, 139-153.

17 Ham GJ, Shaw S, Crockett GM and Wilkins BT (2003) Partitioning of Radionuclides with Sewage Sludge and Transfer along Terrestrial Foodchain Pathways from Sludge-amended Land - A Review of Data. Chilton, NRPB-W32.

18 NDAWG (2005). Assessment of Compliance with the Public Dose Limit: Principles for the Assessment of Total Retrospective Public Doses. NDAWG/2/2005. (http://www.ndawg.org/).

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

Table 1. Exposure pathways considered in prospective methodologies

Release route	Exposed population group	Exposure pathway	Initial Rad Asses	NRPB-W63	NRPB GDCs
Air	Local resident family	Inhalation of radionuclides in the effluent plume	✓	✓	✓
		External irradiation from radionuclides in the effluent plume	✓	✓	✓
		External irradiation from radionuclides deposited to the ground	✓	-	✓
		Consumption of terrestrial food incorporating radionuclides deposited to the ground	✓	✓	✓
Estuary or coastal water	Fisherman family	External irradiation from radionuclides deposited in shore sediments	✓	✓	-
		Consumption of seafood incorporating radionuclides	✓	✓	-
River	Angler family	External irradiation from radionuclides deposited in bank sediments	✓	✓	✓
		Consumption of freshwater fish incorporating radionuclides	✓	✓	✓
		Consumption of drinking water containing radionuclides	✓	✓	✓
	Irrigated food consumer family	Consumption of terrestrial food irrigated with river water and incorporating radionuclides	✓	✓	✓

Table 1. Continued

Release route	Exposed population group	Exposure pathway	Initial Rad Asses	NRPB-W63	NRPB GDCs
Sewer	Maintenance worker (adults only)	External irradiation from radionuclides in raw sewage and sludge	-	✓	-
		Inadvertent inhalation and ingestion of raw sewage and sludge containing radionuclides	-	✓	-
	Sewage treatment workers (adults only)	External irradiation from radionuclides in raw sewage and sludge	✓	✓	✓
		Inadvertent inhalation and ingestion of raw sewage and sludge containing radionuclides	✓	✓	✓
	Farming family living on land conditioned with sewage sludge	Consumption of food produced on land conditioned with sludge and incorporating radionuclides	✓	✓	✓
		External irradiation from radionuclides in sludge conditioned soil	✓	✓	✓
		Inadvertent inhalation and ingestion of sludge conditioned soil	✓	✓	✓
	Children playing in brook which receives treated effluent from sewage works (children only)	External irradiation from radionuclides deposited in bank sediments	✓	✓ models can be adapted	-
		Inadvertent consumption of water and sediment containing radionuclides	✓	✓ models can be adapted	-
	Angler family (river receives treated effluent from sewage works)	External irradiation from radionuclides deposited in bank sediments	✓	✓	✓
		Consumption of freshwater fish incorporating radionuclides	✓	✓	✓
		Consumption of water containing radionuclides	✓	✓	✓
	Irrigated food consumer family (river receives treated effluent from sewage works)	Consumption of terrestrial food irrigated with river water and incorporating radionuclides	✓	✓	✓
	Fisherman family (estuary/coastal water receives treated effluent from sewage works, typically via a river)	External irradiation from radionuclides deposited in sediments	✓	✓	-
		Consumption of fish incorporating radionuclides	✓	✓	-

Table 2. Comparison of prospective methodologies

Aspect of methodology	Environment Agency Initial Radiological Assessment	NRPB-W63	NRPB GDCs
Radionuclides	100 radionuclides	Up to 37 radionuclides – these are important for non-nuclear users. Methodology can be extended for other radionuclides if data is sourced from elsewhere	31 – Currently only cover a few important radionuclides for non-nuclear users
Release routes	Releases to air, river, coast/estuary and sewer.	Releases to air, river, coast/estuary and sewer.	Releases to air, river and sewer.
Exposed population groups and exposure pathways	See Table 1. Sewer maintenance workers are not included.	See Table 1. External radiation from deposited activity from release to air is not included.	See Table 1. Fishermen exposed to discharges into the coast/estuary; sewer maintenance worker; and children playing in a brook flowing from sewage treatment works are not included.
Age groups	Adults, children, infants and offspring (fetus).	Adults. Some indication of doses for other age groups given.	Adults, children and infants.

Table 3. Releases to air – key assumption comparison

Assessment parameter	Environment Agency Initial Radiological Assessment	NRPB-W63	NRPB GDCs
Effective release height	Default of ground-level, but can be scaled by effective release heights up to 80 m.	10 m in example assessment. Data for release heights ground-level to 40 m.	1 m
Dispersion model	Gaussian plume 50%D	Gaussian plume, assuming 60%D in example assessment. Data for range of other weather conditions.	Gaussian plume 50%D
Location of group exposed to inhalation and external radiation doses	100 m	100 m in example assessment. Data available for distances from 100m – 10 km.	100 m
Location of food	500 m	500 m for vegetables and 1 km for meat and milk in example assessment. Data available for distances from 100m – 10 km.	500 m
Food included	Milk, cow meat, cow offal, sheep meat, sheep offal, green vegetables, root vegetables and fruit.	Milk, beef meat, sheep meat, green vegetables and root vegetables.	Milk, milk products, cow meat, cow offal, sheep meat, sheep offal, green vegetables, root vegetables and fruit.

Table 4. Releases to river – key assumption comparison

Assessment parameter	Environment Agency Initial Radiological Assessment	NRPB-W63	NRPB GDCs
River flow rate	Default of 1 m^3/s., but can be scaled for different flow rates.	10 m^3/s for fish and irrigation water exposure pathways and 20 m^3/s for drinking water in example assessment. Doses can be scaled for different flow rates.	1 m^3/s.
Dispersion modelling	Simple dilution model, taking account of loss of activity to particulate phase. Bed sediment concentrations calculated using sediment distribution coefficients.	PC Cream compartment model. Water concentration data is similar to simple dilution model, but empirical model used for bed sediment concentrations.	PC Cream compartment model. Water concentration data is similar to simple dilution model, but empirical model used for bed sediment concentrations.
Transfer to fish	More cautious since derived from a number of sources [eg, Refs 12, 19]	Derived from EU report [Ref 12]	Derived from EU report [Ref 12]
Freshwater fish consumption	20 kg/y adults	20 kg/y adults	20 kg/y adults
Occupancy over sediment	1000 h/y adults	1000 h/y adults	500 h/y adults

Table 5. Releases to coast/estuary – key assumption comparison

Assessment parameter	Environment Agency Initial Radiological Assessment	NRPB-W63	NRPB GDCs
Exchange rate	Default of 100 m^3/s (30 m^3/s for small estuaries, particularly on East coast of Britain), but can be scaled for different flow rates.	630 m^3/s in example assessment. Doses can be scaled for different exchange rates.	Not included.
Dispersion modelling	PC Cream Doris.	Simple dilution model.	Not included.
Shellfish included	Fish, crustacea, mollusc.	Fish, crustacea, mollusc.	Not included.
Fish consumption	Adults 50 kg/y local box Adults 50 kg/y regional box	Adults 100 kg/y	Not included.
Crustacea consumption	Adult 20 kg/y	Adult 20 kg/y	Not included.
Mollusc consumption	Adult 20 kg/y	Adult 20 kg/y	Not included.
Occupancy	Adult 2000h/y	Adult 2000h/y	Not included.

Table 6. Releases to sewer – key assumption comparison

Assessment parameter	Environment Agency Initial Radiological Assessment	NRPB-W63	NRPB GDCs
Raw sewage flow rate	Default of 60 m^3/day, but can be scaled.	43200 m^3/day in example assessment. Doses can be scaled for different flow rates.	60 m^3/day. Scaling methodology is provided.
Partitioning between sewage sludge and treated effluent	Included	Included	Worst case assumption that either 100% to sludge or 100% to treated effluent.
% solids in raw sewage	0.05%	0.05%	0.05%
% solids in treated sludge	5%	5%	5%
Occupancy at sewage treatment works	500 h/y next to sludge tanks and 1500 h/y next to raw sewage tanks	2000 h/y in sewage treatment works	1000 h/y next to sludge tanks for external dose and 2000 h/y in sewage works for inadvertent ingestion and inhalation dose
Sludge spreading rate	8 kg/m^2/y	8 kg/m^2/y	8 kg/m^2/y
Food included	Milk, cow meat, cow offal, sheep meat, sheep offal, green vegetables and root vegetables.	Milk, milk products, cow meat, cow offal, sheep meat and sheep offal.	Milk, cow meat, cow offal, sheep meat and sheep offal.

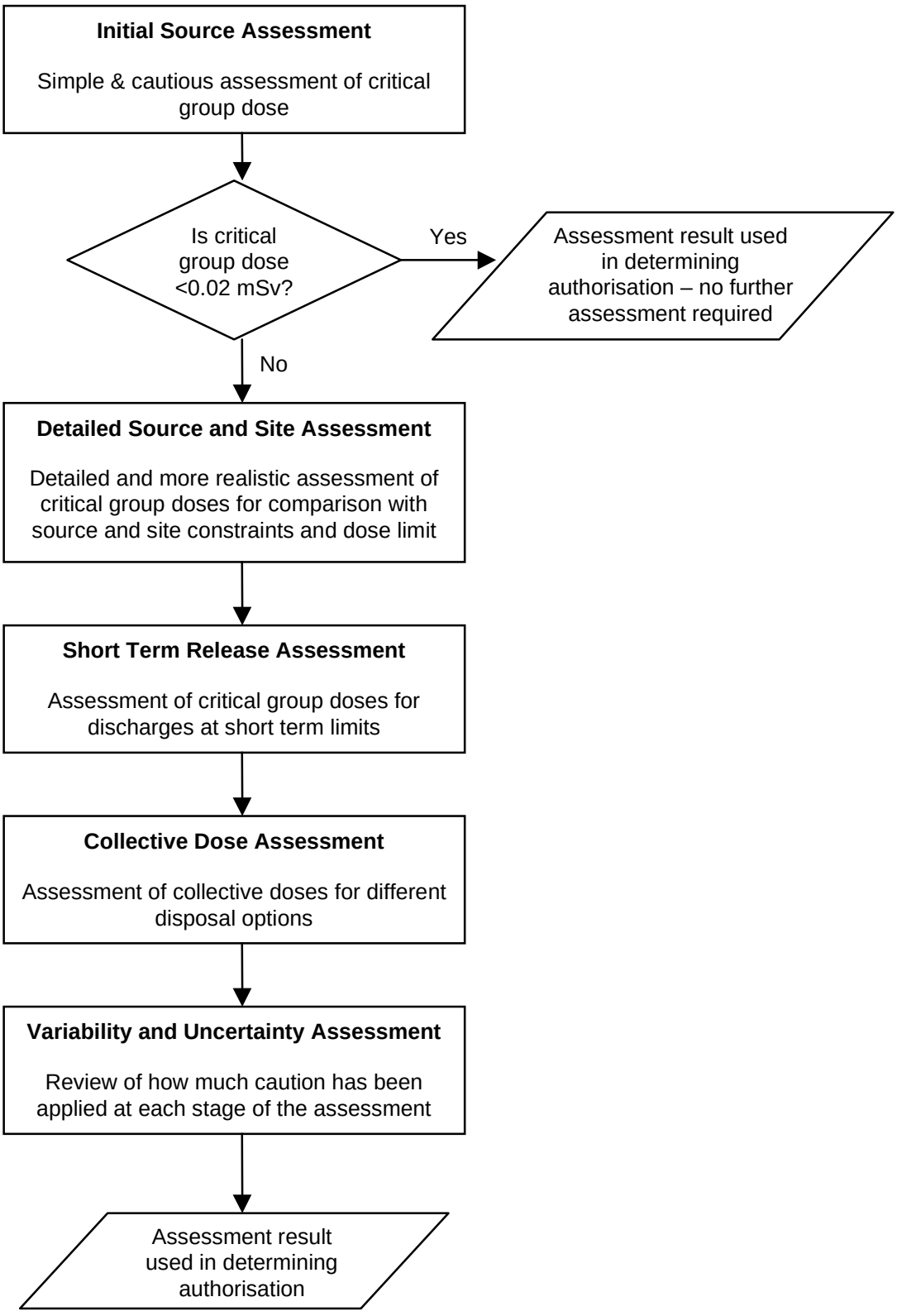

Figure 1 Stages of dose assessment process for discharge authorisations