Guide to calculating doses to biota using this spreadsheet application

To run this spreadsheet, open the Excel file, click “proceed” at the prompt and you will enter the input tab. Double-click the crosshairs panes, to make visible the different tabs. Press F1 to open the control panel with buttons for different actions. The rest is self-explanatory.

1. Assumptions and applicability of the method

The dose calculation method employs a number of inherent assumptions:

- Organisms are represented as ellipsoids
- Concentrations of radionuclides in biota are calculated using simple equilibrium concentration ratios between biota and water, soil or air.
- Radionuclides are distributed uniformly through all tissues of the animal or plant.
- Resulting absorbed doses, both internal and external, are calculated as an average throughout the volume of the organism.
- Doses are calculated as dose rates from equilibrium concentrations of radionuclides in biota.
- Organisms receive external dose at a reduced rate during the fraction of their time spend above ground surface, e.g. birds flying or roosting
- Absorbed fractions for alpha emissions are assumed to be zero for bacteria and unity for all other organisms.
- Calculated doses to micro-organisms are equal to the absorbed dose in the soil or sediment in which they are located.

With regard to the applicability of the method, the most important assumption is that concentrations in biota are in equilibrium with concentrations in the surrounding environmental media. The method cannot be used to assess doses to biota in situations where the concentrations of radionuclides in the surrounding environmental media are changing rapidly.

Generally, it is considered that the activity concentration of terrestrial organisms equilibrate slowly with their surrounding environment. Further, the simple assumption of equilibration between radionuclide concentrations in soil and biota cannot adequately represent the complex dynamics of the contamination of vegetation, soil and biota whilst there is continuing deposition of radionuclides from the atmosphere.

The calculation method as provided is intended for use in a stable contaminated environment, where radionuclide burdens have accumulated over an extended period of time. For prospective assessments of the effects of proposed discharges of radionuclides to the environment, we recommend that predictive models should be used to estimate radionuclide concentrations in soil, air or water as appropriate after discharge for 50 years at the proposed discharge rates, and that the concentrations so estimated used as the basis for calculating doses to biota.

2 Assembling data for the assessment

The data to be assembled will depend on whether the calculation is to be done prospectively, based on predicted radionuclide concentrations in the environment or retrospectively, based on measured concentrations of radionuclides in the environment.

Prospective assessment

For a prospective assessment, as indicated above, concentrations of radionuclides in water, air or soil as required by the spreadsheets should be calculated from assumed rates of discharge over an extended period of time. The data required are:

- For ^{3}H, ^{14}C and ^{35}S as well as Ar, Kr and Xe radionuclides, in the terrestrial environment, concentrations of the radionuclides in air (Bq m^{-3}).
- For other radionuclides in the terrestrial environment, concentrations of the nuclides in surface soil (Bq kg^{-1} dry weight of soil).

Concentrations should be averaged temporally over a period of at least one year, and spatially over an area of at least one square kilometre.

In addition to the calculated concentrations of radionuclides, any site specific data for concentration ratios between organisms and water or soil, based on existing environmental monitoring data, should be assembled. If concentration ratios have already been calculated these may need to be converted into the units required by the spreadsheets, namely:

- For the terrestrial environment, Bq kg^{-1} (fresh weight) of organism per Bq kg^{-1} (dry weight) of soil.
- It is unlikely that any site specific data would be available for concentration ratios of ^{3}H, ^{14}C or ^{35}S but if any are available these should be in the units Bq kg^{-1} (fresh weight) of organism per Bq m^{-3} in air.

If concentration factors are not already calculated, good quality monitoring data for radionuclides in water, soil or air and biota may allow these to be calculated. In doing so the following points should be borne in mind:

- Concentrations in biota and soil, air or water should relate to the same location or locations.
- Concentrations should ideally be averaged temporally over a period of at least one year, and spatially over an area of at least one square kilometre.

Retrospective assessment

In this case, measured concentrations of radionuclides in soil, air or water will be used to initiate the assessment. The same considerations for units and temporal and spatial averaging as for a prospective assessment apply, that is:

- For ^{3}H, ^{14}C and ^{35}S in the terrestrial environment, concentrations of the radionuclides in air (Bq m^{-3}).
- For other radionuclides in the terrestrial environment, concentrations of the nuclides in surface soil (Bq kg^{-1} dry weight of soil).
- Concentrations should ideally be averaged temporally over a period of at least one year, and spatially over an area of at least one square kilometre.

In addition to measured concentrations in soil, available measurements in biota should be assembled bearing in mind the same points about spatial and temporal averaging, and the required units of Bq kg^{-1} (fresh weight) of the organism.

3 Calculation of doses

This section should be read in conjunction with the operating guide for this spreadsheet application. The steps in calculating doses are as follows.

1 Set all soil, air or water concentrations in the spreadsheet to zero and restore the default values for concentration factors and radiation weighting factors. This ensures that any alterations made to the spreadsheet input by previous users are re-set.

2 Enter any site specific concentration factors which you have been able to assemble.

3 Enter the water, air or soil concentrations which you have assembled.

4 Initiate the calculation of concentrations and doses.

5 For a retrospective assessment, at this stage you should compare the calculated environmental concentrations with the measurements which you have been able to assemble. If the calculated results differ markedly from the measured results, the spreadsheets provide a utility which allows you to adjust some of the parameters in the calculation in order to make the calculated results agree with measurements.

6 For a retrospective assessment, if at this stage you have no measured concentrations of one or more radionuclides in the soil, air or water medium but you do have measured values of those radionuclides in sediment or biota, the spreadsheet provides a utility which allows you to use these measured concentrations to estimate concentrations in water, soil or air.

7 Having made any such adjustments re-initiate the calculation of concentrations and doses.

8 Check carefully that all input data is correct and as you intended, then save the calculation results.

4 Sensitivity analyses, and gaps in the data

You may wish to calculate doses to biota using several variants of the input parameters. For example, you can check the sensitivity of the doses you have calculated to the value of the radiation weighting factors by running the calculation a number of times with different values for these factors.

For some organisms and some nuclides, it has not been possible to provide default values for the concentration factor. The internal dose resulting from such organism-nuclide combinations therefore will not be calculated, although a value for external dose will be calculated. The possible importance of the ‘missing’ CF data can be assessed by entering nominal CF values which are similar in magnitude to other CF values for that nuclide. In some cases, for example internal contamination by beta and gamma emitters in small organisms, external radiation dose is likely to be dominant and the ‘missing’ CF value may have little effect on the dose calculation. In other cases, for example internal contamination by alpha emitters, the total dose will depend directly on the ‘missing’ CF value. If credible nominal CF values can produce significant doses that may be taken as indicating a need for measurements to be made in biota (for a retrospective assessment) or attempts to be made to determine a concentration factor from field or laboratory studies (for a prospective assessment).

5 Interpreting results and taking account of uncertainty

Currently, the most reliable ‘benchmarks’ against which calculation results can be checked are the doserates of 40 μGy h^{-1} for terrestrial biota, at which UNSCEAR consider harm to populations and ecosystems is unlikely. In comparing calculation results with these benchmarks, uncertainties in the calculation need to be borne in mind.

At present, any assessment of radiation doses to biota must be regarded as an estimate rather than a precise calculation. The main sources of uncertainty may be summarised as follows.

- The weighting factors of 3 for low energy beta radiation and 20 for alpha radiation are likely to be cautious, especially if it proves that non-stochastic effects are most important in determining harm to ecosystems. The ‘true’ values for these weighting factors may be a factor of 3 to 4 lower, and are most unlikely to be as much as a factor of two higher.
- The methods used to calculate external doses from given concentrations of radionuclides in soils or sediments are cautious, mainly because they assume soil or sediment is uniformly contaminated to an infinite depth. External doses may therefore be over-estimates, but in most circumstances this over-estimate should not exceed a factor of two.
- The greatest uncertainty lies in the values of concentration factor used to calculate internal contamination by radionuclides, and hence internal doses. Concentration factors vary considerably between species and also vary considerably with environmental conditions such as water chemistry and soil type. The true values for concentration factor could easily differ from the recommended defaults by an order of magnitude in either direction.
- For a given level of internal contamination, the methods used to calculate internal dose are quite accurate and should produce results for the average dose within the organism which are accurate within 10%. Doses to different organs may of course differ from this average value if the radionuclides are not distributed uniformly within the organism.

In recognition of these uncertainties, it is recommended that consideration be given to the following points when interpreting calculation results:

- If only default concentration factors are being used and calculated doses are in excess of 5% of the UNSCEAR ‘benchmark’ values, the sensitivity of the result to higher values of concentration factor should be determined and, if appropriate, efforts should be made to acquire site specific concentration factors or direct measurements of radionuclide concentrations in important organisms.
- If site specific concentration factors, or actual environmental measurements, are being used and calculated doses exceed one third of the UNSCEAR ‘benchmark’ values then consideration should be given as to what further investigation might be appropriate. This might involve consideration of the radiosensitivity of the organisms receiving the highest calculated doses – are they amongst the most or least radiosensitive of the organisms covered by the UNSCEAR ‘benchmark’? For a retrospective assessment of an existing contaminated ecosystem, selected biomarker studies and/or ecological investigations may be appropriate.

At this stage in the development of radiological protection criteria for biota, hard and fast rules for the interpretation of calculation results cannot be given. However reasoned judgement using the information in the accompanying report should allow sensible conclusions to be drawn in most cases.