NDAWG
National Dose Assessment Working Group

NDAWG GUIDANCE NOTE 4

Guidance on considering uncertainty and variability in radiological assessments

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1 Introduction and purpose

The National Dose Assessment Working Group (NDAWG) aims to promote the use of good practice and consistent methodologies for assessing radiation dose from planned discharges of radioactive material into the environment. As part of its work the NDAWG publishes reports on key topics on its website (www.ndawg.org). In addition, NDAWG is publishing a series of consolidated guidance notes on key issues related to dose assessments. This guidance forms part of this series of notes and is intended for use by those who are faced with the task of having to consider uncertainty and variability in assessments. It is based on the work of the NDAWG Uncertainty and Variability subgroup which was reported in two NDAWG reports [Refs 1, 2]. Both subgroup reports give details of references where further information and guidance may be obtained.

Most assessments of the doses received by members of the public as a result of routine discharges of radioactive material into the environment are carried out deterministically and the result presented as a single 'point' value. No attempt is made to calculate the range of doses that could be received by members of the public in such assessments. However, if assessments are carried out by different organisations this may give an indication of the inherent variability. The guidance on principles for the assessment of prospective public doses issued by the Environment Agencies, the FSA and the then NRPB [Ref 3] states that 'Where the assessed dose to the critical group exceeds 0.02 mSv/y the uncertainty and variability in the key assumptions for the dose assessment should be reviewed'. This guidance does not require that a full uncertainty analysis is carried out. In most cases the guidance suggests that a qualitative or semi-quantitative review is carried out.

2 Scope

This guidance applies to prospective radiological assessments carried out to determine the possible impact of potential discharges of radioactive waste to the environment. It supports the process of considering uncertainty and variability in a radiological assessment, where the annual effective dose to the critical group dose is greater than 0.02 mSv.

3 Guidance on considering uncertainty and variability

The following steps should be carried out:

- ***Step 1 – Ensure that the purpose and intended audience of the assessment is clear***

  The purpose of the assessment (eg, whether the assessment is intended to calculate the likely dose or whether it is intended just to demonstrate compliance with regulatory criteria) will inform the approach to uncertainty and variability that is required. Whether the assessment is retrospective or prospective will also inform the approach. In the case of a prospective assessment it will be necessary to give consideration to changes in the environment or habits that may occur in the future. Similarly consideration of the intended audience, regulators, experts or members of the public will inform decisions on how the results should be presented.

- ***Step 2 – Ensure that the radiological assessment is realistic***

  Ensure that there is no un-necessary caution in the radiological assessment. Table 1 provides some guidance on areas where caution may be removed.

- ***Step 3 – Determine the type of uncertainty assessment required***

  Guidance on the different types of uncertainty and variability assessments are given in Table 2.

- ***Step 4 – Perform uncertainty/variability analysis***

  Perform the uncertainty/variability analysis, being aware of the pitfalls listed in Appendix 1.

- ***Step 5 – Interpret and present results***

  The presentation of the results of a dose assessment depends on the intended audience for the dose assessment. It is important that sufficient information is presented to fully characterise the distribution of doses. When discussing comparing distributions many assessors simply report the 5^{th}, 50^{th} and 95^{th} percentile values. The minimum and maximum values of dose distributions should be used with caution, if at all. The use of graphical techniques such as box plots may be of benefit in the reporting of the results.

  Care should be taken to ensure that the presentation of numerical values to too great a number of significant figures does not lead to an impression of undue precision being conveyed.

4 Definitions

Uncertainty Uncertainty is a measure of the lack of knowledge of the system that under investigation. Uncertainty in predictions can be grouped into broad categories summarised below.

- Measurement uncertainty; the uncertainty in the field or laboratory measurements on which the model is based.
- Parameter value uncertainty; the uncertainty caused by not knowing the appropriate value of parameters that are used in the model.
- Conceptual model uncertainty; the uncertainty associated with forming a representation of the processes being modelled.
- Computational uncertainty; the uncertainty associated with the representation of the selected model in computational terms.
- Scenario uncertainty; the uncertainty inherent in the assumptions made about the behaviour of, eg, people and animals in the system being modelled.

In principle further measurements or other investigations will enable many of these uncertainties to be reduced.

Variability Variability refers to temporal or a spatial difference in process, eg, transfers in different environment or behaviour or characteristics, such as the amount of different foods consumed by people. Variability cannot be reduced by the acquisition of further information.

In some cases the difference between uncertainty and variability is not clear cut.

5 References

1. NDAWG (1/2005). An Overview of Uncertainty in Radiological Assessments.

2. NDAWG (1/2006). Reviewing Non Nuclear Licensed Site Radiation Dose Assessments Taking into Account Uncertainty

3. 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.

Table 1 – Examples of areas where undue caution may be removed from radiological assessments

Parameter	Guidance on removing caution from radiological assessments
All assessments	
Radionuclide limits	Authorisations to discharge radioactive material into the environment and hence assessments of the impact of such discharges often contain a category such as 'alphas' or 'other betas'. Assessments for these categories are often made on the basis of the 'worst case' nuclide in the group making up all of the discharge. Use more realistic breakdowns of the radionuclides in these groups. Care however, must be taken to ensure that the assessment still remains fit for purpose.
Releases to air	
Stack height	Use effective release height rather than ground-level release.
Meteorological data and dispersion modelling	Use site specific meteorological data and up to date air dispersion model (eg, ADMS, AERMOD).
Population groups	**Local habitants –** Choose local population groups at locations where they actually spend time and from where they source their food. Select foods that are produced in the locality. In the case of prospective assessments habits that could reasonably occur in the future should be taken into account.
Habits (food consumption rates)	**Local habitants –** Use habit data on actual food consumed. Habits profiles as reported in the Radioactivity in Food and Environment Report [Ref 1]are more realistic than assuming two or more foods are consumed at critical consumption rates.
Releases to freshwater	
Environmental concentrations	In the case where an assessment is being carried out for a practice that already exists (for example to support an application for a revised Authorisation), there may already be empirical evidence of the impact of the discharges on the foodchain and the environment. These measurements of concentrations resulting from known historic discharges can be extrapolated to give estimates of concentrations from future discharges.
Exposure pathways	**Water consuming family –** Drinking water may be blended with other water or stored in reservoirs for long periods prior to consumption. Water will be treated prior to consumption with some removal of radionuclides. **Irrigated food consumers –** There may be no crops produced with irrigated water.
Habits (food consumption rates)	**Water consuming family –** Use habits data for freshwater fish consumption in the locality of the discharges. **Irrigated food consumers –** Use habits data for consumption rates of locally produced irrigated vegetables.
Releases to estuary/coastal waters	
Environmental concentrations	In the case where an assessment is being carried out for a practice that already exists (for example to support an application for a revised Authorisation), there may already be empirical evidence of the impact of the discharges on the foodchain and the environment. These measurements of concentrations resulting from known historic discharges can be extrapolated to give estimates of concentrations from future discharges.
Population groups	**Fishing family –** Young children and infants may spend little time on intertidal areas around the site.
Habits	**Fishing family –** Site specific habits data may indicate lower consumption rates for fish or shellfish.
Releases to sewer	
Sewage treatment works (STW)	Radioactive decay prior to reaching a STW may also be taken into account and longer delays prior to application on land.
Exposure pathways and population groups	**Sewage workers –**Human contact with sewage may not be possible and therefore there may be no doses to sewage workers. **Farming family at a farm receiving treated sewage sludge –** Use information on actual spreading rates of sludge to land.

[1] Radioactivity in Food and The Environment 2007. Food standards Agency, Environment Agency, Scottish Environment Protection Agency & Northern Ireland Environment Agency.

	Water consuming family and irrigated food consumers – As per river discharge above. **Fishing family –** As per estuary/coastal waters discharge above.
Habits	**Sewage workers –** Use actual data on occupancy at different parts of the sewage treatment works. **Farming family at a farm receiving treated sewage sludge –** Use habit data on consumption rates. The range of locally produced foods consumed may be restricted by type of land around the site and area of land available. Cows may be indoors in winter (not grazing affected pasture) and sheep may have their diet augmented with feed. **Water consuming and irrigated food consumers –** As per river discharge above. **Fishing family –** As per estuary/coastal waters discharge above.

Table 2 – Different types of uncertainty assessment

Type	Description
Compare with case studies	Uncertainty and variability analyses can be carried out for representative sites as case studies. The results of these case studies can then be used to give an indication of the amount of uncertainty present in the results of assessments carried out for other, similar, sites. Care must be exercised to ensure that the sites considered are comparable
Upper and Lower Bound Assessments	Often the underlying purpose of a dose assessment is not to determine the dose that would be received but to demonstrate that the dose received is not greater than regulatory limits. If this is the case it not necessary to calculate the range of doses that could be received but rather to calculate a reasonable, but not extreme, upper bound on this range. Rather than using distributions of parameter values in models, realistic values that tend to increase assessed doses relative to those obtained using typical values are used. If these calculations result in a dose that is less than the regulatory criterion then it has been demonstrated that, whatever the level of uncertainty in the assessed dose, the dose would not be unacceptable. There are drawbacks in this approach. Whilst each parameter value chosen may be realistic the combination of parameters may represent circumstances and combinations of habits that are not realistic. This can result in an unrealistic upper-bound value for the dose that is in excess of the appropriate regulatory level. A lower-bound assessment can be undertaken in a similar manner.
Partial uncertainty / variability analysis	For sites where the exposure of members of the public is a result of discharges of several radionuclides it is often the case that the doses received are dominated by one of the radionuclides. Alternatively the dose may be dominated by one pathway with the contributions from other pathways bring small. In these cases a full uncertainty analysis would not be an appropriate use of time and other resources. Instead a partial uncertainty analysis relating to the key radionuclide(s) and pathway(s) identified in an initial deterministic analysis should be carried out.
Sensitivity Analysis	Sensitivity analysis is the study of the effect of changes in input values on the calculated output. This can be done by either varying a single parameter at a time to see the effect on the output or by varying a suite of input parameters together. This enable the parameters with the greatest effect on the model output to be identified.
Full uncertainty and variability assessment (Probabilistic assessment)	If the listed above do not allow the issue of uncertainty analysis to be fully resolved a full analysis of uncertainty and variability will need to be carried out. It may be appropriate to employ an external expert in cases where there are unusual pathways or multiple pathways and or nuclides.

Appendix 1 Pitfalls of full or partial uncertainty/variability analysis

- **Selection of parameter values**. In many cases, the ranges in parameter values are chosen by the people carrying out the study and are therefore susceptible to bias. An alternative is to use expert elicitation in some form. There are, however, potential bias and resource issues associated with these. In particular the experts may not be able to consider the parameters that are used in the model but may need to consider quantities that can be directly measured. Also, the experts may be asked for the range on the 'best estimate' or mean value of a parameter but will tend to give a full range for a parameter value based on their knowledge. If the experts disagree and a simple arithmetic aggregation process is used, the range used in the final analysis may be unduly large. For many parameters, there is not sufficient information to enable the distribution of values to be fully quantified and it is necessary to use judgement. Often only maximum, minimum and best estimate values for the parameter will be estimated. Also, in many cases there will be a tendency to concentrate on that part of the range of possible values of a parameter that would result in the largest assessed doses and thereby err on the side of caution. It is better to apply caution to the results of a realistic assessment than to apply caution to the parameters.

- **Sub-transfer processes**. Where a process is being represented as a series of smaller processes (for example the transfer of radioactive material from the atmosphere to milk can be represented as the transfer to pasture, then to the cow and finally to milk) care should be taken to ensure that selection of ranges of parameter values for the sub processes does not result in an unfeasible range for the value of the parameter describing the overall process.

- **Shapes of distributions**. Care should be exercised when selecting the appropriate 'shapes' of the distributions of parameter values. In particular the over use of triangular distributions can lead to the situation where the assessed best estimate value of the dose is a low percentile of the distribution of the dose. Often, other distributions such as normal or lognormal are more appropriate than triangular distributions.

- **Correlation**. The correlations between parameter values need to be taken into account. Although statistical techniques are available to take account of correlations it is not always straightforward to determine to what extent particular parameters are correlated.

- **Balancing of parameter values**. The natures of dose assessments mean that it is often the case that uncertainties in different factors will cancel each other out. For example high consumption of one foodstuff will be compensated for by low consumption of another food.

- **Regulatory criteria**. Unless regulatory targets are expressed in terms of defined confidence limits there is no easy way to judge whether the results of an assessment taking account of uncertainty and variability meet the regulatory criteria.

- **Look at the bigger picture**. Care must be taken to ensure that concentration on uncertainties in parameter values does not lead to other sources of uncertainty such as scenario uncertainty being neglected.

Appendix 2 Use of external expertise

The performance of a full uncertainty analysis is resource intensive and is likely to require the use of expertise that may not be readily available within the organisation responsible for the assessment. If it is decided to employ external experts care should be taken to ensure that:

- The appropriate expert or experts have been selected. Examination of previous assessments carried out by the expert and discussions with past customers may be useful in ensuring that appropriate experts have been selected. In some cases, commissioning of the work by one expert and peer review by a second may give added assurance of the adequacy of the work.
- The extent of the study has been carefully specified to ensure that only the work that is required to meet the needs of Principle 12 is carried out.
- The tools proposed for use by the expert (computer models, databases, etc) are suitable for use and appropriate to the context.
- The work will be documented in a form that is readily scrutinised by third parties.

About NDAWG Guidance Notes

National Dose Assessment Working Group Guidance Notes provide guidance on radiological assessment topics. The UK NDAWG has representatives from Government and its Agencies, nuclear industry, non-nuclear users of radioactive substances, Non-Governmental Organisations and independent experts. The guidance notes are approved at NDAWG meetings and have been consulted upon for a period of 3 months via the NDAWG website (www.ndawg.org).