Proposals for Themes for the IAEA's model testing and comparison programme: MODARIA: "Modelling and Data for Radiological Impact Assessments"

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CONTENTS

1. INTRODUCTION

Radioecological models are used in assessing exposures to humans and impacts on the environment in planned, existing and emergency exposure situations. The results of such assessments are used, for example, in the evaluation of the radiological relevance of routine and accidental releases of radionuclides, to support decision making in remediation work, for the performance assessment of nuclear waste disposal facilities, as well as for clearance and exemption of material with low levels of radioactivity.

Radiological exposures to humans and impacts on the environment are the result of a complex interaction of the properties of the radionuclides involved, environmental conditions, agricultural practices and human habits. Many model parameters are needed to characterize the specific exposure conditions and to quantify the transfer of radionuclides within an ecosystem. All estimated exposures are uncertain to some extent because the parameters used to calculate them are subject to a more or less pronounced variability — even for very well defined boundary conditions — due to the inherently incomplete knowledge about the exposure conditions.

The results provided by radioecological models are necessary to prove compliance with regulatory standards, to support decisions during and after nuclear emergencies and to optimize, for example, the remediation of contaminated sites. In any case, the impact on public health, on public acceptance of decisions and the economy may be considerable.

The IAEA's Environmental Modelling for Radiation Safety (EMRAS II) programme ran from 2009 to 2011. In common with the previous IAEA programmes, Biosphere Modelling and Assessment (BIOMASS) (1996–2002) and EMRAS I (2003–2007), it had the following general objectives:

- To improve environmental assessment models and modelling methods by model testing, comparison and other approaches;
- To develop international consensus, where appropriate, on environmental modelling philosophies, approaches, and parameter values;
- To develop methods for the assessment of radionuclide transfer in the biosphere in areas where such methods were not already available;
- To provide an international focal point for the exchange of information on environmental assessment modelling ;
- To respond to environmental assessment modelling needs expressed by other international organizations and entities.

A special feature of the IAEA's modelling programmes in this area is the possibility of testing models using real environmental data. In many other contexts, models cannot be tested in this way and can only be partly tested or compared. For this reason some priority has been given to model testing with real environmental data in previous programmes.

The EMRAS II programme focused on the development of reference approaches for different fields where radioecological models to assess the transfer of radionuclides in the environment and the resulting exposures to the general population and radiological impacts to flora and fauna were assessed. The following topics were addressed through nine Working Groups:

- **Reference Approaches for Human Dose Assessment**

  Working Group 1 — Reference Methodologies for “Controlling Discharges” of Routine Releases

  Working Group 2 — Reference Approaches to Modelling for Management and Remediation at “NORM and Legacy Sites”

  Working Group 3 — Reference Models for “Waste Disposal”

- **Reference Approaches for Biota Dose Assessment**

  Working Group 4 — “Biota Modelling”

  Working Group 5 — “Wildlife Transfer Coefficient” Handbook

  Working Group 6 — Biota “Dose Effects Modelling”

- **Approaches for Assessing Emergency Situations**

  Working Group 7 — “Tritium” Accidents

  Working Group 8 — “Environmental Sensitivity”

  Working Group 9 — “Urban Areas”

The IAEA has decided to continue these model testing and comparison activities by setting up the Modelling and Data for Radiological Impact Assessments (MODARIA) programme. The MODARIA programme will be launched at a Technical Meeting to be held at the IAEA’s Headquarters in Vienna, Austria, from 19 to 22 November 2012.

In order to identify the interests and needs of potential participants, a questionnaire was sent out. Based on this questionnaire, proposals for the new MODARIA programme were elaborated.

2. NEEDS FOR MODEL TESTING AND COMPARISON

The MODARIA programme has been set up to continue the IAEA’s activities in the environmental area and, specifically, to address the following needs:

- The revised Basic Safety Standards (BSS)[1] have been approved by the IAEA’s Member States and are currently awaiting approval by all co-sponsoring international organizations, i.e. the Food and Agriculture Organization of the United Nations (FAO), the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD/NEA), the United Nations Environment Programme (UNEP) and the World Heath Organization (WHO). The revised BSS formulate radiation protection requirements regarding exposures to the public in planned, existing and emergency exposure situations, as well as regarding radiological impacts to the environment. MODARIA will include topics that would support and facilitate the implementation of the revised BSS.

[1] The revised BSS are contained in the General Safety Requirements publication: *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards — Interim Edition* (IAEA Safety Standards Series No. GSR Part 3 (Interim), Vienna, 2011).

- In general, the value of international exercises to develop and improve environmental assessment models is well appreciated. The IAEA Action Plan on Nuclear Safety recommends strengthening Member States’ capabilities for the assessment of exposures to the public and radiological impacts to the environment.
- The Fukushima Daiichi nuclear accident in 2011 has underlined the importance of harmonized and easy-to-use assessment tools to support decisions on radiological issues.
- A number of Member States have already launched, or plan to launch, nuclear power programmes. For the viable implementation of such programmes it is necessary to have comprehensive capabilities in place for assessing radiological impacts arising from discharges of radionuclides into the environment.
- Member States across the world need to control residues containing enhanced levels of natural radioactivity that are produced during industrial activities or during mining of metals and uranium.
- The appropriate characterization of radioactive contaminants, the assessment of resulting potential impacts and the identification of possible measures to reduce impacts are additional important issues.

The ability of the EMRAS II programme to act as an international focal point for environmental modelling issues was very much appreciated by the programme’s participants. Furthermore, such activities provide support which helps to compensate for the potential loss of knowledge and competence in the areas of radioecology and environmental assessment.

3. POSSIBLE THEMES FOR THE NEW PROGRAMME

3.1. Responses to the questionnaire

To explore the interests and needs of potential participants, a questionnaire was distributed to around 400 institutes and individuals that were involved in, or had expressed interest in, previous IAEA model testing programmes.

The proposed topics and the number of expressions of interests which each topic elicited are summarized in Table 1 below. It is interesting to note that the responses agree well with the spectrum of topics which were discussed during the EMRAS II programme. The main conclusions are as follows:

- The highest interest has been expressed for modelling contamination and exposure in urban environments. This high interest was probably triggered by the Fukushima Daiichi nuclear accident, where exposures to the public are dominated by external doses.
- Regarding the other topics, the number of expressions of interest varies within a relatively narrow range of about 45–90. Significantly, many potential participants expressed an interest in models for estimating exposures due to routine discharges of radionuclides. Guided dose assessment exercises were also high on the list, which may reflect the interest of newcomers in the programme.

TABLE 1. PROPOSED TOPICS AND NUMBER OF EXPRESSIONS OF INTEREST

Topic	**Number of expressions of interest**
Testing models to estimate exposures due to routine discharges	88
Guided dose assessment exercises for specific sites with nuclear installations	67
Exposure from NORM, mining residues and radioactive legacies	67
Biosphere modelling for safety assessments of waste disposal facilities	59
Multiple pathway analysis: Exposures after accidental releases (including countermeasures)	87
Modelling the behaviour of tritium in the environment after accidental releases	44
Application of environmental transfer data	73
Contamination of urban environments: malevolent acts and nuclear accidents	130
Assessing impact to humans and biota in an integrated approach	89
Application of models to estimate exposures to biota	89
Modelling the effects of increased levels of ionizing radiation on biota	57

- All topics related to assessment of exposures to flora and fauna and the modelling of radiation effects on biota attracted high levels of interest.
- A considerable number of potential participants are interested in topics related to tritium.

Potential participants were also asked about the specific radionuclides they were interested in, and the responses were as follows:

- The highest scores were given for carbon-14 and tritium.
- Caesium-137 had the second highest score, which is understandable since it is the most important radionuclide for mid- and long-term considerations after nuclear accidents.
- The radionuclides carbon-14, chlorine-36, selenium-79, technetium-99 and iodine-129 indicate interest in biosphere modelling for radioactive waste disposal facilities.
- Naturally occuring radioactive material (NORM) radionuclides in general, as well as radionuclides arising from natural decay chains such as uranium-238, uranium-235, uranium-234, radon-226, polonium-210 and lead-210, have also been mentioned explicitly by many responders.

Indications for specific ecosystems were given at approximately equal scores for aquatic and terrestrial ecosystems. Interest was expressed in a wide range of ecosystems ranging from arctic to tropical, also including very specific environments such as marsh and semi-natural environments.

3.2. Long standing IAEA model testing and comparison topics

Long-standing topics within the IAEA model testing and comparison programmes (i.e. Validation of Model Predictions (VAMP), BIOMASS, EMRAS I and EMRAS II) are: (a) modelling of tritium and carbon-14; (b) modelling of post-Chernobyl scenarios; and (c) modelling of aquatic systems. The value of continuing with these topics needs to be examined. On the other hand, they have so far proven to be viable topics in terms of numbers of modellers and the quality of work produced. Furthermore, model testing and comparison programmes have important training functions, as well as providing a forum for modellers with the same interests to meet and exchange views.

3.3. Proposals for MODARIA Working Groups

Proposals for the MODARIA programme have been elaborated taking into account potential participants' responses to the questionnaire, as well as the need to facilitate the implementation of the radiation protection requirements set out in the revised BSS regarding exposures to the public in planned, existing and emergency exposure situations and radiological impacts. Proposals for the following Working Groups — related to four main themes — were elaborated:

— **Remediation of Contaminated Areas**

  Working Group 1 — ***Remediation strategies*** and decision aiding techniques

  Working Group 2 — Exposures in contaminated ***urban environments*** and effect of remedial measures

  Working Group 3 — Application of models for assessing radiological impacts arising from ***NORM and*** radioactively contaminated ***legacy sites*** to support the management of remediation

— **Uncertainties and Variability**

  Working Group 4 — Analysis of ***radioecological data*** in IAEA Technical Reports Series publications to identify key radionuclides and associated parameter values for human and wildlife exposure assessment

  Working Group 5 — Uncertainty and variability analysis for assessments of radiological impacts arising from ***routine discharges*** of radionuclides

  Working Group 6 — Common framework for addressing environmental change in long term safety assessments of radioactive ***waste disposal facilities***

  Working Group 7 — Harmonization and intercomparison of models for ***accidental tritium releases***

— **Exposures and Effects on Biota**

  Working Group 8 — ***Biota modelling***: Further development of transfer and exposure models and application to scenarios

  Working Group 9 — Models for assessing radiation ***effects on*** populations of ***wildlife*** species

— **Marine Modelling**

  Working Group 10 — ***Modelling*** of ***marine*** dispersion and transfer of radionuclides accidentally released from land-based facilities

The proposals are described in detail in the following section and will be presented and discussed in full during the first MODARIA Technical Meeting, during which participants are invited to present any further proposals regarding the Working Groups.

4. PROPOSED WORKING GROUPS

4.1. Working Group 1 — *Remediation strategies* and decision aiding techniques

4.1.1. Background

The overall goal of remediation planning in contaminated areas is to identify remedial measures in such a way that they provide an optimum solution for reducing radiological impacts on the population, taking into account the site-specific circumstances, including economic, environmental and social factors.

However, apart from the benefits for the public of reducing radiological impacts, remedial actions may have undesirable impacts which need to be assessed and weighted carefully. Negative side effects may be reflected, for example, in high costs, restrictions in human activities or low acceptance by the population.

A particular challenge is posed by the fact that the various factors to be considered cannot be quantified on the same basis, i.e. many of them cannot be reduced to monetary or dose units alone. Therefore, the implementation of remediation measures following radiological emergencies in the past sometimes resulted in inadequate decisions and ineffectual remediation planning.

Recently, modern decision aiding techniques have been developed to assist in optimizing the emergency response by identifying countermeasures or remedial actions for urban environments, agricultural ecosystems, forests and water bodies. Therefore, it is necessary to evaluate the advantages and drawbacks of these various models, as well as to draw up recommendations on their application in remediation planning.

4.1.2. Objectives

- To analyse the decision making process based on experience gained from past radiological emergencies and remediation efforts, to extract lessons learned and to prepare hypothetical scenarios for the comparison of decision making models;
- To consider new decision aiding models used in other areas in terms of their applicability to emergency response/remediation planning;
- To organize model data exercises and to compare different decision making models;
- To provide recommendations on how to improve the decision making process for emergency response and remediation planning.

Substantial improvements to remediation planning in the event of radiological emergencies could be achieved by a careful and critical analysis of the decision making process during past radiological emergencies such as the Kyshtym, Chernobyl or Goiania accidents. Furthermore, scenarios might be developed for exploring the efficiency of the decisions recommended by different decision aiding models.

Overall, this demonstrates a need for reviewing the decisions that are taken to protect the population and the environment during radiological emergencies and to minimize the consequences of environmental contaminations. Such a review process would help to enhance decision aiding models.

4.2. Working Group 2 — Exposures in contaminated *urban environments* and effect of remedial measures

4.2.1. Objective

After nuclear accidents, external exposure from radionuclides in the plume as well as from radionuclides deposited on the ground is a key exposure pathway. In urban environments, exposure situations are very complex due to the interaction of dispersion, deposition on different surfaces, and exposure geometry. The Working Group will aim to test and improve the capabilities of models used in the assessment of radioactive contamination in urban environments. Specific areas of interest include dispersion and deposition events, short- and long-term contaminant redistribution following deposition events, and effectiveness of potential countermeasures or remediation efforts for reducing human exposures and doses.

4.2.2. Tasks

Several proposed topics for modelling exercises are listed below. The Working Group can carry out two or three exercises within the time frame of the MODARIA project. The exercises will be selected on the basis of participant interest and availability of information for scenario preparation.

(1) *Modelling of field dispersion experiments using tracers:*
- Short-range atmospheric dispersion following small explosions;
- Continuation of work initiated within the EMRAS II programme on simulations of dispersion experiments in the field;
- Data expected to be available for comparison with model predictions.

(2) *Modelling of indoor contamination and remediation:*
- Penetration of contamination into various types of buildings;
- Effects of weather and types of human activity;
- Effects of indoor remediation efforts.

(3) *Modelling of radionuclide transport and dispersion in municipal sewer systems:*
- Routine and periodic releases to a sewer system;
- Exposures to effluent water or sewage sludge;
- Data recently obtained from experiments in Nordic countries will be used as input data for model testing and comparison.

(4) *Modelling for decision making and remediation:*
- Mid- and long-term responses;
- Specified situations such as schools, public buildings, markets, etc.;
- Identification of important modelling endpoints to provide to authorities.

(5) *Modelling of accidental releases affecting urban areas:*
- Atmospheric dispersion:
  - Mid- and long-range,
  - Effects of terrain;
- Deposition (especially effects of wet deposition and snow);
- Effects of countermeasures and remediation efforts.

(6) *Modelling of dispersion and deposition to take into account the effects of complex urban terrain:*
   - Effects of buildings;
   - Localized accumulation of contaminants.

4.2.3. Expected outcomes

- Working Group report;
- Preparation of papers for scientific journals (one per modelling exercise).

4.2.4. Knowledge transfer

Modelling exercises are of interest to experienced assessors and to people new to the field. The Working Groups dealing with urban contamination in earlier programmes had participants from several disciplines and with a wide range of experience. The new Working Group is expected to consist of participants with a similarly wide range of interests, backgrounds and experience.

4.3. Working Group 3 — Application of models for assessing radiological impacts arising from *NORM and* radioactively contaminated *legacy sites* to support the management of remediation

4.3.1. Objectives

Worldwide, there are a number of NORM and radioactively contaminated legacy sites that require radiological assessment in order to decide on their further use. When considering measures for the remediation of already existing sites, the revised BSS recommend that the reference level for annual exposures of the public arising from such sites should be in the range of 1–20 mSv. The actual reference level applied is defined by the national regulatory body, taking into account all local circumstances.

The objective of this Working Group is to compare and further develop radionuclide transport models and radiological impact assessment approaches that can be applied in supporting decision making for the remediation of areas affected by contaminated residues from e.g. the mining industry (uranium, metals, etc.), the phosphate industry and from past activities, i.e. nuclear legacy sites.

4.3.2. Tasks

The following tasks will be carried out in parallel:

- *Development of methodology for radiological impact assessments:* The Working Group will develop detailed recommendations on how to perform radiological impact assessments in support of decision making for the remediation of radioactively contaminated land in accordance with the relevant IAEA recommendations. The methodology developed by this Working Group will be used as a starting point and will be expanded to provide more specific and detailed recommendations for typical situations where the necessity of remediating NORM and radioactively contaminated legacy sites is to be explored and/or the remediation of such sites is required.
- *Development of conceptual models:* Analyses of features, events and processes (FEPs) of relevance for the assessment of radiological impacts on humans, flora and fauna

arising from radioactively contaminated areas will be carried out, drawing on the participants' expert knowledge as well as on existing FEP databases developed in previous projects (the Improvement of Safety Assessment Methodologies for Near Surface Disposal Facilities for Radioactive Waste (ISAM) project, the projects carried out by the International Union of Radioecology's (IUR's) "Radioecology and Waste" Task Group). On the basis of these analyses, generic conceptual models for typical situations will be developed, which can be used as a basis for implementing models to be used in site-specific situations.

- *Development of a set of screening models and databases for integrated impact assessments:* The Working Group will further develop and document a set of screening models and databases that can be used in radiological impact assessments of radioactively contaminated land, taking into account existing and potential future impacts on humans, flora and fauna. This set of models will cover all potentially important transport (groundwater, atmospheric, surface run-off) and exposure pathways. An existing prototype of the models and databases will be made available to the Working Group members at the start of the programme. Training on the use of the models and databases will be provided during the course of the programme.
- *Performance of model–model and model–data comparisons:* For selected scenarios of relevance, model–model and model–data comparisons will be carried out. Some of the scenarios will be provided at the start of the programme, whilst others will be identified and developed during the course of the project. The screening models developed by the Working Group and other existing resources (RESRAD, HYDRUS, the ERICA Tool) will be used by the participants for these comparisons.

4.3.3. Results

The Working Group will produce the following results:

- Technical report describing the methodology for radiological impact assessments in support of decision making for the remediation of contaminated land.
- Report on FEP analyses and generic conceptual models for the assessment of radiological impacts to humans, flora and fauna from radioactively contaminated land.
- A set of screening models and databases for assessing remediation of radioactively contaminated land, with accompanying documentation and user guides.
- Guidance reports and training material on the use of the screening models.
- Report on model–model and model–data comparisons for different scenarios.

4.4. Working Group 4 — Analysis of *radioecological data* in IAEA Technical Reports Series publications to identify key radionuclides and associated parameter values for human and wildlife exposure assessment

4.4.1. Objectives

The assessment of exposures in planned, existing and emergency exposure situations requires situation-specific models and appropriate sets of parameters. Much has been achieved during the two EMRAS programmes in compiling data on environmental transfer. These data have been made available in the form of two Technical Reports Series (TRS) publications — one concerned with the human food chain[2] and another with transfer to wildlife[3]. Both these publications (along with an earlier one on marine systems[4]) are now widely used in assessments to estimate internal and external dose rates to humans and wildlife for different exposure conditions.

The focus of this Working Group is on identifying the most important radionuclides, pathways and parameter values for different source terms and exposure situations using the above TRS publications. This will include both humans and wildlife. Those data gaps which are unlikely to be important will also be identified.

The Working Group will also consider key radionuclides for which the development of a process based approach to modelling is justified in order to identify radioecologically sensitive areas and to achieve appropriate optimization of remedial actions.

4.4.2. Approach

The above-mentioned TRS publications present most of the data as 'global' arithmetic and geometric mean values with corresponding standard deviations. However, there are many data gaps in all three publications, as well as considerable variation in many of the parameter values. A critical evaluation is needed to identify which data gaps may be important in certain types of assessments and which are not.

The parameter value evaluations will be conducted using either: (a) widely available tools such as SRS 19[5] for humans and/or the ERICA Tool or RESRAD for wildlife; or (b) participants' own models. A set of criteria for evaluating the importance of parameter values for humans and wildlife are initially proposed for consideration:

- Source term — the magnitude of associated contamination by different radionuclides.
- Estimation of the relative magnitude and importance of total, external and internal dose from different radionuclides (using the above-mentioned TRS publications) for different radionuclides and radionuclide mixtures, wildlife groups and ecosystems. This will include the dose to humans as well as to a set of reference animals and plants.
- The sensitivity of internal and external doses due to the variability of environmental transfer parameter values for different radionuclides, including:
  - Transfer parameters values for the human food chain and wildlife — soil to plant, plant to animal, soil to organism, water to organism;
  - Distribution coefficients (K_d) for aquatic pathways.

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[2] *Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments* (Technical Reports Series No. 472, IAEA, Vienna, 2010).

[3] *Handbook for Parameter Values for the Prediction of Radionuclide Transfer to Wildlife* (in preparation; to be issued in the Technical Reports Series, IAEA, Vienna).

[4] *Sediment Distribution Coefficients and Concentration Factors for Biota in the Marine Environment* (Technical Reports Series No. 422, IAEA, Vienna, 2004).

[5] *Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment* (Safety Reports Series No. 19, IAEA, Vienna, 2001).

The parameters compiled within each of the relevant TRS publications will be evaluated to determine:

— Which parameter values may be generically representative.

— Which parameters are not generically representative because they are significantly affected by factors such as:
  - ecosystems, agricultural practices and climatic conditions on different continents;
  - chemical and physical forms and soil characteristics (e.g. clay, organic matter content, redox potential of the soil, pH);
  - life cycle stages;
  - quality and quantity of source data used for deriving the parameter value.

This will give an indication of their applicability for both humans and other organisms for different regions of the world. The analysis of the variability in the data will focus on key radionuclides, but will also include less important ones. Significant omissions, based on the above criteria, could then be identified and addressed by participants. Such an analysis would also be useful for deriving guideline values for animal feed.

The analysis of the relative importance of different parameter values for different radionuclides will enable the identification and prioritization of key radionuclides for which a process based approach to modelling may be justified as opposed to a simple empirical approach. For example, process based modelling of radiocaesium or uranium behaviour in soils may provide improved spatial and temporal prediction of food chain contamination allowing radioecologically sensitive areas to be identified. Furthermore, it would facilitate the optimization of soil based remedial actions.

The tasks carried out by this Working Group will provide an insight into data analysis and data evaluation. They are suitable for experienced modellers but also for those who are less experienced in the utilization and analysis of parameter values used for both human and wildlife assessment.

4.5. Working Group 5 — Uncertainty and variability analysis for assessments of radiological impacts arising from *routine discharges* of radionuclides

4.5.1. Background

It is recognized that uncertainty and variability are inherent in any assessment of exposures to the public and radiological impacts to the environment.

Uncertainty arises from unavoidable limitations in the assessment. It reflects the amount of knowledge about the system being investigated and relates to how accurately the doses can be estimated (e.g. the extent to which all of the parameter values in the calculation of doses are known).

Variability refers to real and identifiable heterogeneity or diversity in nature. It refers to the genuine differences that occur both in the transfer in the different environments and between individuals within a group (e.g. differences in how much of a particular food they eat or where they spend their time).

Whether doses are estimated by using measurement data, by applying models, or through a combination of measurements and calculations, the variability and uncertainty contribute to a distribution of possible values. The degree of variability and uncertainty is represented by the shape and extent of that distribution.

When protection of the public in different exposure situations is being assessed, doses may be estimated and the parameter values involved are uncertain and such uncertainties must be addressed. Sensitivity analyses can be useful for identifying which parameters are mainly affecting results determining the overall impacts.

Various publications in the IAEA Safety Standards Series include requirements and recommendations for the consideration of uncertainties. For example, the revised BSS specify that safety assessments which are to be conducted at different stages in the lifetime of an activity or facilities should include, as appropriate, a systematic critical review of any uncertainties or assumptions and their implications for protection and safety.

However, a lack of practical technical guidance for the performance of such a review, including calculations and their interpretation by decision makers, has been identified.

For this reason, it has been proposed to set up a Working Group within MODARIA with a view to discussing and identifying methods and tools for the evaluation of the results of radiological assessments, as well as of their weaknesses and strengths, in order to contribute to the development of reliable guidance for both assessors and decision makers. It is envisaged that in this Working Group regulators will work together with scientists.

4.5.2. Objective

The main objective of this Working Group is to explore and consider the issue of uncertainties and variability in planned situations and, in particular, within the context of assessing and controlling the impact of routine releases from radioactive and nuclear installations to the environment.

4.5.3. Tasks

- Identify possible tools and methods for uncertainty and variability analysis applicable to dose assessments methods and codes for routine radioactive discharges.
- Identify cases and scenarios where information on uncertainty and variability of parameters is available for the testing of methodologies.
- Discussion of the distributions of parameters and data.
- Carry out exercises where sensitive parameters could be identified and analysed, and perform an intercomparison of different methods for uncertainty and variability calculations.
- Discuss how the results of calculations of this kind could be presented and finally interpreted by decision makers.

4.5.4. Expected results

Technical basis for developing guidance on how to perform uncertainty and variability analysis that is applicable to dose assessments for routine releases from radioactive and nuclear installations, including proposals for interpretation and consideration of the results.

4.6. Working Group 6 — Common framework for addressing environmental change in long term safety assessments of radioactive *waste disposal facilities*

4.6.1. Background

Within the framework of performance assessments of radioactive waste disposal facilities, the demonstration of long term safety is a key issue. The EMRAS II Working Group “Reference models for waste disposal” (WG3) focused on describing and illustrating different assessment methods for addressing changes of the human radiation exposure conditions arising from climate change, as well as from the effects of other environmental changes on the use of land, agricultural practices and living habits, etc. The output included a set of recommendations on the content and application of models that address the above issues. These recommendations covered a wide range of initial environmental situations and sites.

One key conclusion from EMRAS II is that there is a need to review the general conceptual understanding on how the future climate may develop on a global scale, and to harmonize the application of that information to the assessment of waste repository safety, including ways of downscaling that change to regional and local scales. The output from such a review could then be used to investigate the application of other EMRAS II conclusions regarding the assessment of human radiation exposures in those changed and transiently changing environments.

4.6.2. Objectives

The objective of this new Working Group is to further develop scientific understanding of how the biosphere may develop from the present to the far future. This will be addressed by:

- Analysing key processes which drive environmental change (mainly climate change), and describing how relevant future systems may develop on a global scale. These drivers are quantitative and can be extracted from existing scientific understanding on global historical climate evolution. This analysis can be used to describe future environments, which we call ‘reference futures and future variants’. These are not predictions, but relevant examples that provide valuable input for solving specific questions in a safety assessment.
- Developing a conceptual framework and models that are valid on a global scale, and considering how that framework can be downscaled to provide the information that is required for site-specific assessments.
- Applying the conceptual framework to a number of case studies (sites) that will illustrate the interaction of site characteristics and its implications for the dose assessment models to be developed. The latter will address: (a) changes in the possibly affected environment prior to any assumed radionuclide release to the biosphere; and (b) changes occurring after or while releases are assumed to occur, including possible transient effects which may be relevant for resulting potential exposures.

4.6.3. Proposed methods and tasks

The work will be divided into the following tasks. Initial tasks can be executed in parallel:

- Identification of processes/features on a global scale that set boundaries on environmental change.

— Review assessment needs for biosphere assessment as identified in EMRAS II and other recent work.
— Define processes on the regional/local scale that are affected by global processes.
— Define alternative ‘reference futures’ if needed for safety performance assessments of specific radioactive waste repositories.
— Elaborate a methodology for deriving global ‘reference futures’.
— Identify sites with available data and test the application of the global model as input in assessments for specific sites. Sites selected should, if possible, represent a relevant range of environmental conditions.
— Apply the methodology for deriving ‘reference futures’ to key dose-relevant biosphere processes, e.g. erosion, radionuclide accumulation, land use, transient effects, and, through model calculations, determine the potential significance for assessed doses.
— Documentation of the Working Group’s activities.

4.6.4. Results

The Working Group will produce a common conceptual framework that can be used in local models for site development. The main output will be a conceptual model describing a global ‘reference future’ with ‘future variants’ which can be used anywhere for any site type. To demonstrate the implications of the concept, a number of examples of how to apply it to specific sites taking into account different conditions at potentially relevant sites will be provided. A model comparison exercise will be reported together with process modelling in ecosystems undergoing the effects of environmental change, including transient processes, and the dose implications will be explored for different site types.

The activities of this Working Group are relevant to all countries developing radioactive waste facilities and so cooperation on this topic is seen as very valuable. Instead of having to develop its own understanding of global change, each country will be able to draw on consolidated and up to date scientific evidence. The Working Group will also demonstrate how to apply that globally relevant information to the development of ‘reference futures’ that are relevant at the site specific level.

4.7. Working Group 7 — Harmonization and intercomparison of models for *accidental tritium releases*

4.7.1. Objectives

The environmental behaviour of tritium after accidental tritium releases is highly relevant to all nuclear facilities that have a significant tritium inventory. The dynamics of tritium in the terrestrial environment are the result of the complex interaction of a number of processes that are subject to hourly, daily and annual variations. Due to the uncertainties of the environmental conditions at the time of the release, predictions are inherently associated with considerable uncertainties. The work performed in the previous IAEA model testing and comparison programmes improved the understanding of many processes related to tritium washout and transfer in aquatic food chains as well as, to some extent, its transfer in the terrestrial food chain. More work is needed to enable reliable assessments of exposures related to accidental tritium releases taking into account actual weather, environmental and agricultural conditions.

4.7.2. *Tasks*

The objective of this Working Group is to further develop the models for accidental tritium releases, to test, and compare those models and to develop harmonized approaches. The work will focus on the modelling of the tritium transfer processes listed below and their integration into an easy-to-use assessment model, including the following tasks:

Analysis of the transfer of tritium in terrestrial ecosystems

A key activity of the Working Group will be the compilation, analysis, and evaluation of experiments to estimate the transfer of tritium under a wide range of environmental conditions. The discussion will focus on the following issues:

- Interception of wet deposited tritium by plant canopies and uptake by leaves
- Uptake of tritium by vegetated and non-vegetated soil
- Transfer of tritiated water (HTO) and the dynamics of HTO in the soil–plant–atmosphere complex
- Re-emission of HTO from soil as a secondary source
- Formation of organic bound tritium (OBT) at night
- Oxidation of OBT during preparation and storage of feed and food
- Turnover of OBT in litter and soil

Recently, the Institute for Radiological Protection and Nuclear Safety (IRSN) in France launched a large-scale project to study the transfer of tritium in the terrestrial ecosystem. The main objective of this project is to better understand and quantify the transfer processes of tritium from the atmosphere (air and rainwater; tritiated hydrogen (HT)/HTO) to grass and soil. The IRSN has defined five key topics that need detailed investigation in order to enable the development of improved models:

- Dynamics of formation of OBT in grass, depending on the contribution from the various compartments of the environment involved: air (water vapour), rainwater, soil (water);
- Dynamics of formation of HTO in soil from an atmospheric source of HT;
- Speciation of tritium in air (HT/HTO);
- Quantification of dry deposition of HTO;
- Quantification of wet deposition of HTO.

In order to address the enormous range of factors that affect the transfer of tritium (e.g. humidity in air and soil, temperature, current and recent rainfall, season, stage of growth etc.), the IRSN project will carry out high frequency (daily) sampling in air, rainwater and soil to reduce uncertainties of tritium transfer coefficients. This project is planned to run for five years starting in January 2013. Its results will provide invaluable input to this MODARIA Working Group.

Intercomparison of models for specific scenarios

Models simulating the transfer of tritium in the environment will be compared for the following scenarios:

— Dry or wet deposition of tritium following dry or wet weather periods;
— Dry and wet deposition of tritium during the day and during the night;
— Dry and wet deposition of tritium during different seasons.

Guidance for application of environmental tritium models:

The application of the models will be discussed, as will the possibilities and limitations of each model. Emphasis will be given to:

— Uncertainty analysis and testing against experimental data;
— Exploring possibilities for model simplification;
— Exploring the need for site-specific data;
— Links to atmospheric transport models;
— Application to fluctuating tritium release.

4.7.3. Results

— Technical report on the compilation of parameters to quantify environmental transport processes;
— Report on the analysis, tests and comparison of models developed for the transfer of tritium in the environment;
— Peer reviewed papers on improved modelling aspects and model comparison exercises;
— Technical report containing guidance for the application of improved and harmonized models for tritium.

4.8. Working Group 8 — *Biota modelling*: Further development of transfer and exposure models and application to scenarios

4.8.1. Objective

The revised BSS require the assessment of the radiological impact on the environment when planning and applying for new nuclear facilities. The objective of this Working Group is to improve Member States' assessment capabilities for protection of the environment by comparing, improving and validating models being used or developed, for biota dose assessment as part of the regulatory process of licensing and compliance monitoring of authorized releases of radionuclides. Outputs from the International Commission on Radiological Protection (ICRP), the IAEA and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) that become available during the course of the MODARIA programme will be considered where relevant.

4.8.2. Tasks

A number of tasks within this Working Group are envisaged:

(1) *Model applications*

Scenarios will be carefully selected for model comparison purposes. This should include model comparison for scenarios and situations which have not yet been considered in EMRAS/EMRAS II, such as emergency exposure situations, terrestrial NORM sites, technologically enhanced naturally occurring radioactive material (TENORM) releases, tropical and permafrost environments.

Consistency should be sought with human exposure assessment. Biota and human exposure and impact modelling should be integrated. Therefore synergies will be set up between the “Biota Modelling” Working Group and other relevant MODARIA Working Groups (e.g. the “NORM and Legacy Sites” Working Group).

(2) *Improved modelling*

— Dealing with non-equilibrium situations

The currently existing assessment models to estimate exposures to flora and fauna have been generally developed for equilibrium conditions. Such models are unlikely to be applicable during the early phase after an accident, for acute or pulsed discharges. Exposures to flora and fauna during emergencies will have only an indirect impact on decision making due to the limited management options. However, radiological impact on the environment is of public interest, and scientifically sound estimates are necessary in order to communicate to the public the extent of such impacts.

Dynamic models may be more appropriate for these situations. Therefore this Working Group proposes to:

- Assess scenarios (source terms/radionuclides) for which dynamic modelling may be required and design specific dynamic modelling scenarios (one for each of the following environments: terrestrial, marine and freshwater);
- Perform a comparison exercise with the available dynamic transfer modelling approaches and identify if, and where, improvements to the models are required. A few approaches already exist that model transfer dynamically (e.g. BURN, MOIRA-PLUS, the Belgian Nuclear Research Centre’s (SCK•CEN’s) D-DAT, ECOMOD), as identified by a dynamic modelling review performed under EMRAS II. Other models designed for human assessment contain dynamic transfer components that could be adapted to non-human biota. Next, compare with results from equilibrium modelling approaches to assess differences in overall annual dose assessments.
- Advise on if and how (aspects of) the dynamic modelling approaches can be integrated into existing tools and how the results of dynamic models would be interpreted;
- Develop a revised wildlife transfer parameter values handbook that will include dynamic transfer modelling parameters (e.g. short- and long-term biological half-lives, transfer parameter).

— Guidance for assessments for heterogeneous distribution of radionuclides in environmental media:

- Define appropriate approaches for ‘averaging’ a heterogeneous source for different reference organisms where only a part of a species population is exposed to the most contaminated area;
- Design a limited number of heterogeneous exposure scenarios and assess the effect of the heterogeneity of a site on dose rates by conducting a sensitivity analysis;

- Identify possible further improvements, such as random walk models.

— Improved dosimetry:

- Due to heterogeneity in dose distribution for some radionuclides, the application of whole-body dose coefficients is a source of uncertainty in dose assessments. However, organ-specific dose rates may be necessary for accurate assessment of effects e.g. where reproduction is the primary concern. However, at present no one knows what the appropriate reference dose is for specific animal tissue (e.g. the lung) or how to combine dose to one organ with doses to other organs to arrive at a 'biota dose equivalent'. Within MODARIA, a critical review could be conducted to investigate this and propose alternatives, based on ongoing and past research in this area;
- Improving the external dosimetry for some reference organisms (e.g. plants, shrubs, trees). This will be carried out in close coordination with the ICRP.

(3) *Training aspects*

The appropriate application of models to different scenarios would benefit from the development of guidance material. We intend to develop best-practice guidance for wildlife impact assessment for a number of scenarios including how to ensure consistency of approach in multi-tiered assessment tools and how to deal with data gaps in screening assessments.

(4) *Deliverables*

— A compilation of parameters for dynamic modelling of the transfer of radionuclides to wildlife species.

— Improved modelling approaches and a report on relevance/requirements for considering dynamic modelling approaches, adequate assessment of site heterogeneity and improved dosimetry depending on the assessment scenario;

— Peer reviewed papers on improved modelling aspects and model comparison exercises;

— Guidance material on radiological impact assessment for wildlife.

4.9. Working Group 9 — Models for assessing radiation *effects on* populations of *wildlife* species

4.9.1. Objectives

In the revised BSS, radiological environmental impact analysis is a requirement when licensing nuclear facilities. In currently applied assessment tools, the absorbed dose rates to reference organisms are the endpoints. However, the ultimate goal of radiological protection of biota is the conservation of species and maintenance of biodiversity and habitats. The exploration of possible impacts on populations is important for the credibility of conclusions drawn on the basis of the currently available assessment approaches as provided by RESRAD (Biota) and the ERICA Tool, as well as the approach developed by the ICRP. Thus, the exploration of possible consequences of radiation exposure for population dynamics has been acknowledged as an important step in testing the ecological relevance of screening values established for absorbed dose (rates) to flora and fauna.

Estimating radiological consequences on populations of wildlife species requires knowledge of exposure conditions, life history characteristics of the organisms exposed, total and time dependent absorbed dose, and dose response relationships for relevant assessment endpoints. Much work has been accomplished in this area by the European Union (EU)-funded Environmental Risk from Ionising Contaminants: Assessment and Management (ERICA) and PROTECT projects, the IUR, UNSCEAR and the ICRP, and, more recently, by the "Population Modelling" Working Group in EMRAS II and the ongoing EU-funded Strategy for Allied Radioecology (STAR) project.

The aim of this Working Group is to continue the development of models that could be applied to assess radiological impacts on populations of various species. The methods will be based on existing experimental data on radiation effects obtained during laboratory and field studies. Key issues such as the comparison of effects of: (a) chronic versus acute exposure; (b) low linear energy transfer (LET) versus high LET radiation; and (c) approximations to deduce species sensitivity distributions based on allometry and other methods in the face of scarcity of data; will be included as well.

4.9.2. Tasks

Different tasks will be considered:

- *Development of methodology for population modelling:* The Working Group will develop methodologies for estimating radiation effects at the population level based on the work performed in EMRAS II and within the EU-funded STAR project. The first step is the comparison and analysis of radiation dose effect models developed for different taxonomic groups, including terrestrial and aquatic invertebrates, fish and mammals.
- *Development of conceptual models:* For species with well-established dose–effect relationships, advanced biology-based mechanistic models will be used to analyse radiation effects as dynamic processes in organisms and novel ecological approaches will be considered to produce relevant predictions for the population level. The work will be performed in close cooperation with international research programmes in order to enable the dissemination of knowledge and experience and its application within MODARIA.
- *Development of a set of population models and databases:* Emphasis will be given to the analysis, evaluation and compilation of population models and radiation dose effect modelling parameters. This will include several simple models and their application to selected cases as well as the summary of population modelling (life history) parameters and radiation effects datasets for a limited number of species, including a dataset for the ICRP reference animals and plants. An introduction to the use of these models and databases will be provided.

4.9.3. Results

The Working Group will provide the following results:

- Development of conceptual models for the assessment of radiological impacts on humans, flora and fauna from radioactively contaminated areas.
- Compilation of a handbook of population models and radiation dose effect modelling.
- Set of population models and databases with model–model and model–data comparisons, with accompanying documentation and user guides.

4.10. Working Group 10 — *Modelling* of *marine* dispersion and transfer of radionuclides accidentally released from land-based facilities

4.10.1. Background

Major international exercises on the modelling of transport and transfer of radionuclides in the marine environment have to date focused on deep sea dumping (the OECD/NEA's Co-ordinated Research and Environmental Surveillance Programme (CRESP); 1980s–early 1990s), disposal of intermediate and high level waste in Arctic coastal seas (the IAEA's International Arctic Seas Assessment Project (IASAP); 1992–1996) and nuclear weapons testing in the South Pacific (the IAEA's assessment at the Mururoa and Fangataufa atolls; 1996–1998). Coastal and oceanographic modelling are covered in several IAEA publications dealing with authorized releases of radionuclides to the marine environment and waste disposal in the deep sea. Several significant developments over the past decade indicate that a new international modelling exercise could achieve significant progress: new developments in modelling (complex three-dimensional hydrodynamic models, optimized coding allowing implementation of complex models, techniques involving various scales and deterministic/statistical approaches, ecological modelling, dynamic transfer models etc.), improved knowledge of oceanographic and atmospheric drivers, an increased database of generic and specific parameters, new knowledge of chemical form-specific biogeochemistry and the effect of environmental change (e.g. ocean acidification) on the fate of radionuclides in the marine environment. The Fukushima Daiichi nuclear accident in 2011 resulted in significant releases to the marine environment, which prompted a large interest from modellers worldwide. A periodic benchmarking exercise open to participants worldwide is necessary in order to appropriately support the reliability of models to be used in Member States when dealing with potential uncontrolled releases of radionuclides to the marine environment.

4.10.2. Objectives

The objective of this Working Group is to compare predictions and to further develop models for the dispersion and transfer of radionuclides in the marine environment that can be used for radiological and environmental impact assessment in support of decision making in the event of accidental releases of radionuclides to the marine environment.

4.10.3. Tasks

(1) Reviewing progress in conceptual approaches to marine modelling of radionuclide dispersion and transfer:

- — Priority radionuclides as relevant for dispersal on different space–time scales, transfer and radiological significance
- — Defining scenarios for model testing and comparison on a local, regional and global scale
- — Definition of simple scenarios for sensitivity and uncertainty studies:
    - Scenario based on comprehensive and reliable dataset collected by the Baltic Marine Environment Protection Commission's (HELCOM's) Monitoring or Radioactive Substances in the Baltic Sea (MORS) project over more than 25 years. This scenario is relevant to a shallow semi-enclosed sea, with multiple sources to be considered (including Chernobyl, European reprocessing plants and coastal nuclear power plants (NPPs)) and input types (atmospheric,

riverine, seawater exchange, and coastal wash-off). The scenarios will include all marine environmental compartments: water, bottom sediments, suspended particles and biota.

(2) Model testing and comparison exercise designed for the different relevant space–time scales under consideration.

(3) Defining scenarios for coastal and open-ocean modelling of Fukushima releases. This development will be undertaken with the involvement of Japanese institutes.

(4) Modelling of dispersion and transfer of radionuclides accidentally released from the Fukushima Daiichi NPP on relevant space- and time-scales. Radionuclide concentrations in seawater, bottom sediment, suspended matter and biota will be considered. Doses to marine biota and doses to humans through marine exposure pathways will be assessed in collaboration with other working groups.

(5) Analysis and evaluation of models for estimating the dispersion of radionuclides in marine environments.

(6) Development of recommendations on methodology, conceptual models and databases to be used in marine modelling and impact assessment (partly in collaboration with other Working Groups).

4.10.4. Results

— Technical report on model intercomparison results.

— Reports and group publications of modelling results for the Baltic and Fukushima scenarios.

— Standing collaboration of modelling groups in Member States using a set of benchmarked models that can be used in emergency situations. Website fully documenting models and providing links to modelling groups and datasets. This activity will be programmatically supported after the end of MODARIA by the IAEA Environment Laboratories.

— Guidance reports and training material on the use of models.