Proposals for Topics for the IAEA's Environmental Network MODARIA II: "Modelling and Data for Radiological Impact Assessments"

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1. INTRODUCTION

Models are essential tools for use in the regulatory control of nuclear facilities and activities in planned, existing and emergency exposure situations. Modelling the fate of radionuclides in the environment and assessing the resulting radiation doses to people and the environment is needed, for example, in the evaluation of the radiological relevance of routine and accidental releases of radionuclides, to assist in decision making during remediation activities, in the framework of long-term safety assessments of nuclear waste disposal facilities, as well as for clearance and exemption of material with low levels of radioactivity.

The assessment of radiation doses to humans and impacts on the environment requires the consideration of many factors and their interaction, including the radionuclides involved, environmental conditions, agricultural practices and human life styles. Many model parameters are needed to characterize the specific exposure conditions and to quantify the transfer of radionuclides within an ecosystem. Estimated exposures are associated with uncertainties, since the parameters used to calculate them are subject to a more or less pronounced variability. This is even the case for relatively well defined boundary conditions due to the inherently incomplete knowledge about the exposure conditions.

Radiological impact assessments 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 Modelling and Data for Radiological Impact Assessment (MODARIA) programme ran from 2012 to 2015[1]. In common with the previous IAEA programmes, i.e. Biosphere Modelling and Assessment (BIOMASS), (1996–2002), and EMRAS I (2003–2007), and EMRAS II (2009–2011), it had the following general objectives:

- To improve environmental assessment models and modelling methods through model testing and comparison;
- To harmonize, where appropriate, environmental modelling philosophies, approaches, and parameter values;
- To address the radionuclide transfer in a wide range of environments conditions, including subtropical and tropical regions;
- To provide an international focal point for the exchange of information on environmental assessment modelling;
- To assist Member States in implementating IAEA Safety Standards in the field of control of exposures to the public and the environment.

The MODARIA I programme was launched during the first Technical Meeting, which was held from 19 to 22 November 2012. MODARIA I focused on the following four key areas, which were addressed through ten working groups:

[1] Hereinafter referred to as MODARIA I.

— **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 MODARIA programme concluded during the fourth Technical Meeting, which was held from 9 to 13 November 2015. All working groups are currently preparing, or have already published, a report on the objectives, methodologies and results of the work done within the framework of the MODARIA programme. All working group reports will be published in the IAEA TECDOC publication series.

The IAEA has decided to continue such model testing and comparison activities by setting up a follow-up programme, i.e. MODARIA II: Modelling and Data for Radiological Impact Assessments. The MODARIA II programme will be launched at a Technical Meeting to be held at the IAEA's headquarters in Vienna, Austria, from 31 October to 4 November 2016.

2. NEEDS FOR MODEL TESTING AND COMPARISON

The MODARIA II 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)[2] have been approved by the IAEA's Member States 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 IAEA developed safety guides in the field of protection of the public and the environment to assist Member States in implementing the related safety requirements regarding exposures to the public in planned, existing and emergency exposure situations, as well as regarding radiological impacts to the environment. MODARIA II will continue to address these activities.
- International exercises to develop and improve environmental assessment models are 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 International Expert Meetings "Decommissioning and Remediation after a Nuclear Accident", "Meeting on Assessment and Prognosis in Response to a Nuclear or Radiological Emergency", "Radiation Protection after the Fukushima Daiichi Accident – Promoting Confidence and Understanding" organized by the IAEA after the Fukushima Accident, have highlighted the importance of reliable assessments of doses to the public for decision making and communication purposes.
- Member States across the world need to manage residues containing enhanced levels of natural radioactivity produced during industrial activities or during mining of metals and uranium.
- The implementation of nuclear power programmes in Member States require comprehensive capabilities for assessing radiological impacts arising from discharges of radionuclides into the environment.

The ability of the MODARIA 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.

[2] 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, IAEA, Vienna, 2014).

3. POSSIBLE THEMES FOR THE NEW PROGRAMME

3.1. SPECIAL PLENARY SESSION DURING THE FINAL MODARIA I TECHNICAL MEETING

In order to identify the interests and needs of potential participants, a special plenary session was held during the final Technical Meeting of MODARIA I, which provided participants with the possibility to present and discuss proposals for a follow-up programme. Seventeen proposals were submitted and these proposals were discussed under the following broad headings:

— **Remediation and decision making**

- Safety assessment for NORM and legacy sites to support remediation
- A method for monitoring spatial distributions of radionuclides at legacy sites
- Decision making in existing exposure situations

— **Exposures in urban environments following accidents**

- Exposure to people in aircrafts when passing contaminated air masses
- Validation of atmospheric dispersion models applied after short-term releases of radionuclides
- Assessing exposures to people in contaminated urban environments

— **Modelling releases to the environment**

- Integrated assessment of exposures to humans and biota for routine discharges
- Environmental models and model parameters for tropical environments
- Exposures to people following accidental tritium releases

— **Radioecological data**

- Time-dependent environmental transfer parameters determined in Japan after the accident in the Fukushima NPP
- Development of a data base for sorption coefficients (K_d)

— **Exposure and effects to wild-life**

- Modelling radiation effects on populations of wildlife species
- Modelling radiation exposures to biota

— **Biosphere modelling for long-term safety assessments of waste disposal facilities**

- Climate change and landscape development in the context of long-term assessment
- Review and enhancement of IAEA-BIOMASS-6 (2003) Reference Biospheres Methodology

— **Marine modelling**

- Modelling the transfer and fate of radionuclides following short-term releases to marine systems

To analyze the proposals in view of the Member States' needs to implement the IAEA safety standards, to develop assessment capabilities, and to ensure appropriate control of exposures to the public, the IAEA Secretariat organized a Consultants' Meeting at its headquarters in Vienna from 29 February to 2 March 2016.

3.2. PROPOSALS FOR MODARIA II WORKING GROUPS

Based on the proposals made and 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 MODARIA II programme were elaborated. Work programmes for the following topics were developed:

— Remediation and decision making;

— Exposures in urban and rural environments following accidents;

— Modelling radionuclide releases to the environment;

— Analysis and evaluation of radioecological data, including radionuclide transfer in tropical and sub-tropical environments;

— Radiation exposures and effects on wildlife;

— Biosphere modelling for long-term safety assessments of waste disposal facilities;

— Marine modelling.

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

4. PROPOSED WORKING GROUPS

4.1. WORKING GROUP 1 — ASSESSMENT AND DECISION MAKING OF EXISTING EXPOSURE SITUATIONS FOR *NORM AND NUCLEAR LEGACY SITES*

4.1.1. Background

Environmental remediation of NORM and legacy waste sites[3] normally involves four main activities: (i) initial site characterization and selection of remediation criteria; (ii) identification of remediation options and their optimization, followed by subsequent development and approval of the remediation plan; (iii) implementation of the remediation plan; and (iv) post-remediation management. Following the completion of each of these main activities, a decision should be made about whether to release the site (or part of it) for either restricted or unrestricted use, or to proceed to the next activity (IAEA W-SG-3.1 and DS468: Remediation Process for Areas with Residual Radioactive Material). Similar assessment and decision processes also apply to activities involving in-situ decontamination and decommissioning of nuclear facilities.

Traditionally, assessments of radionuclide transport/transfer in the environment and effects of radionuclide exposure on human health and the environment are performed to demonstrate compliance with regulatory requirements. Such radiological environmental impact assessments are often needed to characterize the existing contamination condition or to

[3] i.e. those that are affected by contaminated residues from, for example, the mining industry (uranium, metals, etc.), the phosphate industry, or past nuclear research or production activities.

minimize undesirable radiological impacts of proposed remedial measures on humans or the environment in compliance of regulatory requirements, within the context of an overall risk assessment. Results of risk assessments provide one key input to environmental management decisions for NORM or nuclear legacy sites. In recent years, decision making for low- and intermediate-level waste at NORM and legacy sites has been moving towards using a risk-informed, performance-based approach. Decision analyses that also take into account other contributing factors (e.g. economic constraints, stakeholder preferences, etc.) are increasingly being used to aid decisions that aim at addressing waste management issues in a holistic manner, to achieve the optimum solution for disposal, closure and long-term management.

Risk assessment and decision analysis are interconnected activities: the risk assessment provides toolsets and risk information that are a central input to decision making, where the decision analysis can identify the specific needs and guide the selection of exposure scenarios for conducting the risk assessment, or can be used as part of justification and optimization in selecting feasible remedial options.

This working group will develop methodologies and toolsets for assessing radiological impacts and aiding decisions for safe remediation and management of NORM or legacy sites in the short- and long-term. These risk assessments and decision analyses will need to address the following questions:

- Do associated risks justify remedial measures?
- What are the preferred/optimal remedial options?
- Can it be demonstrated that the preferred remedial option can be safely implemented?
- Can long term safety be demonstrated?
- In addition to risks associated with radiological safety, what other factors will drive remedial decisions and how can this be evaluated?
- How can an optimum decision be made in managing the particular contamination situation, considering all the contributing factors?

4.1.2. Proposed objectives

The main objective of this working group is to further develop radionuclide transport and exposure models, as well as radiological impact assessment approaches, that can be applied to support decision making for the remediation of NORM and legacy sites. To build confidence in these exposure assessments, the working group will also conduct model comparisons using monitoring data, where available.

Additionally, the objectives of this working group also include further development of methodologies and toolsets for conducting decision analyses that aid in decision making, i.e.:

Risk Assessment Objectives

- Apply modelling methodologies and tools to existing NORM and legacy sites and facilities, considering regulatory requirements;
- Perform assessments for relevant regulatory endpoints;
- Test safety assessment models against monitoring results;
- Develop assessment protocols;
- Develop visualization of spatial radionuclide distributions and their use as input to impact assessment;

— Train end users (e.g. regulators, operators, other stakeholders) in the use of the risk assessment methodologies.

Decision Analysis Objectives

— Identify types of information required to support decision processes;
— Define "prevailing circumstances" for site specific situations;
— Evaluate arguments for supporting decisions;
— Explore the non-nuclear industry for additional methods, examples and experience;
— Explore different types of remedial options and their effectiveness in blocking/impeding exposure pathways and dose reduction.

4.1.3. Proposed tasks

The following tasks will be carried out in parallel by the Risk Assessment and Decision Analysis Subgroups. Joint sessions/meetings are encouraged to promote technical exchange and feedback between the subgroups. These joint activities will benefit from, amongst other things, the identification of overall project needs, the selection of scenarios for analyses, and the effectiveness in communicating modelling results.

Risk Assessment Tasks

The Risk Assessment Subgroup will continue to further develop modelling methodologies and tools from MODARIA I, perform model comparison and validation to build model confidence, and apply the models to existing legacy sites and facilities – considering regulatory requirements:

— ***Development of a methodology for radiological impact assessments****:* The working group could 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 relevant IAEA safety standards. 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. During MODARIA II, the methodology will be further refined with additional FEP analyses, updated screening tools, and improved databases. The working group will develop a FEP list for mining and other NORM facilities and activities and will derive relevant scenarios.
— ***Improvements to assessment models included in NORMALYSA****:* The code could be improved to incorporate new submodels for source terms, seasonal effects, integrated flow and transport models, and parameter values for different situations. Additional radionuclides or other chemicals of concern may also be incorporated, if warranted.
— ***Performance of model–model and model–data comparisons****:* For selected scenarios of relevance, model–model and model–data comparisons will be carried out to build confidence in models to be used for exposure assessments. Some of the scenarios will be provided at the start of the programme, whilst others will be developed by the working group during the course of MODARIA II. The screening models developed or reviewed by the working group in MODARIA I (RESRAD, HYDRUS, the ERICA Tool) will be used by the participants for these comparisons. As part of this effort, the

working group will conduct sensitivity and uncertainty analyses in collaboration with the planned Working Group 3 (see section 4.3 below).

- ***Application to existing sites and facilities:*** Set up and perform case studies by operators and regulators – integrating with decision making methodologies developed in the Decision Making Subgroup.
- ***Visualization of spatial radionuclide distributions at the Andreeva Bay SNF temporary storage facility in Russia:*** Integration of a device (e.g. Rucksack) for walking surveys for gamma-dose-rate measurements. Testing the use of a tool to visualize the distribution of gamma-dose rates in support of the assessment and/or licensing processes.
- ***Training of end users (regulators, operators, other stakeholders) on use of NORMALYSA:*** Hands on training during working group meetings.

Decision Analysis Tasks

The Decision Analysis Subgroup could perform the following tasks:

- ***Develop lists of "prevailing circumstances" and site specific situations*:** The lists will be developed by categorizing by facility and origin of contamination. Consideration will be given to the required quality of arguments in different scenarios, as well as the need for stakeholder engagement. The lists will be the outcome of balancing competing risks and other factors, and if necessary, resolving conflicts between risk considerations and other decision factors. An effort will be made to bring experience from non-nuclear industry into IAEA guidance (e.g. on stakeholder engagement and conflict resolution), while balancing other decision factors. Specifically, the subgroup will review experience to develop lists (e.g. existing case studies, other IAEA documents, literature review), and survey best practices in other industries, such as mining, oil/gas, chemical, cross-cultural decision making in the construction industry, stakeholder mapping, and soft modelling/problem formulation.
- ***Develop methodologies and toolsets for formalized decision analysis:*** This working group will conduct literature reviews to build on the work of MODARIA I and to start developing methodologies and toolsets for formalized decision analyses using, e.g. the Bayesian approach, to support a risk-informed, robust decision making process for managing NORM and legacy sites. The methodologies will need to: actively involve stakeholders; clearly define the decision analysis by identifying objectives, decision options, and events; and effectively communicate judgements about costs and values, uncertainty, and risks. Particular attention should be given to integrating the decision analysis methodologies and toolsets with the existing framework for assessments of radionuclide transport models and exposure risk.

4.1.4. Expected outcomes

The working group could produce the following results:

- Upgraded methodologies and modelling tools for radiological impact assessments that are internationally consistent;
- Protocols for model verifications that help build confidence in radiological impact assessments;
- Reports from model application to realistic site situations for selected reference cases that represent typical NORM and legacy contamination situations;

- Improved decision making processes as context for technical modelling, for the broader (non-technical) decision context;
- Checklists and a TECDOC to guide Member States through the decision making processes including involvement of the public;
- Recommendations on communication and engagement with relevant interested parties;
- Recommendations for methodologies for decision analyses in support of remediation and closure of NORM and legacy sites; and
- Training materials for self-study and/or use in classroom training on radiological impact assessments. Trained end users for the use of the NORMALYSA software.

4.2. WORKING GROUP 2 – ASSESSMENT OF EXPOSURES AND DOSES PLUS EFFECTIVENESS OF COUNTERMEASURES IN URBAN ENVIRONMENTS

4.2.1. Background

Following a nuclear accident, external exposure from radionuclides deposited on the ground is a key exposure pathway in both the short and long term; external exposure from radionuclides in the cloud and internal exposure from inhalation are also important in the short term while the release is continuing. Other contamination scenarios could result from accidental dispersion of radioactive sources.

In urban environments, the exposure situations are very complex due to the interaction of dispersion deposition on different surfaces and exposure geometry. The shielding effects of buildings are important in reducing exposures and can vary considerably depending on the type of building. In MODARIA I, Working Group 2 carried out a number of exercises to test models against experimental or environmental monitoring data to provide insight into the uncertainty associated with models for use in predicting the dispersion, deposition and long term behaviour of radionuclides released into an urban environment.

An important aspect of the work is the effectiveness of countermeasures that can be taken to reduce exposures following contamination of urban environments. The work of this group is of relevance to Working Group 1 (see Section 4.1 above). In addition, it would be useful if Working Group 2 could interact with the tritium sub-group within Working Group 3 (see Section 4.3 below) to make use of tritium data for testing of atmospheric models.

4.2.2. Proposed objectives

- To analyse the experience in Japan following the accident at the Fukushima Daiichi nuclear site, including carrying out a remediation exercise using a set of monitoring data;
- To review or develop specific areas of urban modelling, in particular the non-heterogeneous nature of the deposition of radionuclides with accumulation in ‘hotspots’ and the transfer of radionuclides to sewer systems;
- To investigate the limitations and possibilities for atmospheric dispersion in urban environments for both releases in an urban environment and a release outside an urban environment;
- To develop a standardized test case for different designs of nuclear reactors and to estimate deposition.

4.2.3. Proposed tasks

The following tasks could be carried out:

— Further development of the exercises carried out in MODARIA I including:
  - Carry out an atmospheric dispersion exercise based on a new data set for Sostanj, which could enable modellers to consider the effectiveness of 3D models and the use of forecasts of meteorological data;
  - Carry out a model comparison for a hypothetical situation involving a release into an urban environment (Boletice);
  - Carry out a modelling exercise to investigate the need for remediation at specific locations in Japan using data obtained following the Fukushima accident.

— Consideration of possible new areas of urban modelling including:
  - The transfer of radionuclides to sewer systems and resulting exposures;
  - Review of the possible radiological impact of aircraft flying through a radioactive plume from an unplanned release;
  - Dispersion and deposition indoors and the relative importance of indoor and outdoor contamination;
  - Initial retention and weathering of radionuclides deposited on urban surfaces;
  - The shielding effects of different building types.

4.2.4. Expected outcomes

— Improvement of urban modelling capabilities, particularly for the dispersion and redistribution of radionuclides in an urban environment.
— Improvement in the knowledge of the effectiveness and impact of remedial measures for urban environments.

4.3. WORKING GROUP 3 – ASSESSMENTS AND CONTROL OF EXPOSURES TO PUBLIC AND BIOTA FOR PLANNED RELEASES TO THE ENVIRONMENT

4.3.1. Background

It is recognized that assessments of exposure and dose from planned releases of radionuclides to the environment would benefit from an integrated approach to modelling for humans and biota, and would facilitate consistent comparisons and better informed decision making. In addition, studies on exposures from radionuclides such as tritium, carbon-14 and radon, and their proper incorporation into the models, would improve the representativeness of the models and enhance our understanding of the importance of these radionuclides.

With regard to the beneficial applications of radiation and radioactive substances, ranging from power generation to uses in medicine, industry and agriculture, the International Basic Safety Standards issued by the IAEA in 2014 states that “radiation risks to workers and the public and to the environment that may arise from these applications have to be assessed and, if necessary, controlled”. In addition, the conventional belief that the standards of environmental control needed to protect the general public would ensure that other species were not put at risk, has progressed to an international trend indicating the need to be able to demonstrate (rather than to assume) that the environment is being protected. In order to

provide the international community with practical guidance on these aspects, the IAEA is developing several documents (e.g. DS427, DS442, DS432 and the revised SRS 19).

Demonstrating that the environment is being protected is usually accomplished by means of a prospective radiological environmental assessment to identify impacts on the environment, to define the appropriate criteria for protection of the environment, to assess the impacts and to compare the expected results of the available options for protection. National and international frameworks exist for the practical implementation of the explicit demonstration of the protection of the environment against ionizing radiations and several methodologies and codes already incorporate some or all aspects of this framework (e.g. CROM8, CROMERICA, RESRAD biota, ERICA tool) and others are being developed.

A logical next step in the MODARIA II programme is to identify methods and tools for carrying out integrated radiological assessments for humans and the environment (biota), in order to contribute to the development of reliable guidance for both assessors and decision makers. The integrated approach is intended to also place focus on radionuclides of particular interest in dose assessments such as tritium, carbon-14 and radon.

The behaviour of tritium in the environment is the result of the complex interaction of many processes that are subject to annual, daily and even hourly variations, which inherently cause uncertainties in related predictions. The understanding of these processes was improved during previous IAEA model testing and comparison programmes. However, more work is needed to enable reliable assessments of exposures related to routine accidental tritium releases taking into account actual site-specific conditions. In MODARIA I, these topics were elaborated in Working Group 7.

Working Group 3 of the MODARIA II programme will be a continuation of the work performed by MODARIA I Working Groups 5 and 7. New aspects of Working Group 3 are considerations of the importance and particularities of carbon-14 and radon in the assessments of exposure and dose for planned releases to the environment. It is also recognized that Working Group 3 will benefit from interactions with the radioecologists in Working Group 4 in the MODAIRA II programme (see Section 4.4 below).

4.3.2. Proposed objectives

The main objective of this working group is to develop and apply an integrated approach to studying the impact of releases to the environment resulting from the applications of radionuclides in energy generation, medicine, research and industry on both humans and biota from ionizing radiation. This working group will also explore in which cases typically there is a need for an explicit assessment of the protection of biota from exposures to planned releases of radionuclides and when this assessment is not necessary, due to the expected trivial radiological effects. It is important that tritium, carbon-14 and radon are included in the integrated approach.

As a sub-task, the modelling of tritium characteristics after short-term releases will be performed, with focus on identified aspects of tritium transfer not yet evaluated or properly modelled. The importance of exposures to carbon-14 and radon should be, if possible, included in this integrated approach.

4.3.3. Proposed tasks

Tasks for developing an integrated approach to modelling and assessing exposure and dose to humans and biota from planned releases of radionuclides to the environment, incorporating if possible the importance of exposures to carbon-14 and radon, include but are not limited to the following:

The working group could focus on the following activities:

- Review and evaluate practical international and national guidance for the demonstration of compliance with requirements for the protection of the environment against ionizing radiations for planned facilities and activities;
- Review and evaluate state of the art tools, calculation tools and methods for performing dose assessments in routine radioactive discharges that can be used in integrated assessments of humans and biota, including uncertainties;
- Explore possible ways to incorporate modelling and/or identify the importance of carbon-14 and radon; and
- Identify a set of cases and scenarios where explicit assessment of the environment would be necessary. Hospital facilities and nuclear power plant facilities will be considered when identifying scenarios.

Furthermore, the working group could:

- Carry out dose assessments for humans and biota in identified scenarios with associated uncertainty analysis;
- Evaluate and compare models, approaches, parameters and other characteristics of the codes used in the assessments, including collaboration with the marine Working Group (7); and
- Discuss the results and give advice to the IAEA on future needs and gaps related to performing integrated dose assessments.

In addition, the tritium sub-group will investigate aspects of tritium transfer that are not yet evaluated and properly modelled. These could include:

- Influence of annual, diurnal and hourly variations of environmental conditions on the transfer of tritium in the environment;
- Model validation through comparison against results of experiments on dispersion of tritium in the environment;
- Derivation and validation of simple models for assessing short (1 day), prolonged (1–3 days) and chronic releases.

4.3.4. Expected outcomes

The resulting integrated approach could reduce uncertainty and improve confidence in regulatory assessments and lead to simplified approaches. This will also lead to improved guidance for biota modelling. Additional outcomes include:

- The analysis of the existing tools, codes and methodologies that can be used in the dose assessments of humans and biota;

- The evaluation of the change in the approach to explicitly assess exposure to biota and to demonstrate compliance with requirements for the protection of the environment against ionizing radiation in routine releases;
- The improvement of the models and codes by comparison with others and better understanding of the uncertainties in these assessments, including where possible, carbon-14 and radon;
- Improved modelling of exposures from tritium and
- Improved understanding of exposures from carbon-14 and radon.

4.4. WORKING GROUP 4 – TRANSFER PROCESSES AND DATA FOR RADIOLOGICAL IMPACT ASSESSMENT

4.4.1. Background

Assessing the radiological impact from radioactivity in the environment requires knowledge of a wide range of transfer processes and related data. This applies both when assessing exposures for people and for biota. It is important to understand the key transfer processes and to recognize the limitations of the way they are included in radiological assessments through parameters, such as root uptake factors or K_d-values (to quantify the distribution of radionuclides between the liquid and solid phase in soils or sediments).

Models used to assess radiological impact can only be an approximation to reality and, therefore, comparisons between model predictions and measurement data obtained in various situations are important to improve understanding of the key processes and to explore the limitations of the models and the uncertainty in model results. The transfer processes and related data will vary depending on the situation of interest; different aspects may need to be considered for planned, existing and emergency exposure situations, respectively. There are also differences depending on the characteristics of the environment of interest.

Much of the past work in this area was relevant to temperate climates and conditions in developed countries. It is important to consider what differences there are in the assessment methodology when considering tropical, semi-tropical or arid environments. This builds on and broadens work that was carried out by Working Group 4 of MODARIA I, Analysis of radioecological data in IAEA Technical Reports Series publications to identify key radionuclides and associated parameter values for human and wildlife exposure assessment. In carrying out this work it will be useful to liaise with Working Group 3 (see Section 4.3 above) which addresses assessments of exposure and data for planned releases to the environment, plus Working Group 5 (see Section 4.5 below) which will consider assessment of exposure and effects to biota.

4.4.2. Proposed objectives

- To consider the impact of the accidental release from the Fukushima Daiichi site in Japan in 2011 and the applicability of existing models and data to the Japanese situation;
- To identify key transfer processes for radioactivity in the environment, in the context of the situation under consideration, for use in radiological impact assessment and to provide analysis of key relevant data;
- To provide advice on the applicability of assessment models to tropical, semi-tropical and arid environments.

4.4.3. Proposed tasks

The following tasks could be addressed; they can be carried out in parallel, possibly through the establishment of sub-groups:

— *Consideration of environmental transfer parameters for radionuclides released from the accident at the Fukushima plant in the context of the assessment of exposures of people and the impact on biota.* The key processes will be considered together with the differences between different regions of Japan and the applicability of parameters determined following the accident at the Chernobyl plant in comparison to those in Japan. The following sub-tasks could be addressed:

- Compile, analyze and evaluate environmental parameters reported after the Fukushima accident, including both the results of environmental monitoring and specific experiments carried out after the accident;
- Consider the key processes of interception and retention of deposited radionuclides by plants; the transfers from soil to plants; transfer to farmed and game animals; transfers in the marine environment; losses of radionuclides through food processing and culinary preparation. Specific consideration will be given to the transfer of radionuclides to rice. In each case, identify where data are scarce and where it is possible to recommend suitable parameter values for use in Japan;
- Consider where the situation in Japan is different from that considered in previous international studies and the relevance of these differences to the assessment of doses to people and the effects on biota.

— *Further analyses of radioecological data in the IAEA Technical Reports Series publications.* The key processes will be identified together with the important parameters that are used in the representation of these processes for radiological impact assessment involving exposures of humans and biota. The application to different exposure situations (i.e. planned, existing and emergency) will have an impact on this analysis. Where possible the data included in the IAEA Technical Reports Series documents will be analyzed and expanded with advice given on the limitations of the use of the parameters generally used for assessments. In particular, the limitations and range of application of equilibrium assumptions, and the use of simple biological half-lives will be considered. The following sub-tasks could be carried out:

- Methods used to model the key processes important for radiological impact assessment will be reviewed together with the way that such processes are included in assessment tools such as IAEA SRS 19;
- Following accidental releases and for routine discharges, the interception and retention of radionuclides by plants is an important factor in radiological impact assessment. It is difficult to obtain new information in this area and much of the data used to develop the parameters and parameter values for these important processes was obtained from work carried out many years ago (e.g. in the 1960s). This original work is not necessarily easily accessible and therefore it will be obtained, and to the extent possible, made available to the scientific community, with any gaps in knowledge identified;
- One parameter that is widely used in assessment tools is the K_d representing the transfer of radionuclides from water to soil and sediment. In MODARIA I, a critical review was carried out of K_d datasets for soil and freshwater systems. This work will be further developed to include K_d-values for marine systems and to

help fill data gaps for prioritized radionuclides and scenarios as identified in MODARIA I;

- Advice will be given on the conditions for application of the K_d approach with help for users to select K_d-values and to recognize situations where it may not be appropriate to use it, as other factors (e.g. bioturbation) are important.

— *Suitability of models and data for use in tropical and other environments.* Much of the work to establish models and data for radiological impact assessment was carried out in temperate climates in developed countries (e.g. Western Europe and the USA) with some extension to semi-tropical regions. The models and data may not be applicable to other locations, including tropical and arid areas. The following sub-tasks will be carried out:

- Review applicability of current assessment methodologies and data for tropical and arid regions, considering factors such as possible exposure scenarios; effects of climate on growing seasons; differences in habit data; the effects of different house types on the shielding from external radiation;
- Consider the availability of transfer parameter values for tropical and arid areas, identifying where these differ from those normally provided in IAEA technical reports;
- Identify measurement datasets obtained in tropical or arid environments that could be used to test existing models, to determine their applicability to other enviroments;
- Identify areas where further research would be beneficial to enable improved radiological impact assessment for both humans and biota.

4.4.4. Expected outcomes

— Information on environmental transfer parameters observed following the Fukushima accident, which will be disseminated to a wide audience.

— Information on the key processes for environmental transfer and the source of key information that is used widely in radiological impact assessments (such as interception factors and retention half-times on plants following direct deposition).

— A global database of Kd values for soil, freshwater and marine systems, with practical guidance on the application of the values addressing uncertainty and the limitations of the Kd approach.

— Information and advice on the applicability of standard models and data for the assessment of the radiological impact in tropical, semi-tropical and arid regions.

4.5. WORKING GROUP 5: EXPOSURE AND EFFECTS TO BIOTA

4.5.1. Background

The revised BSS require the consideration of the radiological impact on the environment when planning and applying for an authorization for new nuclear facilities. During recent years, much time and effort has been devoted to developing models allowing biota dose assessment as part of the regulatory process of licensing and compliance monitoring of authorized releases of radionuclides. Even if the assessments performed until now have not indicated any particular risk of effects on biota under planned exposure situations, there is an increased interest from society on environmental issues, resulting in the need for an explicit

demonstration of the protection of the environment, which will lead to building and reinforcing public confidence.

In existing exposure situations (e.g. post-accidental situations, legacy sites), biota dose assessment could also be useful for the purposes of public information and transparency. At the same time, the optimization of the protection of humans in existing situations should take into account not only the reduction of doses to the public, but also economical, societal and environmental implications. To achieve these aims, efforts in both the simplification and improvement of models, which are currently used for estimation of doses and the associated uncertainties, are necessary. In addition, when assessing radiation exposure for both humans and wildlife, common pathways and processes can be identified, militating for an integration of modelling exposure for both humans and biota. The development of a human-biota integrated assessment model will be under the responsibility of Working Group 3 (see Section 4.3 above). Nevertheless, inputs from Working Group 4 are expected.

The aim of radiological protection of biota is related to higher organizational levels of populations of species and communities of different species rather than for the limitation of individual risks, as is the case for humans. The estimation of possible consequences to populations is an important step in exploring the ecological relevance of dose estimates for flora and fauna.

4.5.2. Proposed objectives

Currently, several assessment approaches and associated tools exist, e.g. the RESRAD-biota-tool, the ERICA tool, and the approach developed by the ICRP. Based on these existing models, the main objective of the working group will be to test, validate and perform intercomparisons and to improve these different approaches/models, with specific consideration to the demonstration of protection at the population level. This work will include both the transfer to biota models and the dosimetric approaches used. Specific attention will be paid to the consistency of the models applied to fulfil regulatory requirements.

The ultimate goal of radiological protection of biota is to avoid harmful effects to populations of living organisms. At the present time, it is acknowledged that models for predicting effects of radiation at the population level are far off being operational for practical assessment. Taking advantage of the work performed in this domain during the EMRAS/MODARIA programmes, the objective of the working group will be to apply and test existing population models with regard to data for different exposure situations.

4.5.3. Proposed tasks

The working group could address the following tasks:

— Validation test, comparison and improvement of conceptual and mathematical models for biota dose assessment:
  - New developments on models already existing (such as RESRAD, ERICA Tool, ICRP approach) and the implications will be explored by the working group;
  - As datasets are starting to appear from post-Fukushima studies in Japan, these could be used – among others – for model testing and evaluation;
  - Model testing and improvement will in particular focus on dosimetric approaches, on spatial dimensions (interaction of spatial distributions of populations and

spatial distribution of radionuclide activities per unit area) and on dynamic modelling.

— Testing and validating population models:
  - Based on the work performed during the EMRAS and MODARIA programmes, the main task will be to test and compare the previously identified population models. This includes testing them against laboratory and field data, if available;
  - Linking to the doses in real situations where there may be a need to regulate, from routine to accident situations, testing whether there are effects at agreed benchmark levels. Determining what is the critical proportion of a population that needs to be affected to cause long-term population effects.

4.5.4. Expected outcomes

— Evaluation of uncertainties (and ways of reducing them if any) associated with the different approaches and models;
— Development of simplified approaches for biota dose assessment ("graded approaches");
— Availability of tested and improved models to estimate possible effects to populations and indication for the necessity of such assessments with regard to regulatory requirements;
— Guidance reports and training materials on the use of models that allow assessments to biota and of models that allow integrated assessments of doses to humans and biota.

4.6. WORKING GROUP 6 — BIOSPHERE MODELLING FOR LONG-TERM SAFETY ASSESSMENTS OF HIGH LEVEL WASTE DISPOSAL FACILITIES

4.6.1. Background

Within the framework of performance assessments of radioactive waste disposal facilities, the demonstration of long-term safety and the compliance with dose criteria for hypothetical members of the public, are key issues. Long-term dose assessments are partially built upon a sound scientific basis, addressing climate change, the development of landscapes and transport processes of radionuclides within the biosphere. They are complemented with a set of plausible assumptions, e.g. with regard to the technological status of future communities and human living habits.

The MODARIA I Working Group "Common framework for addressing environmental change in long term safety assessments of radioactive waste disposal facilities" developed a methodology to evaluate the consequences of climate change and landscape development, including the identification of CO_2 emission scenarios and an approach to relate the long-term CO_2 concentrations in air to the evolution of many environmental variables on a kilometer scale. The methodology is considered to be applicable to a wide range of facilities and site conditions and was suggested to be incorporated into an update of the BIOMASS-6 methodology.

4.6.2. Proposed objectives

The objective of Working Group 6 is to critically review the conceptual basis for long-term dose assessments and, more specifically, the benefits and limitations of the conceptual framework for addressing environmental change in long term safety assessments developed

during MODARIA I. This objective includes an update and extension of the BIOMASS-6 methodology. The focus will be on the practical application, including approaches to quantitatively estimate the long-term exposure of hypothetical members of the public and populations of non-human biota, to provide guidance on how to use site-specific information and available data, and general recommendations on how to estimate the uncertainty budget and communicate the assessment results. This could be addressed by:

- Analyzing existing concepts for long-term dose assessments, addressing, e.g. climate change and landscape development, with regard to their scientific basis and complementary plausible assumptions;
- Critically reviewing the benefits and limitations of the conceptual framework for addressing climate change and landsacpe evolution in biosphere modelling in MODARIA I, identifying conceptual and/or information gaps and further developing it with regard to completeness, consistency and applicability;
- Providing guidance on site characterization (e.g. type of information, level of detail) and the data required for the long-term assessment of radioactive waste disposal facilities, including recommendations on how to use information and data in the most efficient way;
- Extending and refining the BIOMASS-6 methodology, focusing on practical applications and quantitative predictions of the long-term exposure of hypothetical members of public.

4.6.3. Proposed tasks

The work could be divided into the following tasks and initial tasks could be executed in parallel:

- Review of the conceptual framework for biosphere modelling, taking into account:
  - the framework for addressing environmental change developed during the MODARIA I programme;
  - the modelling considerations and results concerning environmental change achieved in IAEA EMRAS II WG3,
  - the results of the IAEA HIDRA project on effects of human distrubance,
  - the experience gained through example applications of the BIOMASS-6 methodology, other relevant assessments, and site characterisation and research activities since the publication of BIOMASS-6 methodology in 2003.
- Analysis of long-term dose assessments with regard to their scientific basis and complementary plausible assumptions and description of the consequences for estimating the uncertainty budget and communicating the assessment results;
- Identification of conceptual and/or information gaps, including, as already identified, further consideration of climate change and landscape develpoment in the first few hundred to 1000 years after disposal operations cease;
- Further development of the framework aiming at completeness, consistency and applicability, including assessment framework for demonstrating environmental protection;
- For selected real or hypothetical waste disposal sites:
  - Analysis of the importance of initial site characteristics and identification of information/data needed for the long-term assessment of these sites,
  - Demonstration of how to use this information in the most efficient way;

— Update and extension of the BIOMASS-6 methodology, including the development of "Biosphere Dose Conversion Factors" (or equivalent simple mathematical models) for a set of reference cases, inland sites, coastal sites and sites representing a range of different ecosystems.

The completion of these tasks will be substantially supported through analysis of results of the already mentioned IAEA projects, a variety of EU projects such as BIOCLIM and BIOMOSA. The tasks will also be supported by the substantial output of collaborative activities in the BIOPROTA Forum for addressing key issues in biosphere aspects of assessment of the long-term impact of contaminant releases associated with radioactive waste management. In particular, this will include the results of the on-going project on Review and Enhancement of the BIOMASS-6 Reference Biospheres Methodology, due to complete in 2017. This project in turn relies on the results and experience gained since 2003 at the national level from many countries.

4.6.4. Expected outcome

The expected outcome could be:

— A handbook describing a systematic, transparent and robust conceptual framework for site specific and site generic biosphere assessments for radioactive waste disposal facilities. The stepwise approach will account for long-term climate change such as modifications of sea level; it will be flexible in order to enable adaptation to the system under assessment and the specific regulatory requirements;
— A report on the scientific basis of existing long-term dose assessments and complementary plausible assumptions. This report will also address the consequences of this hybrid approach, including general guidance on how to estimate the uncertainty budget and to communicate the results of long-term assessments;
— An updated and extended version of the BIOMASS-6 methodology, including easily applicable numerical values/mathematical models to assess the long-term dose to hypothetical members of the public and information to support the demonstration of environmental protection in assessments.

The results of Working Group 6 are relevant to all countries developing disposal facilities for radioactive waste. The results will also be relevant to countries with closed disposal facilities that are still under regulatory control. The link to long-term legacy site management is also noted.

4.7. WORKING GROUP 7: ASSESSMENT OF FATE AND TRANSPORT OF RADIONUCLIDES RELEASED IN THE MARINE ENVIRONMENT

4.7.1. Background

The Fukushima Daiichi accident, which caused significant releases of radionuclides to the marine environment, prompted a considerable interest in the modelling of transport and the transfer of radionuclides in marine systems. Within the frame of the MODARIA I programme, two scenarios were studied: Chernobyl deposition on the Baltic Sea and dispersion of Fukushima releases in the Pacific Ocean. A very good agreement in model-model and model-data has been obtained for the Baltic Sea exercise, whereas blind model-model inter-comparisons for the Fukushima case have resulted in significant differences between them. It has been shown that the main reason for these differences was an extreme

sensitivity to the water circulation in environments characterized by rapidly changing currents. These results raise questions about the use of marine dispersion models when used to support decision making after an accident in the marine environment.

During recent years, many efforts were devoted to emergency situation studies. However, modelling fate and transport of radionuclides in marine environments is also of interest for environmental impact assessment in connection with controlled discharges from various sources, e.g. by the nuclear industry, and the oil and gas industry.

4.7.2. Proposed objectives

— To assess sensitivity and uncertainties in model predictions (in particular in connection with water circulation knowledge) and the relevance of their use to support decision making in emergency situations;
— To improve models describing the fate of radionuclides in marine environments through the addition of processes not yet implemented.

4.7.3. Proposed tasks

— To explore the limitations on the use of dispersion models in marine environments when used to support decision making in emergency situations: For this question, several points will be considered based on scenarios to be defined and on existing and available data sets (e.g. the Fukushima situation):
  - Assessment of the main sources of uncertainties related to the use of the different models tested;
  - Sensitivity analysis focusing on water circulation parameters knowledge;
  - Recommendations on the ability and limitations of the tested models, for the situations in which they are used to support decision making.

— Improvement of models describing the fate and transport of radionuclides in marine environments. So far, models tested take into account the dissolved phase and predict (through simple water-sediment interaction parameters) the contamination of sediments. The working group will work on the improvement of models addressing:
  - Improvement of the description of water/sediment interactions (interaction with Working Group 4 expected);
  - Improvement of the description of physico-chemical processes occurring in sediments; and
  - Integration of a dynamic biota model that allows prediction of the contamination of seafood products.

— Modelling of transport and the fate of radionuclides in marine environments, with the aim of environmental impact assessment; dispersion models can also be used within the framework of environmental impact assessments related to radionuclide discharge in seas. The off-shore oil and gas industries are a source of discharges of natural radionuclides to the marine environment. The ability of dispersion models to predict the long term fate of these discharges will be tested through model-model and model-data (if available) comparisons.

4.7.4. Expected outcomes

— Guidance on the limitations of the models to predict radionuclide dispersion in emergency situations;
— Guidance on the reliability of models for predicting dispersion under different situations (short term or long term);
— Improvement of fate and transport models by addition, in a manageable way, of processes not yet implemented.

5. TRAINING AND GUIDANCE

An important role of the MODARIA II programme will be to provide training and guidance to participants. This can be achieved through additional training sessions during MODARIA II meetings, including sessions before or after the main/annual MODARIA II Technical Meetings (TMs), or scheduled training sessions during the TMs. In addition, the general presentations given during the Plenary Sessions of MODARIA II TMs provide some general background to topics related to radiological impact assessment that are of interest to all participants, which thereby contribute to general development.

Possible refresher training at additional sessions

- Fundamentals of radiation protection – basic principles, different exposure situations, role of the key International Organisations, IAEA Safety Fundamentals and Basic Safety Standards;
- Fundamentals of radiological impact assessments for people, including an overview of process, different considerations for different exposure situations, the representative person, key findings including the relative importance of different exposure pathways for different radionuclides and situations;
- Fundamentals of radiological impact assessments for biota.

Possible training during the MODARIA II sessions

- Use of specific tools for radiological impact assessment, e.g.:
  - For NORM and legacy sites (NORMALYSA),
  - For assessing exposures of biota (e.g. ERICA),
  - For assessing exposures of people (e.g. CROM);
- More detailed session(s) on radiological impact assessment covering examples for different exposure situations, important radionuclides and exposure pathways, and sensitivity and uncertainty analyses.

Suggestions for presentations at Plenary Sessions during annual MODARIA II Technical Meetings

- Overview of relevant epidemiological studies for assessing radiation risk, which could address dosimetry and doses estimated, environmental factors and estimated risks and uncertainties and could include:
  - UNSCEAR attribution of risk report,
  - Studies around nuclear power stations including the German KIKK study and work elsewhere including around UK nuclear sites (COMARE),
  - WHO studies on Chernobyl and Fukushima,
  - Nord-Cotentin studies;
- Results of the UNSCEAR study to compare the radiological impact of different types of electrical energy production;
- Updates on the impact of the Fukushima accident (UNSCEAR and IAEA).