The implications of variability in critical group doses for the control of radionuclide releases

S M Haywood and J R Simmonds

National Radiological Protection Board, Chilton, Didcot, Oxon, UK, OX11 0RQ

Abstract: Assessment of critical group doses is an important part of the system of radiological protection. The critical group is representative of those individuals in the population who receive the highest doses, and the mean dose to the critical group is compared with the dose limit and the dose constraint for members of the public. The nature of the critical group means that some members will receive doses in excess of the mean, and could theoretically lead to individuals receiving doses greater than the dose limit. This paper summarises the results of an illustrative assessment of the distribution in critical group doses for two UK sites, and considers the implications of the results for the system of dose limitation and regulation. A number of key points for debate are discussed.

1. INTRODUCTION

Facilities such as nuclear power stations, nuclear reprocessing plants and radio-pharmaceutical laboratories routinely release radionuclides to the environment. In the United Kingdom, as in most other countries with a nuclear industry, these releases occur under a system of authorisation and regulation which includes the comparison of actual and prospective doses arising from these discharges against dose limits and constraints.

The doses received by individuals in an exposed population due to discharges of radionuclides vary depending upon their location, dietary intakes, habits and physical characteristics. Studies have been undertaken at NRPB to investigate the extent of this variability and some results from this work are presented below. The possible implications of the results for the system of dose limitation and regulation are discussed.

This paper primarily considers the issue of variability in dose in the context of prospective assessments of doses arising from authorised discharges of radionuclides to the environment.

2. BACKGROUND

Controlled releases of radionuclides to the environment from a practice such as nuclear power production are subject to regulation, based largely on the International Commission on Radiological Protection (ICRP) recommendations published in ICRP Publication 60 [1]. The practice has to be justified, the discharges should be such that exposures are kept as low as reasonably achievable and the **dose limit** for members of the public should not be exceeded.

In Publication 60, ICRP also introduced the concept of the **dose constraint** which is the upper bound on the annual doses that members of the public may receive from the planned operation of a single source. As interpreted in the UK, the dose constraint relates to the annual dose to the overall critical group, summed over all exposure pathways, arising from the current and future operations of a controlled source and is therefore relevant to the setting of authorised limits of discharge. The dose constraint does not replace the requirement that exposures are kept as low as reasonably achievable (ALARA): rather, it places an upper bound on the outcome of any optimisation study. Constraints are not dose limits and exceedance of the dose constraint is not necessarily unacceptable, provided the dose limit is not exceeded, the ALARA principle is followed and future assessments are refined.

It is not practical to assess the doses received by each individual member of the public from a discharge, and in the case of prospective doses (ie doses which arise in the future) such an assessment would in any case be impossible. The **critical group** approach is therefore used, in order to obtain an estimate of the likely dose to the most exposed individuals. A critical group comprises those members of the public who, by virtue of their location and habits, are expected to receive the highest exposure from the source in question.

ICRP has recommended that it is the mean dose to the critical group that should be compared with the dose limit or dose constraint, and has stated that the group must be sufficiently small to be reasonably homogeneous in the exposures it receives. In Publication 43 [2], ICRP states that 'The (critical) group should be representative of those individuals in the population expected to receive the highest dose equivalent; the group should be small enough to be relatively homogeneous with respect to age, diet and those aspects of behaviour that affect the doses received.' ICRP further recommends that 'the critical group would not consist of one individual nor would it be very large for then homogeneity would be lost. The size of the critical group will usually be up to a few tens of persons.' Also in Publication 43 it is stated that 'Decisions as to the acceptability of the exposure of the critical group will depend not only on the proximity of the calculated mean dose equivalent to the dose-equivalent limit but also on the expected spread of the distribution of actual dose equivalents.' ICRP suggest that, in general, to satisfy homogeneity the ratio of the maximum to minimum values should not exceed an order of magnitude, but that if the mean dose is approaching the dose limit then the total range should be less, preferably no more than a factor of three.

Inevitably, the doses received by the critical group form a distribution. Some members of the critical group will receive doses which are in excess of the group's mean dose, and this could - in theory - result in some exposures within the group being in excess of the dose limit or constraint, even though the mean dose is within the criteria. In ICRP Publication 43 [2] ICRP justifies the use of a mean value: "because of the maximising assumptions normally used, the dose equivalent actually received will usually be lower than the estimated dose equivalent".

There are two different causes of variation in the distribution of doses received by the critical group. The factors which contribute to the critical group dose (location, habit, environmental concentrations and dosimetry) are both **variable** (for example, they vary between different people because of their individuality) and **uncertain** (even for a specific individuals or environmental processes the factors are not precisely known). While it may be possible, at least theoretically, to reduce or even eliminate uncertainties through increasing knowledge, variabilities will always remain. The work reported below was primarily concerned with the variability in critical group doses, but it is sometimes difficult to distinguish between variability and uncertainty in assessment parameters, and the dose distributions therefore to some extent reflect both types of variation.

3. SOME EXAMPLES OF DOSE VARIABILITY

A study [3] has been undertaken at NRPB to investigate the variability in prospective critical group doses from routine authorised discharges to the environment. Illustrative distributions in individual doses in the critical groups due to authorised discharges from the Sellafield and Sizewell nuclear sites were obtained. The location of these sites is shown in Figure 1.

The aim of the study was to provide an indication of the ranges in doses to critical groups. It was not intended to be a comprehensive dose assessment for the two sites, for the following reasons:

- The doses are not intended to be indicative of current critical group doses. They relate to theoretical discharge levels (the currently authorised levels), and are based on modelling rather than on measured environmental concentrations. Actual discharges are almost always less than authorised levels, and also, in the case of Sellafield, historic discharges contribute significantly to the doses currently being received.
- The doses from discharges to atmosphere and the marine environment were treated separately, where in reality there is some overlap in exposure.
- Not all of the radionuclides discharged at the two sites were included in the study.

FIGURE 1 Location of Sellafield and Sizewell sites

Nevertheless, the results of the study do serve to show the range of results that might be obtained if the variability in critical group doses is quantitatively assessed.

In determining the range in critical group doses, the study took into account possible ranges in environmental transfer data for modelling (including seafood concentration factors and terrestrial foodchain concentration factors), habit data (including ingestion rates and occupancies) and dose coefficients for ingestion and inhalation.

The basis for the ranges on these input parameters varied with the particular parameter. The ranges associated with terrestrial food concentrations were obtained from a study [4] in which the uncertainty and variability in terrestrial transfer parameters was evaluated using expert judgement techniques. For aquatic food concentrations and gamma dose rates the ranges were based on published distributions on the sediment distribution coefficients and on seafood concentration factors.

The ranges on the critical group's habit data were based on various data. In the case of terrestrial foodstuffs, the source was national dietary surveys for the UK. For marine foodstuffs and other marine pathways, data were obtained from habit surveys undertaken on behalf of the UK's Food Standards Agency (then known as the Ministry of Agriculture, Fisheries and Food) for the two sites.   Ranges for other factors, such as inhalation rates and indoor/outdoor occupancy factors were obtained from reviews of the literature. It is emphasised that the habit ranges obtained were those which reflect the habits of the critical group, and not the habits of the population as a whole.

The ranges on the dose coefficients were obtained by varying key biokinetic parameters in the dosimetric models within ranges obtained from the literature. This is an example of a parameter where both uncertainty and variability were included in the ranges because of inherent difficulties in separating out the contributions from these components.

The ranges on the input parameters were then combined using a spreadsheet based package to obtain as output the probability distributions on the doses in the critical group.

Table 1 shows the estimated distribution of doses to the critical group for authorised discharges to atmosphere and to the marine environment for the Sizewell site. The doses from the atmospheric discharges are dominated by the external dose from ^{41}Ar, with terrestrial food pathways contributing relatively little. The dose from the aquatic pathways is dominated by ^{137}Cs ingestion in fish.

Table 1 Distribution of critical group doses for Sizewell

Value	Dose (μSv y^{-1}): Discharges to atmosphere	Dose (μSv y^{-1}): Discharges to marine environment
Mean	17	3.5
Standard deviation	5.4	4.7
Geometric mean	18	2.3
Median	18	2.2
5^{th} percentile	10	0.59
95^{th} percentile	29	11
Ratio of the 95^{th} to the 5^{th} percentile of dose in the critical group	2.9	18.6

The corresponding results for Sellafield are given in Table 2. For Sellafield, the doses from the atmospheric discharges are dominated by ingestion (^{129}I in milk being the most significant food and pathway) and by external dose from activity in air (predominantly ^{41}Ar). In the assessment of the doses from marine discharges, the radionuclide which contributed most significantly to dose is ^{14}C, and the most important pathways are the ingestion of fish and mollusca; however, not all significant radionuclides were included in this part of the assessment, notable omissions being ^{99}Tc and ^{106}Ru, and the inclusion of these would widen the distribution further.

For both sites, the ranges for the doses due to the marine discharges are larger than for the atmospheric discharges. For Sellafield there is a factor of about 9 between the 5^{th} and 95^{th} percentile values, while the factor for Sizewell approaches 20; however, the doses predicted for Sizewell are much smaller than those for Sellafield. The variability in the doses is mainly controlled by the ranges associated with the parameters for the most important radionuclides and exposure pathways. Key contributors to the dose variability are therefore:

- the concentration factor for ^{137}Cs in fish
- the concentration of iodine in milk following deposition
- the percentage of time spent indoors and the shielding provided by buildings.

Table 2 Distribution of critical group doses for Sellafield

Value	Dose ($\mu Sv\ y^{-1}$): Discharges to atmosphere	Dose ($\mu Sv\ y^{-1}$): Discharges to marine environment
Mean	82	52
Standard deviation	21	47
Geometric mean	79	42
Median	80	41
5^{th} percentile	52	15
95^{th} percentile	120	130
Ratio of the 95^{th} to the 5^{th} percentile of dose in the critical group	2.3	8.7

As discussed above the results are only illustrative of the type of results that can be obtained in such a study. If all radionuclides had been considered then both the mean doses and the spread on the ranges would have been greater. Given the ranges in doses obtained it is possible to imagine situations where the cautiously assessed mean dose to the critical group would be within the dose limit but parts of the dose distribution would exceed it.

4. DISCUSSION

The main objective of the study summarised above was to examine the possible distribution of critical group doses as an input to considering possible implications for the system of radiological protection, with an emphasis primarily on the implications for the authorisation of routine discharges of radionuclides to the environment. The results of the study raise a number of possible questions, which are considered below. The 'answers' are the views of the authors, and are not intended to be definitive, but to be a starting point for discussions.

- *Is the mean dose in the critical group the appropriate value for comparison with a dose limit or a constraint? Is it acceptable for the possibility to exist that an individual's dose could exceed the dose limit, if the mean dose for the critical group is within the constraint and the discharges are considered to be ALARA?*

Numerical values for the dose limit and the dose constraint for members of the public have been set in the knowledge that it is the mean dose to the critical group that is to be compared with them. It is likely that different numerical values for these two criteria would have been chosen if a different dose quantity was to be used. It is therefore considered that the mean dose to the critical group should still be the quantity used for comparison with current dose limits and constraints.
If the doses in the critical group can be shown to be ALARA, the exceedance of the dose constraint by a few individuals in the critical group may not be regarded as a major problem. Exceedance of the dose limit by some individuals is of greater concern; however, it should be remembered that the dose limit does not mark an abrupt change in the nature or level of risk.

- *Cautious assumptions are adopted in prospective critical group dose assessments; are these enough to ensure that actual doses would be lower than those estimated, even allowing for variability? If not, should they be made more cautious?*

In prospective dose assessments various assumptions have to be made, for example about the composition and behaviour of the critical group. Such assumptions involve varying degrees of caution partly depending on the aim of the calculation; for example very cautious assumptions may be made to ensure that the dose is very likely to be underestimated, or a more realistic assessment may be made for optimisation purposes. In prospective assessments, the tendency will be to err on the side of caution and to overestimate rather than underestimate, particularly when comparing doses with the dose limit. For example, in the UK it is normally assumed that there could be infants and children living at a particular location, even if there are none at present, while in estimating doses from ingestion of terrestrial foods, foods are all assumed to be locally produced with high intakes of key foods. Also, actual discharges are generally lower than the values contained in the site authorisation. This factors mean that actual doses are likely to be lower than those estimated so it is very likely that doses will be overestimated, and that this will usually – but not necessarily - compensate for the factors introduced by variability.

In dose assessments which will be used as an input to decisions on discharges affecting the operating regime of a controlled source, a realistic approach is required and an overcautious approach should be avoided. It is necessary to make a series of assumptions, and while each assumption individually may seem reasonable the combination can lead to a very unlikely dose estimate. It is therefore thought undesirable to make dose assessments more cautious.

- *Should variability in the dose coefficients be included?*

There is recognised to be variability and uncertainty associated with the values used for dose coefficients but this is not normally considered in assessments as ICRP have specified single value dose coefficients for radiological protection purposes. However, as the calculated dose approaches the appropriate criteria, that variability may be of more concern. It should be noted that the ICRP recommendations [2] on the spread on critical group doses, and the corresponding homogeneity of the critical group, do not specifically address either the contribution from individual variability in the factors affecting dosimetry or variation in the environmental concentrations to which the individual is exposed (the only factor identified in ICRP 43 as contributing to the spread in doses is the variation in habits); it is not clear that the ICRP advice takes either of these aspects into account.

- *Should radiation risks be considered as an endpoint to an assessment?*

The assessment of the risk to which the critical group is exposed adds a further component of variation, due to the variability and uncertainty associated with the risk factor. However, since radiation protection regulations are currently based on radiation doses, it is not thought necessary for risk calculations to form part of the current assessment process in the context of authorisations. In the future, risk is likely to be the common measure used to place radiation issues in perspective with other hazards and pollutants, where there are already moves in the UK to use risk estimates as a common basis for comparison purposes.

- *Should the results of critical group doses be presented in probabilistic way, and if so how?*

Statistical techniques are useful tools to develop understanding of the critical group dose distribution, but great care is needed if such results are presented to a general audience. The careless provision of statistical information may lead to the focusing on extreme values and cause confusion. Such a presentation is probably unhelpful for routine, authorisation purposes. It may however be argued that single value results are meaningless without an associated confidence interval. If probabilistic information is provided, sufficient information must be presented to fully characterise the distribution. The minimum and maximum values of these distributions should be used with caution or not at all. The probability of these values occurring is often uncertain, and such values may be very unrepresentative of the distribution as a whole, and could easily be used out of context.

5. CONCLUSIONS

The objective of this paper was to consider the implications of distributions in critical group doses for assessments relating to authorised limits for discharges, and more widely for the system of radiological protection.

Illustrative results of the distributions in prospective critical group doses were presented for two UK sites. Although preliminary and not comprehensive, the results serve to show the range of results that might be obtained if the variability in critical group doses is quantitatively assessed. Ranges of a factor of an order of magnitude or greater may be observed for some critical group doses, between the 5^{th} and 95^{th} percentile values. Given these ranges, it is possible to imagine situations where the mean dose to the critical group would be within a dose constraint but parts of the dose distribution would exceed it. However, the definition of the critical group, their habits and the selection of other parameters in the dose calculation generally veer on the side of caution, and this, together with the fact that actual discharges are generally lower than the values contained in the site authorisation, should help to ensure that actual doses are less than estimated. It is thought unlikely, although possible, that an individual's dose would exceed the dose limit, if the cautiously assessed mean dose for the critical group is within the limit.

Variability studies are useful when examining the composition of critical groups, to ensure the group adheres to the ICRP homogeneity criteria and, when potential doses are close to the dose limit, to examine the probability of members of that critical group exceeding the dose limit. Such studies are valuable in improving understanding of the nature of critical group doses. When presenting probabilistic results from variability studies, it is important to include sufficient information to fully characterise the distribution; the minimum and maximum values should be used with caution or not at all.

6. REFERENCES

1. ICRP. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Ann ICRP, **21**, Nos 1-3 (1991).
2. ICRP. A compilation of the major concepts and quantities in use by ICRP. ICRP Publication 43. Ann ICRP, **15,** No 1 (1984).
3. T R A Cabianca, C A Fayers, J R Simmonds, C A Robinson and J S S Penfold. The variability in critical group doses from routine releases of radionuclides to the environment. NRPB-M952 (1998).
4. K R Smith et al. Uncertainties in the assessment of terrestrial foodchain doses. NRPB-M922 (1998)