Review of dynamic models for dose assessment of non-human biota – final analysis of questionnaire

Jordi Vives i Batlle and Hildegarde Vandenhove

SCK.CEN

Jordi.vives.i.batlle@sckcen.be

SCK·CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Questionnaire objectives

- Ask for models and approaches in which the transfer part of the assessment is not carried out by means of equilibrium transfer factors.
- Include models using kinetic rates, e.g. biological half-lives, generally described as (bio)kinetic or dynamic.
- Interested in all types of models that can do this, even if the dynamic equations are simplified or if models do not calculate doses explicitly.
- Ask for views on dynamic modelling and its development stage / fitness for purpose / usefulness to assess if ecosystems are protected.

SCK·CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Participants

- 34 participants from 28 institutes:

  Manchester Metropolitan University (UK), AECL (Canada), ANSTO (Australia), CEH (UK), CNSC (Canada), EcoMetrix (Canada), ECOMOD (Russia), ENEA (Italy), Environment Agency (England & Wales), Horia Hulubei (Romania), IAEA (Vienna), IGE (Ukraine), Institute of Physics (Lithuania), IRSN (France), KINS (Korea), NIRS (Japan), NRG (Netherlands), NRPA (Norway), NRSC (China), NTUA (Greece), SCK-CEN (Belgium), Stirling University (UK), STUK (Finland), TUM (Germany), UB (Catalonia), UIAR (Ukraine), University of Portsmouth (UK), Westlakes Scientific Consulting (UK)†.

- 24 models including:

  BURN (in POSEIDON), Arctic food-chain model, DosDimEco, Rowan (AECL), Aquascope, Aquastar, D-DAT, CASTEAUR, Miyamoto (NIRS), IMPACT 5.4.0 , RUR and BioRUR , UNDBE, ECOMOD, Yoschenko (UIAR), Psaltaki (NTUA), BIOCHEM, RADCON, Pathway, MOIRA-PLUS, MAGENTC and AQUATRIT, CHERPAC and ETMOD - developed for wildlife or for humans but which can be adapted to wildlife.

- Full range of answers - Mixed response of scientists, operators and regulators to new tools including their views on simple vs. complex and need to improve methodology vs. need to justify change.

Part A – general information

Model names

BURN (in POSEIDON), Arctic food-chain model, DosDimEco, Rowan (AECL), Aquascope, Aquastar, D-DAT, CASTEAUR, N/A, Miyamoto (NIRS), IMPACT 5.4.0 , RUR and BioRUR , UNDBE, ECOMOD, Yoschenko (UIAR), Psaltaki (NTUA), BIOCHEM, RADCON, Pathway, MOIRA-PLUS, MAGENTC and AQUATRIT, CHERPAC and ETMOD

	a	b	c
Model available? (a) no, (b) yes	35%	65%	-
Platform: (a) spreadsheet, (b) modelling package, (c) Stand-alone	25%	15%	60%
When was the approach developed: (a) 1995-2000, (b) 2000-2005, (c) 2005-2010	5%	50%	45%
Status (prototype or demo, beta version, public release)	10%	45%	45%
Is the model: (a) owned by the developers, (b) published as article, (c) publicly available	57%	10%	33%
User-friendliness: (a) expert, (b) some familiarity, (c) non-expert	50%	9%	41%
If model 'could' be used by non-expert users, what effort required: (a) further development, (b) minor adaptation, (c) no adaptation	41%	35%	24%

STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Part B: Model information

Describe briefly the type of approach (a) biokinetic, (b) biokinetic + alometric, (c) other	52%	14%	33%
Ecosystem: (a) aquatic, (b) terrestrial, (c) all	50%	27%	18%
Radionuclides considered (a) less than 5, (b) 5 to 10, (c) 10 or more	53%	12%	35%

<u>Key model equations and parameters</u>

Most models use first-order uptake and depuration kinetics with biological half-lives to control time behaviour and CF/TFs to control equilibrium amounts. Some models include predator-prey systems (e.g. MOIRA) and others animal/plant physiology and so use consumption, assimilation and growth rates. Some other models use water chemistry information (e.g. BURN). A small number of models are metabolic (ECOMOD, MAGENTC and AQUATRIT). Most sensitive parameters (in general) seem to be the biological half-life and transfer factors. Some of the models are the type of compartment foodchain transfer model used in human assessments, and it needs to be determined further whether they are truly dynamic in respect of the uptake/turnover of radionuclides.

Is the model calibrated with: (a) no calibration, (b) field data, (c) field +laboratory data?	20%	35%	45%
User-friendliness: (a) no dosimetry, (b) available separately, (c) included	44%	11%	44%

SCK·CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Part C: Model information

Is this a foodweb model? (a) No, (b): Yes	47%	53%	-
Can the model assess doses to biota in rapidly changing scenarios, e.g. peak discharges or accidents? (a) No, (b) For transfer only, (c) Yes	19%	14%	67%
Has the model been validated? (a) No, (b) Partially, (c) Yes	0%	25%	75%
Has the approach been used in assessments or case studies? (a) No, (b) For transfer only, (c) Yes	33%	0%	67%

Part D – are dynamic models required?

Are dynamic models required for assessment of doses to biota? (yes / no / maybe) – Please justify your response.		
No - keep it simple / no need to regulate at such fine scale	Yes for research but limited regulatory application	Yes - some applications require it
6	**5**	**21**
The regulatory perspective is to demonstrate the potential for an effect, so keeping it simple is the best. Regulators only need analysing consequences of chronic, long-term and low-level releases essentially at equilibrium in biota. Hardly any real cases where we would need to know the consequences of dynamic situations. Regulation not at that fine of a scale. Conservative equilibrium screening approaches are sufficiently adequate. Potential for poor parameterization or large uncertainties. Dynamic models may have to make extra assumptions not more realistic than assuming equilibrium. For most biota the uptake and depuration kinetics need not be modelled explicitly in order to dose. Current equilibrium tools already sufficient for assessment purposes.	For research purposes e.g. reconstructing past doses after accidental or short term releases. Only if current equilibrium assumptions are not conservative because of dynamic process. The estimates may be affected by the uncertainties of many parameters and procedures. Unsure that the doses assessed by dynamics models are more reliable than those obtained from more simple approaches.	Accidental situations Any short term releases where residence time is shorter than biological half-life.. Where activity concentrations in the medium are changing rapidly e.g. close to inputs. CFs not conservative where ambient concentrations have fallen rapidly and biological half-lives are protracted. In river ecosystems where equilibrium is almost never reached. CF approach not a mechanistic approach to transfer. Decommissioning discharges. Chronic deposition to vegetation under variable aerial releases. Regulators want to understand mechanisms to explain better to public. Important for aquatic e.g. tritium discharges. For highly motile biota. For prediction of activity in plants over a year cycle For prediction of activity within organisms – organs. For incorporation pathways like breathing, digestion, breeding and metabolic procedures. for growing animals.

Part Db – is it a practical approach?

In your opinion, has dynamic modelling of doses to biota advanced enough to become a practical methodology? (yes / shows limited potential / still very much a theoretical subject)

Still very much a theoretical subject	Limited potential	Advanced enough to be practical
6	**15**	**9**
Only applicable for specific sites with limited range of biota.	Just a few radionuclides and a few species might be practical at this time.	There are data available for some common radionuclides and organisms
Variability among sites and taxa is large so the dynamic model has as much uncertainty as the simpler approaches.	Need better uptake/clearance rate constants for most radionuclides, especially RAPs.	Existing approaches demonstrate the method is practical
Scientific basis for modelling redistribution processes and mechanisms, particularly for the short-term following a NPP accident, is not adequate.	The modelling processes are available, but the lack of parameter data is a problem.	For aquatic ecosystems dynamic models developed for humans could be relatively easily adapted for wildlife.
Only applicable in high variability situations where minimum and maximum levels markedly differ from average levels.	Some dynamic models have been developed for human assessment.	Has been attempted for terrestrial models (e.g. FASTer and work in EPIC) bolted on allometric equations. to deposition-soil-plant models developed for human assessments.
More effort needed to accurately determine key dynamic parameters.	Are soil-plant models for human assessment valid for natural environments?.	The dynamics associated with the biological fate of radionuclides within an organism are probably understood well-enough to develop reliable and useful dose models.
Still very much a theoretical subject in respect of metabolic processes (because of lack of detailed scientific knowledge).	IAEA needs to generate more case studies.	Already there are several dynamic models of doses to biota in use. Some are validated and behaving well.
The time to use these models has not arrived yet as more effort is needed in steady-state models for wildlife	Sometimes models fall back on equilibrium parameters when there is insufficient data	Operators and regulators are responsible and recognize lack of scientific knowledge.
	Only use it to generate equilibrium values for application, as long as it added value.	The time to use these models has arrived as these models have been around for a long time
	More robust methods need to be developed.	
	For a realistic model it is necessary to combine with population dynamics.	
	Uncertainty in dynamic parameters	

Part Dc – Problems foreseen?

What hindrances do you foresee to the methodology gaining wider acceptance with operators and regulators?	
Kickback from industry and regulators to keep things simple as tools get more complicated, and need to communicate uncertainty in a clearer way.	5
Belief that equilibrium approaches already available are fit for purpose.	4
High variability of data requirements	3
Limited availability of parameters and associated reliability / uncertainty issues	8
Limited validation with field data to guarantee reliability before gaining acceptance	3
More experience with the methodology / more experienced modellers required	4
Increased uncertainty with little or no gain in conclusion	1
Additional costs	1
Fear of adding more regulation	1
Fear of getting mixed-up with environmentalist campaigning	1
Lack of (apparent) transparency in the models for when they rely on equilibrium based parameters	1
Many discharges are regulated on an annual release basis so we don't need dynamic data	1
Doses to biota generally very low, so why bother with refining the assessments?	1
The methodology is too complicated in using for screening purposes. It can be used in the Tier II or Tier III stages of assessment.	3
Is it appropriate to model biota doses to greater time resolution than many human dose assessments?	1
Need to define countermeasures for dynamic scenarios	1
Diversity of possible approaches so need to consolidate / agree on the right models	2
poorly understood trophic relationships	1
Risk of setting unrealistically low criteria of acceptable exposure levels.	1
Most operators & regulators don't have access to needed expertise and will usually settle for simpler approaches	1
Same hindrances than for justifying protecting non-human biota	1

Part Dd – reliability issues?

What do you see as the principal issues affecting reliability of dynamic models in assessments?	
Limited field / species data for parameterisation	8
Validation problems due to the limited number of cases where dynamic models might be tested rigorously.	5
High variability with location/site and with numerous taxa requires more extensive data requirements	3
Increased complexity with little or no gain in conclusion.	3
The lack of or uncertainty on the additional data / set of dynamic parameters	8
More experienced modellers required	1
Need to factorise time behaviour of species (e.g. migration)	1
Issues of applying laboratory data to the field	1
Lack of willingness of developers to conduct blind tests.	1
Individual differences between organisms (the variability of biota)	2
Inadequate knowledge of the redistribution processes and mechanisms of various radionuclides in varying environmental conditions and their time-dependencies.	3
Need to provide good spatial resolution	1
Perceived lack of accurate models	1
Sensitivity of the parameters	2
The research for dynamic models for non-human biota has started late; thus there are still many gaps and issues.	1

SCK·CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Part Dd – Likely scenarios?

List any specific scenarios you can imagine that would be particularly appropriate for using dynamic modelling	
Accidental scenarios with pulse releases - e.g. on water bodies; dose reconstruction in the aftermath of a NPP accident	15
For regulators Uranium mining releases may top the list, followed by Ra-226, and then probably Po-210 - mobility and toxicity	2
Pulsed discharges in nuclear e.g. reprocessing facilities	2
Any facility that releases radioactive effluent episodically and/or in the vicinity of inputs.	4
Spills (from nuclear installations) and the effect on mussels and/or shrimps in the near-land coastal zone.	1
Ba and Ra releases from the oil and gas industry (North Sea) - concentrations change rapidly	1
River discharges, especially of defined duration (intermittent release), including medical releases	2
Decommissioning discharges	2
Planned shutdowns / startups	1
Tritium and other river discharges	3
Species with critical organs	1
The air-borne radionuclide deposits on plants, and then into ecosystem food-chain through interception and translocation.	1
Assessment of dose to biota in context of sea-to-land transfer	1
Long time dynamic OBT measurements during constant HTO exposure of different biota from fertilization until OBT equality of parents and offspring.	1
Any environment that experiences strong seasonal variability (e.g. tropical monsoons)	1
Testing the reliability of equilibrium models for growing animals.	1

SCK·CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Conclusions

- Many models identified but must check if they are all fully dynamic in respect of the transfer to biota part.
- Opinions lean on dynamic models being required for some applications vs. research or just not (21/5/6).
- However, most people think they have limited potential vs. being practical enough or just a theoretical possibility (15/9/6). Reason most quoted is limited dynamic parameter information and uncertainty.
- Main hindrances to establishment: limited availability of parameters (8), industry and regulators wanting to keep things simple as tools get more complicated (5).
- Main reliability issues seen to be limited field / species / reliable parameter data for parameterisation (8) and validation problems due to the limited number of cases where dynamic models might be tested rigorously (5).

NAB5

Slide 12

NAB5 OK .... these could provide scenarios .... but would they provide data against which to validate??

.... and would dose reconstruction at Chernobyl have to include dynamic exposure modelling? .... ie contaminated air mass/external deposition? Nobody has touched on this have they - tend to be more transfer orientated?

Nicholas Beresford, 2011-01-11

SCK·CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Conclusions from the exercise

- Potential test scenarios identified:
  - Most people identified accidental scenarios with pulse releases - e.g. on water bodies; dose reconstruction in the aftermath of a NPP accident (15)
  - U mining releases
  - ^{226}Ra and ^{210}Po at legacy sites
  - Ra releases from oil industry
  - Decommissioning discharges
  - Nuclear fuel reprocessing aquatic discharges
  - River discharges
- 65 publications referring to dynamic models identified!
- These could provide useful dynamic scenarios, but would they provide data against which to validate?

Conclusions from the exercise

- Responses were sent before the Fukushima accident
- A prophetic quote from one participant:

> If a radioactive accident situation similar to the “BP oil spill in the Gulf of Mexico which flowed for three months in 2010” occurs, where the effect on humans is much less but the effect on non-human biota is much more, then the usage of a dynamic model for non-human biota would be appropriate...

- It seems potentially useful to add an extra question: If you answered that dynamic assessment of transfer and dose to biota was not justifiable, have your views changed since the Fukushima accident?
- …or is it a “leading” question? (discuss)

SCK·CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

What next – report chapter

- Part 1: review of the methodology for dynamic modelling (main principles, assumptions and equations).
- Part 2: Information on dynamic models identified in questionnaire in tabulated form as we did in EMRAS BWG report and also PROTECT Deliverable 4, citing 65 papers.
- Part 3: comparison figures with main points made by questionnaire participants. Some points (e.g. lack of parameterisation or validation data) appear in more than one answer so they may need to be combined.
- Part 4: There may be more models out there which could be adapted, so we should acknowledge this and give some guidance overview of what would be needed for models for different ecosystems derived for human assessment to make them applicable to wildlife. Well thought out mechanistic models should of course be readily adaptable to both - a point for future development.

SCK·CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

What next – EMRAS III

- Following a fair degree of support for at least developing dynamic assessment, and in view of recent developments, it is proposed to take the theme of dynamic modelling of transfer to EMRAS III.
- Consolidate guidance of what would be needed for applying dynamic models of transfer to wildlife.
- Conduct review of dynamic parameters for critical radionuclides relevant to accidents in nuclear installations, identifying uncertainties and data gaps.
- Compile data / design scenario for model comparison. Obvious candidate: Impact of Fukushima accident releases to marine biota. Endpoint: integrating the time-dependent dose rates over the duration of the accident and identification of possible effects. Other scenarios also possible, e.g. Fukushima terrestrial, NORM or river discharges.
- Publications: review of dynamic parameters and results of intercomparison excercises.

Copyright notice

SCK•CEN
Studiecentrum voor Kernenergie
Centre d'Etude de l'Energie Nucléaire

Stichting van Openbaar Nut
Fondation d'Utilité Publique
Foundation of Public Utility

Registered Office: Avenue Herrmann-Debrouxlaan 40 – BE-1160 BRUSSEL
Operational Office: Boeretang 200 – BE-2400 MOL