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

Jordi Vives i Batlle

SCK.CEN

Jordi.vives.i.batlle@sckcen.be

Copyright © 2010 SCK•CEN

Introduction

- Interest in recent years regarding dynamic models for protection of non-human biota
- Current assessment models mainly CF-based
- Potential case for dynamic-based models for nonequilibrium scenarios
  - Pulsed discharges
  - Decommissioning situations
  - Accidents
- Modelling group agreed to look at the current state of the art on dynamic modelling:
  - Look at what models are around
  - Assess the need and demand for dynamic models
  - Produce chapter for the final TecDoc

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.
- Typically to include models using kinetic rates, e.g. biological half-lives, and are described as (bio)kinetic or dynamic.
- Interested on all types of models that can do this, even if the dynamic equations are simplified or if models don't calculate doses explicitly.
- Ask for views on dynamic modelling and its development stage / fitness for purpose / usefulness to assess if ecosystems are protected.

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

Results so far

- 13 participants from 10 institutes: AECL (Canada), CEH (UK), CNSC (Canada), Institute of Physics (Lithuania), IRSN (France), NRG (Nederlands), NRPA (Norway), SCK•CEN (Belgium), University of Portsmouth (UK), Westlakes Scientific Consulting† (UK).
- Several models including: BURN (NRG Nederlands), Arctic food-chain model (NRPA), DosDim (SCK•CEN), AECL approach, Aquascope & Aquastar (Portsmouth), D-DAT (Westlakes, now SCK•CEN) and CASTEAUR (IRSN)
- Developed for wildlife or for other purposes but can be adapted for 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 name and model developer
- References (reports or publications, if available)
- Platform (spreadsheet, stand-alone application, on preexisting software, e.g. ModelMaker)
- When was the approach developed
- Status (prototype, beta version, public release)
- Is the model owned by the developers or is it in the public domain?
- Does the model require an expert user / developer or can it be used directly by non-expert users?
- If model 'could' be used by non-expert users, what adaptations / developments would be required?

Part A – general information

Model names	BURN (in POSEIDON), Arctic food-chain model, DosDimEco, No name, Aquascope, Aquastar, D-DAT, CASTEAUR		
Please cite appropriate references (reports or publications, if available)	All approaches referenced		
Model available? (a) no, (b) yes	25%	75%	-
Platform: (a) spreadsheet, (b) modelling package, (c) Stand-alone	56%	22%	22%
When was the approach developed: (a) 1995-2000, (b) 2000-2005, (c) 2005-2010	11%	67%	22%
Status (prototype, demo, beta version, public release)	13%	38%	50%
Is the model: (a) owned by the developers, (b) published as article, (c) publicly available	22%	22%	56%
User-friendliness: (a) expert, (b) some familiarity, (c) non-expert	22%	22%	56%
If model 'could' be used by non-expert users, what effort required: (a) further development, (b) minor adaptation, (c) no adaptation	29%	14%	57%

Parts B, C: Model information

- Type of approach (e.g. biokinetic, allometric, metabolic, etc.)
- What ecosystems, organisms and radionuclides does the model consider?
- Basic model equations (if available)
- Overview of dynamic model parameters (e.g. rate constants, biological half-lives, etc.)
- Is the model calibrated with field data, laboratory data or both?
- Dosimetry (if available)
- Is this a foodweb model?
- Model validation history
- Model validation and assessment record

Part B: Model information

Model names	BURN (in POSEIDON), Arctic food-chain model, DosDimEco, AECL, Aquascope, Aquastar, D-DAT, CASTEAUR		
Please cite appropriate references (reports or publications, if available)	All approaches referenced		
Describe briefly the type of approach (a) biokinetic, (b) biokinetic + allometric, (c) other (DEB, metabolic…)	67%	33%	-
Ecosystem: (a) aquatic, (b) terrestrial, (c) all	78%	11%	11%
Radionuclides considered (a) less than 5, (b) 5 to 10, (c) 10 or more	38%	13%	50%
Key model equations and parameters	All models use first-order uptake and depuration kinetics,some models include physiology and so use consumption, assimilation and growth rates. Some models use water chemistry information. Most sensitive parameter: biological half-life.		
Is the model calibrated with: (a) no calibration, (b) field data, (c) field +laboratory data?	33%	33%	33%
Calculate doses: (a) no dosimetry, (b) available separately, (c) included	56%	22%	22%

Part C: Model information

Model names	BURN (in POSEIDON), Arctic food-chain model, DosDimEco, No name, Aquascope, Aquastar, D-DAT, CASTEAUR		
Please cite appropriate references (reports or publications, if available)	All approaches referenced		
Is this a foodweb model? (a) No, (b): Yes	63%	38%	-
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	0%	22%	78%
Has the model been validated? (a) No, (b) Partially, (c) Yes	0%	33%	67%
Has the approach been used in assessments or case studies? (a) No, (b) For transfer only, (c) Yes	30%	11%	56%

Part D – opinion on approach

- Are dynamic models required for assessment of doses to biota?
- Has dynamic modelling of doses to biota advanced enough to become a practical methodology?
- What may hinder wider acceptance with operators and regulators?
- What are the principal issues affecting reliability of dynamic models in assessments?
- What specific scenarios would be particularly appropriate for using with dynamic modelling.

Part Da – are models required?

No - keep it simple / no need to regulate at such fine scale	Yes for research but limited regulatory application	Yes - some applications require it
2	3	8
The regulatory perspective is to demonstrate the potential for an effect, so keeping it simple is the best.	For research purposes e.g. reconstructing past doses after accidental or short term releases (e.g. Chernobyl, Krasnoyarsk…).	Accidental situations
Current regulatory framework requires only analyzing consequences of chronic, long-term and low-lwvel releases essentially at equilibrium in biota.	Only if current equilibrium assumptions are not conservative because of dynamic process.	Any short term releases where residence time is shorter than biological half-life
Hardly any real cases where we would need to know the consequences of dynamic situations.		Where activity concentrations in the medium are changing rapidly
Altogether, we are not regulating at that fine of a scale.		Argument that application of CFs provide a conservative estimation is invalid where ambient concentrations have fallen rapidly and $T_{B1/2}$s are protracted.
Conservative equilibrium screening approaches are sufficiently adequate.		In the vicinity of inputs where concentrations experience rapid changes.
Potential for poor parameterization		In river ecosystems where equilibrium is almost never reached.
		CF approach not a scientifically sound / not a mechanistic approach to transfer.
		Decommissioning discharges.
		Chronic deposition to vegetation under variable aerial releases.
		Regulators keen on knowing more about speciation of radionuclides and physiological consequences in terms of uptake and toxicity.

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

Part Db – Is it practical?

Still very much a theoretical subject	**Limited potential**	**Advanced enough to be practical**
1	7	4
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.	Existing approaches demonstrate the method is practical
	More field data required for certain isotopes/ecosystems.	For some ecosystems and radionuclides dynamic models developed for humans could be relatively easily adapted for wildlife. This is especially true of aquatic models.
	Logical development because good dynamic models have been developed for human dose assessment in particular cases.	Has been attempted for terrestrial models (e.g. FASTer and work in EPIC) bolted on allometric $T_{1/2}$ equations etc. to deposition-soil-plant models developed for human assessments. For terrestrial ecosystems need to consider if soil-plant models for human agricultural foodchain models are valid for natural environments.

Part Dc – Hindrances foreseen?

Kickback from industry and regulators to keep things simple as tools get more complicated	4
Belief that equilibrium approaches already available are fit for purpose	3
High variability of data requirements	2
Limited availability of parameters	2
Validation with field data to guarantee reliability before gaining acceptance	2
More experienced modellers required	1
Increased uncertainty with little or no gain in conclusion	1
Additional costs	1
Fear of adding more regulation	1

Part Dd – reliability issues?

Limited field / species data for parameterisation	6
Validation problems due to the limited number of cases where dynamic models might be tested rigorously	3
High variability of location/site/taxa requires more extensive data requirements	2
Increased complexity and uncertainty with little or no gain in conclusion.	2
The uncertainty on the additional set of dynamic parameters	1
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
Unwillingness of developers to conduct blind tests	1

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

Part Dd – Likely scenarios?

Accidental scenarios with pulse releases - dose reconstruction	6
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 reprocesing facilities	2
Any facility that releases radioactive effluent episodically and/or in the vicinity of inputs.	2
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 with time.	1
River discharges, especially of defined duration (intermittent release)	1

Conclusions

- Models identified: BURN, Arctic food-chain, DosDim, AECL, Aquascope & Aquastar, D-DAT & CASTEAUR
  - Mostly biokinetic, aquatic, public domain, > 10 radionuclides, calibrated and validated in some form + published.
- Opinions lean on dynamic models being required for some applications vs. research or just not (8/3/2).
- Most think they have limited potential vs. being practical enough or just a theoretical possibility (7/4/1).
- Main hindrances to establishment: perceived complexity & belief equilibrium models good enough.
- Main reliability issues seen to be limited field data for parameterisation and limited test cases for validation.

Conclusions

- Test scenarios identified:
  - Chernobyl dose reconstruction with dynamic modelling of exposures from air
  - 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
- These could provide useful dynamic scenarios, but would they provide data against which to validate?

What to do next

- Part 1 of chapter: review of the methodology for dynamic modelling (main principles, assumptions and equations).
- Part 2: Information on dynamic models identified in questionnaire, similarities and differences.
- Part 3: comparison tables / figures with main points made by questionnaire participants.
- Part 4: Future developments. As is likely there are more models out there which could be adapted than we've identified, guidance overview of what would be needed for models for different ecosystems derived for human assessment to make them applicable to wildlife.
- Objective of chapter is to give an idea of the state of the art plus peer reception of dynamic modelling methods.

Publications identified

Citation	Reference
Beaugelin-Seiller et al. (2002)	Beaugelin-Seiller K., Boyer, P., Garnier-Laplace J. & Adam C. (2002). CASTEAUR: a simple tool to assess the transfer of radionuclides in waterways. Health Physics, 84(3), 539-542.
Beaugelin-Seiller et al. (2003)	Beaugelin-Seiller K., Adam C (2003). Sélection d'un jeu de paramètres radioécologiques associés au prototype CASTEAUR. IRSN/DPRE, fiche technique SERLAB/03-010 (révision du rapport SERLAB/00-14) 57p.
Beaugelin-Seiller, K. (2005)	CASTEAUR V0.2 – Module dosimétrique. IRSN/DEI, rapport SECRE/05-002, 34 p
Boyer et al. (2005)	Boyer P., Beaugelin-Seiller K., Ternat F., Anselmet F. and Amielh M., (2005) A dynamic box model to predict the radionuclide behaviour in rivers for medium and long-term periods. Radioprotection, Suppl. 1, vol. 40 (2005) S307-S313.
Brown et al. (2004)	Brown, J. , Børretzen, P. , Dowdall, M. , Sazykina, T. & Kryshev, I. (2004). The derivation of transfer parameters in the Assessment of Radiological Impacts to Arctic Marine Biota Arctic, 57 (No.3), pp. 279-289.
Boyer, P. (2007)	CASTEAUR V0.2 – modèles biotiques. Équations et paramètres. IRSN/DEI, rapport SECRE/07-018, 23 p
Duchesne et al. (2003)	Duchesne, S., Boyer, P. & Beaugelin-Seiller K. (2003) Sensitivity and uncertainty analysis of a model computing radionuclides transfers in fluvial ecosystems (CASTEAUR): application to 137Cs accumulation in chubs. Ecological modelling, vol. 166, 257-276.
Fievet and Plet (2003)	Fiévet, B. and Plet, D. (2003) Estimating biological half-lives of radionuclides in marine compartments from environmental time-series measurements. Journal of Environmental Radioactivity, 65, 91-107.
Fievet et al. (2006)	Fiévet, B., Voiseux, C., Rozet, M., Masson, M. and Bailly du Bois, P. (2006) Transfer of radiocarbon liquid releases from the AREVA La Hague spent fuel reprocessing plant in the English Channel. Journal of Environmental Radioactivity, 90, 173-196.
Heling et al. (2009)	R. Heling & R. Bezhenar, 2009. Modification of the dynamic radionuclide uptake model BURN by salinity driven transfer parameters for the marine foodweb and its integration in POSEIDON-R. Radioprotection 2009, Vol. 44(5), 741 – 746.
Lepicard et al. (2004)	S. Lepicard, R. Heling, V. Maderich 2004, POSEIDON/RODOS models for radiological assessment of marine environment after accidental releases: application to coastal areas of the Baltic, Black and North Seas. JER 2004, Vol. 72(1-2), 153-161.

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

Publications identified

Citation	Reference
POSEIDON (2000)	POSEIDON report 2000
Rowan & Rasmussen (1997)	Rowan, D.J. and J.B. Rasmussen. 1997. Reply-Measuring the bioenergetic cost of fish activity in situ using a globally dispersed radiotracer (137Cs). Canadian Journal of Fisheries and Aquatic Sciences 54: 1955-1956.
Rowan et al. (1997)	Rowan, D.J., J.B. Rasmussen, and L.A. Chant. 1997. A bioenergetics approach to modeling seasonal patterns in the bioaccumulation of radiocesium, p. 399-405. In G. Desmet et al. [ed.] Freshwater and Estuarine Radioecology, Elsevier.
Rowan & Rasmussen (1996)	Rowan, D.J. and J.B. Rasmussen. 1996. Measuring the bioenergetic cost of fish activity in situ using a globally dispersed radiotracer (^{137}Cs). Canadian Journal of Fisheries and Aquatic Sciences 53: 734-745.
Smith et al. (2002)	Smith, J.T., Bowes, M. & Denison, F.H. (2002) Modelling the dispersion of radionuclides following short duration releases to rivers. Environment Agency, R&D project P3-074/TR, 96 pp, Environment Agency R&D dissemination centre, Swindon.
Smith et al. (2005)	Smith, J.T., A.A. Bulgakov, R.N.J. Comans, A.V. Konoplev, A.V. Kudelsky, M.J. Madruga, I.N. Ryabov, O.V. Voitsekhovitch, G. Zibold (2005). The “AQUASCOPE” simplified model for predicting 89,90Sr, 131I and 134,137Cs in surface waters after a large-scale radioactive fallout. Health Physics, 89, 628-644.
Smith et al. (2006)	Smith, J.T., Bowes, M.J., Denison, F.H. (2006). Modelling the dispersion of radionuclides following short duration releases to rivers: Part 1. Water and sediment. The Science of the Total Environment, 368, 485-501.
Smith (2006)	Smith, J.T. (2006) Modelling the dispersion of radionuclides following short duration releases to rivers: Part 2. Uptake by fish. Science of the Total Environment, 368, 502-518.
Vives i Batlle et al. (2007)	Vives i Batlle J, Balonov M, Beaugelin-Seiller K et al. (2007) Inter-comparison of unweighted absorbed dose rates for non-human biota. Radiat Environ Biophys 46 (4):349-373
Vives i Batlle et al. (2008)	Vives i Batlle, J., Wilson, R.C., Watts, S.J., Jones, S.R., McDonald, P. and Vives-Lynch, S (2008) Dynamic model for the assessment of radiological exposure to marine biota. Journal of Environmental Radioactivity 99(11), 1711-1730.
Whicker et al. (2007)	Whicker, F.W., Garten, Jr., C.T., Hamby, D.M., Higley, K.A., Hinton, T.G., Kaplan, D.I., Rowan, D.J. and R.G. Schreckhise. 2007. Cesium-137 in the environment: radioecology and approaches to assessment and management. NCRP Report No. 154. National Council on Radiation Protection and Measurements, Bethesda.