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D 9.73 – Knowledge gaps to improve E&T
Report on key factors contributing to the overall uncertainties in radiological impact and risk assessment models - Output from the TERRITORIES Workshop 1

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Abstract

On November 14 – 15th, 2017, the first workshop within the EU – CONCERT funded project TERRITORIES task 4.1 (i.e. CONCERT sub-subtask 9.3.4.1), led by CERAD/NMBU, was organized in Oslo, entitled "Key factors contributing to uncertainties in radiological risk assessment".

The main objective of this first workshop in the TERRITORIES project was to discuss the key factors contributing the most to overall uncertainties when linking source term and deposition to ecosystem transfer, and to human and environmental radiological impact/risk assessment models. The TERRITORIES workshop included 28 participants, i.e., scientists, regulators, industry representatives, and experts on general public related issues, from 10 countries (Croatia, Czech Republic, Estonia, Finland, France, Germany, Japan, Norway, Spain, Sweden)

The Workshop was successful in addressing different aspects associated with factors contributing to impact and risk modelling uncertainties, and how these uncertainties could be reduced, and by organising this workshop more as a dialogue between regulators, industry, general public and scientists. Thus, all the participants were extremely active in the discussions held during the workshop (including those held during coffee breaks). Special mentioned are the chairs of the sessions, the speakers, the moderators and secretaries of the group work sessions, without whom the workshop could not have been carried out.

List of Acronyms

ALLIANCE	European platform on radioecology research
BfS	German Federal Office for Radiation Protection
BIOPROTA	International platform on the long-term assessment of radionuclides released into the biosphere from radioactive waste disposals
CEPN	French research and development centre in the fields of optimisation of radiological protection and comparison of health and environmental risks associated with energy systems
CERAD	Norwegian Centre for Environmental Radioactivity
CIEMAT	Spanish Centre for Energy, Environment and Technology
CONCERT	European Joint Programme for the Integration of Radiation Protection Research under Horizon 2020
CROM	Code developed at CIEMAT to assess the radiation exposure of humans from radionuclide releases into the environment
CROMERICA	Code developed at CIEMAT to assess the radiation exposures of humans and biota from radionuclide releases into the environment
EnviroCase	Finnish consulting company for managing environmental research and risk assessments
ERA	Environmental risk assessment
E&T	Education and training
Facilia	Swedish consulting company for environmental and health risk assessments, safety assessments in radioactive waste management and radiation protection
HARMO	International initiative on harmonisation within atmospheric dispersion modelling for regulatory purposes
IAEA	International Atomic Energy Agency
IRSN	French Institute for Radiation Protection and Nuclear Safety
MCNP	Monte Carlo N-Particle Transport Code
MELODI	European platform on low dose radiation risk research
MODARIA	IAEA programme to improve capabilities in the field of environmental radiation dose assessment
NERIS	European platform on preparedness for nuclear and radiological emergency response and recovery
NMBU	Norwegian University of Life Sciences
NORM	Naturally occurring radioactive material
NRPA	Norwegian Radiation Protection Authority
pdf	Probability density function
RESRAD	Family of codes developed at Argonne National Laboratory to assess radiation exposures of humans and biota from environmental contamination with radionuclides
RQ	Risk quotient
SCK•CEN	Belgian Nuclear Research Centre
SKB	Swedish Nuclear Fuel and Waste Management Company
SSM	Swedish Radiation Safety Authority
TERRITORIES	European research project within radiation protection that is part of the H2020 grant agreement 662287 – CONCERT (To Enhance unceRtainties Reduction and stakeholders Involvement TOwards integrated and graded Risk management of humans and wildlife In long-lasting radiological Exposure Situations)
UPM	Polytechnical University of Madrid
UT	University of Tartu
WP	Work package

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1. Introduction and Objectives

TERRITORIES (To Enhance unceRtainties Reduction and stakeholders Involvement TOwards integrated and graded Risk management of humans and wildlife In long-lasting radiological Exposure Situations) has three main objectives:

- To fill the requirements that emerged after the recent Fukushima experience and the publication of International and European Basic Safety Standards.
- To reduce uncertainties to a level that can be considered fit-for-purpose (graded approach).
- To bridge between NORM and post-accident (after transition phase) exposure situations, monitoring *vs* modelling, humans *vs* wildlife populations, experts *vs* decision makers *vs* the general public in management (integrated approach).

Within WP4 (Strategic and integrated communication, education and training) of the **TERRITORIES** project (i.e., subtask 9.3.4 of CONCERT), one of the objectives is to identify and communicate to appropriate audiences the existing capabilities, key uncertainties, needs and knowledge gaps in radiological risk assessment and management for humans and wildlife in long-lasting radiological exposure situations. To reach this objective, a number of workshops will be organised through the 3 years of the project.

The first workshop held was directly linked to TERRITORES task 4.1 (i.e., CONCERT Sub-subtask 9.3.4.1), where the aim is to identify key factors contributing the most to overall uncertainties when linking models simulating environmental dispersion and transfer processes, exposure and resulting dose estimates together, to finally characterize and manage risks associated with long-lasting radiological exposure situations.

The workshop was entitled "Key factors contributing to uncertainties in radiological risk assessment". The main objective of this first workshop was to discuss the key factors contributing to overall uncertainties when linking source term and deposition, to ecosystem transfer, and to human and environmental radiological impact/risk assessment models. Valuable discussions were achieved by obtaining feedback from modellers, experimentalists and stakeholders.

This workshop was held together with TERRITORIES second workshop entitled "Communication of uncertainties of radiological risk assessments to stakeholders" as the topics of these two workshops were closely connected, and people were encouraged to participate in both of them. The summary of the second workshop is given in Deliverable report D 9.74 "TERRITORIES Workshop on: Communication of uncertainties of radiological risk assessments to stakeholders".

The joint organization of the workshops allowed the optimization of TERRITORIES resources, and facilitated the participation of different stakeholders in both events. In addition, the scientific knowledge presented in the workshop on "Key factors contributing to uncertainties in radiological risk assessment", gave a useful background for the workshop on "Communication of uncertainties of radiological risk assessments to stakeholders".

Both workshops were held in Oslo, Norway, on November 14-16th, 2017. The first two days focused on the first workshop, while the third day focused on the second workshop. Both workshops were sponsored by the Center for Environmental Radioactivity (CERAD), a Center of Excellence at the Norwegian University of Life Sciences (NMBU), Norway (https://www.nmbu.no/en/services/centers/cerad).

2. Workshop organization

The workshop was organized as part of the EU CONCERT project TERRITORIES, in cooperation with the Center for Environmental Radioactivity (CERAD), a Norwegian Center of Excellence at the Norwegian University of Life Sciences (NMBU), Norway, and Centro De Investigaciones Energeticas, Medioambientales Y Tecnologicas (CIEMAT), Spain. The workshop venue was Thon Hotel Slottsparken in Oslo, Norway, situated close to the park around the Norwegian Royal Palace.

To address the organization of both workshops, an organising committee was established, integrated by the TERRITORIES participants: Lindis Skipperud (NMBU, Norway), Almudena Real (CIEMAT, Spain), Martin Steiner (BfS, Germany), Rodolphe Gilbin and Marie Simon-Cornu (IRSN, France) and Alan Tkaczyk (TU, Estonia).

The organising committee held several video conferences to prepare the programme of both TERRITORIES workshops. The draft titles of the lectures and potential speakers were proposed. Once the draft programme was agreed, the proposed speakers were contacted, asking if they would be willing to participate in the workshops.

Workshop discussion

The detailed workshop program for "Key factors contributing to uncertainties in radiological risk assessment" can be found in Annex 1. The workshop was divided into three sessions, each with introductory oral presentations from both TERRITORIES partners and external invited experts. The oral presentations were followed up with group discussions, with specific prepared questions to discuss.

The first session was entitled "Uncertainties in monitoring data and other data of importance for models" and chaired by L. Skipperud (CERAD/NMBU). The lecturers and topics for the oral presentations were:

- Martin Steiner (BfS): Interaction between experimentalists and modellers.
- Brit Salbu (CERAD/NMBU): Uncertainties in radionuclide source term.

The main question asked for Session 1 group discussions was "How can we better deal with uncertainties associated with data input?". Annex 3 lists the main question and sub-questions for the different sessions.

The second session was entitled "Uncertainties in models". The session lasted over two half days and was chaired by B. Salbu (CERAD/NMBU) and J. Brown (NRPA). The lecturers and topics for the oral presentations were:

- Martin Steiner (BfS): Overview of modelling uncertainties.
- Juan Carlos Mora (CIEMAT): Analysis/discussion of the uncertainty budget and the different contributions to the total uncertainty – a case study using CROM-8 (CROMERICA).
- Justin Brown (NRPA): Attempting to deal with uncertainties within the ERICA integrated approach.
- Marko Kaasik (UT): Overview of HARMO initiative including uncertainties.
- Ari Ikonen (EnviroCase, Ltd): Uncertainties and their management in conventional radionuclide transport and dose assessment models for nuclear waste management.
- Ulrik Kautsky (SKB): Ecosystem approach in the assessment of radioactive waste.
- Rodolfo Avila (Facilia): Probabilistic analyses, sensitivity and uncertainty and analyses, Bayesian methods.

The main question asked for Session 2 group discussions was “Which uncertainties can be addressed by improved modelling?”.

The third session was entitled “Reducing uncertainties: How far should we go/can we go?” and this session was chaired by J. C. Mora (CIEMAT). The lecturers and topics for the oral presentations were as follows:

- Jordi Vives i Battle (SCK•CEN) (by Skype): Applicability and limitations of available radioecological models.
- Danyl Pérez-Sanchez (CIEMAT): Terrestrial environmental transfer models for long-term radiological assessment.

The main question asked for Session 3 group discussions was “How do we reduce the overall uncertainties in impact and risk assessment?”

The group discussions were provided by dividing the participants into 3 different groups, putting people from industry, regulatory authorities and research institutes/academia together. The groups had each a pointed moderator and secretary, who kept the discussion going and taking notes for plenum presentations (See table 1).

Table 1. Group moderators and secretaries

Group Moderators	Group Secretaries
Avila, Rodolfo	Mauring, Koit
Kautsky, Ulrik	Tkaczyk, Alan
Crouail, Pascal	Mora, Juan Carlos
Gallego, Eduardo	Skipperud, Lindis
Skuterud, Lavrans	Urso, Laura
Mora, Juan Carlos	Iospje, Mikhail
Peltonen, Tuomas	Real, Almudena
Hosseini, Ali	Kaasik, Marko
Kuca, Petr	Vilbaste, Martin
Fojtikova, Ivana	Justin Brown
Tucaković, Ivana	
Gómez-Ros, José M.	

Participants

The workshop on “Key factors contributing to uncertainties in radiological risk assessment” included 28 participants from 10 countries (Croatia, Czech Republic, Estonia, Finland, France, Germany, Japan, Norway, Spain, Sweden) (Annex 4). Among the participants, there were scientists, regulators, industry representatives, and experts on general public related issues. There were also representatives of several European platforms on radiation protection such as ALLIANCE, NERIS and MELODI (Figure 1).

Figure 1. Participants of TERRITORIES Workshop 1 "Key factors contributing to uncertainties in radiological risk assessment". Photo: Almudena Real

Dissemination

Regarding the dissemination of the workshops, once the programmes were agreed, the events were announced using different tools. The programmes were disseminated through the TERRITORIES blog (https://territoriesweb.wordpress.com/) and webpage (http://territories.eu).

The workshops were also announced in the following webpages: EJP-CONCERT Project (http://www.concert-h2020.eu/en/Events/20171114_TERRITORIES); the Radioecology Exchange (http://www.radioecology-exchange.org/news-and-media/news/territories-project-%E2%80%93-workshops), NERIS Platform (http://www.eu-neris.net/index.php/home/newsletters/142-territories-workshops.html).

In addition, the information of the TERRITORIES workshop was distributed by e-mail to all TERRITORIES members and the European Radioecology Alliance (ALLIANCE) members.

The information of the TERRITORIES workshops was also distributed in Spain through the national Horizon 2020 webpage (https://eshorizonte2020.es/mas-europa/otros-programas/euratom/eventos/workshops-proyecto-territories_ejp-concert-h2020).

3. Minutes from Session 1 “Uncertainties in monitoring data and other data of importance for models”

This section refers to uncertainties of input data utilized in ecosystem transfer models, environmental impact and risk models. Input data are usually based on experiments and direct measurements (e.g., concentrations ± std dev of variables), or indirectly for calculated or estimated values for variables (e.g., transfer coefficients, dose estimates). In addition, uncertainties associated with representative sampling, procedural yields, precision and accuracy are included in the term Experimental or Measurement uncertainties.

3.1. Overview of the presentations and plenum discussions

The main focus points from the oral presentations of Session 1 were:

- “A tendency prevails … that experimentalists (i.e., those producing empirical data in the lab or in the field) while striving for empirical facts or evidence, and modellers (those producing theoretical constructs) as anchored in theoretical grounds, pursue research in separate scientific worlds each, …” (R. Matyssek and G. M. J. Mohren, Trees (2012) 26:1679–1682).
- Experimentalists and modellers mutually depend on each other. Scientists within each category would benefit from joint research efforts through synergistic effects.
- Uncertainties associated with the source term (i.e., releases of radionuclides from a source) are categorised as conceptual uncertainties (i.e., model bias or discrepancy from real life due to lack of knowledge or deliberate exclusion of relevant mechanisms, processes or phenomena). In addition to activity concentration, the source term characteristics should therefore include information on radionuclide speciation and particle characteristics, being relevant for many release scenarios and having major implications for deposition and ecosystem transfer modeling.
- Bridging between experimentalists and modellers is not enough. Further bridges to experts in related scientific disciplines (efficient knowledge building), to end-users (practical application of models) and to stakeholders and society (acceptance) might be beneficial.

There was a discussion concerning the reasons behind providing more refined models, notably in the case of the wild boar model as developed by BfS. The answer lies in the requirement to provide greater trust between experts and stakeholders and is connected to improved communication. For example, in Germany the limit for Cs-137 in foodstuffs is 600 Bq/kg, but there is a challenge to ensure that all wild boar meat is below this level. The development of such a model provides insight into the reasons for the extremely variable contamination levels, thus creating confidence that regulators appropriately understand the radiological situation. An opinion was given that a critical number of experimentalists and theoreticians was required to make real headway. There was a short debate concerning whether all variables used in the model need to be measureable. The point was made that as advances in measurement techniques continue there may be variables that cannot be measured today, but may be quantifiable in the future (the example of the dosimetry associated with extremely small objects was alluded to).

To identify which processes are important, research-based models can be used, and by performing sensitivity analyses on a suite of different models key processes and variables can be identified.

Experimentalists and modellers should discuss what the focus should be before going into the field or conducting lab experiments. A joint conceptual understanding can improve the situation greatly.

3.2. Discussion session (group work)

The main question for this group discussion was "*How do we reduce the overall uncertainties in impact and risk assessment?".* There were also given a set of other questions to keep the discussion going (see Annex 3).
Why do we want to improve the quality of input data used in impact and risk models? Because there is a need to improve the reliability of model output such as predictions. There is a need to improve the characterisation of radionuclide contamination, the temporal and spatial variability and in so doing refine the reproduction of such data. Finally, there is a requirement to fill gaps in our knowledge, thus there is a need for robust monitoring programme design (to characterise variability).

There is a need for a complete-as-possible characterisation of site-specific samples collected (e.g., pH, grain size, microbiota, biota species, activity concentrations, Kd). In handbooks presenting transfer factors, such data are not available. Uncertainty in measurement, in itself, is important because this gives an indication of how confident we are in the measurement (need to have a robust mean value +/- standard deviation). Geographical and time information is also required. The experimentalists need to say how confident they are with measurement accuracy and precision, and how confident they are about understanding the natural system (variability and conceptual uncertainty).

<u>Measurement uncertainties</u> or experimental uncertainties is assigned to variability of input data based on experiments and direct measurements (e.g., concentrations ± std dev of variables), or indirectly for calculated or estimated values for variables (e.g., transfer coefficients, dose estimates). In addition, uncertainties associated with representative sampling, procedural yields, precision and accuracy are included.

<u>Uncertainty linked to characterisation of data distribution.</u> Concept of representativeness of samples – do we have enough samples to represent the population, i.e., derive a robust statistical distribution? Also linked to this – there are spatial and temporal aspects for representativeness – do we have sufficient input data to provide an acceptable characterisation of changes over time and heterogeneity (in, for example, media activity concentrations, deposition levels etc.)?

<u>Scenario uncertainty</u> – are the input data (collected over a finite time and space) suited for extrapolation to other conditions (prospective or retrospective)? This also links to the idea of sampling representativeness. You may collate input data for 'normal conditions' (of river flow, tidal events), but critical events may occur under abnormal conditions such as high river flows or storm surge events where you can have a sudden, massive redistribution of contaminants.

Conceptual or model uncertainty is assigned to model bias or discrepancy from real life due to lack of knowledge or to deliberate exclusion of relevant mechanisms, processes or phenomena. Model uncertainty can be divided into subcategories; uncertainties in model structure (e.g., scientific hypotheses, key processes and associated equations), model resolution (e.g., spatial and temporal) and model code (e.g., algorithms, numerical solvers). Furthermore, model uncertainty will depend on the correspondence (or lack thereof) between model input requirements and available data

<u>Experimentalists need to define the practical constraints associated with measurements</u>: what is feasible to measure, what is challenging to characterise, and what kind of data cannot be obtained today. Thus, it is important for modellers to have some understanding of the field conditions and the

laboratory-experimental conditions. Preferred models are the ones that utilize directly measureable quantities as input variables (i.e., clearly linked to the International System of Units (SI)). Models that employ non-numerical not-measurable input variables are more difficult to utilize for describing ecosystem transfer, biological uptake and effects. However, such models have been utilised for assessing risks; e.g., non-numerical variables such as low, medium and high risk.

The input and output quantities for the model(s), depends on the specific cases, e.g. for contaminated forest case: input – activity of the soil; output – activity in trees, plants and animals. If the lab or field derived data set is small, it seems self-evident that the uncertainty would be large. Where extrapolation approaches/surrogates or proxies have been used, again the uncertainty may be large. At a conceptual, qualitative level, it seems self-evident that the speciation/physico-chemical form must be an important factor dictating the behaviour and fate of radionuclides in environmental systems. We know how critical these factors can be in terms of biological interaction and impacts. Most of the models currently employed don't really account for speciation to a satisfactory degree (if at all).

<u>Those uncertainties that have been identified from earlier/published detailed analyses.</u>

Fieldwork data are of vital importance. The only decisive method to evaluate a model is to run it with real-life input data and compare its output with real-life (measured) data sets. The intercomparison runs with artificially generated data are useful to quantify the discrepancies between the models, but they leave open the question, whether any of compared models is accurate enough. If the compared models give highly different results, then we can conclude that at least some of them have severe problems to reproduce the reality, but we don´t know, which ones. However, the good coincidence of models with each other does not necessarily mean that they perform well – they may contain common inadequate assumptions that make all these models biased.

Fieldwork data are extremely important for validating the models used in radiological assessments – e.g., input data, data for parameterisation, data for validating default values – so essential for all steps of the assessment.

There is a question over what type of fieldwork data the modellers have access to. Ideally there should be good dialogue between the modeller and experimental fieldwork practitioner. The modellers should have some input at the early planning stages of the field campaign so that the most suitable type of information is collated and the representativeness of the sampling is adequate (i.e. the modellers might be able to assist with sampling design).

Regarding how the source term affects the uncertainties in models - It is actually difficult to answer this because, we tend to use single deterministic values (e.g. instantaneous release of X Bq of a given radionuclide) for the source term. Without using a distribution/probability density function (pdf) of the source term input data, it is difficult to say anything about the effect this would have on the output uncertainty (i.e. cannot undertake a 'global' uncertainty analysis).

The way uncertainty in the source term is often accounted for, is through consideration of worst case scenarios – assuming (highly) conservative/pessimistic release situations. There is also uncertainty linked to other components of the source term – most notably the physico-chemical from of released particles. Traditionally, for atmospheric releases, simplifying assumptions have been made (e.g. assume the release of a given radionuclide is present as an aerosol). If consideration is not given to hot particles, this may lead to substantial underestimation of deposition in the near field and possibly overestimation of deposition in the far field – radionuclides carried over long distances.

The variance in release with time might theoretically contribute substantially to uncertainty. Taking the example of an atmospheric release and a distant location from the release point, it is possible to see that the timing of the release may play an extremely important role in determining the impact. It is possible that the wind may blow contamination directly towards a populated area during one hour, but that the wind direction could change substantially within the next hour. Similar consideration might be made for wet and dry deposition – if the timing of the release coincides with heavy rainfall deposition will be enhanced. Again, this is normally accounted for by considering 'worst case' meteorological conditions – those conditions leading to maximum deposition in a given area from a large suite of historical meteorological data.

A well-known statement about this subject exists in scientific slang: "*garbage in – garbage out*." Discrepancies due to poor knowledge on the source propagate through the entire modelling chain and make the final results unrealistic.

A note was made that input data can be empirical or in some cases not. For example, output from one model can be input to a second model etc. Uncertainties can be conceptual.

Stakeholder dialogue was considered as being important to identify which uncertainties that might be of importance for the prediction done by the stakeholders. The model used also dictates the input data required. Interaction between modellers and empiricists should be a standard approach.

The details of the input data affects the level of detail in the output from the model. Inverse calculations can inform data requirements. Simple models were seen as beneficial – few parameters and therefore not data hungry. Real life measurements were considered to be important – and these should be as 'close as possible to the end-point'. If data are not available then models are important in making predictions.

Figure 2. Group work in progress. Photo: Lindis Skipperud

4. Minutes from Session 2 "Uncertainties in models"

4.1. Overview of the presentations and plenum discussions

The oral presentations of Session 2 stated:

- Models fit for purpose: the purpose of a model determines the degree of acceptable uncertainties affecting the predicting output.
- There is an increasing demand for knowing the uncertainty budget of quantitative predictions/forecasts (politicians, decision makers, stakeholders, society).
- Modelling uncertainties can be classified as aleatory uncertainty (true heterogeneity over space and time), and as epistemic uncertainty arising from lack of knowledge (e.g., missing data, parameters and scenario uncertainties), and the latter can be reduced by further investigations.
- It is essential to know and communicate all potential contributions to the overall uncertainty budget. From practical point of view, it is recommended to consider the major contributions in detail but deal with minor contributions in a generic/simplified way.
- Even if you think a model is conservative (e.g. CROM), specific case studies can show that this is not the case.
- Interpolation and extrapolation uncertainty - To account for missing data for instance in time series, different statistical methods, simulations, interpolation or extrapolation techniques are applied (e.g., Bayesian) and uncertainties are thereby introduced.
- Focus is often only on parameter uncertainty. No universally applicable approach to sensitivity analysis exists. The challenge is to select an appropriate approach.
- An alternative to detailed uncertainty analyses could be "what if" scenarios.
- Seasonal variations may affect long-term consequences. An equilibrium approach using concentration factors might significantly underestimate radionuclide concentrations compared to a dynamic model.
- The statistical approaches of the HARMO initiative (collaboration in atmospheric modelling) might also be used to quantify the performance of a radioecological model if slightly modified. Since activity levels can vary significantly, the HARMO equations should be used with the logarithms of the activity levels.

The use of probability density functions (pdfs) in models was considered. In the case of meteorological prognoses it was noted that in a practical sense the use of pdfs for parameter values was limited. Numerical uncertainty seems to be much more important for complex models, e.g. meteorological advection-dispersion models, than it is for simple models. There seemed to be some contention regarding one of the speaker's points that numerical uncertainty is normally not an important consideration. It seems that in some cases it can be. A comment was made that a distinction between assessment and research models might be useful. However, in reality, the distinction may not be so clear. Defining the purpose of the study was considered to be extremely important. For example, for compliance one might opt for a simplified model with conservatisms. A comment was made that decision making does not require solid scientific underpinning in some cases. Research often requires the implementation of robust models. It was opined that since the source term arguably introduces the major part of uncertainty, simple radioecological models may be fit for purpose in many cases, but mostly true when focusing on emergency situation.

There was some consideration that uncertainty budget calculations should include correlations. In the IAEA MODARIA programme, consideration of correlations was encouraged, but it appears that no one really looks at this. Correlated variables appear to be a problem for all statistical methods. The point was made that dose coefficients have significant uncertainties but these are not taken into account when assessing doses. Furthermore, we do not attribute doses to a real person only to a hypothetical one – consider the reference person that is neither male nor female. Regarding describing uncertainties, communication of uncertainties to the general public may not be as difficult as anticipated. The point was also made that there are models associated with harm, i.e. risk of cancer from a given exposure etc., which also have an attributed uncertainty. A discussion ensued in relation to conservatism in parameter estimation. The point was made that it is often difficult to know when a value is conservative. Taking the example of Kd, it is also sometimes challenging to know which value is a worst case value – e.g. highest Kd may be maximisation of external exposure from say sediment but minimisation of internal exposures via aquatic phase contamination and transfer through the food chain. Emphasis should be placed as far as possible on site-specific measurements where one knows, at least, the given variables were measured simultaneously and exist in reality (avoid combining unrealistic variables/parameters in a calculation).

4.2. Discussion session (group work)

The main question for this group discussion was “*Which uncertainties can be addressed by improved modelling?”.* A set of other questions to keep the discussion going were also provided (see Annex 3).

To improve model predictions experimentalists, modellers and stakeholders should communicate, and it seems very beneficial to organise joint workshops discussing model concepts, input data needed and processes to be included. So far, most experimentalists are measuring a series of variables at sites, focusing on quantities which are assumed relevant for estimation of hazards. Thus, the modellers should be more active, telling experimentalists, which are the best experimental designs for model validation, which input data are needed to obtain good quality output quantities.. This is quite challenging because the different researcher groups typically use different model concepts.

Experimentalists need to define the practical constraints of the studies they are performing. It would be an advantage for modellers to familiarise themselves with the experimental set-ups and get involved in various aspects of the work, e.g. advise on sampling design and to specify exactly which measurements relate to the parameterisation (or validation) of their models.

In a practical sense you need organisational structures where experimentalists and modellers have more contact. An example could be integrated institute sections working on radiological assessments which have scientists working both with experiments and models but this is seldom the way things are set up in departments. Meeting, at least during seminars and workshops, should be encouraged.

Information on the uncertainties in model output can be achieved by validating model predictions with real-life field data. In this way, we can make some advances towards quantifying the overall uncertainty. A guess can then be made regarding which factors contributes the most to the uncertainties, making corresponding corrections (in set parameters, input data or model itself) and making another (model) run. Finally, the initial and improved model can be run with another independent data set (not the one that was used for improvements) checking whether results have been improved.

There are different ways to identify the uncertainties in predicting model results. For the model, per se, uncertainty analysis by running the model probabilistically can be utilized (Monte Carlo simulation or the like). If we want to consider the influence of various parameters we run local (e.g. alter a parameter by a given percentage and see what influence that has on the output results) or global sensitivity analyses (look at the correlation of a given parameter with the output via correlation coefficients, Spearman rank etc.). The contribution of parameters to overall uncertainty can be further looked at by replacing distributions with single values and seeing what influence that has on the output uncertainty.

There are also ways to look at uncertainty in model results by running the models for different scenarios, which addresses (to some extent) scenario uncertainty. Regarding model uncertainties, there is a famous quote by George Edward Pelham Box "Essentially, all models are wrong, but some are useful". So we know that we may possibly never have a completely true representation of the natural processes occurring. How this can be tackled in practice is through model-model intercomparison. This will at least give a spread in results or provide an indication of the uncertainty associated with a suite of equally robust assessment models.

Regarding how we deal with uncertainties in models, several approaches are available: We often consider worst-case scenarios and make conservative assumptions. With radiological risk assessment models we are often concerned with answering the question ‘is this practice/release harmful or not’. We wish to avoid at all costs saying that a practice/release is NOT harmful when the reality is the opposite. So we introduce pessimism – select parameters that will maximise exposure, select protective dose thresholds where we are sure that the probability of detriment at doses below the threshold is acceptably low. Of course this requires a certain amount of judgement (which also has associated uncertainty) and there is a trade-off between the need to err on the side of caution and the need to avoid being overly pessimistic.

Tiered assessments are often employed, where we start from the position of conservatism (with great uncertainty) and move towards more and more refined assessments with much more data but less uncertainty.

Some knowledge-related uncertainties can be reduced by further experimentation, by going into the lab or into the field and making more measurements. Of course the overall uncertainty, if including a large component of variability, will not necessarily be reduced with additional analyses.

Through model-model intercomparison, one can identify outliers – maybe some models are not fit for purpose or don’t provide a very convincing simulation of the processes being studied. “Unforeseen complexities often make it the case that more research will not result in less uncertainty.”

In general, strong relation between model predictions and real-life measurements is necessary. Testing the models with many measurement results and gradual model improvements of an iterative kind will enhance the accuracy gradually. Perhaps new real-life measurements also would be needed.

In ERICA, many of the methods applied in deriving Predicted No-Effect benchmarks and applying risk quotients were adapted from the field of eco-toxicology. We draw on tools developed in the field of radiation physics when we apply our dosimetric models. We draw on tools developed in experimental biology when we start to look at the effects of radiation – comet assay, micronucleus test, epigenetics etc.

Specifically with regard to uncertainty analyses, we had some success in getting leading experts in the field involved during the ERICA project. This was achieved through workshops (like this one). There needs to be some incentive for getting experts involved – not always enough to have expenses paid for a meeting – so maybe some thoughts need to be given in that direction: the prospect of joint publications or, if a consultant, new collaborative project tasks?

Some consideration was given to transfer coefficients (concentration ratios, transfer factors) where we often have summary tables without background information. One might also consider using food web models as alternatives, e.g. allometric models, but then there is often a challenge to validate them. It is beneficial to look at alternative models to understand the underlying processes.

5. Minutes from Session 3 “Reducing uncertainties: How far should we go/can we go?”

5.1. Overview of the presentations and plenum discussions

Environmental impact and risk models for demonstrating the safety of final repository (long term):

- Extremely long timescales and radionuclides for which data are often missing represent a specific challenge.
- Indicative nature of results (no forecast of real future doses to humans and non-human biota). The focus is on safety relevance.
- Process-based approaches might help to reduce uncertainties specific to long timescales.
- Environmental changes represent a challenge (change of parameter values, new processes relevant, etc.).
- Uncertainties: typically only data uncertainties (sensitivity analysis), in some assessments explicit parameter selection criteria, scenario uncertainties often addressed independently.
- Ecosystem approach to modelling is an alternative model simplification using Kd values and concentration ratios (CR). This requires, however, a detailed characterization of the studied ecosystem at a given specific site (site-specific mapping and characterisation).

There was some discussion about the pedigree analysis (i.e., interpretation of information displayed as a family tree) and if such tool has this been easy to apply in practice? The speaker from EnviroCase shared his experience and considered that it is suitable to have a group working independently on scoring the quality of the knowledge base – the analysis is subjective, but having many individuals involved helps to mitigate biases.

5.2. Discussion session (group work)

The main question for this group discussion was “*How do we reduce the overall uncertainties in impact and risk assessment?”.* A set of other questions was also given to keep the discussion going (see Annex 3),

For environmental risk assessments (ERA), published studies have shown that parameters characterising the radionuclide transfer models showed the highest sensitivity and contributed the most to the uncertainty in the predictions of doses to biota. The most important ones often relate to the mobility and bioavailability of radionuclides in the environment, for example soil-to-plant transfer factors, the bioaccumulation factors for marine biota and the gut uptake fraction for terrestrial mammals.

Regarding the question "How good are the models with regard to their specific purpose?" one can reference a paper published in the J. Radiol. Prot. 30 (2010) 265–281, where this subject was considered for ERA. The specific purpose in that case was 'screening models'. In order to answer the question "Can initial screening tiers be used with a high level of confidence?" the study looked at three available risk assessment models: ERICA, EA R&D128 and RESRAD-Biota. Screening level assessments were compared using input data from four sites (France, USA and two sites in Canada) covering different source term types – nuclear power plants, fuel fabrication, uranium mines etc. The outputs of these models varied considerably in terms of estimated risk quotient (RQ) and the radionuclide–organism combinations identified as being the most limiting. A number of factors were identified as contributing to this variability: values of transfer parameters (concentration ratios and Kd) used; organisms and life history stages considered; different input options and how these are utilised in the assessment; assumptions as regards secular equilibrium; geometries and exposure scenarios. This large variation in RQ values between models means that the level of confidence required by users is not achieved for this particular case of ERA screening models. So even though we think we have been conservative in applying environmental risk assessment models, the jury is still out on whether this is actually the case.

The question was asked regarding "What limitations do we see for risk assessments?". The adequacy of accounting for the source term, especially in relation to the physico-chemical form of radionuclides, is often a challenge. At the moment, many of the models we use simply do not account for this adequately.

A clear limitation of the environmental risk assessment relates to the suitability of the concentration ratio (CR) model for some exposure situations, in particular for accidental exposure situations where interception by vegetation is important and where the system is highly dynamic. Similar arguments can be made for transfer to animals as their radionuclide body burdens will reflect the changing concentrations in the food that they are eating. There is a huge amount of uncertainty in applying a steady-state model to this type of situation, and using the CR model is arguably untenable.

Environmental Risk Assessment – has to focus on sediment-water partitioning (Kd), ecosystem transfer including biological uptake (TC, CR) and effects. We actually have sophisticated models for the dosimetry part (based on advanced radiation transport modelling codes like MCNP). Although we have uncertainties linked to radiation weighting factors (dose-rate, species, end-point dependent) we probably know enough to be able to apply conservative values for alpha radiation to ensure that we don't underestimate (harm relevant) exposure levels. We also know quite a lot about radiation effects, at least the ball-park doses and dose-rates below which various effects are unlikely. For transfer on the other hand, the uncertainties are still great. For example, some of the recent Kd databases like IAEA TRS-479 (for freshwater) provide values for some radionuclides (e.g. I and Mn) that range more than 3 to 4 orders of magnitude.

We have already mentioned not accounting for speciation/physico-chemical forms of radionuclides in food chain transfer models as being a limiting factor. This is actually much more a challenge than it might initially seem. We need to transpose the detailed information we have on hot particle characteristics and radionuclide speciation into parameters that are useable within the available transfer models. A challenge is that physico-chemical forms are not always directly related to bioavailability and many of the relevant ecosystems are highly dynamic (think for example of estuarine mixing zones with rapid changes in sediment loads, salinity, water chemistry, magnitude and direction of water flow with time).

Power analysis to estimate the number of observations you need to obtain acceptable statistics is a useful tool: this is a way to reduce the number of samples required to provide robust information for model parameterisation.

6. Summing up and conclusion

The TERRITORIES Workshop on "Key factors contributing to uncertainties in radiological risk assessment" was successful in addressing the different aspects giving uncertainties in models and how these uncertainties could be reduced, by organising a dialogue and obtaining feedback from regulators, industry, general public and scientists. 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 fieldwork. 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 importance of an adequate communication of the uncertainties to the different end-users (stakeholders) and 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.

Some important points from the discussions were:

- Input data can be empirical or results of models, and each type of input data has its specific uncertainty.
- Sensitivity of a parameter within a specific model should be communicated to the experimentalists.
- Monitoring can help to quantify the source term by means of inverse calculations (late phase) – data assimilation over time giving better statistics.
- The main contributors to the uncertainties, associated with the input data, are:
    - Appropriate characterization of natural variability.
    - Uncertainties associated with sampling.
    - Uncertainties related with the correct interpretation of the data.
    - Uncertainties of measurements (both in laboratory and in situ).
- A common understanding of the conceptual models by experimentalists and modellers should be achieved. This understanding should be used to improve experimental techniques and models iteratively.
- Using tools (e.g., sensitivity analysis or uncertainty analysis), factors contributing the most to uncertainties can most often be identified and quantified.
- The uncertainties that can be reduced in a model depend on the model you are considering and input data you would need.
- There is an optimum complexity of the models. The model should be flexible enough to represent reality, with a minimum number of parameters: As complex as necessary, as simple as possible.

- To reduce the overall uncertainties by modelling, it is advisable to combine generic knowledge with site-specific data to obtain better predictions (reduce uncertainties).
- Models can help to identify and understand relevant environmental processes.
- Models can guide the design of sampling and monitoring campaigns.
- The goal of the assessment has to be taken into account (quick response versus optimization in long-lasting situations).
- You reduce the uncertainty until you are sure that the individuals/populations are protected (graded/tiered approach).
- If you can't demonstrate sufficient protection with the graded/tiered approach, you should reduce uncertainties in the models, doing research.
- To determine where to put effort to reduce model uncertainties:
    - 1st identify the key factors that matter most.
    - 2nd identify which of these key factors are easiest to reduce.
- How to measure the reduction of uncertainty? If you reduce the calculated doses by a factor of 10, you can assume that your model is now less conservative, provided that the model is still conservative.

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.

All the participants were extremely active in the discussions held during the workshop. Special mention must be made of the chairs of the sessions, the speakers as well as the moderators and secretaries of the group work sessions, without whom the workshop could not have been carried out. The participants agreed that this workshop and dialogue was useful and that this kind of dialogue should continue on a regular basis.

Figure 3. Discussions continued into the coffee breaks. Photo: Almudena Real

7. Annexes

Annex 1: Program of the workshop

Annex 2: Dissemination

Annex 3: Questions for the group work sessions

Annex 4: Participant list

Annex 1: Program of the workshop

TERRITORIES Workshop on:

Key factors contributing to uncertainties in radiological risk assessment

14-15 November 2017. Thon Hotel Slottsparken, Oslo, Norway

The objective of this workshop is to discuss the key factors contributing to overall uncertainties when linking deposition and ecosystem transfer to human and ecosystem radiological impact and risk assessment models, obtaining feedback from modellers, experimentalists and stakeholders.

Time	**Lecturer**	**Title**
November 14th, 2017		
09:00 – 10:00	*Coffee/Tea*	
Session 1: Uncertainties in monitoring data and other data of importance for models (*Chair: Lindis Skipperud*)		
10:00 – 10:10	Lindis Skipperud (NMBU)	Welcome and scope of the workshop
10:10 – 10:40	Martin Steiner (BfS)	Interaction between experimentalists and modellers
10:40 – 11:10	Brit Salbu (NMBU)	Uncertainties in radionuclide source term
11:10 – 12:40	Group work	***How can we improve uncertainties associated with data input?***
12:40 – 13:00	Group work reports and discussion	
13:00 – 14:30	*Lunch*	
Session 2: Uncertainties in models (*Chair: Brit Salbu*)		
14:30 – 15:00	Martin Steiner (BfS)	Overview of modelling uncertainties
15:00 – 15:30	Juan Carlos Mora (CIEMAT)	Analysis/discussion of the uncertainty budget and the different contributions to the total uncertainty – a case study using CROM-8 (CROMERICA)
15:30 – 16:00	*Coffee and tea*	
16:00 – 16:30	Justin Brown (NRPA)	Attempting to deal with uncertainties within the ERICA integrated approach
16:30 – 17:00	Marko Kaasik (UT)	Overview of HARMO initiative including uncertainties

November 15th, 2017		
Session 2: Uncertainties in models – cont. (*Chair: Justin Brown*)		
09:00 – 09:30	Ari Ikonen (EnviroCase, Ltd)	Uncertainties and their management in conventional radionuclide transport and dose assessment models for nuclear waste management
09:30 – 10:00	Ulrik Kautsky (SKB)	Ecosystem approach in the assessment of radioactive waste
10:00 – 10:30	Rodolfo Avila (Facilia)	Probabilistic analyses, sensitivity and uncertainty and analyses, Bayesian methods
10:30 – 11:00	*Coffee and tea*	
11:00 – 12:30	Group work	***Which uncertainties can be improved by modelling?***
12:30 – 13:00	Group work reports and discussion	
13:00 – 15:00	Lunch	
Session 3: Reducing uncertainties: How far should we go/can we go? (*Chair: Juan Carlos Mora*)		
15:00 – 15:30	Jordi Vives i Battle (SCK•CEN) -by videolink	Applicability and limitations of available radioecological models
15:30 – 16:00	Danyl Pérez (CIEMAT)	Terrestrial environmental transfer models for long-term radiological assessment
16:00 – 16:30	Coffee and tea	
16:30 – 17:30	Group work	***How do we reduce the overall uncertainties in impact and risk assessment?***
17:30 – 17:50	Group work reports and discussion	
20:00	Social GET-TOGETHER/DINNER, (sponsored by Center for Environmental Radioactivity CERAD, Norway)	

Annex 2: Dissemination of the TERRITORIES Workshop on: “Key factors contributing to uncertainties in radiological risk assessment”

TERRITORIES PROJECT BLOG

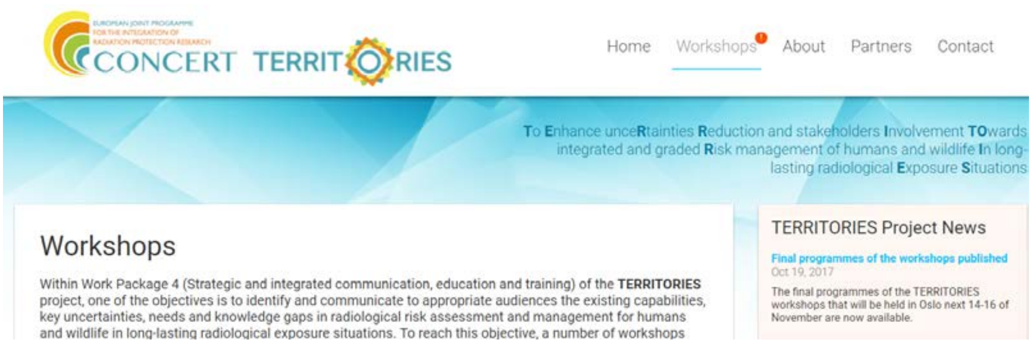
Final programmes of the TERRITORIES Workshops in Oslo

19 october, 2017

The final programmes of the TERRITORIES workshops that will be held in Oslo next 14-16 of November are now available.

Workshop 1: **Key factors contributing to uncertainties in radiological risk assessment** (14-15 November 2017). **TERRITORIES Workshop 1_Final Programme_2017-10-24**

Workshop 2: **Communication of uncertainties of radiological risk assessments to stakeholders** (16 November 2017). **TERRITORIES Workshop 2_Final**



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To Enhance unceRtainties Reduction and stakeholders Involvement TOwards integrated and graded Risk management of humans and wildlife In long-lasting radiological Exposure Situations

Workshops

Within Work Package 4 (Strategic and integrated communication, education and training) of the **TERRITORIES** project, one of the objectives is to identify and communicate to appropriate audiences the existing capabilities, key uncertainties, needs and knowledge gaps in radiological risk assessment and management for humans and wildlife in long-lasting radiological exposure situations. To reach this objective, a number of workshops

TERRITORIES Project News

Final programmes of the workshops published

Oct 19, 2017

The final programmes of the TERRITORIES workshops that will be held in Oslo next 14-16 of November are now available.

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CONCERT | Events | TERRITORIES 2: workshops - Oslo - Norway

TERRITORIES: 2 workshops - Oslo - Norway

November 14 - 16, 2017

Both workshops will be held in **Oslo, Norway**, **November 14-16th 2017**

Thon Hotel Slottsparken, Wergelandsveien 5, 0167, Oslo

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- **November 14-15, 2017**
  Workshop 1:
  Key factors contributing to uncertainties in radiological risk assessment
- **November 16, 2017**
  Workshop 2:
  Communication of uncertainties of radiological risk assessments to stakeholders


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Fecha de Fin: 16 de noviembre
Dirección: Thon Hotel Slottsparken, Wergelandsveien 5, 0167, Oslo

Annex 3: Questions for the group work sessions of the TERRITORIES Workshop on: "Key factors contributing to uncertainties in radiological risk assessment"

TERRITORIES Workshop on:

Key factors contributing to uncertainties in radiological risk assessment

14-15 November 2017. Thon Hotel Slottsparken, Oslo, Norway

QUESTIONS FOR THE WORK GROUP SESSIONS:

- ***Session 1: Uncertainties in monitoring data and other data of importance for models (1.5 h).***
  How can we better deal with uncertainties associated with input data?
  - Which uncertainties are associated with input data?
  - What input is important for the modellers to get from experimentalists?
  - What uncertainties are easy to identify?
  - How important are real life measurements – fieldwork data?
  - How does source term affect the uncertainties in models?

- ***Session 2: Uncertainties in models (1.5 h).***
  Which uncertainties can be addressed by improved modelling?
  - How can experimentalists and modellers communicate and work together?
  - How do we identify the uncertainties in model results?
  - How do we deal with uncertainties in models?
  - How to we reduce these uncertainties?
  - How can radioecology bridge to existing knowledge in related disciplines?

- ***Session 3: Reducing uncertainties: How far should we go/can we go? (1.0 h).***
  How do we reduce the overall uncertainties in impact and risk assessment?
  - Which overall uncertainties are associated with ***impact and risk assessment***?
  - How good are the models with regard to their specific purpose?
  - What limitations do we see? What is the implication of these limitations?
  - Where can we put in the effort to reduce the model uncertainties? What gives the best effect?

Annex 4: Participant list of the TERRITORIES Workshop on: "Key factors contributing to uncertainties in radiological risk assessment"

All the participants were extremely active in the discussions held during the workshop (including those held during coffee breaks). Special mention must be made of the chairs of the sessions, the speakers and the moderators and secretaries of the group work sessions, without whom the workshop could not have been carried out.

	Participant	Organization, Country
1	Avila, Rodolfo	Facilia, Sweden
2	Brown, Justin	NRPA, Norway
3	Egan, Michael	SSM, Sweden
4	Fojtikova, Ivana	SURO, Czech Republic
5	Gallego, Eduardo	UPM, Spain
6	Gilbin, Rodolphe	IRSN, France
7	Hosseini, Ali	NRPA, Norway
8	Ikonen, Ari	EnviroCase, Ltd, Sweden
9	Iospje, Mikhail	NRPA, Norway
10	Kaasik, Marko	TU, Estonia
11	Kautsky, Ulrik	SKB, Sweden
12	Kuca, Petr	SURO, Czech Republic
13	Kuroda, Yujiro	Fukushima Medical University, Japan
14	Mauring, Koit	TU, Estonia
15	Mora, Juan Carlos	CIEMAT, Spain
16	Naito, Wataru	AIST, Japan
17	Navrud, Ståle	NMBU, Norway
18	Parviainen, Lauri	Posiva (BIOPROTA), Finland
19	Peltonen, Tuomas	STUK, Finland
20	Pérez-Sanchez, Danyl	CIEMAT, Spain
21	Real, Almudena	CIEMAT, Spain
22	Schneider, Thierry	CEPN, France
23	Salbu, Brit	CERAD/NMBU, Norway
24	Skipperud, Lindis	CERAD/NMBU, Norway
25	Skuterud, Lavrans	NRPA, Norway
26	Steiner, Martin	BfS, Germany
27	Tkaczyk, Alan	TU, Estonia
28	Tucaković, Ivana	Ruđer Bošković Institute, Croatia
29	Urso, Laura	BfS, Germany
30	Vilbaste, Martin	TU, Estonia