NDAWG
National Dose Assessment Working Group

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Paper 10.05: Uncertainty and Variability in Dose Assessments

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1 Background

The first meeting of the NDAWG held in April 2002 agreed that a sub-group should be established to consider the issues of uncertainty and variability in the assessment of radiation doses. The subgroup was duly established and held 6 meetings between September 2002 and October 2005. During this time the sub-group has produced 2 reports aimed at giving advice to those carrying out dose assessments. During the period that the sub-group has been in operations it has been chaired by representatives of the Food Standards Agency. Other members of the sub-group have come from the Health Protection Agency, the Environment Agency, consulting organisations and independent experts.

The advice produced by the sub-group has been aimed at giving an overview of uncertainty and variability within dose assessments and providing guidance to those who need to review assessments taming account of uncertainty. Overviews of this advice are given below.

2 An overview of uncertainty in radiological assessments

The first report produced by the sub-group (NDAWG/1/2005) gave an overview of uncertainty and variability in dose assessments intended for those faced with the prospect of carrying out such assessments but do not have an extensive background in the area.

The advice starts with an introduction to some of the terminology used within assessments of uncertainty and variability and attempts to describe the different forms of uncertainty and variability.

2.1 Uncertainty

Uncertainty in radiological assessments can be grouped into broad categories:

- *Measurement Uncertainty:* The uncertainty in the field or laboratory data on which has been used to develop the models used in the assessment.

- *Parameter Uncertainty:* The result of not knowing the most appropriate values to assign to the parameters in the models used in the assessment.

- *Conceptual Model Uncertainty:* The uncertainty associated with representing the processes (eg, transfer of radioactive material in the environment) which are being modelled as part of the assessment.

- *Computational Uncertainty:* Resulting from simplifications or changes made to the model when converting it into software.

- *Scenario Uncertainty:* Uncertainty arising from the assumptions made in representing, for example, the habits of members of the critical group.

- *Ignorance:* Whilst this is not strictly a category of uncertainty there is a need at times to recognise that 'we simply do not know' and that there is an inherent limit to the reduction of uncertainty.

2.2 Variability

Variability refers to the actual differences that can occur both in transfer in different environments and between individuals in a group. It is not possible to reduce variability by improving knowledge.

2.3 Role of expert judgement in uncertainty analyses

Guidance is given on the use of expert judgement in the performance of uncertainty and variability analyses especially when expert judgement is used to derive parameter values. This advice is summarised below:

- In the context of assessments of routine discharges of radioactive material the environments of interest have generally been well characterised and models of such environments are mature. Formal expert elicitation of uncertainties is therefore most likely to be appropriate for the definition of parameter values and distributions.

- Expert elicitation does not increase the amount of information that is available. The process translates what is known into a useful form. Expert elicitation cannot be used to overcome ignorance.

- Expert elicitation can be undertaken using either individuals or groups. The use of well structured procedures can limit the amount off bias present in the process when dealing with both groups and with individuals.

- It is legitimate for those taking part in an expert elicitation exercise to question whether a parameter correctly defined and to redefine the parameter so that a correct distribution can be arrived at.

- Expert elicitation is a resource intensive process and, as such, is not appropriate for those sites where the impacts of discharges of radioactive material are small. These techniques are appropriate for circumstances where discharges could result in doses approaching the relevant dose constraints or for the derivation of generic parameter distributions for use at a wide range of sites.

2.4 Pitfalls in uncertainty analyses

A number of the pitfalls that have arisen during the performance of analyses of uncertainty and variability are described and advice given as to how to avoid them. This is summarised below:

- If during the expert elicitation process there is disagreement on the range of values that a parameter may have the use of simple arithmetical aggregation of the ranges proposed can result in an unduly large range being used for the parameter.

- The application of cautious assumptions to parameter values at different stages throughout an assessment process can lead to excessive caution. It is often better to apply caution to the results of a realistic assessment.

- In many cases several parameters are used to represent a process. The ranges of the individual parameters may all seem reasonable but can result in an unrealistic range of

values for the process being represented. For example transfer of deposited radioactivity to milk can be parameterised in terms of the interception of the radioactivity by pasture, the amount of pasture consumed by cattle and the transfer of ingested activity to milk, or it could be represented as a complete process.

- The use of triangular distributions in probabilistic assessments for parameters whose minimum, maximum and most likely values are known can result in overestimation of doses with the most likely value being well below the median or mean value. Other distributions, such as normal or lognormal distributions, are often more plausible representations of environmental variables.

- It is difficult to incorporate correlations between parameter values in an uncertainty analysis. Whilst it may be known that two parameters are correlated the degree of correlation is hard to quantify.

- Whilst there may be large ranges in parameter values used in an assessment of the doses received the range of the doses calculated may be fairly narrow. This can result in people questioning the results of the uncertainty study.

- Quality is closely related to uncertainty. Key to the ultimate acceptability of an assessment is rigorous quality control of the models and data used, effective checking and peer review.

- Unless regulatory targets and limits are expressed in terms of defined confidence limits there is no easy way to use the distributions of results from assessments using uncertainty and variability with the regulatory criteria.

- Care must be taken to ensure that concentrating on the uncertainty in the values of parameters does not lead to other forms of uncertainty, such as methodological or scenario uncertainty, being neglected.

- Effort can be expended unnecessarily on ascertaining the range of value for parameters that do not materially affect the outcome of the assessment.

- Care should be taken in interpreting the extremes of distributions of results. Values at the extremes of distributions can represent the combination of several possible, but unlikely, circumstances giving rise to an unrealistic combination.

2.5 Presentation of the results of probabilistic dose assessments

One method of analysing uncertainty and variability is to carry out a probabilistic analysis. The results of such an analysis are however difficult to communicate. Some suggestions for communicating the results are:

- If an uncertainty analysis is carried out, this will result in a large amount of information to be presented. The presentation and communication of this information gives rise to its own challenges. A particular challenge is that the information has to be communicated to both scientific and lay audiences.

- Graphical methods of presentation may be useful, work by the then NRPB [Ref 1] has shown that box-plots can be used to give graphical representations of value, spread and symmetry of a range of values and are particularly useful for comparative purposes. When presenting results of a dose assessment the following characteristics could be presented, median, percent above a chosen dose limit or constraint and values of chosen percentiles (eg, 5^{th} and 95^{th} percentile).

- The results of assessments are often presented to two or more decimal places. This can imply a precision in the results which could not be justified given the underlying uncertainties and it may be worth adding a comment explaining this.

3. Reviewing non nuclear licensed site radiation dose assessments taking into account uncertainty

Principle 12 of the Principles for the Assessment of Prospective Public Doses [Ref 2] requires that "where the assessed mean critical group dose exceeds 0.02 milliSv per year, the uncertainty and variability in the key assumptions for the dose assessment should be reviewed". This requirement can present problems for the organisation responsible for the assessment. The sub-group therefore developed some guidance for those who have to carry out such assessments. This advice was published in the second report of the sub-group (NDAWG/1/2006).

3.1 Alternatives to uncertainty analysis

The performance of a full uncertainty analysis is not the only means by which the requirements of Principle 12 can be met. A number of alternatives are available. Brief details of these are given below:

- Most prospective assessments are not carried out with the purpose of calculating the doses that are received by members of the public. Rather they are carried out with the aim of demonstrating that the doses from the proposed discharges do not exceed a regulatory target or limit. In these cases an assessment can be carried out using realistic values for parameter which result in a higher assessed dose than that obtained using typical parameter values. If this assessment results in a dose which is less that the relevant limit or target it has been demonstrated that whatever the level of uncertainty in the assessed dose the dose is not unacceptable. Care, however, must be exercised to ensure the correct interpretation of a dose calculated in this manner.

- Many sites for which an assessment is being carried out are not new sites but are currently discharging radioactive material into the environment. The results of monitoring can be used to assess the effects of future discharges with less uncertainty than is present in assessments which make use of modelling only. The utility of this approach can be limited when the limits of detection for some nuclides are high in relation to the expected concentrations (eg, Ru-106 and Pu-241 in milk).

- For many sites a mixture of radionuclides are discharged and the assessed doses received by members of the public are dominated by one nuclide. Alternatively the assessed dose may be predominately via one pathway. In such cases a partial uncertainty analysis concentrating on the key nuclide(s) and pathway(s) identified from the initial deterministic analysis can be undertaken.

- If a standardised screening approach is used for a dose assessment many of the parameters used will be generic values. Often these values are the most extreme values that could reasonably be expected within UK circumstances and not appropriate to the site being considered. Often these generic parameter values can be replaced by site specific values. This requires that those carrying out assessments have knowledge of the models that they are using and the default parameter values used.

- In some cases the uncertainty in dose estimates results from uncertainty in the habits and behaviours of members of the critical group. A range of scenarios can be identified which represent different combinations of habits and behaviours. Dose estimates can be calculated and reported for each of these scenarios.

- Often there is more than one computer code or model available for representing environmental processes. Use of alternative models or hand calculations can help address model uncertainty or identify model structural errors.

- The purpose of dose assessments is often to demonstrate to members of the public that risks and doses are controlled and managed within authorised limits. The public does not always accept the assurances of scientists. Even when no uncertainty analysis has been carried out the presence of uncertainty in dose assessments should be explicitly stated.

3.2 Use of an iterative approach to dose assessment taking uncertainty into account

As can be seen from the above discussion an iterative approach can be applied to the consideration of uncertainty in dose assessments. This can start with a simple generic approach based on estimated doses per unit discharge. In many cases this will be sufficient and it is not necessary to further consider uncertainty apart from acknowledging that it exists. If the dose is greater that 0.02 mSv/y a more detailed assessment using site specific data can be carried out. If the dose is still greater than 0.02 mSy/y it will be necessary to review the uncertainty in the key assumptions made in the assessment. The aim is to consider how much caution has been applied at each stage and evaluate the extent to which doses have been over estimated. The following factors could be considered in such a review:

- Prospective assessments are based on the proposed authorised discharge limits. These contain headroom above the amounts of radioactivity it is likely that the site will discharge in practice. Reduction in the headroom will result in a reduction in the assessed dose.

- Many discharge Authorisations contain unspecified categories of radionuclides. These are often described as ‘total alpha’ or ‘other beta’. When carrying out assessments cautious assumptions are often made about the identity of these nuclides. Often all the discharged activity is assumed to be the nuclide which gives rise to the highest dose. This in turn results in an over estimate of the dose. Use of a more realistic breakdown of the nuclides within the groups will result in a more realistic estimation of the dose.

- An important area when considering the amount of caution that may be present in an assessment of doses is the assumption that have been made as to where members of the critical group are located when they are exposed to radioactive material. Often it is assumed in screening assessments that they are located close to the site and the use of site specific information can result in a reduction in the assessed doses.

- Similarly the location of food production assumed in an assessment will markedly affect the assessed doses. Again screening models will make use of default pessimistic assumptions and the use of site specific information can result in a reduction in the assessed dose.

- The habits of the critical group used in an assessment are an important contribution to the uncertainty in the assessed dose. The amounts of different foods that are consumed are often based on generic national data. The use of site specific data if available will reduce this uncertainty.

3.3 The use of external experts in carrying out or assisting in uncertainty analyses

If after the staged approach outlined above has been used or considered there is still a need to review the uncertainty, the use of external experts to assist in or carry out such a review should be considered. If it is decided to make use of external experts care should be taken to ensure that:

- The appropriate expert has been selected.
- The scope of the study has been specified so that only work necessary to meet Principle 12 is carried out.
- The tools that the expert is proposing to use are appropriate.
- The study will be documented in a form that is readily scrutinised by third parties.

4 Need for future work

The Uncertainty and Variability sub-group is currently in abeyance having met, it believes, as much of its Terms of Reference as it could. Are there, however, other areas of uncertainty and variability that the sub-group could usefully consider within the context of the NDAWG at

this stage? It has been suggested that the sub-group could carry out and document some case studies.

5 Conclusion

It is believed that the sub-group on uncertainty and variability in dose assessment has produced useful guidance for those faced with dealing with these issues and the group is no longer active. Any suggestions for other areas that the sub-group could consider if reactivated would be considered by the NDAWG steering group.

6 References

1 Walsh C, Jones KA and Simmonds JR (2000). Variability in critical group doses: the implications for setting authorised dose limits for discharges. Chilton, NRPB-M1221.

2 Environment Agency, Scottish Environment Protection Agency, Department of Environment, Northern Ireland, National Radiological Protection Board, Food Standards Agency. Radioactive Substances Regulation (2002). Authorisation of discharges of radioactive waste to the environment. Principles for the assessment of prospective public doses. Interim guidance.