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TERRITORIES Workshop on: Multidisciplinary forum to discuss the scientific basis for reducing uncertainties and improving risk assessment

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Abstract

During 13 and 14 June 2018, the second TERRITORIES workshop planned under CONCERT Sub-subtask 9.3.4.3 (*Development and implementation of E&T activities for appropriate audiences*), led by CIEMAT, was organised in Madrid on "**Multidisciplinary forum to discuss the scientific basis for reducing uncertainties and improving risk assessment**".

The objective of this workshop was to get feedback from experts in different scientific disciplines, on the application of the two guidance documents that are being developed in TERRITORIES on design of environmental monitoring for dose assessment and for support to remediation; and to select the appropriate level of complexity in models. The workshop focused on methodologies to reduce uncertainties related to sampling and monitoring strategies and the quantitative handling of the various types of uncertainties that play a major role in radioecological modelling, including conceptual model uncertainty and scenario uncertainty.

The TERRITORIES workshop on "Multidisciplinary forum to discuss the scientific basis for reducing uncertainties and improving risk assessment" had 26 participants from 9 different countries, including 8 experts in various disciplines not directly related with the TERRITORIES project. The participants were highly active in the discussions held during the workshop. Special mention must be made to the speakers, the session chairs, and the moderators and secretaries of the Group Work Sessions. All of them have contributed to the success of the workshop and, directly or indirectly, to this Deliverable.

List of acronyms

ALLIANCE	European platform on radioecology research (http://www.er-alliance.eu/).
BfS	German Federal Office for Radiation Protection.
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.
CIEMAT	Spanish Centre for Energy, Environment and Technology.
CR	Concentration Ratio.
CRMP	Comprehensive Radiation Monitoring Plan.
CROM	Generic environmental model for effective dose calculations in humans (ftp://ftp.ciemat.es/pub/CROM).
ECOFOR	SVAT Forest radioecological model.
EPA	Environmental Protection Agency.
E&T	Education and Training.
EJP-CONCERT	European Joint Programme for the Integration of Radiation Protection Research under Horizon 2020 (http://www.concert-h2020.eu/en).
EU	European Union.
IAEA	International Atomic Energy Agency (https://www.iaea.org/).
ICRU	International Commission on Radiation Units & Measurements.
IRSN	French Institute for Radiation Protection and Nuclear Safety.
Kd	Solid/liquid partition coefficient.
LARUEX	Environmental Radioactivity Laboratory, University of Extremadura, Spain.
LBNL	Lawrence Berkeley National Laboratory.
MARSSIM	Multi Agency Radiation Survey and Site Investigation Manual (US EPA).
NORM	Naturally Occurring Radioactive Materials.
NPP	Nuclear Power Plant.
NRPA	Norwegian Radiation Protection Authority.
OK	Ordinary Kriging (Interpolation method).
PHE	Public Health England.
QAQC	Quality Assurance-Quality Control.
RMSE	Root Mean Square Error.
SCK•CEN	Belgian Nuclear Research Centre.
STAR	Strategy for Allied Radioecology. European Research Project funded by the 7th Framework Programme of EURATOM (https://www.radioecology-exchange.org/content/star).
SVAT	Soil-Vegetation-Atmosphere Transfer.
TERRITORIES	To Enhance unceRtainties Reduction and stakeholders Involvement TOwards integrated and graded Risk management of humans and wildlife In long-lasting radiological Exposure Situations. European research project funded in the framework of the EJP-CONCERT [grant agreement No 662287] (http://territories.eu/; https://territoriesweb.wordpress.com/).
UT	University of Tartu, Estonia.
WFD	Water Framework Directive.
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), is part of the EJP-CONCERT project. TERRITORIES has three main objectives:

- To meet 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 NORM vs post-accident (after transition phase) exposure situations, monitoring *vs* modelling, human *vs* wildlife population, experts *vs* decision-makers *vs* the general public in management (integrated approach).

One of the aims of CONCERT Sub-task 9.3.4 on strategic and integrated communication, education and training, led by UT, is to "i*dentify 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*".

The Sub-subtask 9.3.4.3, led by CIEMAT, is in charge of the development and implementation of education and training activities for appropriate audiences, including stakeholders, professionals and students. Within this Sub-subtask, three workshops were planned to be organised, with the aim to encourage the discussion on key issues on risk assessment in long-lasting exposure situations, including socio-ethical aspects, between researchers and stakeholders. The first workshop on "**Communication of uncertainties of radiological risk assessments to stakeholders**" was organised the 16th of November 2017, in Oslo. The objective of the workshop was to discuss the implications and relevance of uncertainties in radiological risk assessments for different stakeholders, and work out how these uncertainties can be better communicated, obtaining feedback from regulators, industry, scientists and the general public on this subject. In this workshop, the focus was on the uncertainties related to radiological risk assessments in long-lasting exposure situations (both NORM and post-accidental exposure situations). Ethical and social uncertainties were not explicitly addressed in this workshop. The results were published in the EJP-CONCERT Deliverable D9.75 (available at https://territories.eu/assets/files/publications/D9-75_D-TERRITORIES-Workshop_Oslo-16-Nov-2017_24012018_approved.pdf).

The second workshop planned under Sub-subtask 9.3.4.3 took place at CIEMAT (Madrid, Spain) during 13- 14 June 2018 on the topic "**Multidisciplinary forum to discuss the scientific basis for reducing uncertainties and improving risk assessment**". The aim of the workshop was to get feedback from experts in different scientific disciplines, on the application of the two guidance documents that are being developed in TERRITORIES: to design environmental monitoring for dose assessment and for support to remediation; and to select the appropriate level of complexity in models. The workshop focused on methodologies to reduce uncertainties related to sampling and monitoring strategies and the quantitative handling of the various types of uncertainties that play a major role in radioecological modelling, including conceptual model uncertainty and scenario uncertainty.

Summaries of the talks and the discussions held during the Group Work sessions are included in this deliverable. Based on these contents, the lessons learned for each of the Sub-subtasks of 9.3.1 (*Quantifying variability and reducing uncertainties when characterizing exposure of humans and wildlife by making the best use of data from monitoring and of existing models*) are presented as a final result of the workshop.

2. Workshop organisation

To address the organization of the workshop, a Programme Committee was established, consisting of the TERRITORIES participants: Martin Steiner (BfS, Germany); Juan Carlos Mora, Danyl Pérez-Sánchez and Almudena Real (CIEMAT, Spain); Marie Simon-Cornu (IRSN, France), Justin Smith (PHE, UK); Jordi Vives i Batlle (SCK•CEN) and Alan Tkaczyk (UT, Estonia).

A survey was made among the TERRITORIES members to find suitable dates for the workshop. Taking into account the availability of the TERRITORIES members, it was finally decided to hold the second workshop on 13-14 June 2018, in the facilities that CIEMAT has in Madrid. The venue was previously approved by the TERRITORIES Management Board.

The Programme Committee held several video conferences to prepare the programme of the workshop. 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 were willing to participate in the workshop.

The detailed programme of the workshop on "Multidisciplinary forum to discuss the scientific basis for reducing uncertainties and improving risk assessment" is presented in Annex 1. The workshop was structured in four sessions: Introductory session; Session 1 on "Sampling and Monitoring Uncertainty"; Session 2 on "Conceptual model uncertainty" and Session 3 on "Quantifying model improvement". In addition there were two "Group Work Sessions" to discuss specific aspects on topics related with the three technical sessions (Annex 1). To encourage the active participation of all the attendees in the discussions, four small groups (7-9 persons) were created. Each group had a moderator (not involved in TERRITORIES) a secretary and a support assistant (both TERRITORIES members) (Annex 2). The secretary and support assistant were in charge of taking notes and presenting a summary of the discussions held in the group in the plenary session that followed each of the "Group Work" sessions. To stimulate the discussions some questions were prepared in advance by the TERRITORIES members (Annex 3), and were distributed to all participants.

Regarding the dissemination of the workshop, once the programme was agreed, the event was announced using different tools. The programme was disseminated through the TERRITORIES webpage (https://territories.eu/) and blog (https://territoriesweb.wordpress.com/).

The information about the workshop was also announced in the Radioecology Exchange (http://www.radioecology-exchange.org/news-and-media/news/territories-project-%E2%80%93-workshops) and distributed by e-mail to all the members of TERRITORIES, EJP-CONCERT, CONFIDENCE and ALLIANCE.

One aim of the workshop was to attract as many students as possible. Grants for students were advertised through the TERRITORIES webpage, and the information was sent to several universities in Madrid (UCM, UPM, UAM).

The workshop on "Multidisciplinary forum to discuss the scientific basis for reducing uncertainties and improving risk assessment" had **26 participants from 9 countries** (Belgium, Estonia, France, Germany, Ireland, Norway, Spain, UK, USA) (Annex 4). Among the participants, 8 were experts in various disciplines not directly related with the TERRITORIES project.

A customised web-based survey was distributed to all the participants, to have feedback on scientific-technical aspects, as well as on organizational aspects (Annex 5).

Figure 1. Participants of the TERRITORIES workshop on "Multidisciplinary forum to discuss the scientific basis for reducing uncertainties and improving risk assessment" (Photograph: Almudena Real, CIEMAT).

3. Summary of the presentations and discussions held during the workshop on "Multidisciplinary forum to discuss the scientific basis for reducing uncertainties and improving risk assessment"

3.1. Summary of the presentations of the Introductory Session.

The introductory session was chaired by Marie Simon-Cornu (IRSN, France) and Almudena Real (CIEMAT, Spain), and included the following presentations:

- ***Introduction of TERRITORIES* Sub-subtask 9.3.1**. *Juan Carlos Mora (CIEMAT, Spain)*

The TERRITORIES Sub-subtask 9.3.1 (Quantifying variability and reducing uncertainties when characterizing exposure of humans and wildlife by making the best use of data from monitoring and of existing Models, led by CIEMAT) aims at developing a methodology to reduce uncertainty and to quantify variability in space and time in the radioactive characterization (in terms of activity concentration or ambient dose equivalent in the various environmental compartments) of long-term contaminated territories, to provide fit-for purpose information for environmental diagnosis and prognosis of long-lasting exposure situations, taking account of stakeholder's concerns.

For long-lasting exposure situations, one crucial input is to know where and to what extent radionuclides are present in the various environmental compartments in order to assess radiological exposure of humans and wildlife according to relevant pathways. Such information is gained from monitoring and/or modelling, both associated with uncertainties that propagate to risk estimates.

As improved models will be tested, probably including new process-based models, with the intention of reducing the uncertainties associated with existing - simple models, a methodology based on adequate metrics for testing model performance will be also developed in parallel in order to quantify the improvement of these improved models. The results of this methodology, comparing the performance of both sets of models, will be analysed and a guide will be produced to describe the methodology together with the application of such a methodology to test cases.

Within TERRITORIES Sub-subtask 9.3.1 two guidance documents will be produced: (1) A guidance for optimised implementation and use of monitoring, which will include the review of radiological characterisation methodologies aiming at reducing the uncertainties to better assess spatial and time variability, (2) A technical guidance with recommendations about the desirable fit-for-purpose level of complexity.

- ***Introduction to Case-Studies and Scenario-Related Uncertainties.*** *Danyl Perez-Sánchez (CIEMAT, Spain)*

The objective of this presentation was to make a general description of the main sources of uncertainty in environmental assessment models: parameter uncertainty, model conceptual uncertainty and scenario uncertainty. In the presentation we describe the sources and types of uncertainties that need to be considered in risk assessment analysis, mainly focus in Scenario uncertainties related with environmental radiological impact assessment. We also consider how to take into account the qualitative and quantitative information to develop conceptual and computational model and their impact on the overall uncertainty.

A fundamental goal of uncertainties analysis is to estimate the distribution of the risk associated within a given scenario, considering the main sources of uncertainty (parameter, model and scenario). The parameter uncertainty (also named data uncertainty) is associated with the values of the parameters that are used in the implemented models and it arises from variability of the parameters in space and time. The model conceptual uncertainty arises from an incomplete knowledge or lack of understanding of the behaviour of the systems, the physical processes, the site characteristics and their representation using simplified models and computer codes. Most of the uncertainty in the conceptual model has two contributions: the first is completeness (i.e. are all the important physical and chemical process represented in the model?), the second is suitability (i.e. have the choices made regarding dimensionality, discretisation, scale, time dependence, etc. been shown to provide meaningful result given by the system characteristics and the problem statement?). The scenario uncertainty is used in a variety of contexts with slightly different meanings. For applications in risk assessment analysis in different domains, the term scenario is used to describe a particular set of sequence of events and conditions. In environmental risk analysis, a scenario describes a qualitatively different type of release. For safety analysis of nuclear waste disposal sites, such scenarios consider disruptive events external to the disposal system, such as volcanism, seismicity, human intrusion and climate change. In remediation of a contaminated site, the term scenario is used to describe hypothetical or generic individual exposure. The definition of the “critical group or representative person” in the scenario development may also constitute an important source of uncertainty related to scenario.

The three classes of uncertainty (model, parameter and scenario) are related to each other. This means that uncertainties can be handled in different ways, and might be considered as model, parameter or scenario uncertainties within any single iteration of a risk assessment.

In risk assessment the main types of natural uncertainty include: epistemic uncertainties and aleatory uncertainties, arising from the random nature of the underlying processes. The aleatory uncertainties refer primarily to variability of risk assessment parameters, spatially, temporally or across a population. Another type is the epistemic uncertainties, arising from a lack of knowledge and also called type B or related to knowledge. The aleatory uncertainties refer primarily to variability of risk assessment parameters, spatially, temporally or across a population. This lack of knowledge may be related to parameters, models and scenario in environmental risk assessment. In contrast, epistemic uncertainty associated with scenarios is related to the concept of completeness and representatives.

Scenario uncertainty refers to incomplete knowledge about the states of the system where the exposure occurs, including not only the situation at the moment of the assessment, but also the situation in the past (for retrospective assessments) and in the future (for prospective assessments). This includes uncertainty in environmental properties, the sources and speciation of contamination, time and spatial variation, etc. Definition of exposure pathways and relations is important aspect to evaluate scenario related uncertainties in radiation dose assessment models.

When considering scenario uncertainties related to the assessment and evaluation of radiation doses, two factors at least have to be considered: level of exposure and the appropriate habits. The way that both factors are assessed will depend largely on the purpose of dose assessment (assessment context) and should be established at the outset. We also have to consider prognostic dose assessment (assessment of dose to future individual and populations) or retrospective dose assessments (assessment of dose to past individuals and populations) are requested. The context of the dose assessment deals with the following exposure pathways: exposure pathways for the aquatic environment and exposure pathways for atmospheric and terrestrial environment.

The main conclusions are that the model and scenario uncertainties arise from the (simplified) mathematical representation of the conceptual models and the imprecision in numerical solutions implicit in mathematical models. Inherent uncertainties include model structural errors, and computational and mechanistic uncertainties. The models are always a simplified version of the reality of the system being simulated, and the degree of accuracy needed depends on the intended model application.

- ***Introduction of the Fukushima Case Study.*** *Justin Smith (PHE, UK)*

The aim of this presentation was to provide some background information to the Fukushima case study in terms of the monitoring data that have been included in the TERRITORIES Library Database (TLD) and how these data will be used. Note that this presentation was focused on the Fukushima case study of TERRITORIES Sub-subtask 9.3.1 (Quantifying variability and reducing uncertainties when characterizing exposure of humans and wildlife by making the best use of data from monitoring and of existing models) and did not detail works about Fukushima performed in Sub-subtask 9.3.2 (Reducing uncertainties when characterizing exposure scenarios, accounting for human and wildlife behaviour, and integrating social and ethical considerations in the management of uncertainties) and 9.3.3 (Stakeholder engagement for a better management of uncertainty in risk assessment and decision-making processes including remediation strategies).

The presentation began with a review of the events that lead to the Fukushima Daiichi NPP accident on 11 March 2011 and the consequences of the loss of power to the site. The actual source term for the atmospheric release is not known exactly, but it has been estimated that it included about 130 PBq of ^{131}I and 20 PBq of ^{137}Cs (and a similar quantity of ^{134}Cs). Because of its relatively long radioactive half-life (~30 years) the radioactive contamination of the region is today dominated by ^{137}Cs.

The most contaminated regions within 100 km of the Fukushima Daiichi NPP are forested by evergreen coniferous and broadleaf deciduous trees. Forests are of concern because they act as a potential long term source of exposure to humans and populations of flora and fauna. Therefore, the characterisation of the pattern of contamination following deposition is important for post-accident analysis. Part of this analysis includes modelling and the Fukushima dataset can be used to evaluate model performance which is one of the aims of Sub-subtask 9.3.1 in the TERRITORIES project.

Many measurement campaigns were carried out in the years after the accident to measure quantities such as deposits, inventories, concentrations and depuration fluxes and to measure forest characteristics such as stand age, stand density, tree height, trunk diameter, biomasses, litterfall rate and litter & soil characteristics and precipitation. The campaigns carried out from 2011 to 2013 were reviewed and collated by IRSN in 2017 (*Gonze M.A & Calmon,P. Sci. Total Environment, 601–602: 301–316, 2017*).

Gonze & Calmon performed a meta-analysis on these collated measurements to produce a site averaged dataset and demonstrated that radiocaesium concentrations in coniferous vegetation over the period 2011 to 2013 could be satisfactorily related to fluxes and inventories based on a simple dynamic model that accounts for the key transfer processes of interception, depuration and incorporation into inner organs.

IRSN plans to extend the period of their meta-analysis to 2016 and to use the data to evaluate the performance of a more complex model. This evaluation will include sensitivity and uncertainty analysis and a quantification of model improvement as required by Sub-subtask 9.3.1 of the TERRITORIES project.

- ***Introduction of the Belgian NORM Observatory Site Case Study.*** *Jordi Vives i Batlle (SCK•CEN, Belgium)*

This presentation introduced the Belgian observatory site, a calcium fluoride sludge heap from the Belgian phosphate industry located in the vicinity of Ham, Belgium. A description of the site was given, focusing on the presence of waste from phosphate ores processed as fodder and fertilisers and its impact on the local vegetation. This site is effectively a natural laboratory that can provide a reliable source for radioecological model parameters. Hence, part of the waste storage area has been made available for research as an observatory site and SCK•CEN has installed in it a monitoring station as part of project TERRITORIES. Note that this presentation was focused on the Belgian case study of Sub-subtask 9.3.1 (Quantifying variability and reducing uncertainties when characterizing exposure of humans and wildlife by making the best use of data from monitoring and of existing models) and did not detail works in the same area performed in Sub-subtask 9.3.3 (Stakeholder engagement for a better management of uncertainty in risk assessment and decision-making processes including remediation strategies).

We described how we are using the station to monitor cycling of naturally occurring radionuclides (soil, sludge, tree roots, bark, wood, branches, needles, litter) as well as the monitoring of sunlight and hydrological cycles by means of sap flow sensors, light sensors, soil moisture probes, piezometers, rain gauges, temperature sensors, etc. integrated in an electronic data logging system. In addition to sampling, we described how we are deriving independent data for validation and the implementation of the soil-vegetation-atmospheric transfer (SVAT) model ECOFOR.

The presentation concluded with a brief overview of the radiological status of the site. It was concluded that, as the site is not publicly accessible, external exposures are negligible for the public. The ambient dose rate is just a few times above natural background in open air. Radon levels are slightly above the natural background but the concentration is comparable to what exists in dwellings in Flanders. Hence, the main interest of the site is not radiological exposure but as a natural laboratory to uncover mechanisms for transfer of pollutants to a very relevant type of ecosystem.

3.2. Summary of the presentations and discussions held in Session 1: Sampling and monitoring uncertainty

3.2.1. Summary of the presentations of Session 1.

The session was chaired by Justin Smith (PHE, UK) and Juan Carlos Mora (CIEMAT, Spain), and included the following presentations:

- ***Scene Setting: Reduction of Uncertainties in the Sampling and Monitoring Processes.*** *Juan Carlos Mora (CIEMAT, Spain)*

The problem of uncertainties associated with sampling and monitoring processes is recognised since long time, not only in radioecology but also in many other scientific and technical fields, as chemistry. It is also recognised that this component can be the most important in many situations, especially when variability among independent samples is large. Obviously this is not the only component for the variation amongst values of any quantity being determined, and there are other to be determined, as the uncertainty of a defined measurement technique, the uncertainty associated with the laboratory preparation of a sample, the natural temporal and spatial variability in a sampling zone or even inside a single sample, and others. All of them should be adequately characterised and taken into account when reporting an expected value of a given radioecological magnitude. Although a lot has been written on measurement uncertainty (*BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP and OIML. JCGM 100:2008. GUM 1995 with minor corrections. Evaluation of measurement data — Guide to the expression of uncertainty in measurement. 2008*), and most laboratories implement adequate protocols on the issue, also natural variabilities must be adequately characterised, and the uncertainty associated with sampling should be recognised and quantified.

Obviously the guidance being developed within TERRITORIES is not the first document on the characterization of uncertainties associated with sampling in radioecology, and even the International Commission on Radiation Units & Measurements (ICRU) and the International Atomic Energy Agency (IAEA) have published technical documents on this or has included chapters related with the problem *(Journal of the ICRU. ICRU Report 75. Sampling for Radionuclides in the Environment. Oxford University Press. 2006; International Atomic Energy Agency. Environmental and Source Monitoring for Purposes of Radiation Protection. Safety Guide No. RS-G-1.8. Vienna. 2005)*. This document intends to develop a summary of the most used techniques for the characterization of this sampling uncertainty, providing technical guidance on its practical implementation, and some recommendations on the reduction of this sampling uncertainty. To demonstrate the practical view of the guidance, tests will be done in the framework of TERRITORIES project applying the recommendations to the Territories Library.

A good characterization of variability is also important, and many methods exist to address it, providing even numerical methods to optimise the number of samples needed for a good characterization (*MARSSIM 2000,* https://www.epa.gov/radiation/download-marssim-manual-and-resources). A review of these methods and a suggested methodology will be included in this document.

- ***Sampling Procedures in Routine Monitoring: Purpose of the Monitoring Campaign.*** *F. Javier Guillén (LARUEX, Spain)*

The design of sampling campaigns has a crucial importance for the success of a monitoring campaign. The objectives should be stated in a clear and well defined way, either if the goal of the sampling is the compliance of reference levels or the determination of activity levels. These objectives will also define part of the sampling design: what kind of samples to take, sample size, etc. The location of the sampling point should be considered taking into account where the analysis will be carried out. In the case of a sample station, its location and obtaining the corresponding permits should be also considered. On the contrary, if samples are brought back to the laboratory to be assayed, sample conservation during transport should be contemplated. There is no general rule for this, it should be done taking into account the type of sample (soil, water, foodstuff, …) and the target radionuclide (anthropogenic, naturally occurring, radon, tritium, iodine, …). The use of clean containers and appropriate tools is one of the most important things to guarantee the success of a sampling campaign. In short, when designing a sampling campaign, one must think of every single possibility at any scale, from the paper to write down the sample name/code to how to get the sample and to transport them. Finally, it must be considered that a bad sampling design or badly executed sampling campaign would imply the complete failure of the analysis, regardless of how well analysis are done or the compliance with reference levels.

- ***Sampling and Monitoring Uncertainties Associated with the Water Framework Directive.*** *Simon O´Toole (EPA, Ireland)*

The Water Framework Directive (WFD) (2000/60/EC) established a framework for the management, protection and improvement of the quality of water resources across the European Union. For the first time, a strategy for the protection of all waters including rivers, lakes, estuaries, coastal waters and groundwater, and their dependent wildlife/habitats was established under one piece of environmental legislation.

The WFD introduced two elements to cover all surface waters – "good ecological status" and "good chemical status". Good ecological status is defined in terms of the quality of the biological community, hydrological characteristics and general physico-chemical characteristics. Good chemical status is expressed in terms of compliance with quality standards for chemical substances at the EU level.

Subsequent directives to the WFD (the Environmental Quality Standards Directive (2008/105/EC) and the Priority Substances Directive (2013/39/EC)) classified 45 existing chemicals, biocides, plant protection products, flame retardants and metals as Priority Substances and Priority Hazardous Substances, the latter being of concern. Annual Average and Maximum Allowable Concentration standards were set for these substances in water and biota.

This presentation concentrated on surface water assessment and examined the obligations of EU Member States to implement appropriate systems for effective monitoring. It focused on the uncertainty associated with designing monitoring strategies (location, frequency, seasonality) and undertaking sampling programmes (sampling, preservation, transport) to comply with the WFD. Attention was drawn to the implementation of Operational and Surveillance monitoring programmes and selecting appropriate monitoring points, parameters and matrices. The variability and representativeness of sampling techniques (water and biota), analytical method compliance with the QAQC Directive (2009/90/EC) and risk assessment was considered. It also briefly considered the use of novel monitoring techniques such as Passive Sampling and Effects-Directed Analysis for targeted Investigative Monitoring. The presentation concluded by demonstrating how uncertainty in data can influence risk quotients and risk assessment, and ultimately result in inappropriate programmes of measures.

- ***Ambient dose equivalent monitoring in the Belgian NORM observatory site*** *Johan Camps and Jordi Vives i Batlle (SCK•CEN, Belgium)*

A presentation was given on Aerial surveys of historical contaminations in Belgium (presented by Jordi Vives i Batlle on behalf of Johan Camps of SCK•CEN). This focused on airborne investigation of ground contamination by means of helicopters equipped with gamma detectors. Description of equipment and methodology, including the important concept of circle of investigation, were given. Results of an SCK•CEN – IRE intercomparison were presented, as well as explanation of how aerial surveys can provide guidance to NORM remediation projects. The lecture concluded with presentation of results from the airborne monitoring of the Belgian NORM site which is part of TERRITORIES.

- ***Organisation of the Environmental Monitoring: Lessons Learnt from Fukushima.*** *Mélanie Maître, Pascal Croüail and Thierry Schneider (CEPN, France)*

In post-accident situations, the implementation of the environmental monitoring is essential for characterising the radiological situation of the affected territories, as well as, allowing people living in such territories to understand what is at stake in their own environment and so helping them to become actors of their own radiological protection. In this context, roles played by institutional and non-institutional actors are determining factors to set up a sustainable monitoring, reach a consensus and so encourage the citizen vigilance.

This work proposes an analysis of the Japanese situation 6 years after the Fukushima accident, in order to provide feedback experiences of the environmental monitoring implemented to cope with the post-accident situation. This analysis consists in (i) identifying the environmental schemes implemented following the Fukushima accident (ii) mapping the different actors who come into play in such situations and (iii) highlighting some local experiences developed by local associations or municipalities within the affected territories.

These overall goals have been achieved by interviewing different Japanese actors involved in the practical setting up of the environmental monitoring within the Fukushima prefecture. In this way, feedback experiences, points of view and comments have been collected from both institutional actors (e.g. Japan Nuclear Safety authority, Health and Labour Ministry, Fukushima prefecture, etc.) and local actors (e.g. local associations, municipalities, citizens, etc.) in November 2016.

Results of this study clearly show that the environmental monitoring implemented in Japan after the Fukushima accident gathers multiple actors on both national and local levels. The *'Comprehensive Radiation Monitoring Plan' (CRMP)*, set up by the Japanese government since August 2011 proposes a national monitoring system concerted, coherent and embracing all environmental compartments. However, all the results obtained under this plan are published online without harmonization. This leads to confusion on the published results, which besides are not largely consulted by the local population.

Indeed, at the local level, the mistrust towards government leads people living in the affected territory to implement their own environmental monitoring. However, these local data are heterogeneous and often redundant with the CRMP but have all the trust of their initiators.

In this context, the remaining issue consists in knowing how to go towards a better sharing between results produced by institutional and non-institutional actors. It appears that scientific experts, often involved in both sides, could play a key role in sharing these results, which represents a strong lesson learnt for the preparedness phase.

- ***A Multiscale Bayesian Data Integration Approach for Mapping Air Dose Rates around the Fukushima Dai-ichi Nuclear Power Plant.*** *Haruko M. Wainwright (Lawrence Berkeley National Laboratory, USA)*

This work presents a multiscale data integration method to estimate the spatial distribution of air dose rates in the regional scale around the Fukushima Daiichi Nuclear Power Plant. We integrate various types of datasets, such as ground-based walk and car surveys, and airborne surveys, all of which have different scales, resolutions, spatial coverage, and accuracy. This method is based on geostatistics to represent spatial heterogeneous structures, and also on Bayesian hierarchical models to integrate multiscale, multi-type datasets in a consistent manner. The Bayesian method allows us to quantify the uncertainty in the estimates, and to provide the confidence intervals that are critical for robust decision-making. Although this approach is primarily data-driven, it has great flexibility to include mechanistic models for representing radiation transport or other complex correlations. We demonstrate our approach using three types of datasets collected at the same time over Fukushima City in Japan: (1) coarse-resolution airborne surveys covering the entire area, (2) car surveys along major roads, and (3) walk surveys in multiple neighbourhoods. Results show that the method can successfully integrate three types of datasets and create an integrated map (including the confidence intervals) of air dose rates over the domain in high resolution. Moreover, this study provides us with various insights into the characteristics of each dataset, as well as radiocaesium distribution. The method has been implemented by Japan Atomic Energy Agency, and used for characterizing the regional-scale temporal evolution of air dose rates and for optimizing monitoring network.

- ***Optimizing flight-line distance for characterizing contaminated soil, an application of geostatistics; case-study of Fukushima nuclear disaster, 2011.*** *Pedram Masoudi, Mathieu Le Coz, Marc-André Gonze, Charlotte Cazala (IRSN, France)*

Following Fukushima nuclear disaster in 2011, several airborne measurements were performed in order to survey soil contamination at different dates. These surveys are gamma-ray measurements along flight-lines, converted to cesium-137 deposit on the ground. This study is applied to the 8th airborne survey, acquired in November 2013, with a flight-line distance of <1 km, which is relatively lower compared to the previous surveys. Here, the objective is to find a relation between flight-line distance and quality of soil contamination characterization.

Ordinary Kriging (OK), which is an interpolation method, was used in order to estimate contamination concentration, i.e. cesium-137 deposit, within six different square tiles of ~20 km length, located within 100 km from the Fukushima nuclear power plant. The point OK was used to estimate cesium-137 deposit at validation points, successively to calculate the error of estimation through the Root Mean Square Error normalised by the data average (nRMSE). The Block OK was hired to produce contamination map on square blocks of 250 m. Within each of six tiles, the OK estimators were applied over different selections of flight-lines of decreasing density. The correctness rate is calculated for produced contamination maps by comparing them to the reference map, i.e. the contamination map using all the flight-lines.

The calculated nRMSE (correctness rate) are correlated positively (negatively) with the flight-line distance. Increase of flight-line distance for ~1 km, increases the nRMSE by ~3.5%, and decreases the correctness by ~1%. A sensitivity analysis was also conducted to find out the influence of variography analysis, which is a subjective task, on the relations. The effect of variography was found to be limited to 6%; i.e. 94% of variation of the nRMSE and the correctness rate is due to data configuration, here the selected flight-line. It means that the relation between the nRMSE, the correctness rate and flight-line distance are reliable. Finally, the validity of the relations in the six tiles with different geographical specifications confirms the generalization ability of the developed relations.

3.2.2 Group Work on Session 1.

The following aspects related with session 1 “Sampling and monitoring uncertainty” (see questions in Annex 3), were discussed during this Group Work Session:

- **Purposes of sampling and monitoring: Use of the results obtained.**

Generally, “sampling” might appear mostly related to research activities (to find data for modelling, spatial distribution), whereas “monitoring” would be more related to operational/routine surveillance in timescale (to demonstrate compliance with regulation and for assessment purposes).

For some, sampling uncertainty is one part of monitoring uncertainty (the other part being measurement uncertainty), whereas for others the word “sampling” is related only to traditional field sampling followed by indoor (laboratory) measurement, and the word “monitoring” is related to *in situ* measurement (installing some instruments for surveying the changes).

The purposes of sampling and monitoring include:

a) *To characterise the situation/System understanding*: to characterise the source term, the extent of the contamination; the variations with time (including historic characterization of the site); the potential countermeasures to be applied and their efficiency.

b) *To calibrate, validate and improve research predictive models*. It was emphasised that it should be strongly recommended not to use the same dataset for calibration and validation, even though sometimes a second data set is not available. If sampling and monitoring results are abundant, the assessment can be done based in the available measurements and the models might not be needed.

c) *Regulatory purposes*: the results are very useful to control whether regulatory requirements are accomplished, assuring Society that the population and the environment are protected. The data can be used to feed an operational model (for risk assessment, predict future risks, etc.); for official surveillance for risk assessment/management; for risk assessment/ management; for informing the Society, etc.

d) *To give answers to Society concerns, and to "make the radioactivity visible",* i.e. engaging the population (lay people) to measure by themselves. We must learn how to properly communicate uncertain results to the general public.

- **The design of a sampling and monitoring programme: impact of the spatial scale.**

  The sampling and monitoring programme must be designed in agreement with regulators and other stakeholders. Trust on the design of the monitoring program is needed.

  When designing the sampling and monitoring programme, the impact of the programme on the environment (e.g. interaction of the populations with their environment and potential disruption of their normal habits) should be taken into account.

  The design of the sampling and monitoring programme depends on:

  - The **objectives**, which can go from research model/system understanding to operational purposes. The sampling and monitoring programme needs to be fit-for-purpose.
  - **The characteristics of the site.** The available information about the site (e.g. source term in an accident) and the available models will allow to define the range/scale for the sampling and monitoring programme (wider or smaller), and to go to more detail in spatial or temporal resolution (increased sampling/monitoring frequency), when needed (i.e. in the more contaminated zones, neglecting the less contaminated zones).
  - To determine the spatial distribution of the contamination, what is relevant for the design of the sampling and monitoring programme, the use of new techniques (e.g. cars, helicopters), would facilitate to have a spatial coverage of the environmental observations.
  - The **measurement limitations** and **controlling factors** (e.g. the representativeness of sampling). The use new techniques will improve taking measurements.
  - The **cost** would limit the design of the programme. The use of interpolation techniques allows filling some gaps between data, reducing the number of measurements needed, and therefore reducing costs.

- **How to optimise a monitoring programme to adequately characterise the variability of the contamination?**

  The aspects that can help to optimise a monitoring programme include:

  - The **objective** of the programme will determine the exact number of data that is really needed, to be sure that the programme is fit-for-purpose. The objective might be refined adaptively. In some scenarios, and depending on the aim, one might focus more on the important pathways which might have an impact on the population. MARSIM approach is a good example.
  - The **frequency of sampling** should be related to the "smoothness" of the variation (e.g. in Fukushima nowadays the monitoring is being reduced since the variations are less than before). It is important to have a long-term monitoring programme, because although the contamination peak is short, the radioactive contamination is long-lasting.

- **Optimise the cost of the programme**. For example the number of person-hours required can be reduced by using technologically advanced solutions (e.g. to solve the difficulty of sampling).
- **Engage the local population (consider the stakeholders opinion).** The expectations of the local population should be taken into account (e.g. feedbacks from Fukushima clearly show that even if the radiological situation is clearly characterised now, the local population wants that the monitoring continues). It is also important to consider the population's concerns (e.g. in Fukushima, the monitoring of the forest is very interesting for a scientific point of view (estimation of transfer factors, etc.) but what really concerns the population is if forest products, like mushrooms or sensaï, can be eaten). The multi-attribute analysis should take into account stakeholder's opinion.
- **Optimise the consideration of local measurements in the official monitoring.** Citizen monitoring can help to characterise the environment and to better know the situation. If some hot spots are found, experts can assess the location in more detail using appropriate equipment

- **Recommendation for achieving representative sampling and monitoring results.**

  The recommendations discussed included:
  - **Perform adequate design** of the monitoring programme, using as much previous information as possible before beginning measuring or sampling.
  - Representativeness of the results will depend on the **purpose of the study/programme**. Sometimes continuous measurements are needed, for instance for assuring the quality of water for human consumption.
  - **Widely share data and metadata**. Transparency in the results obtained and optimised use of resources. If data and metadata are shared, there will be no need to make new measurements (e.g. in the case of Fukushima, lots of data were gathered and shared).
  - **Collaborating with other disciplines which perform contaminants measurements** will avoid to repeat the samplings if they were already carried out for other reasons.
  - **Apply reliable interpolations.** The sampling might be coupled with some new models. Here the data could be used as validating the models.
  - **Measurement cost should be taken into consideration.** Cheaper and lower-accuracy measurements could be used first. Then, expensive high-accurate measurements can be performed if needed (i.e. pre-characterization phase for having supporting data for characterization).

- **What components of uncertainty (i.e. measurement technique, preparation, and sampling) and variability (i.e. temporal and spatial) do you think are important in your model?**

  It depends on which uncertainty and variability components can be controlled and/or reduced. It will also depend on the process that is modelled. In any case, every component of uncertainty and variability should be considered and discussed, in order to avoid over- or under-estimations.

  Usually, variability components are predominant over the uncertainty ones. Variability cannot be reduced but only quantified.

  Uncertainty of measurement, preparation and sampling can be kept small, since they are performed according to standardised procedures in every laboratory, accreditations and good practices standards. Larger uncertainty comes from the sampling strategy rather than from measurement or preparation (the last two should be accurate enough; i.e. if your measurement uncertainty is very high, there is no use in doing sampling). Sampling is important because it is related to the description of the system (e.g. a good sampling design is needed to capture the exponential behaviour of ^{137}Cs in soil depth). In the case of bio-samples, we should also pay attention to the displacement of the specimens.

3.3. Summary of the presentations and discussions held in Session 2 “Conceptual model uncertainty” and Session 3 “Quantifying model improvement”.

3.3.1. Summary of the presentations of Session 2 and 3

Session 2 on Conceptual model uncertainty, was chaired by Philipp Hartmann (BfS, Germany) and Jordi Vives i Batlle (SCK•CEN, Belgium), and included the following presentations:

- ***Scene setting.*** *Philipp Hartmann (BfS, Germany)*

Conceptual model uncertainty deals with simplifications needed to translate a conceptual model into mathematics and originates from an incomplete understanding and/or simplified representations of modelled processes as compared to reality. This type of uncertainty is often not considered when quantifying the total uncertainty budget of a model output. However, neglecting conceptual model uncertainty may lead to total uncertainty bands that are not sufficiently wide.

Examples of how to quantify conceptual model uncertainty can be found in the fields of hydrology, epidemiology, ecology, agronomy. Different techniques, ranging from the combination of residual analysis and the standard Bayesian method to multi-model inference and multi-model-averaging techniques can be used. However, these approaches are only feasible if experimental data are available and different types of uncertainties can be assumed to be additive. If no data but several alternative model structures are available, then model comparison can be carried out under the pre-requisite that the models have a similar parameterisation. If data are not available, at least expert elicitation and a well-documented qualitative analysis are possible.

In radioecology, conceptual model uncertainty has not been addressed in a systematic way so far. However, it plays an important role in radioecological models, e.g. if simplified model structures and/or empirical model parameters are used, if certain processes are neglected or if processes known to be of stochastic nature are not mathematically treated as such.

- ***Model-related uncertainties when applying process-based models to a radioecological observatory (illustrated with example from the Belgian NORM observatory site).*** *Jordi Vives i Batlle (SCK•CEN, Belgium)*

The presentation dealt with the uncertainties arising when applying dynamic process radioecological models to an observatory site. Because this topic is very broad, the presentation was illustrated with an example from the Belgian NORM observatory site, for which the SVAT (Soil-Vegetation-Atmosphere Transfer) model ECOFOR is being adapted. The presentation began with a general introduction of the modelling process, emphasising that a model is a conceptual and simplified image of reality and as such not only every measurement has an uncertainty, but also the mathematical representation of any process. Every modelled value has an associated uncertainty arising from empirical and conceptual sources.

We discussed how parameters are always based on incomplete or uncertain data and the problems arising when models are validated against scenarios with incomplete information. Sensitivities and uncertainties in models were explained. In particular we discussed the issues related to modelling the radionuclide cycling in forest with focus on ECOFOR. The basic conceptual layout of such model was presented, with emphasis on issues arising from the simplified representation of the hydrology, plant transport sub-model and the link of element transport to water transport. Key model parameter requirements for a model at this level were discussed, aiming to answer the question: what is the minimum data you need for a whole model and what requirements does this pose to experimentalists. The final part of the talk showed how ECOFOR was implemented in the Belgian NORM site, with examples of the kind of extrapolations and generalisations made to cover for insufficient data, a presentation of model results and a concluding summary of the modelling uncertainties.

- ***About uncertainties of non-radioactive atmospheric pollution modelling.*** *Fernando Martín (CIEMAT, Spain)*

Modelling is a very important tool for scientific research in atmospheric pollution. It is based on atmospheric models which simulate the physical and chemical processes (e.g. emission, meteorology, transport and diffusion, chemical transformations and deposition of pollutants) of atmospheric pollutants. The developed models are frequently used for air quality assessment, forecast, pollutant source impact analysis and abatement air pollution strategies (planning).

An overview about the uncertainty of atmospheric modelling for air pollution was presented. Main concepts are similar to other type of modelling, for example, those used for radiological protection. It is pointed out that even in European legislation there is an official definition of model uncertainty and model quality objectives are set up. Uncertainty is estimated by computing some metrics comparing the model outputs against the observations. Some of the most used metrics for estimate air quality model uncertainty were shown and some important tools, as the FAIRMODE Delta Tool, were described. The sources of uncertainty are modelling errors, input errors and stochastic uncertainty and some examples were shown. Most of uncertainty in air quality modelling is coming from uncertainties in the inputs, especially from the pollutant emission data due to the huge amount of pollutant emission sources and their spatial and time variability.

A discussion about how to reduce the model uncertainty was presented. Modelling errors can be reduced if better but more complex models or better input data are used. However, there is a paradox because better models imply more complex models, which need more input data providing more input data errors. It seems that there is a limit to decrease the model uncertainty. Other option to reduce the model uncertainty is the post processing of the model outputs using data assimilation or fusion to reduce model bias using observed concentrations in air quality stations, or data assimilation to improve spatial resolution.

- ***Reducing the uncertainties of atmospheric dispersion modelling using geostatistical techniques.***
  Mark R. Theobald[1,2], Marta G. Vivanco[1], Juan Luis Garrido[1], Fernando Martín[1], Inmaculada Palomino[1], Massimo Vieno[3] and David Simpson[4,5]
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Atmospheric concentrations estimated by atmospheric dispersion and air quality models are subject to considerable uncertainty. This uncertainty originates from various sources, such as uncertainty in the model input data (e.g. emission sources, meteorology, land cover, etc.), simplified or missing processes and simulation constraints (e.g. spatial and temporal resolution). Data assimilation, i.e. the combination of model output data with observations (or other data sources) can be used to reduce the uncertainty of model predictions. Two examples of data assimilation are presented to illustrate how geostatistical techniques can be used to reduce the uncertainty of air quality predictions.

The first example shows how model bias can be reduced spatially through the interpolation of the residuals (observed concentration minus modelled concentration at each measurement site). A novel interpolation method (empirical Bayesian Kriging in ArcGIS) is used since it can be used for data with moderate spatial trends (unlike other methods such as ordinary Kriging) and is more accurate than other Kriging methods for small datasets. Since the spatial relationships between sites may differ for urban and rural locations, the residuals are interpolated for the rural and sub(urban) sites individually and then added to the original model estimates. These rural and sub(urban) concentration maps are then summed, weighted by population density to get the final bias-corrected map.

The second example shows how the spatial resolution of an air quality model can be artificially increased by combining coarse-resolution model output with high-spatial resolution emission data and simple dispersion fields. This approach can significantly increase air quality model performance and can even produce better results than the application of the air quality model at a higher spatial resolution, which is computationally expensive.

These examples illustrate the potential of geostatistical techniques to improve the model estimates of atmospheric concentrations although the limitations and applicability of the techniques must be considered, such as the strong influence of outliers in the observations for the first example and the limitation of the second example to primary pollutants.

Session 3 on Quantifying model improvement, was chaired by Alan Tkaczyk (UT, Estonia) and Martin Steiner (BfS, Germany), and included the following presentations:

- ***Scene setting.*** *Marko Kaasik (UT, Estonia)*

This study is based on TERRITORIES Library Database (TLD) data: Belgian NORM site, Norwegian Fen site and Fukushima accident. The soil-to-organism concentration ratio (CR) approach is tested: CRs based on these measurements are compared to the CR values from the literature, which are in use e.g. in CROM and ERICA tools.

- To apply any statistical validation approach, a homogeneous set of site-wise soil-organism pairs is needed. This is a big challenge, because the TLD data are characterised by large variability due to:
    - different organisms (trees, grass, moss, lichen, soil worms);
    - different organs (roots, stem, branches, leaves/needles);
    - different soil layer depths;
    - different nuclides;
    - isolated sub-sites with a number of samples of a specific type.
- Thus, often the concentration ratios are calculated by averaging over few samples only. The main conclusions are:
    - The whole tree approach, based on weighted average concentrations in tree organs and tested only for Belgian NORM site so far, works rather well.
    - Transfer factors for moss and lichen at the Belgian NORM site are found to be several times lower than the ones based on CROM and ERICA.
    - The variability between sites is in the same order of magnitude with the concentration ratio itself.
    - Differences between relatively close species are big, e.g. pine and spruce tree at Fen site.
- In further studies it will be interesting to check how much, in comparison with CR, the process-based models, which include the information on growth conditions, soil chemistry etc., can explain the variability between the sites and close species?

- ***Quantifying improvement achieved by a process-based approach for predicting Cs-137 transfer in Fukushima forests over 2011-1016.*** *Marc-André Gonze, Philippe Calmon and Christophe Mourlon (IRSN, France)*

We present results obtained in the course of the TERRITORIES Sub-subtask 9.3.1 regarding the quantification of improvements achieved in a dynamic forest model, based on 6 year observations of radiocesium (^{137}Cs) in Fukushima coniferous forests contaminated by atmospheric fallouts. Our goal is to illustrate the process of improvement itself rather than to analyse observations and discuss transfer mechanisms in details. After presenting the selected dataset, we briefly describe the improvements achieved in a "simple" pre-existing model developed after Chernobyl (RODOS, BIOMASS & EMRAS projects), then assess the benefit gained through the quantification of models' accuracies for both "simple" and "improved" approaches.

Prior to modelling, we conducted a detailed review of literature data acquired from 2011 to 2016 at tens of forest sites located in the Fukushima and neighbouring prefectures. The focus was put on even-aged cedar and cypress plantations which were by far the most investigated forests in Japan. Thousands of Cs measurements in tree vegetation and soil layers were collected from the literature and analysed, including concentrations, inventories or tree depuration fluxes. To reduce the variability between sites, all radioactive quantities were normalised by the atmospheric deposit estimated at each site. Then, they were log-averaged among sites to evaluate a mean evolution of Cs contamination in Japanese coniferous forests.

In order to incorporate the knowledge gained from Fukushima observations, significant model improvements were achieved during the last 2 years, mainly in the frame of the AMORAD project (https://www.irsn.fr/en/research/research-organisation/research-programmes/amorad/Pages/AMORAD-program.aspx). In particular, major efforts were put in the refinement of the conceptual approach and the development of semi-mechanistic parameterizations, now relying on hydrological or eco-physiological characteristics of the forest (e.g. biomass dynamics, K cycle). In order to estimate relevant parameter values and associated uncertainties, a comprehensive review of forest and climate characteristics throughout middle Japan was first conducted. A few "hardly measurable" parameters could not be estimated otherwise than by calibrating each model against the 6-year observations. Probabilistic simulations accounting for parameter uncertainties were then carried out, for each model separately. The models accuracies were estimated as the Mean Squared Logarithmic Error for each of the multiple predicted endpoints.

We demonstrated that the model accuracy was significantly improved for predicted Cs inventories, depuration fluxes and concentrations in tree organs. This could be attributed to the differentiation of the canopy into foliage and branch compartments with distinct characteristics and a better consideration of the influence of ecophysiology & hydrology on foliar transfer mechanisms.

3.3.2. Group work on Session 2 & Session 3

The following aspects related with "**Conceptual model uncertainty"** and **"Quantifying model improvement"** (see questions in Annex 3), were discussed during this Group Work Session:

- **Where does "conceptual uncertainty" play a role in your field?**

Conceptual uncertainty **may change according to the area of observation and the area of impact considered.** Conceptual uncertainty is **model specific and case specific**. It might be either irrelevant (if only measurements are used) or of minor importance (if conservative screening models are deliberately applied).

Conceptual uncertainty **represents either knowledge about processes that are not included in the model**, **or lack of knowledge about certain processes.** As models have to simplify the processes the conceptual uncertainties have to be considered. However, due to the difficulties to calculate these uncertainties, in many cases are not discussed nor taken into account, especially for complex models.

In a **research context**, conceptual uncertainty might be a benchmark for model quality. In radioecology, however, many models build upon similar concepts and differ only in the number and type of model parameters. Conceptual uncertainty has only rarely (if at all) been dealt with in radioecology until now (e.g. in the European project STAR, interaction matrices were put forward but were not used as tools for comparing conceptual models). Although comparison benchmarking of different numerical models is becoming common in research (perhaps more in the climate modelling community than in the radioecology community), there are not many systematic comparisons of conceptual modelling.

In a **regulatory context**, the conceptual uncertainty in models is often not important, since regulators follow a given scheme (yes/no answers instead of quantitative answers). Usually regulators treat the conceptual uncertainty as “unknown unknowns” and consider it as an academic subject only. However, for radiation protection purposes, the conceptual uncertainty should be estimated, since the aim is to protect, with a given degree of conservatism. Not considering conceptual model uncertainty may lead to uncertainty bands that are not sufficiently wide. For natural radionuclides and conservative assessments if the uncertainty bands are underestimated, threshold values may be overcome. Conceptual uncertainty might be **important for communication to stakeholders**. Communication requires a balance of quantity (not too much, not too little) and of level of detail (transparent and understandable).

- **How can you be sure that your model represents reality?**

It is important to define what is “a good representation of reality”.

Representation of reality will depend on the purpose of the model, since representing reality (or a part of it) is not always the objective (i.e. in some cases conservatism is needed). Taking the example of food safety, if quantifying the current ingestion exposure situation is the only objective, then quantification of the hazards (pollutants, RNs, microbes…) in foods as they are eaten can be the most fit-for-purpose approach. In this “total diet studies” approach, a full “from farm to fork” model may not be expected. On the contrary, if the objective is to identify in the foodchain where are the main triggers to lower the exposure, then a “from farm to fork” may be needed.

Representation of reality will depend on the model considered. Often screening approaches are the first step that triggers more detailed investigations.

Comparing the outputs of the model with real values (measurements) in different situations can show if a model represents (aspects of) reality feasibly. Results should fit, but it has to be taken into account that there is a range of uncertainties (both from the model and the measurements). Models need to be validated using datasets different to those used to calibrate the model. Separation of calibration and validation datasets in a standardised approach could/would provide more objective proficiency testing. However, it has to be noted that model calibration is not sufficient and could be misleading. If a model reproduces data in a specific situation, this is not enough to say that it represents reality, since this the model should take into account relevant processes and must reveal the system functioning in different exposure situations. A model reproducing components of reality creates confidence.

In general, models only represent a limited part of reality. It may be possible to perform a retrospective assessment (based on historical data) to decide if a model represents a present situation. The degree of detail is sufficiently high if all available knowledge of the processes involved is included in the model.

- **What does "model quality" mean to you in your field?**

Quality has different meanings for different stakeholders. Model quality was first discussed in the context of “software quality“. Representing reality is important, but even more having well documented, traceable and transparent algorithms for the operational codes. In the USA, for operational codes, model quality means that the model represents a good quality assured traceable simulation code, following strict QA/QC processes (see for example US EPA/100/K-09/003).

Different characteristics can indicate the quality of a model. The importance of these characteristics will depend on the purpose of the model. For research models accuracy, precision and transferability could be the most important quality criteria. In the case of assessment models, transparency and traceability are important quality criteria.

Characteristics that need to be considered to determine the quality of a model include:

- Model transferability (general applicability). How universal is the model? This can be demonstrated by inter-comparison running different scenarios.
- The ability to show trends in model results.
- Reproducibility of the model results.
- “Fit for purpose” of the model.
- Simplicity of the model.
- Robustness of the model parameters.
- A mechanistic representation of the relevant processes.
- Predictable capability/forecast. This is an added value when the purpose is to extrapolate beyond the time period used for calibration of the model.
- The model reproduces reality.
- Accessibility and user-friendliness (for non-expert user) and documentation, although these criteria relate more to its software implementation than to the model itself.

Model quality is gained as a **continuous improvement process** (heuristic method).

- **How to measure a change (improvement) in the quality of a model? Is a single number sufficient to quantify model quality?**

Model quality involves the knowledge of the best available modelling technique, the time required to run the model (speed) and the level of detail of predictions/forecasts.

Each model has its specific pros and cons. It is often more important to understand these specific pros and cons than to have a “better model”. Improving model quality should not be misinterpreted as a competition of existing models, which often have been designed for specific purposes.

The improvement of a model can be determined by:

- Assessing the differences between measurements and predictions or between two models results, using adequate statistical methods.
- Its general applicability, although it remains unclear how to quantify this.
- Increase inter-calibration and proficiency testing: models comparison increases confidence in predictions (e.g. climate change modelling). Intercomparison exercises at all levels of complexity could be helpful.
- Feedback from end-users: how they feel about the quality of the model, the results, the user-friendliness.

There was a consensus in that a single number is not sufficient to quantify model quality. Qualitative aspects, e.g. traceability and understandability might be equally important.

- **How does model complexity influence parameter and conceptual uncertainty?**

It was generally agreed that as the complexity of the model increases, the number of parameters, and hence the parameter uncertainty, typically increases, while the conceptual uncertainty decreases. However, if you are able to measure the new parameters well, parameter uncertainty does not necessarily have to increase in a complex model.

It was argued that optimum model complexity is closely related to the acceptable level of uncertainty. The reasonable complexity of a model can depend on the regarded time scale. From aggregated parameters to multiparametric approaches (e.g. K_d as a function of pH, OM, clay, silt…) and to full mechanistic model (PHREEQC model) there is a “sweet spot” of adequate model complexity, implying the lowest achievable uncertainty. A certain level of uncertainty has to be accepted.

A simple model can be more robust (not give weird results in extreme cases). Often parametric models are sufficient, e.g. parameterised K_d values (“smart K_d”). A detailed understanding of important processes is not always necessary, and it has to be taken into account that a complex model will need a large amount of data to support it. Nevertheless, a more complex model might lead to increased confidence.

Multi-tiered modelling approaches offer a balance between parameter demand and complexity /realism of assessment. These approaches go from aggregated parameters (tier 1) to parametric relations (tier 2) and process orientation (tier 3). A toolkit with different models for different purposes would be ideal. Several models for specific applications are often better than one big (unified) model.

4. Feedback from participants

Eleven participants answered the questionnaire (Annex 5), mostly anonymously (only four persons identify themselves). The feedback was quite positive, as is shown in the tables below.

Question	**Score**					
	1	**2**	**3**	**4**	**5**	**NA**
The content was as described in publicity materials	--	--	--	5	6	--
The material was presented in an organised manner	--	--	--	3	8	--
The presentations were adequate in time and style	--	--	1	3	7	--
The workshop was applicable to my job	--	--	3	3	5	--
The place of the workshop was suitable for me	--	--	--	4	7	--
The venue was suitable	--	--	--	2	9	--
I enjoyed the opportunity to engage in the group work	--	--	--	4	7	--
For me, the group work was an effective and important part of the knowledge and information exchange during the workshop	--	--	2	3	6	--
I would recommend this workshop to others	--	--	--	5	6	--
I would be interested in attending a follow-up, more advanced workshop on this same subject	--	--	--	5	5	1

(1= strongly disagree; 5= strongly agree)

	Too short	**Appropriate length**	**Too long**
Given the topic, the length of the workshop was	1	10	--

Please rate the following	**Poor**	**Fair**	**Good**	**Very good**	**Excellent**
Visuals	--	--	3	5	3
Acoustics	--	1	4	3	3
Meeting space			2	5	4
The programme overall			2	4	5

For the other questions included in the survey, which were optional, the answers received were:

- How did you hear about this workshop?
  - Her/his institute
  - Colleagues
  - Invitation letter
  - Member of TERRITORIES project
- What are your most valuable takeaways from this workshop?
  - The need to occasionally interact and learn from colleagues in other disciplines.
  - General overview of the problem and approaches
  - The need to occasionally interact and learn from colleagues in other disciplines.
  - The group work ('brainstorming') can be really useful for clarify and gain insight into the many-sided problems, such as, for example, uncertainties and risk assessments; as was demonstrated in this workshop.
- Which aspects of this workshop could be improved?
  - Video-conference.

Only one “further comment” was received: “*Thanks for the possibility to participate*”

5. Summing up and lessons learned

The objective of the workshop on "Multidisciplinary forum to discuss the scientific basis for reducing uncertainties and improving risk assessment" has been achieved, obtaining feedback from expert scientists in different disciplines, valuable for the two guidance documents that are being developed in TERRITORIES 9.3.1 (To design environmental monitoring for dose assessment and for support to remediation; and To select the appropriate level of complexity in models).

The workshop had a good acceptance, with 26 participants from 9 different countries. Among the attendees, there were 8 experts in different scientific disciplines, not directly related with the TERRITORIES project work. It must be stressed that all participants were extremely active in the discussions held during the workshop. Special mention must be made of the excellent work done by the chairs of the sessions, the speakers and the moderators and secretaries of the group work sessions, which has been crucial for the success of the workshop.

As it was previously mentioned, one aim of the workshop was to "attract" as much students as possible. Unfortunately, the dates of the workshop (13-14 June) were not the most adequate for students to attend, since is time of exams in the Spanish Universities. Therefore, only PhD students participating in the TERRITORIES project participated in the workshop.

Based on the content of the conferences and the discussions held during the workshop, mainly during the Group Work sessions, the following lessons have been learned:

- *Lessons learned for "Guidance to design environmental monitoring for dose assessment and for support to remediation" (Sub-subtask 9.3.1.1).*

Sampling/monitoring is carried out for a number of distinct purposes such as site characterisation, model calibration, regulatory purposes or public reassurance. The monitoring/sampling program should be designed to best fulfil the required purpose. This may need to be done in collaboration with stakeholders.

The spatial scale of the contamination may impact on the type of monitoring/sampling that is carried out and may necessitate an iterative approach. For example, for a large area of many square kilometres it may be possible, depending on the radionuclide and type of radiation, to conduct an initial survey by aeroplane or car to obtain a broad understanding of the level and distribution of the contamination. Depending on the aims of the monitoring/sampling programme smaller regions may then be studied in more detail, for example if there is concern about potential levels of exposure and there is a desire to reduce the level of uncertainty in the assessment. This is essentially part of the optimisation of the monitoring/sampling programme and must take into account the overall objectives of the programme. Optimisation must also be considered when measuring the temporal variation in contamination; this might be achieved through the use of appropriate technology such as fixed automated monitoring stations. The aim is to achieve the goals of the monitoring programme at minimal cost. This is consistent with the US EPA Multi Agency Radiation Survey and Site Investigation Manual (MARSSIM) approach. If the aim is for public reassurance then citizen science programmes may be a useful addition to more formalised programmes.

One of the main requirements for achieving representative sampling and monitoring results is to ensure that an adequate design of the monitoring programme is carried out. Key inputs to such a design include developing an understanding of the site, the contaminants, the transport systems involved, the exposure scenarios and again the purpose of the programme. Collaboration with other disciplines also involved in the monitoring of contaminants can be beneficial for example in characterising transport process and pollutant dynamics at a site. The use of models to provide focus to the monitoring programme can be helpful.

The components of uncertainty and variability that are important to the characterisation of contaminants at a site also depend on the purpose of the monitoring programme. Uncertainty components typically relate to uncertainties in the sampling and measurement processes and can be considered to be under control, while variability components reflect the natural variability in the environment which can be considerable and difficult to control. However, in general all components should be considered in order to determine their impact on the aims of the monitoring programme.

<u>Lessons learned for "Guidance to select the appropriate level of complexity in models"</u> (Sub-subtask 9.3.1.2).

Mathematical models, which are always an incomplete representation of reality, and the codes implementing them, have many different purposes, for operators, regulators and even for the general public. For that reason should be understood that the results of the different models depend on the objective for which they were designed. Also, should be pointed out that the quality of a model depends, amongst others, on the goal of it (should be fit-for-purpose), and its predictability capacity.

Very simple models, many times using empirical multiplicative aggregated factors, have been widely used – and are still used - in radioecology for the sake of simplicity, for robustness and often for a deep lack of understanding on the behaviour of the radionuclides in the environment. An example of this are the models used for the conservative prospective assessment of the impact of new nuclear installations. These models predict measurable quantities in the environment (as concentrations or ambient equivalent dose) which are further needed to calculate the effective dose, which is ultimately the limiting quantity used by decision makers and to inform to the people on the risk. Often these simple/screening models are also used to trigger more detailed investigations in some specific situations.

However, there is a consensus on the need of improving the knowledge associated to these models for several reasons. Although acknowledged that for some applications engineers or regulators achieve necessarily conservative results using simple models, appropriate for the optimization of new installations, or for protection purposes, in other cases more accurate results are needed. For example, if too conservative models unduly burden the possibility of the use of nuclear technologies. Moreover it is recognized than quality of a model is enhanced through a continuous process of, many times, slight improvements.

For that reason efforts in research and development of improved, more complex, radioecological models, are needed. Of course, is important to keep a balance between the effort needed in the development of new models and the needs, what was named under TERRITORIES project "an appropriate level of complexity". Should be however, kept in mind than improvement of the models does not raise a competition between different models.

It has to be highlighted the difficulty of collecting good quality data which can be used to compare with the results of already existing models, mostly because of the different objectives that models and measurements have, but also due to the use of average values in the models instead of point measurements (spatially and temporally), among other reasons. A single number is not enough to indicate the quality of a model. And finally, at least two different sets of data are needed: one to calibrate the model and a second one to validate it.

Some good examples exist of application of the models, improvement and development of fit-for-purpose models and comparisons of different complexity models with the same sets of data, are being collected. This is the case of using existing models, as the old Symbiose models, or IAEA SRS-19 based models, to predict the behaviour of the radioactive contamination (mostly Cs-137) in forests ecosystems in Fukushima prefecture, and the comparison with the use of more complex models, as the new Symbiose models or newly developed process-based models which consider the different parts of the trees and layers of the soils. Another example is the comparison of simple transfer factors to calculate the concentration of natural radionuclides in trees growth in a NORM site in Belgium, with more complex box models representing the ecosystem. The models to recreate the behaviour of artificial radionuclides in the beaches, affected by tides, currents, winds and many other phenomena, which increase their accuracy when more boundary conditions are included, should also be mentioned.

Quantitative tools would be helpful in the decision of what level of complexity should be selected for modelling a given radionuclide in a given situation, according with the user's needs.

Lessons learned for "Uncertainties propagation and sensitivity analysis in modelling" (Sub-subtask 9.3.1.3).

Regarding **uncertainty analysis in radioecology,** the definitions and technical terms used for addressing the different types of uncertainty involved in a model are not unequivocal within the radioecological community. When discussing the various contributions to the overall uncertainty, it is wise to briefly define each contribution before entering the details of discussion or before any calculation is carried out, in order to avoid misunderstandings. Especially, finding a common definition for conceptual uncertainty is nontrivial since analysis of this type of uncertainty is not yet prevalent in the radioecological community.

The general consensus has been achieved that **conceptual model uncertainty** represents either knowledge about processes that are not included in the model, or the lack of knowledge about certain processes. Uncertainty in numerical methods is not part of conceptual model uncertainty.

In general, radioecological models build upon a few mathematical structures (multiplicands, ordinary differential equations, parametric functions) and differ only in the number and type of model parameters. Therefore, it is not expected that conceptual model uncertainty would vary much among radioecological models.

If **conceptual model uncertainty** is not considered, it may lead to overall uncertainty bands that are not sufficiently wide. For example, for natural radionuclides and conservative assessments, if the uncertainty bands are underestimated, threshold values may be overcome.

Conceptual uncertainty might be important for communication to stakeholders. Communication requires a balance of quantity (not too much, not too little) and of level of detail (transparent and understandable).

It is necessary to quantify the **conceptual model uncertainty** in a systematic way in order to investigate better its effect on overall uncertainty. A methodology needs to be developed and applied to some specific examples.

Parameter uncertainty (also named within the radioecological community as data uncertainty) plays a fundamental role as this type of uncertainty is associated with the values of the parameters that are used in the implemented models. Although parameter uncertainty was not a main topic of the workshop, it was agreed that if the complexity of the model increases, the number of parameters, and hence the parameter uncertainty, typically increases.

Regarding the **scenario uncertainty**, this term is used in a variety of contexts with different meanings. Several contexts were pointed out during the discussion:

i) For applications in risk assessment analysis for which the dose is the endpoint, the term scenario is used to describe a sequence of events and conditions.
ii) In environmental risk analysis, a scenario describes a different type of release i.e. source term.

iii) For safety assessment analysis of nuclear waste disposal sites, scenarios not only relate to the typical path of exposure i.e. groundwater rise and irrigation with contaminated groundwater but also can be disruptive events external to the disposal system, such as volcanism, seismicity, human intrusion and climate change.

iv) In remediation of a contaminated site, the term scenario is used to describe hypothetical or generic individual exposure.

In general, the **scenario uncertainty** is handled using a 'what if' approach. When the scenario is not specified properly, the risk may be underestimated, overestimated or mischaracterised. Underestimation may occur if relevant situations are not considered. Overestimation may occur if irrelevant situations are considered.

When the **role of monitoring and sampling uncertainty** was discussed, general consensus was achieved that monitoring and sampling uncertainties can be considered part of scenario uncertainty since they have an impact on the exhaustive description of events and conditions related to a scenario.

Monitoring campaigns are carried out in post-accident situations to characterise the contamination or to deal with operational/routine surveillance in time and in space. Sampling campaigns are related to research activities. Uncertainty related to monitoring and sampling activities can be reduced by optimising their design. Optimal design is highly dependent on the purpose of the assessment to be carried out; in other words, there is no design which is the global optimum for all situations!

It is acknowledged that intrinsic variability of the quantities to be measured can be quantified but not reduced. The focus of an optimal monitoring or sampling campaign is to obtain representative sampling and monitoring results.

The main lessons learned regarding **quantifying model improvement** are the following:

a. The purpose of a modelling activity determines the criteria for establishing model performance in radioecology. In fact it has an impact on:
    i. The choice of the model.
    ii. The representativeness of available data i.e. available data cannot be representative of a location in general!
    iii. The proper sampling strategy.
    iv. The choice of the adequate metric to test model performance.

b. A single number (one metric) is not sufficient to quantify model quality. In fact qualitative aspects, e.g. traceability and simplicity of model output also play a role and need to be considered. Hence, quantitative criteria and quantitative criteria should be both considered and merged into a *performance table* to be used to quantify model performance.

The last workshop of TERRITORIES will take place the days 19-20 March 2019 in Queen's College, Oxford, UK. A Programme Committee was created in June 2018, and several videoconferences have already taken place. The workshop will be on "**Assessing risks from radioactive legacy sites and how to better present uncertain information**". A first version of the workshop programme has been announced in the TERRITORIES webpage (http://territories.eu) and posted in the TERRITORIES blog (https://territoriesweb.wordpress.com/). Using Eventbrite, a page has been created for people to register their interest to participate in the workshop.

6. ANNEXES

6.1. Annex 1: Programme of the TERRITORIES workshop on "Multidisciplinary forum to discuss the scientific basis for reducing uncertainties and improving risk assessment".

TERRITORIES Workshop on

Multidisciplinary forum to discuss the scientific basis for reducing uncertainties and improving risk assessment

13th and 14th of June, 2018; CIEMAT, Madrid, Spain

The **objective** of the workshop is to get feedback from experts in different scientific disciplines, on the application of the two guidance documents that are being developed in TERRITORIES to design environmental monitoring for dose assessment and for support to remediation; and to select the appropriate level of complexity in models. The workshop will focus on methodologies to reduce uncertainties related to sampling and monitoring strategies and the quantitative handling of the various types of uncertainties that play a major role in radioecological modelling, i.e. conceptual model uncertainty and scenario uncertainty. The workshop discussions and presentations can be enriching for last year students of scientific careers and PhD students in the field of radioecology, and therefore their participation is encouraged.

Wednesday 13th June 2018

Time	Title	Lecturer
Introductory session. *Chairs: Marie Simon-Cornu (IRSN, France) and Almudena Real(CIEMAT, Spain)*		
09:00 – 09:15	Welcome to CIEMAT and scope of the workshop	Almudena Real (CIEMAT, Spain)
09:15 – 09:35	TERRITORIES WP1 introduction	Juan Carlos Mora (CIEMAT, Spain)
09:35 – 09:55	Introduction to case-studies and scenario-related uncertainties	Danyl Perez-Sánchez (CIEMAT, Spain)
09:55 – 10:10	Introduction of the Fukushima case study	Justin Smith (PHE, UK)
10:10 – 10:25	Introduction of the the Belgian NORM observatory site case study	Jordi Vives i Batlle (SCK•CEN, Belgium)
10:30 – 11:00	*Coffee and tea*	

Session 1: Sampling and Monitoring Uncertainty. *Chairs: Justin Smith (PHE, UK) and Juan Carlos Mora (CIEMAT, Spain)*		
11:00 – 11:20	Scene setting	Juan Carlos Mora (CIEMAT, Spain)
11:20 – 11:40	Sampling procedures in routine monitoring: Purpose of the monitoring campaign	Francisco Javier Guillén (LARUEX, Spain)
11:40 – 12:00	Sampling and monitoring uncertainties associated with the Water Framework Directive	Simon O´Toole (EPA, Ireland)
12:00 – 12:20	Ambient dose equivalent monitoring in the the Belgian NORM observatory site	Johan Camps and Jordi Vives i Batlle (SCK•CEN, Belgium)
12:20 – 12:40	Organisation of the Environmental Monitoring: Lessons Learnt from Fukushima	Mélanie Maître (CEPN, France)
12:40 – 14:00	*Lunch*	
14:00 – 14:20	A Multiscale Bayesian Data Integration Approach for Mapping Air Dose Rates around the Fukushima Dai-ichi Nuclear Power Plant	Haruko M Wainwright (Lawrence Berkeley National Laboratory, USA)
14:20 - 14:40	Optimizing flight-line distance for characterizing contaminated soil, an application of geostatistics	Pedram Masoudi (IRSN, France)
14:40 – 15:40	Group Work Session 1	
15:40 – 16:10	*Coffee and tea*	
16:10 – 17:00	Group Work Session 1 reports and discussion	

Thursday 14th June 2018

Time	Title	Lecturer
Session 2: Conceptual model uncertainty. *Chairs: Philipp Hartmann (BfS, Germany) and Jordi Vives I Batlle (SCK•CEN, Belgium)*		
09:00 – 09:20	Scene setting	Philipp Hartmann (BfS, Germany)
09:20 – 09:40	Model-related uncertainties when applying process-based models to a radioecological observatory (illustrated with example from the Belgian NORM observatory site)	Jordi Vives i Batlle (SCK•CEN, Belgium)
09:40 – 10:00	About uncertainties of non-radioactive atmospheric pollution modelling	Fernando Martín (CIEMAT, Spain)
10:00 – 10:20	Reducing the uncertainties of atmospheric dispersion modelling using geostatistical techniques	Mark Theobald (CIEMAT, Spain)
10:20 – 10:50	*Coffee and tea*	
Session 3: Quantifying model improvement. *Chairs: Alan Tkaczyk (UT, Estonia) and Martin Steiner (BfS, Germany)*		
10:50 – 11:10	Scene setting	Marko Kaasik (UT, Estonia)
11:10 – 11:30	Quantifying improvement achieved by a process-based approach for predicting Cs-137 transfer in Fukushima forests over 2011-1016	Marc-André Gonze (IRSN, France)
11:30 – 12:30	Group Work Session 2 & 3	
12:30 – 12:50	Group Work Session 2 & 3 reports and discussion	
12:50 – 13:00	Closure of the workshop	Juan Carlos Mora and Almudena Real (CIEMAT, Spain)
13:00 –	*"Spanish Tapas" Lunch*	

6.2. Annex 2: Organization of the Group Work Sessions of the TERRITORIES workshop on "Multidisciplinary forum to discuss the scientific basis for reducing uncertainties and improving risk assessment"

GROUP 1			**13 June**	**14 June**
Guillen	**Javier**	**LARUEX**	**Coordinator**	
Pérez-Sánchez	**Danyl**	**CIEMAT, Spain**	**Secretary**	
Février	**Laureline**	**IRSN, France**	**Support**	
Maître	**Mélanie**	**CEPN, France**		**Coordinator**
Hartmann	**Philipp**	**BfS, Germany**		**Secretary**
Smith	**Justin**	**PHE, UK**		**Support**
Tkaczyk	Alan	UT, Estonia		
Moraleda	Montserrat	CIEMAT, Spain		
GROUP 2				
Mrdakovic Popic	**Jelena**	**NRPA, Norway**	**Coordinator**	
Zebracki	**Mathilde**	**IRSN, France**	**Secretary**	
Mora	**Juan Carlos**	**CIEMAT, Spain**	**Support**	
Martín	**Fernando**	**CIEMAT, Spain**		**Coordinator**
Theobald	**Mark**	**CIEMAT, Spain**		**Secretary**
Kaasik	**Marko**	**UT, Estonia**		**Support**
Real	Almudena	CIEMAT, Spain		
Escribano	Alicia	CIEMAT, Spain		
Iosjpe	Mikhail	NRPA, Norway		
GROUP 3				
Wainwright	**Haruko**	**LBNL, USA**	**Coordinator**	
Masoudi	**Pedram**	**IRSN, France**	**Secretary**	
Gonze	**Marc-André**	**IRSN, France**	**Support**	
O'Toole	**Simon**	**EPA, Ireland**		**Coordinator**
Vives i Batlle	**Jordi**	**SCK·CEN, Belgium**		**Secretary**
Steiner	**Martin**	**BfS, Germany**		**Support**
Mauring	Koit	UT, Estonia		
Simon-Cornu	Marie	IRSN, France		

6.3. Annex 3: Questions for the group work sessions of the TERRITORIES workshop on "Multidisciplinary forum to discuss the scientific basis for reducing uncertainties and improving risk assessment".

- ***Session 1: Sampling and Monitoring Uncertainty***
    - In your opinion what are the purposes for sampling and monitoring (how will the results be used)?
    - To what extent does spatial scale impact on design of sampling and monitoring programme?
    - How would you optimise a monitoring programme to adequately characterise the variability of the contamination, bearing in mind that continued sampling and monitoring comes at a cost.
    - What are you recommendations for achieving representative sampling and monitoring results?
    - What components of uncertainty (e.g. measurement technique, preparation and sampling) and variability (e.g. temporal and spatial) do you think are important?

- ***Session 2:* Conceptual model uncertainty & Session 3: Quantifying model improvement**
    - Where does "conceptual uncertainty" play a role in your field?
    - How can you be sure that your model represents reality?
    - What does "model quality" mean to you in your field?
    - How to measure a change (improvement) in the quality of a model? Is a single number sufficient to quantify model quality?
    - How does model complexity influence parameter and conceptual uncertainty?

6.4. Annex 4: List of participant in the TERRITORIES workshop on "Multidisciplinary forum to discuss the scientific basis for reducing uncertainties and improving risk assessment".

All participants were highly 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 had been carried out.

	Participant	**Organization, Country**
1	Dvorzak, Alla	CIEMAT, Spain
2	Escribano, Alicia	CIEMAT, Spain
3	Février, Laureline	IRSN, France
4	Gonze, Marc-André	IRSN, France
5	Guillen, Francisco Javier	LARUEX/U. Extremadura, Spain
6	Hartmann, Philipp	BfS, Germany
7	Iosjpe, Mikhail	NRPA, Norway
8	Kaasik, Marko	UT, Estonia
9	Maître, Mélanie	CEPN, France
10	Martín, Fernando	CIEMAT, Spain
11	Masoudi, Pedram	IRSN, France
12	Mauring, Koit	UT, Estonia
13	Mora, Juan Carlos	CIEMAT, Spain
14	Moraleda, Montserrat	CIEMAT, Spain
15	Mrdakovic Popic, Jelena	NRPA, Norway
16	O'Toole, Simon	EPA, Ireland
17	Pérez-Sánchez, Danyl	CIEMAT, Spain
18	Real, Almudena	CIEMAT, Spain
19	Simon-Cornu, Marie	IRSN, France
20	Smith, Justin	PHE, UK
21	Steiner, Martin	BfS, Germany
22	Theobald, Mark	CIEMAT, Spain
23	Tkaczyk, Alan	UT, Estonia
24	Vives i Batlle, Jordi	SCK•CEN, Belgium
25	Wainwright, Haruko	LBNL, USA
26	Zebracki, Mathilde	IRSN, France

6.5 Annex 5: Survey distributed among the participants to get feedback on the workshop “Multidisciplinary forum to discuss the scientific basis for reducing uncertainties and improving risk assessment”.

Feedback for TERRITORIES Workshops

We thank you for attending the workshop in 2018 June in Madrid. To evaluate the effectiveness of the workshops, we ask for your assistance in completing this evaluation. Your feedback will help to improve future TERRITORIES workshops. Thank you in advance for your contribution.

This is an anonymous survey, but You will be given a chance to include Your name and e-mail at the end of the survey, if you would like more information about the survey results.

The content was as described in publicity materials

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

The material was presented in an organized manner

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

The presentations were adequate in time and style

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

The workshop was applicable to my job

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

The pace of the workshop was suitable for me

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

The venue was suitable

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

I enjoyed the opportunity to engage in the group work

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

For me, the group work was an effective and important part of the knowledge and information exchange during the workshop

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

I would recommend this workshop to others

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

I would be interested in attending a follow-up, more advanced workshop on this same subject

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Given the topic, the length of the workshop was

- ○ Too short
- ○ Appropriate length
- ○ Too long

Please rate the following

	Poor	Fair	Good	Very Good	Excellent
Visuals	○	○	○	○	○
Acoustics	○	○	○	○	○
Meeting space	○	○	○	○	○
The program overall	○	○	○	○	○

How did you hear about this workshop? (Optional)

What are your most valuable takeaways from this workshop? (Optional)

Which aspects of this workshop could be improved? (Optional)

Any further comments? (Optional)

Your Name (Optional)

Your E-mail (Optional)

What are your most valuable takeaways from this workshop? (Optional)

Tu respuesta

Which aspects of this workshop could be improved? (Optional)

Tu respuesta

Any further comments? (Optional)

Tu respuesta

Your Name (Optional)

Tu respuesta

Your E-mail (Optional)