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Executive Summary

In June 2016 the third COMET sponsored workshop was organised, focusing on modelling in radioecology. The objective of this workshop was to discuss modelling as fit for purpose, by organising a dialogue and obtaining feedback from modellers, experimentalists and stakeholders on this subject.

Radioecological models are essential tools for use in assessing environmental impacts and risks from radionuclides in the environment, or as research tools for developing underpinning process understanding. The COMET Workshop 3 addressed whether radioecological models and available data can be described as “fit for purpose”, by organising a dialogue and obtaining feedback from modellers, experimentalists and stakeholders. Since there is no universal ideal model, the broad range of purposes of radioecological models has been reviewed and specific requirements identified. For example, the role of research models to interpret data and enhance process understanding, and the role of assessment models to apply that understanding to practical situations, was debated, emphasising the connection between them. Approaches to assessing the suitability of radioecological models for those purposes were discussed. Leading experts gave overviewing talks on key areas requiring consideration, but there were also opportunities for informal and round-table discussions.

A key aspect of this workshop was to improve the interaction between modellers and experimentalists, since a closer cooperation is expected to create a better compatibility between model developments and experimental studies. In addition, the workshop provided guidance on the development of radioecological models for specific purposes, including the desired degree of conservatism, the acceptable level of uncertainty and the optimisation of model complexity. Developing strategies to minimize the overall predictive uncertainty of model output is one of the challenges. The benefits and limitations of process-based approaches and extrapolation methodologies to fill data gaps were addressed in this context. Approaches to the validation of radioecological models were reviewed and evaluated.

The workshop initiated a dialogue that will improve the quality and robustness of radioecological models and make them more suitable for scientific applications and a broad range of assessment purposes, bridging to other radiation protection platforms and taking into account their specific needs.

List of Acronyms

CAN	Spanish Accelerator Centre
CERAD	Center for Environmental Radioactivity
COMET	Project Coordination and Implementation of a Pan-European Instrument for Radioecology. FP7 EURATOM funded project.
ICRP:	International Commission on Radiological Protection.
IRA	Initial Research Activities.
MCDA	Multi-criteria decision analysis
NMBU	Norwegian University of Life Sciences
MODARIA	Modelling and Data for Radiological Impact Assessments
SRA	Strategic Research Agenda.
IAEA	International Atomic Energy Agency

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1. Introduction

The main objective of COMET Workshop 3 was to address whether radioecological models and available data can be described as “fit for purpose”, by organising a dialogue and obtaining feedback from modellers, experimentalists and stakeholders. A key aspect of this workshop was to improve the interaction between modellers and experimentalists, since a closer cooperation is expected to create a better compatibility between model developments and experimental studies. Hypothesis-based models can guide the planning of laboratory and field work. Conversely, experimental investigations should be conducted in a way to obtain the maximum benefit for model development and improvement. At the workshop there should be discussed the role of research models to interpret data and enhance process understanding, and the role of assessment models to apply that understanding to practical situations, emphasising the connection between them.

In addition, such a workshop aimed to provide guidance on the development of radioecological models for specific purposes, including the desired degree of conservatism, the acceptable level of uncertainty and the optimisation of model complexity. Developing strategies to minimise the overall predictive uncertainty of model output is one of the key challenges. The benefits and limitations of process-based approaches and extrapolation methodologies to fill data gaps were addressed in this context. Approaches to the validation of radioecological models were to be reviewed and evaluated.

The workshop was expected to initiate a dialogue that will improve the quality and robustness of radioecological models and make them more suitable for scientific applications and a broad range of assessment purposes, bridging to other radiation protection platforms and taking into account their specific needs.

2. Models fit for purpose – Organisation and Venue

The workshop was organised by the EU project: Coordination and implementation of a pan-European instrument for radioecology, COMET.

The organising committee was put together with the following COMET participants: Lindis Skipperud, Rafael García-Tenorio, Jordi Vives i Batlle, Juan Carlos Mora, Martin Steiner, and Brit Salbu. The workshop was hosted by one of the partners of the COMET project, the University of Seville, in the Spanish Accelerator Centre (CNA), in collaboration with COMET partner Center for Environmental Radioactivity (CERAD) at the Norwegian University of Life Science (NMBU). The CNA is located in an area of the town devoted in 1992 to the Seville World Exposition There were 55 participants at the conference from the following countries: Norway, UK, Belgium, Russia, Ukraine, France, Spain, Sweden, Austria, Czeck Republic, USA, Romania, Portugal, Japan, Finland, Germany and Estonia. These were scientists, both experimentalists and modellers, and stakeholders in a balanced mix (see Fig. 1).

Picture 1. Participants of COMET workshop "Models fit for purpose" (Photo: Rafael G. Tenorio

3. Models fit for purpose - programme

3.1 Plans for the program

The detailed program for the workshop is attached as appendix I. The key questions addressed at the workshop were:

- What is the purpose of the models?
- Why do we need radioecology models?
- What should an ideal radiological model look like?
- How is the interactions between the modellers and the experimentalist?
- What is the model/data requirements?

Therefore, the workshop was divided into five main sessions – addressing purpose, fit, needs and interactions, plus five parallel sessions devoted for fit for purpose models and data in different environments (atmospheric, marine, terrestrial and transfer to humans). The workshop's main structure was as follows:

June 15th afternoon: Purpose: Why do we need radioecology models?

June 16th before noon: Interaction between modellers and experimentalists

June 16th afternoon: Fit: What should an ideal radiological model look like?

June 17th before noon: Needs: Model/data requirements?

June 17th afternoon: Model-specific session – parallel sessions

The contents of these sessions are summarised in turn below.

4. Minutes from the session "Purpose: Why do we need radioecology models? (Chair: Brit Salbu)

4.1 Overview of the presentations

Jordi Vives i Batlle: The session started with the presentation "Models: What are they for?" by Jordi Vives i Batlle, giving an overview of fundamental aspects of mathematical models. The lecture aimed to bring some points of reflection about modelling, stated thereinafter. A mathematical model is an abstract and simplified representation of an object or system. Good models reasonably represent the key features in a simplified way and allow predicting the system behaviour with time.

Model development starts with defining an achievable goal for the model, the boundaries of the model to be developed and the appropriate level of detail. A model should be sufficiently complex to be realistic, yet sufficiently simple to be practical.

The second step is to develop a conceptual model, usually by performing a FEP (features, events, processes) analysis of the system and defining an interaction matrix. The interaction matrix represents the compartments of the ecosystem to be modelled and the processes that transport radionuclides from one compartment to another.

In the third step, the processes to be modelled are represented by mathematical equations, e.g. analytical equations and differential equations. The set of mathematical equations can then be solved using commercial simulation packages or implementing the equations in software code. Jordi Vives i Batlle suggested using a simulation package for prototyping, then transferring the prototype to software code in a higher programming language, e.g. C++.

The last steps are important to ensure the overall quality of a model: Model calibration, i.e. defining the numerical values for the model parameters, model verification, i.e. testing the correctness of the mathematical model, and model validation, i.e. testing the agreement between model predictions and real data. The data used for model validation should be different from those used for model calibration. Model validation involves a philosophical aspect: Models can be confirmed by the agreement between prediction and observation. This confirmation, however, is inherently partial. Strictly speaking, a model can never be fully validated.

Martin Steiner: The second talk, by Martin Steiner, addressed the question of what an ideal radioecological model should look like. A radioecological model is always the combination of the mathematical model structure, a set of discrete values or probability distributions for the model parameters and a set of model assumptions. The quality or robustness of a model depends on the combination of structure, parameter values and assumptions. Evaluating one of these components separately is one of the most frequent mistakes.

Unfortunately, there is no universally applicable best model. A high-quality radioecological model should well predict the desired endpoints (e.g. activity concentrations in environmental media, dose to humans, and dose to biota) with respect to its specific purpose. The purposes of radioecological models can broadly be subdivided into research and assessment models. Research models are used to gain knowledge about the nature and the characteristics of processes, to gain knowledge about the relevance of processes (process sensitivity), to gain knowledge about the relevance of a model parameter within a given model (parameter sensitivity) and to guide further experimental and/or theoretical work. The purposes of assessment models include conservative (prognostic) assessments, e.g. for demonstrating compliance with dose limits, the calculation of high percentiles of the endpoint(s), and the best (retrospective) estimate of human radiation exposure, e.g. for epidemiological studies.

Martin Steiner suggested the following list of guidelines for high-quality radioecological models:

- Specify the purpose of the model and its scope
- Specify the acceptable uncertainty of the model results
- Have a (basic) knowledge of the dominant processes
- Make the model as detailed as necessary but as simple as possible
- Restrict yourself to key processes, unless a research model is used for investigating process sensitivity
- Use model parameters constant in time, especially for long-term predictions
- Be aware of correlations between model parameters; if possible revise the mathematical structure of the model to minimise correlations
- Assess the overall uncertainty of the model results
- Validate (not only calibrate!) your model; calibration might be sufficient for site-specific models
- Bridge between modellers and experimentalists before and/or during model development
- Consider the needs and expectations of model users

Igor Linkov: The third presentation of this session was given by Igor Linkov and it dealt with top-down and bottom-up approaches for integrating judgement in environmental models. Top-down approaches are judgement driven and seek for an optimum solution in view of goals, alternatives and constraints. Bottom-up approaches start with the fundamental characteristics of each alternative, calculate radiation exposure and the associated risk, which will then be compared with limits, thresholds or reference values. The main challenges for decision makers are parameter uncertainties, model uncertainties and modeller/scenario uncertainties. These uncertainties can partially be addressed by specific techniques but require also expert estimates and expert judgements.

Multi-criteria decision analysis (MCDA) methods evolved as a response to the observed inability of people to effectively analyse multiple streams of dissimilar information. MCDA methods provide a means of integrating various inputs, e.g. empirical data or model results, with stakeholder/technical expert values. Risk-based MCDA approaches provide a tool for organising and integrating various types of information to perform a ranking of decision alternatives and ensuring better informed decisions. Using the heavily polluted harbour of New York and New Jersey and different options for the disposal of contaminated sediment as an example, Igor Linkov explained a real, complex multi-criteria decision making process.

Igor Linkov concluded that there are clear benefits of using formal risk and decision analysis methods. They provide

- Opportunities to explore trade-offs among diverse objectives,
- Means for exploring the implications of uncertainty and the value of reducing it, and
- A quantitative framework to implement adaptive management.

However, efforts to apply these approaches include a number of practical issues and challenges. These are:

- Under-estimating the level of effort required to accomplish effective deliberation through the use of decision analysis,
- Determining who can/should be involved in value/preference elicitation,
- Intolerance for transparency in decision-making, and
- The misconception that decision analysis is a substitute for an actual decision.

4.2 Discussion session

Purpose of modelling

The participants of the workshop agreed that radioecological models are generally necessary to predict future contamination levels and doses to humans and biota or to assess an existing exposure situation. Regulators use models to demonstrate compliance with dose limits or to demonstrate that an exposure situation is "safe". The type of information that regulators and decision makers need includes the numerical values of the model results, their uncertainty and the degree of conservatism. A high degree of conservatism might be a problem if decision makers have to choose between different options. There is a risk of wasting resources and money. If the model concept is wrong, even demonstrating that the model is conservative at all might be difficult.

In emergency exposure situations radioecological models are indispensable to predict the potential radiological situation before the passage of the radioactive cloud. Radioecological models provide information on the most likely affected area, the point in time when the radioactive cloud will pass this area and the levels of wet and dry deposition. After the passage of the radioactive cloud, model predictions complement measurements, which in turn can be used to update the model predictions. Realistic radioecological models in post-accident situations provide a basis to justify and optimise countermeasures and remediation strategies.

General requirements

Most requirements are purpose-driven. In general, radioecological models should be based on good science and be well documented, including their underlying assumptions. Communication of uncertainty is considered to be essential for regulators and decision makers.

Link between modellers and experimentalists

There was a broad consensus that radioecology would benefit from a strong link between modellers and experimentalists and mutual exchange. A PhD student noted that experimentalists often study details without knowing the larger context of their investigations. The mutual exchange between experimentalists and modellers is expected to improve the way in which experiments are performed. Knowing the "larger picture" and a continuous communication between experimentalists and modellers is expected to ensure that all data necessary for model development will be collected.

Open questions

A dominant contribution to the overall uncertainty of a radioecological model might arise from a lack of knowledge of the source term. In this case, a simple radioecological model that only marginally increases the overall predictive uncertainty might be adequate. Many predictions after the Chernobyl accident were wrong because of an insufficient knowledge of the source term and its characteristics. A lack of knowledge of the source term may lead to an underestimation of transport processes, e.g. colloidal transport of Pu in the vicinity of Mayak.

There was a broad consensus that assessments for chemical pollutants and radionuclides should be conceptually performed in a similar way. The relation between "classical" models for pollutants and radioecological models should be clear and understandable. A harmonisation of both types of assessments is desirable. Some participants suggested building upon modelling approaches from related environmental disciplines, e.g. using knowledge of the currents in oceans for marine transport modelling. Another good example is the prediction of the partition coefficient K_d using hydrogeochemical speciation models such as PHREEQC. Some "classical" models, however, are based on conservative concepts and parameters. For the forest fires in Ukraine, for example, high-quality information on the source term with a time resolution of one day was available but "classical models" did not use this information.

Some participants emphasised that the risk assessment of biota faces many open questions. For example, there is a lack of knowledge of the consequences of multiple stressors and the dosimetric models for biota might be too simplistic.

5. Minutes from the session "Interaction between modellers and experimentalists" (Chair: Marie Simon Cornu)

5.1 Overview of the presentations

Juan Carlos Mora: This presentation started by indicating that models have two main purposes: predicting future events based on past observations and understanding underlying processes in a sequence of events. The process of the development of a model was illustrated with the gravity models, developed since the dawn of the humanity with a constant interaction between theoretical models and experiments. The process is a constant challenge of model against reality and it sometimes needs the development of new instruments (as was in the example the development of the telescope or the differential calculus) or paradigms (as the change of the centre of coordinates of the model from the Earth to the Sun). This is of course the same situation in radioecology which is a scientific discipline relatively new in comparison, where new theoretical and experimental advances and perhaps changes in the paradigms will be needed in order to improve our knowledge in the processes and for the improvement of our predictions. He also pointed out the necessity of validating the models and the need of being cautious with the results of the models which must be verified against reality. He also indicated the benefit of developing models which make predictions beyond the boundaries of what experiments can measure. This situation pushes experimentalists in developing new techniques, and also the opposite, performing measurements which challenge the models would force them to improve their capabilities.

Rafael Garcia-Tenorio: The next presentation emphasised that there is a need for interrelation between both experimentalist and modellers. If there is a lack of 'useful data' from a modelling perspective, the experimentalist might have these data. Modellers and experimentalists do not benefit from the same type of data and equipment. Experimentalists say that modellers simulate things that we do not have the conditions to support. Experimentalists on the other side can 'go on' making 'their' measurements. But it is possible to transform various measurements into parameters needed by the model? The association between modelling = conceptual work and experiments = hands-on work should be avoided. The conclusion is to collaborate from the origin of the problem.

Igor Linkov emphasised the need of integrating judgement into environmental models. Decision models and data collection is for management. How much modelling and experimentalism do we need? Igor Linkov has been both modeller and experimentalist and then moved on to social science. The challenge as perceived by him is that one cannot do models without data but also modellers are very uncertain about model structure. Adding to this is that in real life you can use only one model most of the times. Also model perception is an issue. There is a tendency to "go for mechanistic models" and when we do not know all the processes we use statistical models. More rarely used methods involve Bayesian and decision models. We need a framework for using models for making decisions. Decision analysis is the field that tries to fit this together – risk analysis, modelling, monitoring, cost and stakeholder opinions. The parting thought in this lecture was that risk assessment is a part of resilience.

5.2 Discussion session

The sum of the discussion groups was that modellers and experimentalists should work together, and some positive experiences of interaction were given. It is better not to have experimentalists vs modellers but to go together. When experimentalists start experimenting, they have some kind of conceptual model in their mind. It is important to validate a model with independent data. Data quality is also an issue for models.

In nuclear reactors, why do we all have our own models and do not share them? There will be different models but the issue is how you use them. The funding mechanism is partly responsible for this. The same thing could be said for data.

The discussion continued – why not joining forces to develop the models? But this was counteracted by saying that different models answer very specific research questions. Also there is a lack of communication. We should collaborate to address common problems and choose tools, but there are barriers between disciplines, and again there are the funding issues. There have been initiatives such as COMET Initial Research Activities (IRAs) or IAEA projects such as MODARIA, where modellers have collaborated. But many times there were only modellers together trying to validate their model, not so much 'joining forces' with experimentalists. Another member of the audience said in practice it is not possible to have a 'comprehensive, one size fits all' model. Some are simpler, some are more process based, etc. and different models give different answers so it is not possible to claim there is a best one.

Discussion of the first sub-group

This group discussed the benefits of working together towards common goals. Both modellers and experimentalists need to choose their tools appropriate to what needs are to be answered. The experimentalists can improve the knowledge if they know what parameters the modellers needs for the models. And vice versa, the experimentalists can help modify the models if the model does not reflect what they know goes on in nature.

Discussion of the second sub-group

No science is purely experimental or theoretical, but both are needed. This need for integration is observed in all research fields requiring collaboration between experimentalists and modellers. Experimentalists often forget what is needed to test the models. We need to understand each other. Modellers should understand how the measurement techniques work in order to ask for and optimize request of measurements. We should learn in radioecology from what was done in other fields. Experimentalists don't need to understand in detail how models work, but their limitations and needs. If the question is "what is the bioaccumulation in fish", fish is too generic, there would be a huge variability, the model must be very detailed if all data should be put against the model. There is a need to reach a balance between variability and of the available knowledge. Some models have to be calibrated in their parameters. How can a decision maker combine models and measurements? Both can be valuable and information can come from both.

The interaction between modellers and experimentalists needs to be improved in the field of radioecology. Together they need to identify key parameters and then identify key radionuclides. Some experimentalists assume Kds are key parameters because some models are using them. But, the huge uncertainty of Kds give huge uncertainty in the results of the models. Kd is a model (division) and measure something macroscopic, therefore a huge variability should be observed. There is a need for a more detailed description to understand the process. A compromise between detail and complexity of the model must be achieved. Sensitivity analysis are very important to study the influence of each parameter in the model in order to achieve such a balance.

6. Minutes from the session "What should an ideal radioecological model look like?" (Chair: Jordi Vives i Batlle)

6.1 Overview of the presentations

Martin Steiner: The first presentation focussed on deterministic vs. probabilistic models, with focus on whether probabilistic models are always the better choice or not. Deterministic and probabilistic models are both widely used for research and assessment models. Among the probabilistic approaches 1D Monte Carlo simulations dominate in radioecology, followed by Bayesian methods, probabilistic-possibilistic hybrid methods and 2D Monte Carlo simulations. In principle, probabilistic models allow more realistic predictions. Compared to deterministic models, however, they require an increased effort to obtain high-quality data for their model parameters (e.g. probability distributions, including their uncertainties and correlations). High percentiles and potential correlations between the model parameters present specific challenges. The lecture gave recommendations how to select the most suitable modelling approach depending on the modelling purpose, the quality of available data and the proximity of the model results to critical thresholds.

Céline Duffa and Marie Simon-Cornu: The second presentation discussed the case of radioecological models used, or to be used, by the IRSN technical crisis centre, which are designed to be «fit-for-purpose» for an emergency use. The first example is the model PAZ which provides post accidental zoning, and is a "constrained" version of a flexible platform, SYMBIOSE. The second one is STERNE, a modelling tool dedicated to provide a first dispersion and transfer forecast to help experts and decision makers in case of marine accidental contamination. These models are optimised to obtain fast results for the first analysis of any radiological situation.

Marc-André Gonze: The third presentation discussed the fitness for purpose of spatial modelling of aquatic and terrestrial systems, presenting a modular and flexible approach in which the spatial description of the continental biosphere (i.e. landscape model) relies on the use of multiple frames (0D, 1D or 2D) and spatial interactions to deal with the exchanges of mass, energy or information between them. The construction of a landscape model is performed by a spatial pre-processor which generates all geographical, geometrical and topological information required for performing spatial simulations of the fate, transport and dosimetric impact of radionuclides with the desired level of complexity. Examples of application were given for various case studies, with a focus on the modelling of space and time evolution of ambient dose rates in the terrestrial region within 80 km from Fukushima-Daiichi NPP. Geostatistical modelling was mentioned as a convenient tool to establish the geographical distribution of radionuclide deposits, and associated spatial uncertainties, from Japanese measurements of ambient dose rates through both in-situ gamma spectrometry and airborne surveys. This spatial approach was shown to be relatively simple, flexible and adaptable to various RA situations.

Juan Carlos Mora Cañadas: The final talk focussed on understanding uncertainties in models, explained that model uncertainties appear when models are confronted with reality, leading to an iterative optimisation process. Evaluation of the uncertainty associated with any modelled value, within the range of validity of the model, must be carried out. Sources of uncertainty in models (arising from model limitations) should be clearly distinguished from variability (arising from to real and identifiable heterogeneity or diversity in nature). Model uncertainty comprise the effect of conceptual simplifications, the numerical methods used for solving the model, the uncertainties in the definition of the scenario, the associated with the measurements (and measured parameters), the modelled or estimated parameters as well as uncertainties arising from the modellers themselves. All these uncertainties and variabilities should ideally be described by appropriate probability distribution functions. The talk discussed different uncertainty propagation techniques such as Monte Carlo analysis, and concluded by pointing that communication of the results is a non-trivial problem of the evaluation of uncertainties.

6.2 Discussion session

Martin Steiner's talk elicited some discussion. It was mentioned by some from the audience that if one is interested in the order of magnitude of a given result, a simple conservative approach can be applied, like the CF approach. If this approach says that the system studied is critically close to limit values then one should apply the probabilistic approach. The parts of the model that we do not know so well are where the biggest uncertainty will dominate. Several models could run for a same case and probabilistic analysis could be done for the output (something that was referred to as "ensemble technique").

The ensuing discussion session revolved around the following questions:

- How should a radioecological model be constructed?
- For a particular application will we need one model or a 'tool kit' of several models?
- Should we aim to modularise our models?
- Should we always construct a formal conceptual model before beginning implementation of a mathematical model, or is it sometimes better to first play with some mathematical ideas?
- How should we optimally use probabilistic and deterministic models? Are there circumstances where one or the other is preferred and are there other circumstances where the two approaches yield complementary insights?
- What roles should be played by sensitivity and uncertainty analyses?
- What is the optimal complexity of a model? Is this a meaningful concept?
- How should spatial and temporal inhomogeneity's be addressed? How should we represent processes occurring at grid-scales smaller than that of our model?
- Should assessment models be conservative? If so, to what extent? Can conservatism be defined for complex models with multiple relevant outputs?
- What level of uncertainty is acceptable in assessment model results?

In order to discuss this, the session was divided into two groups which dealt separately with the first and last four questions, respectively.

Discussion of the first sub-group (questions 1 – 4)

In the first group (steered by Jordi Vives i Batlle), the discussion was guided by questions but not necessarily limited to answer them. The first intervention was to point out that in IAEA projects practical guidance of methodologies for developing models are described, which works well enough. The most important thing is that the objective of the model (in this context this is for assessment models) should be defined. Another participant pointed out that in the Erica tool, to quote an example, the first step is to "State your problem", and secondly to state what is the concept, although nobody uses the documenting option in this way (users go directly to the assessment). The key point of all this is that the most important step is to state clearly the purpose of the model before starting the conceptual modelling stage, and that even at this early point there should be harmonisation between modellers, experimentalists and stakeholders (the future users of the model in many cases).

The discussion then progressed to the different phases of the modelling process as discussed in Jordi Vives' earlier lecture: development of conceptual model, functionality specification, architectural design, coding, calibration, verification, validation and documentation. These steps are well described in the literature so it was concluded there was no need to discuss a "recipe" but instead the discussion was about how these different phases of the modelling cycle fit together. For example, it was discussed that, in a modelling team, in practice, different people will have to deal with different parts of this process (for example, the coder is not always the same person that develops the conceptual model). In addition, there are many instances in which a model is part of a set of several models that have to be coupled, so in other words models can become part of a toolkit instead of a single model.

What was agreed above all else was that a model should not be developed before constructing a conceptual model. This is the second essential step in the modelling cycle, right after the aforesaid step of stating the problem. There are several methods for conceptual model development, and a well-accepted systematic method to build conceptual models which allows to put a structure to the problem is the use of Interaction Matrices. However, it was pointed-out that this is not the only system, and that others are also available and equally powerful, such as using object-oriented platforms for model development like ModelMaker, Amber or Ecolego, a software tool where the structure of the model in terms of flows, compartments and influencing variables can be set-up and changed from the very beginning, even before putting the governing equations for the processes. A Conceptual model can also be a diagram or 'mindmap' showing the processes.

A discussion of what level of detail should be included in the models ensued. This was considered to be very important. One of the key aspects is to understand what is circulating in the model. It should never be "Becquerel", but physical aspects such as particulate matter, colloids, solutes, water, etc. with due regard paid to their different behaviour. It was mentioned that for regulators conceptual methods are important to understand situations, and that stakeholders/end users should be involved since the beginning of the conceptual design of a model because they can help to identify the questions. A member of the audience wondered how many times this is done.

Other points made at the session are that the model development must be transparent, that decision of what information is not needed to include in the model can be done since the very beginning and that conceptual formulation is already a simplification of real processes and, as such, it involves some decision about what amount of information is (deliberately) lost in order to isolate and simplify the problem.

Discussion of the second sub-group (questions 5 – 8)

In the second group (steered by Marie Simon-Cornu), the discussion focussed on the issue of modelling uncertainties. First to be tackled was model complexity in decision making. Debaters pointed out that decisions are not better with information above a certain level. Human nature causes a tendency to obtain all information, but excessive information does not necessarily help to make better decisions. So, in order to react in a crisis, first responders are generally satisfied with well-focused information that is sufficient to select a pre-defined strategy. First responders need easy-to- use tools that also require limited (but pertinent) information. Comprehensive models that spew lots of data may be useful in the back-office but not in the crisis centre.

On the topic of probabilistic assessments, it was discussed that probabilistic models give probabilistic results (probability distributions) that require “interpretation”. “Uncertain” results however are very difficult to communicate to decision-makers. Consensus is necessary, for example, on what is an acceptable percentile.

Regarding spatial uncertainty discussions touched on whether spatial uncertainties matter, e.g. in case of varying weather conditions. Participants responded affirmatively, e.g. in the case of monitoring (the uncertainty may determine the spatial resolution of monitoring points) or in the case of countermeasures such as relocation. Narrow plumes might be problematic. Often, the assumption of a maximum exposed individual works quite well. Temporal variation is also important. Seasonal variations might be important for model development and validation. Many factors depend on season, such as leaf area index for trees, the hydrology cycle of sols, etc.

It was discussed that uncertainty analysis should be part of the model development. For example, sensitivity analysis in which one performs an identification of parameters that are important or negligible is important. Uncertainty analysis of complex models might result in uncertainties of several orders of magnitude; hence a purely mathematical handling of uncertainty might not be practical.

The session concluded with a discussion of what constitutes "acceptable uncertainty". Sometimes we have to live with uncertainty (limited knowledge, time pressure). Sometimes uncertain values are “fixed” by convention, e.g. dose coefficients. A special challenge occurs in waste repositories and long-term predictions of potential doses. It is important to clearly communicate the scientific basis of dose assessment and the conventions and, as part of this, to communicate the sources of uncertainty.

6.3 Final wrap-up session

In the final wrap-up session it was agreed that better decisions are not necessarily achieved by increasing information; that first responders rely on clear and simple information. It is also clear that it is difficult to communicate uncertain results to decision makers. The problem should be stated clearly at the beginning of the modelling process, the stakeholders can sometimes be involved at the conceptual modelling stage, uncertainty and sensitivity analysis should be part of the model development and we should communicate well the sources of uncertainty of model predictions to the end users of the information produced by the models.

7. Minutes from the sessions "Needs: Model/data requirements." (Chair: Juan Carlos Mora Canadas)

7.1 Overview of the presentations

Jerzy Bartnicki: This talk (which was moved forward from the afternoon session), was on nuclear emergency dispersion modelling. Jerzy Bartnicki presented work done on modelling real events in Norway, where there is a crisis committee ready to model the source term for a nuclear accident or detonation, leading to decisions. He presented the SNAP model, which is a severe nuclear accident program. He showed examples of application of the model to real events.

Brit Salbu: The next presentation introduced the existing uncertainties in the determination of the source term and in the dynamic transfer of the radionuclides. The focus was on the fact that many sources of uncertainty are recognised in the whole process since the release of the radionuclides to the dose or risk assessment. As uncertainty implies lack of knowledge, a better knowledge of every step in the process is needed to reduce it, and this is also the case in the source term, where the size and the chemical form of the released particles are important. Those factors are intimately related with the bioavailability of the different species which must be taken in the kinetics while modelling the behaviour of those radionuclides in the environment. It must be recognised that particles are released during all types of severe nuclear events and therefore it is essential to implement them in source term and transport models. For this is essential than experimentalists and modellers share the same conceptual concepts.

Wolfgang Raskob: The next presenter introduced the issue of performing model validations, which is an important part of model development but sometimes difficult to achieve. Validation should be considered since the very beginning of the development of a model, including a qualitative knowledge of the complexity of the model and the existence of enough data available to test all the functionalities of the model. In the validation process, individual parameter values must be tested against reality. If they are valid then a sensitivity analysis can be carried out to identify the more important parameters which should be further validated. If they are not valid model features and endpoints should be ideally revised. Validation in a very simple model (as a simple K_d selection) would basically imply the validation of a proper selection of the K_d value while, on the contrary, a process-based model with many features would require more effort in the process. Balance should be met in the development of the model between complexity and performance. And of course, modellers must interact with experimentalists in the design of their validation experiments and modellers should be present during the experiments in order to understand the difficulties in the experiments designed by models. Endpoints of the model should not be the only quantities to be compared with reality, as the result might be a fortuitous and lucky successful combination of totally wrong parameters and sub-models. Instead stepwise validation might be preferred. Good practices for the development and validation of a model include:

- Create comprehensive documentation of the model which should be open and accessible.
- Boundaries and limitations of the model should be defined (and acknowledged).
- Data from external sources should be preferred.
- Inputs and outputs should be clearly defined.
- Uncertainties of the results should be provided (if possible).
- Ideally, the tests of the models should be performed by external users.
- Sensitivity analysis should be performed to identify more important parameters.
- Validation should be carried out in stepwise tests and sub-models should be validated.
- Model intercomparisons are necessary in order to cover conditions not covered in experiments.

8. Minutes from the sessions “Fit for purpose – specific models parallel sessions"

8.1 Fit-for-purpose models and data for terrestrial forests (Chair: Martin Steiner)

8.1.1 Overview of the introduction lectures

Jordi Vives i Batlle: Process and data identification in a radionuclide forest model

Jordi Vives i Batlle gave an introduction lecture entitled “Process and data identification in a radionuclide forest model”. He emphasised that a radioecological model for forests should be sufficiently complex to be realistic but sufficiently simple to be practical. It should consider the interactions between soil, vegetation and atmosphere and include the water and energy fluxes, which determine the radionuclide fluxes. The talk detailed how a soil/vegetation/atmosphere (SVAT) model can be developed, using as example the ECOFOR model developed by the author at SCK-CEN. The talk dealt with model conceptualisation and process selection with a focus on simplifying the hydrology problem, the plant uptake and translocation processes (evapotranspiration influence on root uptake and sap flow). A list of parameters required for different parts of the model was intended to provide a basis for discussions on a parameter wish list for experimentalists. The talk concluded with some highlights of the ongoing process of verification and testing of the ECOFOR model.

Philippe Calmon, Marc-André Gonze: Radiocaesium dynamics in Fukushima forests: data review and modelling

The second introduction lecture by Philippe Calmon and Marc-André Gonze dealt with the radiocaesium dynamics in Fukushima forests. Published data on the radiocaesium contamination in Japanese forests in the period from 2011 to 2013 were used to improve the understanding of the mechanisms that determine the migration of radionuclides in forest ecosystems and to define "reference forests" (reference coniferous, deciduous and mixed forests) for radiological impact assessment studies. The talk focused on the dynamic processes relevant during the first year(s) after an atmospheric contamination (wet and dry deposition, incorporation and redistribution within trees, throughfall, stemflow and litterfall). To facilitate the comparison between different sites, Cs-137 data (activity concentrations, fluxes) were normalised to the respective Cs-137 deposition, expressed in Bq/m². Data for "reference forests" have been derived by averaging the log-transformed normalised data of the Japanese sites investigated. The tree depuration flux (sum of throughfall, stemflow, and litterfall) at different Japanese sites agrees well with the data obtained for a Norway spruce forest in Southern Bavaria after the Chernobyl accident. It can well be described by the forest model TREE4. During the period investigated, litterfall contributed most to the tree depuration flux, flowed by throughfall and stemflow. The model predictions of radiocaesium concentrations in needles and branches are satisfactory. In summary, the Japanese data turned out to be highly valuable for improving our understanding of tree depuration mechanisms and model realism. The Japanese data sets are consistent but show some spatial, temporal and inter-species variability. The depuration kinetics after the Fukushima accident is similar to that measured in German forests after the Chernobyl accident.

8.1.2 Discussion session

Purpose and relevance of forest models

There was a debate on the general relevance of radioecological models for forests. Forests are considered to be a challenge for the radiation protection of humans only in rare cases. Forests tend to stabilise the radiological situation, thus preventing the contamination of surface water. After a nuclear accident or at NORM sites, forests could be useful to reduce the spread of contamination. At sites, where radioactive waste is deposited close to the surface, trees will most likely not be accepted, since deep tree roots might damage barriers and facilitate the transport of radionuclides.

Desired output

Regulators usually prefer tiered approaches to human and environmental risk assessments, taking into account the purpose of the assessment and the specific situation to be evaluated. High-quality assessment models should provide results (e.g. contamination levels and doses to humans and non-human biota) that are as realistic as reasonably achievable. The desired endpoints are different parts of trees and edible forest products, such as wild mushrooms, wild berries and game. Time-dependent transfer factors may pose a problem, especially in the case of radiostrontium. From a regulator's point of view, a forest model should also provide the basis for calculating doses to non-human biota.

Model complexity and data requirement

Although the process-based model ECOFOR has been designed to be "sufficiently complex to be realistic but sufficiently simple to be practical", some participants of the workshop remarked that this model is too complex and requires data for too many model parameters. Yet it is a lot simpler than forestry models like ANAFORE, which can have hundreds of parameters and be very complex because they include a lot of ecological processes (e.g. the physico-chemical and biological behaviour of nutrients, micronutrients with applications to woodland management). ECOFOR is considered to be a research model rather than an assessment model, but one aiming to be a platform for model abstraction in the search towards a simple radioecological assessment model for forests. It could provide a sound basis for identifying the most relevant processes (process sensitivity) and developing simplified assessment models. The development of assessment models should be guided by the question, what endpoints are important for assessing the radiological risk of humans and the environment. One participant suggested to bridge to ecology and ecotoxicology, since these scientific disciplines are expected to face similar challenges when assessing risks.

Sensitivity and uncertainty

Several participants emphasised the importance of sensitivity analyses and the quantification of the overall predictive uncertainty. In the case of water-mediated transport processes the element-specific partition coefficient K_d is expected to be the most important model parameter. For sensitivity analyses, but also when evaluating the applicability of a forest model to other sites, it is essential to differentiate between input parameters (which usually are site-specific) and model parameters (which should ideally be generally applicable).

Attention should also be paid to the source term. After the Chernobyl accident, for example, large activities were deposited close to the reactor as fly ash, whereas the source term of the Kyshtym disaster is quite different.

Model-specific criticism

The forest model ECOFOR developed at SCK-CEN focusses on water-mediated transport processes. One participant remarked that water fluxes are important for radiocaesium but not for radiostrontium. The model concept is therefore expected to limit the application to other radionuclides.

Concerning the French model TREE4, the question was raised if the good agreement of model predictions and measurements demonstrates the quality of the model or is only the result of "calibrating" the model output to measured data. According to Philippe Calmon, good agreement has been observed for three data sets. The most important parameters, interception fraction and weathering rate, are only moderately variable. These two main parameters for short-term predictions cannot directly be measured and therefore have been determined by "calibrating" the model to measured data obtained at Japanese forest sites. The model predictions agree well with data obtained at a forest site in Southern Germany after the Chernobyl accident. The experience after the Fukushima-Daiichi nuclear power plant accident demonstrated that predicting the spatio-temporal deposition pattern remains a challenge. Deposition strongly depends on rainfall and rainfall intensity.

8.2 Fit-for-purpose models and data for the marine environment" (Chair: Juan Carlos Mora Canadas)

Raul Periañez performed the presentation entitled: "Behaviour of the radionuclides in the marine environment. Transport processes" where he provided information on different specific models and processes within marine modelling.

The uncertainties that can be accounted for in these models include:

- Uncertainties in the Parameters (which are site specific). If we only need to calculate the dissolved radionuclides in water we will only use horizontal/vertical diffusivities coefficients. However if movement in the sediment is desired more parameters are needed, as the kinetic rates, kds, particle sizes, density, sediment thickness and porosity, etc.

- Uncertainties in the Numerical solution, due to the discretisation and approximation of the solution. Usually second order approximations are used in the approach.

- Uncertainties in the Water circulation. Intercomparisons can provide estimations (for instance in the international MODARIA project). Comparisons in real cases as in Fukushima.

The specific case of Fukushima (strong currents) was used in the intercomparisons carried out in the MODARIA project. In this case all the compared models were 3D models. The main source of discrepancy was circulation. If same circulation, same diffusion coefficients and same bathymetry was used, the differences were reduced to a factor 2. On the other side, if currents were calculated discrepancies of 6 orders of magnitude were found.

In conclusion, large differences are obtained in highly dynamic systems with strong and variable currents, and therefore difficulties are found in developing operative models for DSS (which has been set up as the objective of MODARIA II's group on marine modelling).

Interpretation of results is difficult. Sometimes measurements are presented using "magical" interpolation analysis (which are not optimal) with very few number of measurements. In those cases 3D models provide better results. There is a need of communication between modellers and experimentalist in order to not use those kinds of interpolations when there are good models.

8.2.1 Discussion session

Questions were raised about the Fukushima simulation where modelling appears to have been successful in predicting the transport of the plume. Concentration predictions were about one order of magnitude, influenced probably by uncertainty of the source term information used in the early days after the accident. This estimation was done live. Validation studies with dispersion models that used the initial estimations of the source term have shown that due to the complex meteorological situation its validation was difficult. An experiment to compare models and CBTO data and the results after using a 2015 new description of the source term showed that timing predictions are good but there still divergences in concentrations.

One question was - can something be done to better determine the source term and improve the predictions after a nuclear accident? Things like improving key parameters such as the vertical range of the release, particulate composition and associated aerodynamic resistances, physical properties of the gases released – as much as possible - are plausible strategies. From the meteorological viewpoint, good metrological data is also important.

Participants mentioned other aspects like the case of iodine which can take different forms e.g. gas, aerosol, etc. Also mentioned were political and communication problems immediately after Fukushima. Every country with a crisis centre made their own studies, under the assumption of nuclear meltdown because INITIALLY Japan assigned a level 5 to the accident, which was subsequently revised down. International issues after analysis hampering communication is one important factor. Refining the inventory of the reactor has been another problem. The range assigned by the IAEA s between 12 -20 PBq for Cs, for example.

The real question is to help decision makers and this is not only about modelling but about communication. It was also discussed whether real forecasts of weather can be used in the assessment. In the case explained there was not much different between analysis and forecast. There were in the immediate period of the Accident several different predictions. So, how to improve our predictive capabilities? The important thing is to have all the experts work together rather than every country establishing its own interpretation. This could be better if it had been handled at the transnational level.

CTBTO made one of the best assessments using their monitoring network so monitoring information is important and the exchange of this information via an open system e.g. IAEA would be very useful.

Reliability of the forecasting models seems more reliable at the global range than at the local range which is where the affected people are although on a few days e.g. 2 the dispersion patterns can be reasonably well predicted.

Aquatic dispersion was also mentioned. Is there any chance of improving the predictive capabilities for marine modelling? Here the problem is more difficult because the situation depends on two terms; what was deposited from atmosphere (incorporating the uncertainties in calculating the source term and its atmospheric dispersion and deposition) and as an extra the uncertainties in what volumes of contaminated water were being released in the early phase of the accident, and with what timing.

To improve what can be done we would need more monitoring data, better data on deposition processes, for example.

For the models used in marine dispersion it must be recognised than these models are better used in late phases of the accidents for their understanding. Wolfgang Raskob indicated that his group implemented a 3D model (myocean) connected with JRODOS atmospheric modules. They try to answer questions, but it takes long time (1 month). Raul Periañez indicated that for every facility you need a model site specific (prepared for that site) that could be used instantaneously. The problem is to know if this aim can be achieved.

It is recognised that the characterisation of the sediments: porosity, particle sizes etc. is where bigger gaps are found for the application of the models.

9. Conclusions

The COMET Workshop 3 was successful in addressing whether radioecological models and available data can be described as "fit for purpose", by organising a dialogue and obtaining feedback from modellers, experimentalists and users. A broad range of purposes of radioecological models was reviewed and specific requirements were identified. For example, participants debated the role of research models to interpret data and enhance process understanding, and the role of assessment models to apply that understanding to practical situations, emphasising the connection between them. Approaches to assessing the suitability of radioecological models for those purposes were also discussed. Leading experts gave overviewing talks on key areas requiring consideration, but there were also opportunities for informal and round-table discussions.

Invited stakeholders and representatives of other European radiation protection platforms communicated their expectations and needs as to radioecological models. They also helped to identify the types of radioecological models that are still lacking for specific purposes or do not fully meet their requirements. The discussions included the challenges related to the implementation of the Euratom Basic Safety Standards.

A key aspect of this workshop was to improve the interaction between modellers and experimentalists, since a closer cooperation is expected to create a better compatibility between model developments and experimental studies. Hypothesis-based models could guide the planning of laboratory and field work. Conversely, experimental investigations should be conducted in a way to obtain the maximum benefit for model development. The workshop discussed the role of research models to interpret data and enhance process understanding, and the role of assessment models to apply that understanding to practical situations, emphasising the connection between them.

In addition, the workshop provided guidance on the development of radioecological models for specific purposes, including the desired degree of conservatism, the acceptable level of uncertainty and the optimisation of model complexity. Developing strategies to minimise the overall predictive uncertainty of model output is one of the challenges. The benefits and limitations of process-based approaches and extrapolation methodologies to fill data gaps were addressed in this context. Approaches to the validation of radioecological models were reviewed and evaluated.

The workshop can be seen as having initiated a crucial dialogue that will improve the quality and robustness of radioecological models and make them more suitable for scientific applications and a broad range of assessment purposes, bridging to other radiation protection platforms and taking into account their specific needs.

The participants agreed that this workshop and dialogue was useful and that this kind of dialogue should continue on a regular basis. Therefore there were suggestions that the workshop should be held every second or third year as a series of workshops.

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Annexes:

Annex 1: Detailed program for the COMET Workshop ”Models fit for purpose”

Annex 2: Participant list

Annex 3: List of Questions for the Workshop

Annex I: Workshop program

Time	Lecturer	Title
June 15th, 2016		
14:00 – 14:15	Brit Salbu	Welcome and scope of the workshop
Purpose: Why do we need radioecology models? (Chair: Brit Salbu)		
14:15 – 14:35	Jordi Vives i Batlle	Models: What are they for?
14:35 – 14:55	Martin Steiner	What should an ideal radioecological model look like?
14:55 – 15:15	Igor Linkov	Top-down and Bottom-up Approaches for Integrating Judgment in Environmental Models: Methodology and Case Studies
15:15 – 15:45	Coffee and tea	
15:45 – 17:00	Group work	***Purpose of radioecology models***
17:00 – 17:30	Group work reports and discussion	
June 16th, 2016		
Interaction between modellers and experimentalists (Chair: Marie Simon Cornu)		
09:00 – 09:30	Rafael G-Tenorio	The need of interaction between modellers and experimentalists – from the experimentalists' point of view
09:30 – 10:00	Juan Carlos Mora Cañadas	The need of interaction between modellers and experimentalists – from the modellers' point of view

10:00 – 10:30	Coffee and tea	
10:30 – 11:30	Group work	***Interaction modellers – experimentalists: Defining each other's requirements***
11:30 – 12:00	Group work reports and discussion	
12:00 – 14:00	Lunch	
Fit: What should an ideal radiological model look like? (Chair: Jordi Vives i Batlle)		
14:00 – 14:20	Martin Steiner	Are probabilistic models always the better choice? or: Deterministic vs. probabilistic models: Are probabilistic models always the better choice?
14:20 – 14:40	Céline Duffa / Marie Simon Cornu	Which models should be used to support a technical crisis centre
14:40 – 15:00	Marc-André Gonze	Fit-for-purpose spatial modelling of environmental systems
15:00 – 15:20	Juan Carlos Mora Cañadas	Understanding uncertainties in models
15:20 – 15:50	Coffee and tea	
15:50 – 17:00	Group work	***Fit for purpose***
17:00 – 17:30	Group work reports and discussion	
	Social GET-TOGETHER in the evening, sponsored by Center for Environmental Radioactivity CERAD, Norway	
June 17th, 2016		
Needs: Model/data requirements (Chair: Juan Carlos Mora Cañadas)		
09:00 – 09:20	Philippe Ciffroy	Stakeholder's experience in assessing exposure to chemicals, the case of MERLIN-EXPO
09:20 – 09:40	Russell Walke	So you want to build a model: platforms and implementation
09:40 – 10:00	Jorge Molinero	Innovative approaches to modelling the transport of contaminants in groundwaters

10:00 – 10:20	Coffee and tea	
10:20 – 10:40	Brit Salbu	Uncertainties in source term and dynamic transfer of radionuclides
10:40 – 11:00	Wolfgang Raskob	Model validation – how do we do this?
11:00 – 12:00	Discussions	
12:00 – 14:00	Lunch	

Model-specific session – parallel sessions				
14:00 – 15:00	***Fit for purpose models and data for the atmospheric environment***		***Fit for purpose models and data for the transfer to humans***	
Introduction lectures	Jerzy Bartnicki (15 min)	Nuclear emergency dispersion modelling	Marie Simon Cornu (15 min)	Modelling transfer to humans - possibilities and uncertainties
Discussions	Debate between modellers and experimentalists on key input data/factors required for the models		Debate between modellers and experimentalists on key input data/factors required for the models	
15:00 – 15:30	Coffee and tea			
15:30 – 17:00	***Fit for purpose models and data for the marine environment***		***Fit for purpose models and data for terrestrial forests***	
Introduction lectures	Raul Perianez (20 min)	Marine transport models - possibilities and uncertainties	Jordi Vives i Batlle (15 min)	Process and data identification in a radionuclide transfer model for pine forests
			Philippe Calmon (15 min)	Data/model intercomparison with post-Fukushima measurements in forests.

Discussions	Debate between modellers and experimentalists on key input data/factors required for the models	Debate between modellers and experimentalists on key input data/factors required for forest models. Listing of the main experimental measurements required to link to forest model parameters.
17:00 – 17:30	Wrap-up session by Lindis Skipperud	
17:30	Closing workshop	

Annex II Participant list

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Annex III Questions for the Workshop discussions

Purpose: Why do we need radioecology models?

- Why do we need models?
- Assessment – what is needed?
- Do our models reflect the needs of the different end users and who are our end users?
- Who are the different types of individual and group that may make use of models?
- What different types of model are there? (research, assessment, scoping, exploratory, regulatory...)
- What relationships exist or should exist between radioecological models and models used in other aspects of the environmental sciences (hydrogeological, hydrogeochemical, systems ecological models etc.)

Interaction between modellers and experimentalists

- How can radioecological models guide laboratory experiments, sampling campaigns, field investigations, baseline monitoring surveys and long-term monitoring programmes?
- How should laboratory experiments and field studies be conducted to best inform radioecological model development, parameterisation and validation, e.g. type and number of data, supplementary information, sampling strategy, quality estimation and control.
- How to better interact with experimentalists for model Validation purposes?
- What are appropriate procedures for model validation?
- Should laboratory and field studies ever be conducted prior to the development of a conceptual radioecological model?
- Should laboratory and field studies be conducted after formulation of a conceptual radioecological model but before formulation of a mathematical radioecological model?

Fit: What should an ideal radiological model look like?

- How should a radioecological model be constructed?
- For a particular application will we need one model or a 'tool kit' of several models?
- Should we aim to modularise our models?
- Should we always construct a formal conceptual model before beginning implementation of a mathematical model, or is it sometimes better to first play with some mathematical ideas?
- How should we optimally use probabilistic and deterministic models? Are there circumstances where one or the other is preferred and are there other circumstances where the two approaches yield complementary insights?
- What roles should be played by sensitivity and uncertainty analyses?
- What is the optimal complexity of a model? Is this a meaningful concept?
- How should spatial and temporal inhomogeneities be addressed? How should we represent processes occurring at grid-scales smaller than that of our model?

- Should assessment models be conservative? If so, to what extent? Can conservatism be defined for complex models with multiple relevant outputs?
- What level of uncertainty is acceptable in assessment model results?

Needs: Model/data requirements for the implementation

- What requirements is needed for implementation?
- What data is missing?
- Which types of radioecological models for which purposes are missing? (could be combined with an evaluation of stakeholders' needs)
- Should models be implemented directly in high-level code or through the use of simulation packages?
- How should models be documented?
- How can the quality of implementation be assured?
- To what extent should computer models be made 'user friendly', e.g. through use of graphic user interfaces?
- Are issues with the numerical stability of model solutions a thing of the past?
- Are there advantages in analytical approaches as a complement to numerical approaches, since analyses can facilitate system understanding?

Model-specific session – parallel sessions

- Debate between modellers and experimentalists on key input data/factors required for models.
- Listing of the main experimental measurements required to link to model parameters.

Forest modelling specific questions

- How can the large number of processes at soil / tree / atmosphere be sufficiently simplified in a practical forest model? (especially hydrology and plant transport)
- What are the desired outputs of a forest model and what format they should be in?
- How model parameter / input requirements link to experimental measurements?