The 2nd International Conference on Radioactivity in the Environment (Eds. P. Strand, P. Børretzen & T. Jølle)
p146–149. NRPA: Østerås.

Models and approaches available to estimate the exposure of non-human biota: An international comparison of predictions

Nicholas A. Beresford[1+], Mikhail Balonov[2], Karine Beaugelin-Seiller[3], Peer Børretzen[4], Justin Brown[4], Jing-Jey Cheng[5], David Copplestone[6], M. Doi[7], Sergey Gaschak[8], Slava Golikov[9], Jan Horyna[10], Ali Hosseine[4], Brenda J. Howard[1*], F. Jasserand[11], Sunita Kamboj[5], Tatjana Nedveckaite[12], Geert Olyslaegers[13], Tatiana Sazykina[14], Jordi Vives i Batlle[15], Tamara Yankovich[16] & Charley Yu[5]

[1]Centre for Ecology & Hydrology, UK; [2]International Atomic Energy Agency, Austria; [3]L'Institut de radioprotection et de sûreté nucléaire, France; [4]Norwegian Radiation Protection Authority, Norway; [5]Argonne National Laboratory, USA; [6]England & Wales Environment Agency, UK; [7]National Institute of Radiological Science, Japan; [8]International Radioecology Laboratory, Ukraine; [9]Institute of Radiation Hygiene, Russia; [10]SÚJB, Czech Republic;[11]GALINEO, France; [12]Institute of Physics, Lithuania; [13]SCK-CEN, Belgium; [14]SPA-Typhoon, Russia; [15]Westlakes Scientific Consulting Ltd., UK; [16]Atomic Energy Canada Limited, Canada. [+]Corresponding author – CEH-Lancaster, Library Av. Bailrigg, Lancaster, LA1 4AP, UK; Email: nab@ceh.ac.uk; [*]presenting author.

INTRODUTION

Over the last decade, there have been a number of models and approaches proposed to estimate the exposure of non-human biota to ionising radiations. Some countries are now using these within their national regulatory frameworks for nuclear and other sites which may be releasing radioactivity to the environment. To date, validation of these approaches has been limited and there has been virtually no attempt to compare the outputs of the different models being applied. To address this gap, a new *Biota Working Group* (BWG; http://www-ns.iaea.org/projects/emras/emras-biota-wg.htm) was formed by the IAEA as part of the EMRAS (Environmental Modelling for Radiation Safety) programme in November 2004. The primary objective of the EMRAS BWG, as set by its participants, is: '*to improve Member State's capabilities for protection of the environment by comparing and validating models being used, or developed, for biota dose assessment (that may be used) as part of regulatory process of licensing and compliance monitoring of authorised releases of radionuclides'*. Initial exercises are directed at the comparison of screening level models. The models and approaches being considered by the BWG encompass those being developed and applied in the USA, Canada, France, Belgium, Russia, Lithuania and the UK, as well as the outputs of international programmes.

Here we report on a recently conducted exercise to compare the underlying assumptions of the various approaches and discuss the future scenario testing planned within the BWG.

MODELS AND APPROACHES

The group participants use, or are developing, either: (i) biota dosimetry models; or (ii) models/frameworks to estimate both the transfer of radionuclides to biota and doses received in contaminated environments. The models and approaches which have participated in the BWG to date, are briefly described below.

RESRAD-BIOTA

The RESRAD-BIOTA code (http://www.ead.anl.gov/resrad) was designed to be consistent with and provide a tool for implementing the US DOE *Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (USDOE, 2002). Three levels of evaluation are available, ranging from Level 1 in which conservative assumptions are made but few inputs are required, to Level 3 in which fewer assumptions are made, but more site- or receptor-specific input data are required. The code includes a kinetic-allometric approach (Higley *et al*., 2003) to estimate the transfer of radionuclides to animals. The internal and external dose conversion coefficients (DCCs; relating unweighted absorbed dose to media or biota activity concentrations) are estimated using a Monte-Carlo transport code.

FASSET

Assessment framework developed under an EC 5th Framework project (Larsson *et al*., 2004). Transfer from contaminated media to a range of terrestrial and aquatic reference organisms is estimated using concentration ratios (CRs), predominantly derived from the literature, which are presented as look-up tables. DCCs are presented for geometries representative of species corresponding to the reference organisms. For terrestrial systems, DCCs were estimated using a Monte-Carlo approach. For aquatic systems a different numerical approach was used, absorbed fractions being calculated by a random sampling method and the fitting of energy-dependent absorption functions, separately considering emitted photons and electrons.

England and Wales Environment Agency 'R&D 128'

Similar approach to FASSET, although a more limited range of organisms and radionuclides are considered (Copplestone *et al*., 2001); DCCs are estimated using the same methodology as used by FASSET for aquatic systems. Guidance is provided on how to estimate CR values if they are missing for a given radionuclide-organism combination (Copplestone *et al*., 2003); this has also been adapted for use within the FASSET framework

Atomic Energy Canada Limited approach

Multi-tiered approach ranging from hyperconservative Tier 1 to more realistic Tier 3. Where possible site specific CR values are used to estimate activity concentrations in receptor biota. If this is not possible CRs from the Canadian literature and international reviews (including FASSET) are used in combination with allometric approaches from RESRAD-BIOTA. For screening purposes, hyperconservative internal and external DCCs, which are not corrected for organism size, are applied (Amiro, 1997). For more realistic assessments, DCCs from Blaylock *et al*. (1993), FASSET or RESRAD-BIOTA are used as appropriate.

ECOMOD

Developed by SPA-Typhoon, ECOMOD uses stable chemical analogues and ratios of radionuclides to determine the concentrations of radionuclides in aquatic biota (Sazykina, 2000). The model is dynamic and can make predictions under conditions of changing radionuclide concentrations. The model is particularly suited for radionuclides that are analogous to, or isotopes of, biologically active chemical elements. ECOMOD uses previously published absorbed fractions across a range of ellipsoids to estimate unweighted absorbed doses for a limited number of radionuclides.

LIETDOS-BIO
Approach being developed to address contamination issues associated with nuclear power production in Lithuania. A combination of FASSET and predominantly Russian language literature is used to source CR values. An in-house Monte-Carlo transport code is used for DCC derivation.

SCK-CEN approach
Approach being developed in Belgium, in which the estimation of absorbed doses is based on the Point-Kernel (corrected with a build-up factor) and the Bethe-Bloch methodologies; CR values are derived from review publications.

EDEN
A software tool designed to estimate absorbed doses for user-defined (ellipsoid) geometries using Monte-Carlo calculations.

EPIC-DOSES3D
This programme uses probability distributions of chords/segments lengths (1D array) inside organisms, from external or internal sources, together with appropriate radiation absorption functions to estimate absorbed doses (Golikov & Brown, 2003). The method for describing phantoms, allows DCC values to be calculated for organisms of any size or form.

SÚJB approach
This approach uses integration of point sources to estimate absorbed doses.

All of the approaches which consider the transfer of ^{3}H and ^{14}C use a specific activity approach relating biota activity concentrations to those in air; some approaches consider only tritiated water (e.g. Copplestone *et al*. 2001), whilst others also consider OBT (e.g. FASSET).

COMPARISON EXERCISES

Provisional results are available from two simple intercomparison exercises designed to compare the predicted whole-body activity concentrations for selected radionuclides in a range of non-human biota assuming a scenario of 1 Bq per unit (kg, l or m^{3}) of media. Unweighted internal and external dose conversion coefficients have also been compared for a selection of the reference animal geometries currently being proposed by the ICRP (http://www.icrp.org/ docs/Environm_ICRP_found_doc_for_web_cons.pdf), in environmentally relevant media.

Provisional results indicate that DCCs for internal exposure compare well between the different models; typically coefficients of variation are <20% of the mean. Where variation is greater it is as a consequence of different daughter products being included (e.g. ^{238}U) within the estimation of DCC. Variation is greater for external exposure DCCs and this may partially be a consequence of differing media geometries being assumed. Whilst external doses from β-emitters are low there is considerable variation between the different approaches. However, it is questionable whether whole-body external β-doses should be considered for some low energy β-emitters (e.g. ^{3}H and ^{14}C). Potential sources of variation (e.g. media geometry assumptions) between the different models are now being examined in detail.

Predicted activity concentrations compare well for some radionuclide-organism combinations and less well for others. A complete evaluation of this exercise is needed. There are some extreme comparisons which may result from two of the approaches making assumptions in the lack of advised CR values.

PLANNED SCENARIOS

Two scenarios are in the final stages of planning to enable the participants to compare their outputs to observed measurements. The first of these is Perch Lake (Canada) for which extensive datasets for water, sediment and a range of freshwater biota radionuclide (^{90}Sr, ^{137}Cs, ^{3}H and ^{60}Co) activity concentrations are available over a period of *circa* 50 years. Water chemistry data are also available for those participants who require this information. The second scenario will consider terrestrial ecosystems in the Chernobyl exclusion zone. Available data include ^{137}Cs and ^{90}Sr activity concentrations in soil, invertebrates, various plant species, amphibians, reptiles and a range of mammalian species. Soil activity concentrations for other radionuclides (e.g. ^{106}Ru, ^{60}Co, ^{144}Ce) are also available to allow model intercomparison. The results of studies planned within the ERICA project (http://www.erica-project.org/) to determine actinide activity concentrations in small mammals and amphibians will also be included, as will the results from TLDs attached to small mammals.

The BWG welcomes other participants: however, any models/approaches added to future scenario comparisons would first have to participate in the two exercises described here so that we can assess and understand any differences in methodology.

REFERENCES

Amiro, B.D., 1997. Radiological dose conversion factors for generic non-human biota used for screening potential ecological impacts. J. Environ. Radioact., 35, 37-51.

Blaylock, B.G., M.L. Frank and B.R. O'Neal, 1993. Methodology for estimating radiation dose rates to freshwater biota exposed to radionuclide in the environment. ES/ER/TM-78.Oak Ridge National Laboratory, Tennessee.

Copplestone D., S. Bielby, S.R. Jones, D. Patton, P. Daniel and I. Gize, 2001. Impact assessment of ionising radiation on wildlife. R&D Publication 128. ISBN 1 85705590. Environment Agency, Bristol.

Copplestone D., M.D. Wood, S. Bielby, S.R. Jones, J. Vives and N.A. Beresford, 2003. Habitat regulations for Stage 3 assessments: radioactive substances authorisations. R&D Technical Report P3-101/SP1a. Environment Agency, Bristol.

Golikov, V. and J.E. Brown, 2003. Internal and External Dose Models. Deliverable report 4 for EPIC. EC Inco-Copernicus project ICA2-CT-2000-10032. Norwegian Radiation Protection Authority, Østerås, Norway.

Higley, K.A., S.L. Domotor, & E.J. Antonio, 2003. A kinetic-allometric approach to predicting tissue radionuclide concentrations for biota, J. Environ. Radioact., 66, 61-74.

Larsson C-M, C. Jones, J-M. Gomez-Ros, and I. Zinger, (2004) *Framework for assessment of environmental impact of ionising radiation in major European ecosystems*. Deliverable 6 for the FASSET project Contract No. FIGE-CT-2000-00102. Swedish Radiation Protection Authority, Stockholm.

Sazykina, T.G., 2000. ECOMOD - An ecological approach to radioecological modelling. J. Environ. Radioact., 50, 207-220.

USDOE, 2002. A graded approach for evaluating radiation doses to aquatic and terrestrial biota.Technical Standard DOE-STD-1153-2002. U.S. Department of Energy, Washington D.C.