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DELIVERABLE 2:
A study of stakeholders views on radioecological needs in Europe in the next 5-10 years

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The objective of the FUTURAE project is to evaluate the potential for establishing deeper and sustainable collaboration in radioecology in Europe possibly in the form of Network(s) of Excellence.

The project started in October 2006 and is to end by September 2008.

Project Coordinator: Institute for Radiological Protection and Nuclear Safety

Contractors:

Institute for Radiological Protection and Nuclear Safety	IRSN
Swedish Radiation Protection Authority	SSI
Centre for Ecology and Hydrology	CEH
Belgian Nuclear Research Centre	SCK·CEN
Research Centre in Energy, Environment and Technology	CIEMAT
University of Antwerp	UA
Radiation and Nuclear Safety Authority	STUK
Jozef Stefan Institute	JSI
Norwegian Radiation Protection Authority	NRPA

Executive Summary

Within FUTURAE, the overall objective of work package 2 (WP2) is to "assess the present and future needs of end-users, and the related requirements with respect to the assessment and management of the impact of radionuclides on man and the environment". To achieve this, WP2 collated information on future needs and requirements from end-users of radioecological research/expertise within Europe, including regulators, industry, international and non-governmental organisations.

Consortium members and the End-User Group then reviewed the collated information presented in a draft report. The review was used as the basis for discussions at an End-Users workshop on needs and requirements (Stockholm; 12-13 June 2007). This deliverable is based on the outcome of the consultation process and the details the discussions, conclusions and recommendations from the associated workshop.

All background material, including detailed responses to the questionnaire and detailed discussions from the workshop, is published in the Annex 1 of D2 [Moberg *et al.*, 2007].

The need for radioecology identified by stakeholders revolved around the same themes, whether within academia, regulators, industry and other groups, as summarised in the Figure.

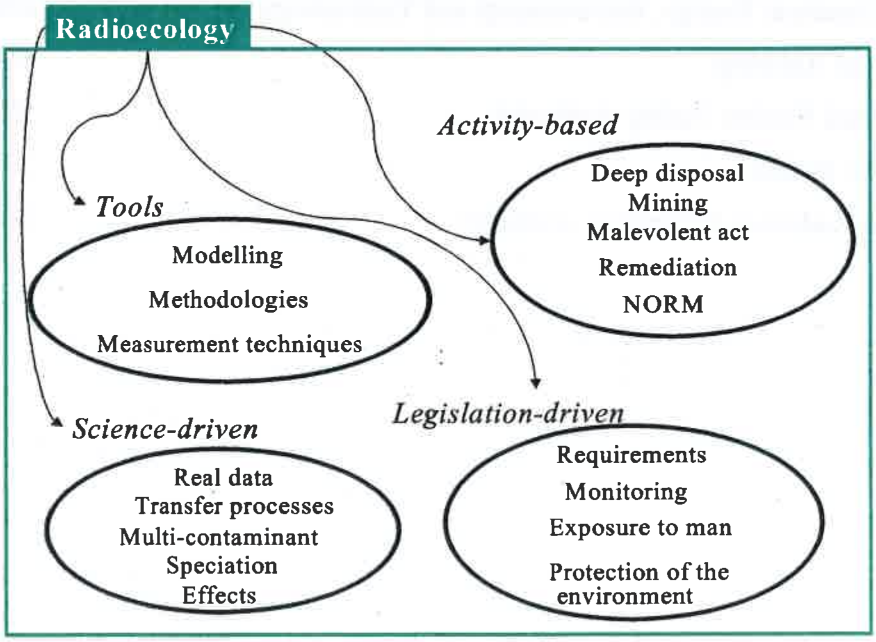

Figure: Illustration of radiological needs identified in the survey.

FUTURAE will take these findings forward to suggest over-arching topic areas, which would benefit from research at a European level within Work Packages 3 and 4.

Annex 1 of D2:

Leif Moberg, Irene Zinger, Brenda Howard, Nick Beresford, Hildegarde Vandenhove, Jean-Christophe Gariel, Almudena Agüero, Catalina Gasco, Jacqueline Garnier-Laplace, Tarja Ikäheimonen, Branko Konic, Astrid Liland (2007) Background material. Annex 1 of D2: A study of stakeholders views on radioecological needs in Europe in the next 5-10 years. EC project Contract N°FI6R-CT-2004-508847.

Acknowledgment

The FUTURAE Consortium would like to thank all the End-User Group participants who attended the workshop and especially those stakeholders who have filled in the questionnaire for their valuable contributions and inputs.

Participants of the FUTURAE Workshop on radiological needs for the future, held in Stockholm 11-12 June 2007

List of all organisations that contributed to the making of this report, i.e. End-Users Group, Respondents to the questionnaire and Consortium members.

Country	Organisation
	European Commission
	International Atomic Energy Agency
Belgium	Agency for Radioactive Waste and Enriched Fissile Materials - NIRAS/ONDRAF
Belgium	Belgian Nuclear Research Centre - SCK·CEN
Belgium	Federal Agency for Nuclear Control FANC
Croatia	Institute for Medical Research and Occupational Health - IMI
Finland	Ministry of the environment
Finland	Posiva OY
Finland	Radiation and Nuclear Safety Authority - STUK
Finland	TVO

Country	Organisation
France	Agence Nationale pour la Gestion des Déchets Radioactifs - ANDRA
France	Commissariat à l'Énergie Atomique – CEA
France	Electricité de France
France	Institute for Radiological Protection and Nuclear Safety - IRSN
Germany	Federal Office for Radiation Protection – BsF
Germany	National Research Centre for Environment and Health – GSF
Italy	ENEA- Marine Environment Research Centre (ex-employee)
Netherlands	Ministry of Housing, Spatial Planning and the Environment - VROM
Netherlands	Nuclear Research and consultancy Group – NRG
Norway	Institute for Energy Technology - IFE
Norway	Norges naturvernforbund
Norway	NorseDecom
Norway	Norwegian Food Safety Authority
Norway	Norwegian Radiation Protection Authority - NRPA
Norway	Reindeer Husbandry Administration
Norway	The Norwegian Oil Industry Association – OLF
Poland	Central Mining Institute - GIG
Romania	CNE Cernavoda
Slovenia	Jožef Stefan Institute
Spain	Research Centre in Energy, Environment and Technology - CIEMAT
Sweden	Swedish Nuclear Fuel and Waste Management Co - SKB
Sweden	Swedish Radiation Protection Authority - SSI
Switzerland	Federal Office of Public Health
UK	Centre for Ecology and Hydrology - CEH
UK	Environment Agency (England & Wales)
UK	Foods Standards Agency
UK	Scottish Environment Protection Agency - SEPA
UK	Welsh Assembly Government
USA	Savannah River Ecology Laboratory

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1 Introduction

Radioecology in the context of this project was defined as a branch of environmental sciences devoted to a specific category of stressors, namely natural and artificial radioactive substances. Radionuclides have some aspects in common with other groups of pollutants, particularly metals, particular with regard to their transport, fate, speciation, bioavailability and biological effects at various organisational levels. However, they differ with respect to their external irradiation pathway, radiation dosimetry and decay products. In this project, we consider these key issues related to all sources of radioactivity including routine and accidental releases, deep and surface disposal of radioactive wastes, areas of high natural radioactivity and environmental contamination/waste products linked with the NORM industry, and malevolent uses of radioactive substances.

Radioecological research requires qualified personnel, with competence in a variety of scientific areas, specific technical resources and dedicated tools. For the broader area of nuclear fission and radiation protection, several international organisations have highlighted that there may be inadequate expertise in the future and expressed their concern.

In this context, it is important to specify current and future needs and requirements in radioecology as identified by end-users representing industry (nuclear and non-nuclear), regulators, non-governmental organisations, scientific experts and international organisations.

Within FUTURAE, the overall objective of work package 2 (WP2) is to "assess the present and future needs of end-users (authorities, industry, decision-makers, scientists, higher education, international organisations *e.g.* IAEA, ICRP), and the related requirements with respect to the assessment and management of the impact of radionuclides on man and the environment". To achieve this, WP2 collated information on future needs and requirements from end-users of radioecological research/expertise within Europe, including regulators, industry, international and non-governmental organisations. The research community views have already been collated within WP1 [Vandenhove *et al.*, 2007].

Consortium members and the End-User Group then reviewed the collated information presented in a draft report. The review was used as the basis for discussions at an End-Users workshop on needs and requirements (Stockholm; 12-13 June 2007). This deliverable is based on the outcome of the consultation process and the details the discussions, conclusions and recommendations from the associated workshop.

All background material, including detailed responses to the questionnaire and detailed discussions from the workshop, is published in Annex 1 of Deliverable 2 [Moberg *et al.*, 2007].

2 FUTURAE WP2 survey into radioecological needs

2.1 Collation of information

To collate information on future requirements for radioecology we used two approaches: (i) a survey of end users and (ii) a review of relevant output from a number of European sources.

The survey at the European level, using a questionnaire, was aimed at determining what the key drivers would be in the future for radioecological research. This would provide underpinning information for assisting FUTURAE to evaluate the feasibility of network(s) of excellence in radioecology to maintain and enhance the required competence and sustain collaboration in assessment and management of the impact of radionuclides on man and the environment.

Information on current and future needs and requirements in radioecology was collated through publicly available reports. These included the GRS report (Gesellschaft für Anlagen und Reaktorsicherheit mbH) and reports from research programmes such as the ERICA and EURAC projects, which are all detailed in Section 3.

2.1.1 Questionnaire

The questionnaire was designed to collate information on end-user needs. The questions asked were:

1. Identify areas of interest within the field of radioecology (tick one or more):
    - Human exposure
    - Protection of the Environment
    - NORM/TeNORM
    - Multi-contaminants (radionuclides + heavy metals or organic chemicals etc)
    - Nuclear waste repositories
    - Remediation
    - Prevention of potential malevolent use of radioactive materials
    - Others.

2. Has your organisation published of research requirements?
   If yes, please provide web address or other details of how they can be obtained. What period do these documents cover?

3. Briefly summarise any radioecological needs you foresee over the next 5-10 years
   [Include research/monitoring/modelling as appropriate]

The questionnaire was distributed by the Consortium partners to selected geographical regions as follows:

- IRSN: France
- CEH: UK, Ireland and Romania
- SCK-CEN: Belgium, Germany, Netherlands, Luxemburg, Austria, Switzerland
- CIEMAT: Spain, Portugal, Italy, Greece
- STUK: Sweden, Finland, Denmark, Estonia, Latvia, Lithuania
- JSI: Slovenia, Slovakia, Czech Republic, Poland, Hungary, Bulgaria
- NRPA: Norway, Iceland, Faroe Islands

2.2 Results

The information collated has not been attributed to specific organisations, but some information is reported at country level.

From all the questionnaires sent out (over 50), 27 questionnaires were received from four end-user categories, as follows:

- two international organisations;
- two non-governmental organisations;
- nine industrial organisations;
- fourteen regulators.

The origins of the responses were Austria, Belgium, UK (England, Wales and Scotland), Germany, Finland, France, Netherlands, Norway, Poland, Romania, Slovenia, Sweden and Switzerland. Due to the fairly small sample size some interpretation may be influenced by personal interests/knowledge of the people who answered the questionnaire. Table 2.1 summarises all entries, irrespective of the end-user category or country.

2.2.1 Areas of interest within the field of radioecology

Over 50 % of respondents had similar areas of interest (Table 2.1a). Overall human exposure and the environment were considered of equal importance. Interest in remediation and prevention of potential malevolent use of radioactive materials was reported mainly by regulators (Table 2.1c) and appears to also be country-dependent (Table 2.1b).

Other areas of interests were reported by five organisations, namely:

- transport and security issues (mainly related to possible accidental releases) and implications for the environment. Biological effects on non human species (could be considered under Protection of the Environment);
- protection of animal feedstuffs and food, animal exposure;
- radon, modelling, measurement technique;
- source and environmental monitoring; legislative and regulatory aspects of the protection of human and environment;
- natural background.

Table 2.1a: Summary of WP2 questionnaire results irrespective of origin.

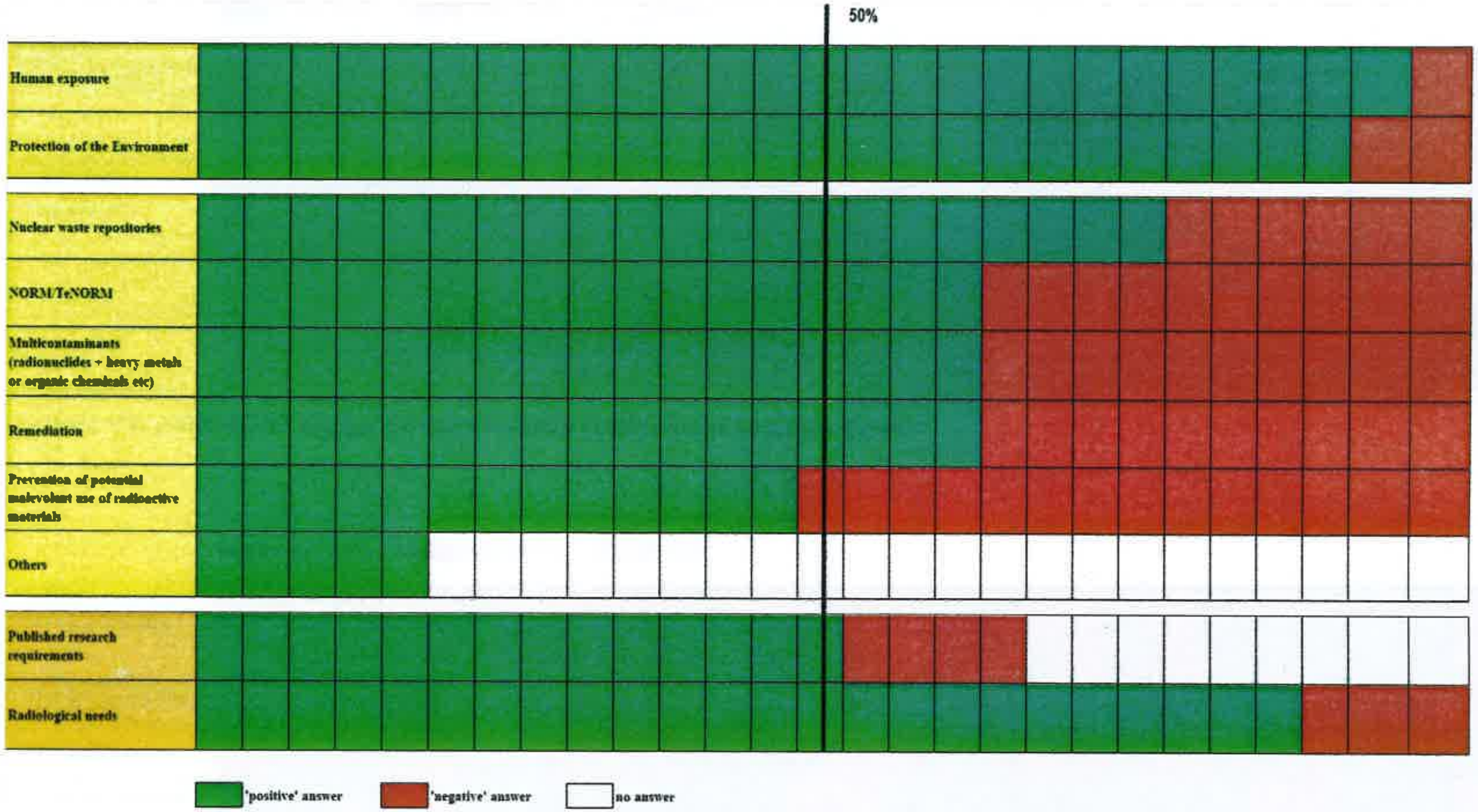


Table 2.1b: Summary of WP2 questionnaire results by country (UK – United Kingdom, RO – Romania, SF – Finland, N - Norway, B - Belgium, F-France, SW – Sweden, NL - Netherlands, P - Poland, CH - Switzerland, D - Germany and International organisations).

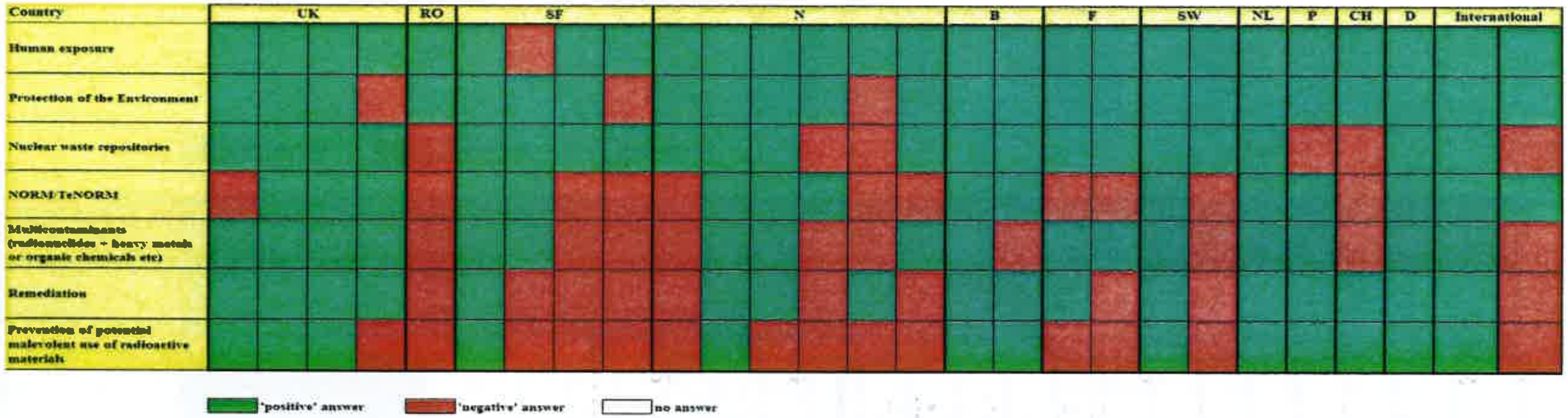
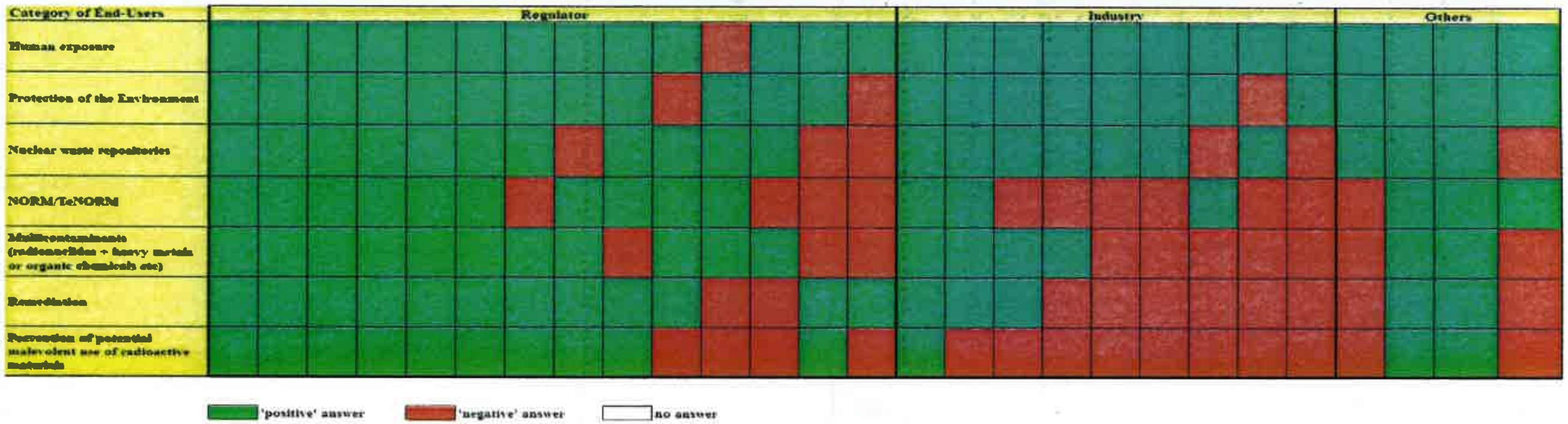


Table 2.1c: Summary of WP2 questionnaire results by type of End-User.



2.2.2 Publication of research requirements

Almost half of the respondents publish research requirements, as listed in Annex 1. Of the other organisations, only four replied that they did not do so while the others did not answer, as illustrated in Table 2.1. The priorities of the respondents will be discussed below for selected countries; note not all of these can be considered 'radioecology'.

UK

Different authorities have their own priorities dealing with policy changes that may occur over the next five years; published research requirements also vary from regular specific requirements to longer term strategies. Areas of interest include:

- radioactive waste management covering aspects such as:
    - disposing of very large volumes of VLLW;
    - review of practices for dealing with HLW;
    - addressing societal perceptions with regard to site selection for a repository;
    - developing approaches and guidance for reworking waste packages;
    - developing supporting site information for site selection of a repository;
    - understanding HLW and spent fuel safety cases and implications for waste acceptance;
    - assessing different conditioning options for dealing with challenging ILW waste forms;
    - dealing with policy changes that may occur over the next five years; and
- radioactive substances risk assessment issues:
    - developing assessment models (confirming model parameters, atmospheric modelling, GIS implementation of assessment models, dealing with uncertainties etc);
    - standard settings for radioactive substances (dealing with ICRP recommendations, defining exemption levels);
    - testing and validating assessment approaches (particularly for protection of the environment);
    - evaluating the appropriateness of sampling and monitoring programmes;
    - emergency preparedness;
    - developing the process for responding to media claims/public doubts;
    - studies on radionuclides released by UK gas cooled reactors (specific to the UK) such as ^{35}S where there is interest in the form released and associated environmental behaviour.

Finland

The regulatory body prioritises research topics on the basis of social demand, the need for new information and the contribution to radiation safety. Topical research themes during the strategy period 2007-2011 related to health effects include low radiation doses, non-targeted effects of radiation, non-cancer diseases and individual susceptibility. STUK's research activities continue in developing the measurement of radiation doses, good practices for optimising patient exposure and preparedness for radiation accidents. A new field of research focuses on radiation protection for living organisms, the goal being to put the future policies drawn up by the International Commission on Radiological Protection (ICRP) into practice. Another new field of emphasis is the development of measurements to meet the needs of security control and security arrangements. The objective is to efficiently counteract radiation and nuclear terrorism.

Some general themes of relevance for radioecology from industry include:

- the evolution of biosphere conditions at potential disposal sites:
  - climate change – evolution of the biosphere in general,
  - topographical and overburden evolution,
  - vegetation succession and fauna colonisation of emerging new areas;
- radionuclide transport and distribution in the biosphere:
  - the geosphere-biosphere interface (GBI),
  - site-specific models,
  - gaseous releases (in particular C-14), taking into account gas formation and transport processes in the biosphere system, and also gases arriving in the biosphere system that emanate from bedrock or from the repository itself,
  - uncertainties concerning transformation and transport processes at the GBI and in the biosphere and the effects of gas generated in the biosphere,
  - vegetation growth modelling,
  - the role of flora with respect to radionuclide distribution within the main food-webs of wildlife, and
  - radionuclide ingestion by humans through the consumption of berries, mushrooms and game;
- impact on non-human biota.

Ecosystem models derived from site studies also help to understand the behaviour of the ecosystem, estimate the retention times of substances and describe distributions and flows of radionuclides and other substances. Modelling tools are developed to enable use of dynamic, complicated and connected biosphere (sub)models with minimum effort.

<u>France</u>

The Ministry of Research periodically publishes "Research Strategy and Programmes on the Management of Long-Lived and High Level Radioactive Waste" as set out by the 'Law of the 31 December 1991'. The spirit of the law encompasses protection of the environment and health as well as the welfare of future generations. One of its research programme periods currently covers 2002 to 2006. Current research deals with the separation-transmutation of long-lived elements, deep geological storage, conditioning and storing of wastes. Results will be used for decision-making by parliament in 2006 regarding the most appropriate management option of these wastes.

As part of its research into the feasibility of a deep geological waste repository, Andra is conducting a programme to acquire data on the clay medium. The research programme seeks to consolidate knowledge already acquired about the subsurface and the phenomena affecting it, and check that existing computer-based models are relevant. The programme calls on every branch of the earth sciences. Radioecological data concern mainly Cs and Sr, Cl-36 modelling development, chlorine speciation in environment, foliar transfer and long-term behaviour of elements in soils.

Sweden

The goal of the projected long-term research in radioecology is to produce and communicate knowledge about the processes that influence transport of radioactive substances in the environment and their uptake in food chains.

There is a continuous need for studies of the migration of radionuclides to better understand the long-term behaviour of radionuclides in the environment, in particular in relation to repositories for radioactive waste. There is also a need for better knowledge about naturally occurring radionuclides for example concerning the exposure from NORM containing drinking water from private wells. In addition to field studies and laboratory experiments there is a need for more reliable prediction models.

Protection of the environment will be an important part of the radioecological research for the coming years. In many respects the questions are similar to those in environmental surveillance but more research is foreseen in the research area between radioecology and biology/radiation biology. Lack of information has been identified concerning the biological effects of ionising radiation on non-human biota. To estimate the risks for non-human biota (as well as for humans) knowledge is needed on the dose-response curve and the long-term changes in the distribution and concentrations of radionuclides in the environment. Of particular interest are low doses and chronic exposures.

The research should provide knowledge that is of value for radiation preparedness in the form of reliable models and strategies for the collection and interpretation of data, predictions, and recommended actions in case of incidents.

Research is needed to better understand the dose from radioactive contamination in the urban environment and how the radiation dose outdoors and indoors is dependent on different processes including remediation. Measuring techniques are important in this research.

2.2.3 Radioecological needs foreseen over the next 5-10 years

The majority of respondents also identified radiological needs over the next 5-10 years, as summarised in Tables 2.2 to 2.4. Annex 1 lists in details all the received information.

Regulators broadly identified radioecological needs in the areas of long-term impacts of repositories, multi-contamination, modelling, monitoring, impact of malevolent acts and research on NORMS, refer to Table 2.2.

Industry identified monitoring, modelling and increased data collection as needing efforts to better support regulatory requirements, see Table 2.3. Combining disciplines and coordination of effort would also help in decreasing duplication and increasing efficiency.

Table 2.2: Summary of radioecological needs listed by regulators

Research related to long-term impacts of nuclear waste repositories
Multi-contamination
Long-term impacts of radionuclides
Contaminant pathways: speciation, transfer processes, transfer modelling
Research NORM/TeNORM, impact of NORMs from uranium mining
Modelling tools, models supported by data
Maintain expertise in case of emergencies, remediation techniques, phytotechnology
Monitoring methodologies and technology
Protection against malevolent use of radionuclides

Table 2.3: Summary of radioecological needs listed by industry

Legal requirements (on discharges, on monitoring - early warning)
Assessment of the derived emission limits calculations based upon empirical data
Multi-contamination
Filling data gaps via coordination of efforts
Link radioecology/modelling with reference biosphere for long-term prediction
Modelling human exposure focussing on a limited number of radionuclides at international level
Long-term impacts of radionuclides
Long-term monitoring
Modelling, better models, simple models supported by better (transfer) data (e.g. experimentation)
More realistic models, including dynamic models, supported by *in-situ* data for verification
More data and dynamic modelling on semi-natural ecosystems
Lack of radioecological data
Develop better classification of soil systems
Information in biological half-lives
Develop better tools and methodologies to evaluate/manage risk for man related to nuclear activities

Table 2.4: Summary of radioecological needs listed by stakeholders other than regulators and industry

Adapt modelling from other disciplines
Increase data on radionuclides that may come from illicit usage
Harmonisation of principles
Radiological research on transfer parameters, mechanisms, modelling and long-term prediction
Improved computer tools for assessments of the radiation exposure of humans and non-human biota
Monitoring techniques
Develop inter-comparison exercises in different fields
Development of the radioecological databases
Improved methodologies in different fields
Improved models and methodologies for rapid decision-making

2.3 Summary

Figure 3.1 has been compiled as a way to illustrate radioecological needs based on the results of the WP2 questionnaire, as described in Section 2.

It was possible to identify overlaps and issues specific to one organisation (Table 3.1) between the different respondents types, *i.e.* regulators, industry and others excluding the research community.

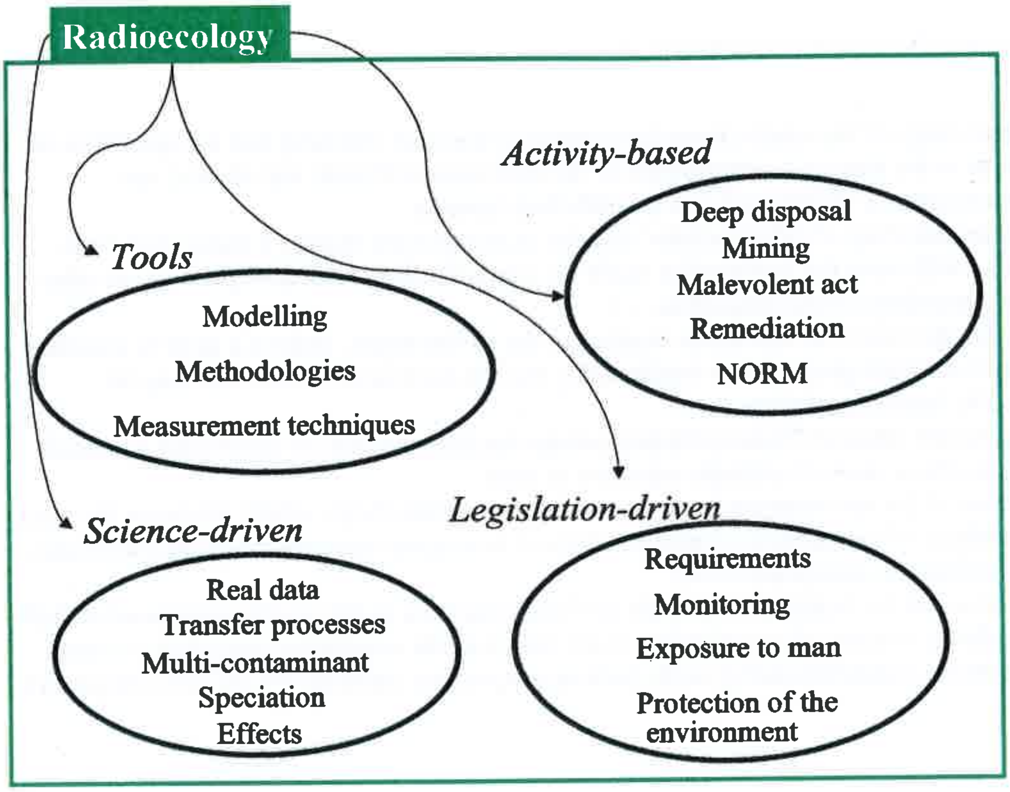


Figure 3.1: Illustration of radioecological needs identified in the survey.

Table 3.1: Overlaps and dissimilarities of issues reported by the various types of respondents to the WP2 questionnaire.

Overlaps	Specified by one group
Monitoring NORM Long-term impacts from repositories Modelling supported by real data Multi-contaminants Transfer processes	Impact of malevolent acts Impacts around mines Speciation Methodologies to cope with missing data Inter-comparisons

3 Radioecological needs from other sources

As stated in the introduction, a number of reports and initiatives were considered as they identified areas of radioecological needs for the future.

3.1 EC coordination meeting on radioecology needs

In 2003, the EC held a meeting to discuss the future of radioecology [EC, 2003]. One of its main objectives was to promote discussions within the radioecological scientific community on future research needs and priorities. A number of scientific gaps were identified during the meeting that posed European-wide problems requiring further research, divided into two classes.

"Basic science":

- A better knowledge of the source terms (accidental or nominal releases) and the speciation of radionuclides in the various compartments of the environment (biotic and abiotic) are paramount to correctly understand and quantify their transfer.
- The adequate mastering of radionuclides' transfer in ecosystems require a major shift from equilibrium-coefficients (an assumption made for simplification) to time-dependent, or other parameters-dependent coefficients (Kds,…).
- Especially for the variety of life forms existing in the environment, there is a need to construct knowledge on the biological uptake mechanisms and the associated effects that may be exacerbated by bioaccumulation.
- Paralleling current research focus in human radioprotection, the lack of knowledge is crucial on the effects of low doses in chronic exposure to biota.
- The protection of the environment issue is one facet of radioecology, which promotes the need to grasp problems of extrapolation between levels of biological organisation (from molecular, through individual, to ecosystem level).
- Data acquisition on the behaviour and effects of radionuclides in the environment need to shift from an academic context of investigation (each radionuclide considered separately) to more realistic situations characterized by multi-pollutant exposures (radioactive and non-radioactive pollutants).

"Applications":

- Strengthening the link between experimenters and modellers is an important problem with a European dimension.
- There is a need to update/improve uncertainties in radioecological guides such as the IAEA 364 on transfer factors that the Agency cannot afford to carry out on its own.
- There is a need to promote the regulation of industrial TeNORMs, a problem that is not yet appropriately grasped, and that definitely requires international progress.
- There is a need to expand practical knowledge (as well as more detailed scientific understanding) on the behaviour in the environment of long-lived radionuclides (^{129}I, ^{99}Tc, ...).
- It is also of much importance to strengthen European capabilities and efficiency in the field of emergency preparedness where exchange of information and networking are essential.

Extract from [EC, 2003]

It was recognised that there was a recent decline in radioecological research within Europe (apart from a few countries), but that it was important to preserve competence and expertise in radioecology at a European level. The major question was how to best achieve this goal.

3.2 The International Union of Radioecology

In 2003, the IUR [Brechignac, 2003] proposed that:

> "Another, perhaps more ambitious, solution is to create a Radioecology Network of Excellence (NoE), but that would need to include four essential features. Indeed, the success of a Network of Excellence in maintaining competence would be highly dependent on the willingness of the "big players" to establish and implement it with a real European spirit, instead of focusing on their own interests. This is particularly crucial in the current European context where there are only a few large Institutes with sufficient strength to establish a credible NoE. The recommendations for a radioecology Network of Excellence would therefore be:
>
> 1) to be focused on science rather than policy and regulation, at least in the first stage,
> 2) to be grounded on an "ERA platform" to be constructed, that would result from the networking of European laboratories holding technical and experimental capabilities, and to facilitate wide European access to this platform,
> 3) to include in its Joint Programme of Activities significant experimental and modelling research work, both EU- and nationally-funded,
> 4) to involve an independent expert and international entity in the overall guidance of the Network for ensuring the best balanced orientations of its activities."

The "Radioecology and Waste" Task Force of the International Union of Radioecology (IUR) published their Report 6 (IUR, 2006a) that provides an overview of the available knowledge related the behaviour of ^{14}C, ^{36}Cl, ^{99}Tc, ^{237}Np, ^{238}U in both terrestrial and aquatic ecosystems. Interaction matrices were developed for terrestrial and aquatic environments and identify the main components and processes that describe the behaviour of the radionuclides in these two broad environment types. For each studied radionuclide, the most important processes that need to be considered in long-term assessments were identified and recommendations are given for these processes on research needed for filling in data and knowledge gaps.

Possible approaches for improving the models have been outlined. By identifying the most important processes, it should be possible to reduce the complexity of the models, but justification must be given to move from a detailed model to a simplified model that is fit for the assessment purposes. The recommendations are now being carried forward as the Task Group continues to work in this area, including expanding work to more radionuclides.

Two other IUR Task Groups, one on protection in a multi-pollution context and the other on protection of the environment from ionising radiation, have carried out web-based questionnaires and identified areas of knowledge gaps in a number of areas that deserve further R&D [IUR, 2006b; IUR, 2006c respectively]. The main organisations who responded were universities and research institutes, with some regulators and very few industries.

In IUR Report 4 [2006b] nineteen respondents provided their opinions of multipollution research deficiencies and priority areas for future R&D multipollution programmes. These can be summarized, in order of priority, as follows.

1. We need to better understand how the multipollution context affects the behaviour of a single pollutant (e.g. migration, bioavailability of U where there are other chemical contaminants present.

2. We need to investigate additive and synergistic effects.
3. We need to consider the ecological response of biota to both radioactive and non-radioactive chemical stressors.
4. We rely too much on single stressors exposure experiments.
5. We rely too much on single pollutant scenarios in contaminant behaviour studies.
6. We need to investigate how environmental parameters affect the behaviour of multiple stressors in order to propose the most adequate remediation strategies.
7. We need to better understand and estimate uncertainties in a multipollution context.

In IUR Report 5 [2006c] forty-one respondents provided their opinions of environmental ionising radiation research deficiencies and priority areas for future R&D programmes. These knowledge gaps where split into five areas:

- the need for frameworks or approaches for the protection of the environment (1 statement, 4 opinions);
- transfer of radionuclides in the environment;
- effects of ionizing radiation on biota;
- dosimetry, and
- gaps in the assessment frameworks to demonstrate protection of the environment from ionising radiation.

The above needs, as decribed in detail within these two reports, are encompassed within the broad findings reported here for the FUTURAE survey.

3.3 The ERICA project

ERICA (Environmental Risk from Ionising Contaminants: Assessment and Management) was an EC partly funded FP6 project (Contract Number: FI6R-CT-2004-508847). The objective of ERICA was to provide an integrated approach to scientific, managerial and societal issues concerned with the environmental effects of contaminants emitting ionising radiation, with emphasis on biota and ecosystems. The final outcome of the project is the ERICA *Integrated Approach to assessment and management of environmental risks from ionising radiation*, using practical tools. Part of the work of the project provided an external forum for discussion and debate on a wide range of issues relating to assessment and management of environmental risks.

Areas of lack of knowledge or data were identified during the ERICA project, promoted by interactions between the Consortium and other organisations. Issues listed below were more detailed than the answers from the FUTURAE WP2 exercise, but some of the themes are nonetheless overlapping.

Source terms, transfer and uptake are all aspects where the information is patchy, and there are shortcomings in our ability to predict environmental radionuclide concentrations both under dynamic and steady-state conditions. Further complicating factors arise from seasonality and chemical speciation [ERICA D7a Part 2, 2004]. Areas where more research effort was identified as being required were:

- On site (near field) air concentrations, *e.g.* H-3, C-14.
- Seasonality, for example, data collected in one season and applied at a different

season. Other environmental variables such as temperature, rainfall. (Note this is also important for dose response and effects analysis).

- Fill data gaps on transfer factors for specific biota and specific radionuclides. It will be important to determine (on a site specific basis, perhaps using a sensitivity analysis) whether this should be done by using conservative estimates or measurements.
- Source-term speciation and its influence on the transfer and uptake of radionuclides, including metabolism and internal distribution within biological organisms.
- Transient conditions. There is a lack of experience with the methodology for estimating radioecological impact under transient conditions, such as those caused by a spill, upset conditions, and accidental releases. This includes the dynamics of radionuclide uptake, dosimetry under time dependent conditions (e.g. a growing egg), and effect evaluation. This is also related to uncertainty/knowledge gaps with respect to temporal and spatial averaging.
- To address gaps in biological effects data.

For transfer in particular, there is clearly plenty to do but it is less clear how much detailed mechanistic information is needed, such as on migration and accumulation, under dynamic conditions. Concentration ratios represent the empirical total sum of many different processes and factors – the habits of the organism with regard to: diet; the food chain through which the organism takes up radionuclides; any bio-magnification through the food chain; the dynamics of radionuclide uptake and clearance; etc. The key problem is that it is not practicable to derive empirical transfer factors for all of the [radionuclide / ecosystem / reference organism] combinations. Moreover, because there is relatively little quantitative information or understanding of the processes and mechanisms involved, extrapolating from the measured values only becomes a source of substantial uncertainty [ERICA D7c, 2005].

3.4 The GRS report

An assessment of the situation concerning centres of competence in the fields of Nuclear Fission and Radiation Protection was carried out with the intention to draw strategic conclusions regarding further needs in these fields, based on the actual situation and perceived future developments. The study was initiated by the programme committee for the Euratom research and training programme in the field of Nuclear Energy and carried out the exercise; a Panel of four independent experts from Germany, France and Czech Republic was set up. The Panel prepared a questionnaire comprising a comprehensive set of questions aiming at the acquisition of information needed to carry out the assessment exercise. The Panel mentioned few direct needs on radioecology in their report [GRS[1], 2003]. It was mentioned that research on bio-accumulation should be encouraged because it is linked to the problems of chronic contamination of humans and environment. Also the issue of radiation effects on environmental ecosystems was mentioned (at this time the EC FASSET project (2000-2003) had been launched). Another major issue for future work mentioned was radioecological risk management applied to contaminated sites and territories. It would be necessary to attract new experts to this field of socio-economic relevance.

In addition to these few examples a more detailed list of future activities in the field of radiation protection, considered by the participants in the exercise was listed without any examination or evaluation of the Panel. From that list, the following needs and future

[1] GRS - Gesellscahft für Anlagen und Reaktorsicherheit mbH

activities (partly detailed) of relevance for radioecology were highlighted by the respondents of their questionnaire.

- Radiation Exposure to Humans
  - Internal exposure of the public by chronic ingestion and research of potential bioaccumulation phenomena after chronic exposure. This research could have an impact on the biokinetics of radionuclides and internal dosimetric models.
  - Development of methods for analysis of long-lived radionuclides, such as, Tc-99, I-129, Np-137, Cs-135 by mass spectrometry.
- Characterisation of irradiation by Natural Sources
  - Risk assessment and environmental impact of depleted uranium containing Munitions.
  - Correlation of indoor radon measurements with radon progeny measurements, in soil radon and indoor and outdoor in situ gamma spectrometry measurements.
  - Data collection of natural environmental radioactivity data, evaluation of these and publication as Atlas.
- Environmental Transfer of Radioactive Substances
  - Further code development following the technology advancement in computer sciences towards the direction of convergence of model predictions and reality. Data assimilation and uncertainty analysis on atmospheric dispersion models on complex terrain.
  - Further development and coupling of the hydrological and radionuclide transport codes. Uncertainty analysis, calibration and validation of the coupled codes.
  - Experimental investigation of radionuclides on aerosols with respect to particle size. Sampling and specialisation of natural and technologically enhanced radionuclides in atmospheric aerosol.
  - Application of environmental impact techniques to the data collected to verify compliance with safety standards.
  - Advance statistical analysis, further development of advanced statistical techniques for evaluating monitoring data from various sources.
  - Using top predators for the assessment of the environmental radioecological situation.
  - Radionuclides speciation from mine and pound waters of the plant for uranium ores processing.
  - The identification and characterisation of some other polluting agents found in mine and pond waters.
  - The risk assessment for humans and environment affected by the increased number of the pollution agents.
- Radiation Effects on Environmental Ecosystems
  - Radiation effects in natural populations of aquatic organisms based on the assessment of the distributions of structural chromosome damage.
  - Conceptual model of responses of organisms, populations and ecosystems to all possible dose rates of ionising radiation in the environment.
- Restoration
  - The design and development of some efficient equipment for the mining sites cleaning-up, sites affected by the uranium ores extraction and processing.
  - The study of chemical processes from waste disposal site.
- Radioecological Risk Assessment and Management

- Radiological risk assessment from low- and medium-level waste deposits facilities. Studies of long-lived naturally occurring and waste related radionuclides in the environment using mass spectrometry.

3.5 The EURAC project

The EURAC Project [EURAC, 2006] aimed to assess current and potential levels of postgraduate provision in selected linked disciplines associated with radiological protection and radioecological competence within universities and other higher education institutes of the EU and new entrant nations in the context of demand. Based on consultations with European stakeholders EURAC proposed actions that could be taken by European Institutions and relevant organisations in Member States to secure the future of nuclear radiological protection, radiochemistry, and radioecology postgraduate education in an expanded EU.

The survey of European Stakeholders confirmed that there were significant current and future needs for personnel trained to masters-level and beyond in the broad area of radiological protection. However, even though the EURAC project showed a need for expertise in environmental pathways, environmental impact and radioecology, particularly from the 'government' and 'research' stakeholders, it did not elaborate on the more scientific needs in radioecology. In a proposed outline of a European masters degree in Radioecology, three general components are mentioned: behaviour of radionuclides in the environment; assessing the risk to man and environment; and risk management and emergency planning. In EURAC-II, proposals from the first EURAC project have been implemented.

3.6 Nordic Nuclear Safety Research

The Nordic Nuclear Safety Research (NKS), a cooperation between the five Nordic countries, is presently investigating research needs in radioecology for the coming years. General needs are foreseen for example concerning:

- transport and ecological transfer of radionuclides in terrestrial environments;
- radioactivity in foodstuffs;
- dose assessments;
- marine environments of special importance;
- radiation effects in biota: case studies at locations with high concentrations of radionuclides, studies of reference ecosystems and reference species for Nordic environments; and
- syntheses of earlier radioecological studies of Nordic interest.

A future need is also seen for systems of:

- mobile measurements;
- standardisation;
- sampling/measurement strategies for contaminated material, - areas, - foodstuffs;
- clearance of bulk material and other specific situations; and
- radionuclide analytical techniques and inter-comparisons.

Many of these research areas are also relevant in the context of emergency preparedness and radioactive waste.

3.7 Survey of the research community within FUTURAE

The objective of the FUTURAE Work Package 1 (WP1) was to inventory and assess the current level of research capacity, human resources, infrastructure, research programmes and level of funding in the domain of radioecology in Europe.

In total 354 questionnaires were sent out in 2006 (additional short questionnaires were sent out in March 2007) and 89 filled in questionnaires were returned [Vandenhove *et al.*, 2007]. Except for Cyprus, Luxembourg and Malta, at least one reply was received from each EC country. Additional replies from the non-EC countries, Switzerland and Norway, were also received. Most replies were obtained from universities (44), followed by research institutes (28), government authorities (12) and consultancies (5).

The source of funding for research and modelling activities in radioecology is almost equally shared between government authorities, organisation's own funds and national research funds. International public funding represented only 10 % of the total.

Overall, there seems to be a good coverage of different research disciplines and modelling capacity by the responding organisations. Some areas were identified where little work was carried out, *e.g.* processes in estuaries ecosystems, transfer and radiation effects studies on reptiles and amphibians.

More than 80 % of the universities and 50 - 60 % of the research institutes and government authorities provide training in radioecology.

3.7.1 Radioecological needs for the future

Overall, most organisations responding to the WP1 questionnaire gave a positive view of the future for radioecology. For the different aspects surveyed, *i.e.* personnel, funding, education and infrastructure, about 80 % of the organisations expect an increase or maintain a steady state.

According to organisations from nuclear countries, activities expected to increase were related to:

- radiation dispersive devices and radiological attacks,
- multiple pollution,
- NORM,
- effect of radiation on the environment, and
- waste disposal.

For non-nuclear countries, areas in radioecology where most increase was expected were:

- multiple pollution,
- waste disposal,
- site and environmental remediation, and
- radiation dispersive devices and radiological attack.

Figure 3.2 illustrates the general perspectives for radioecology in the future for specific issues within the research community.

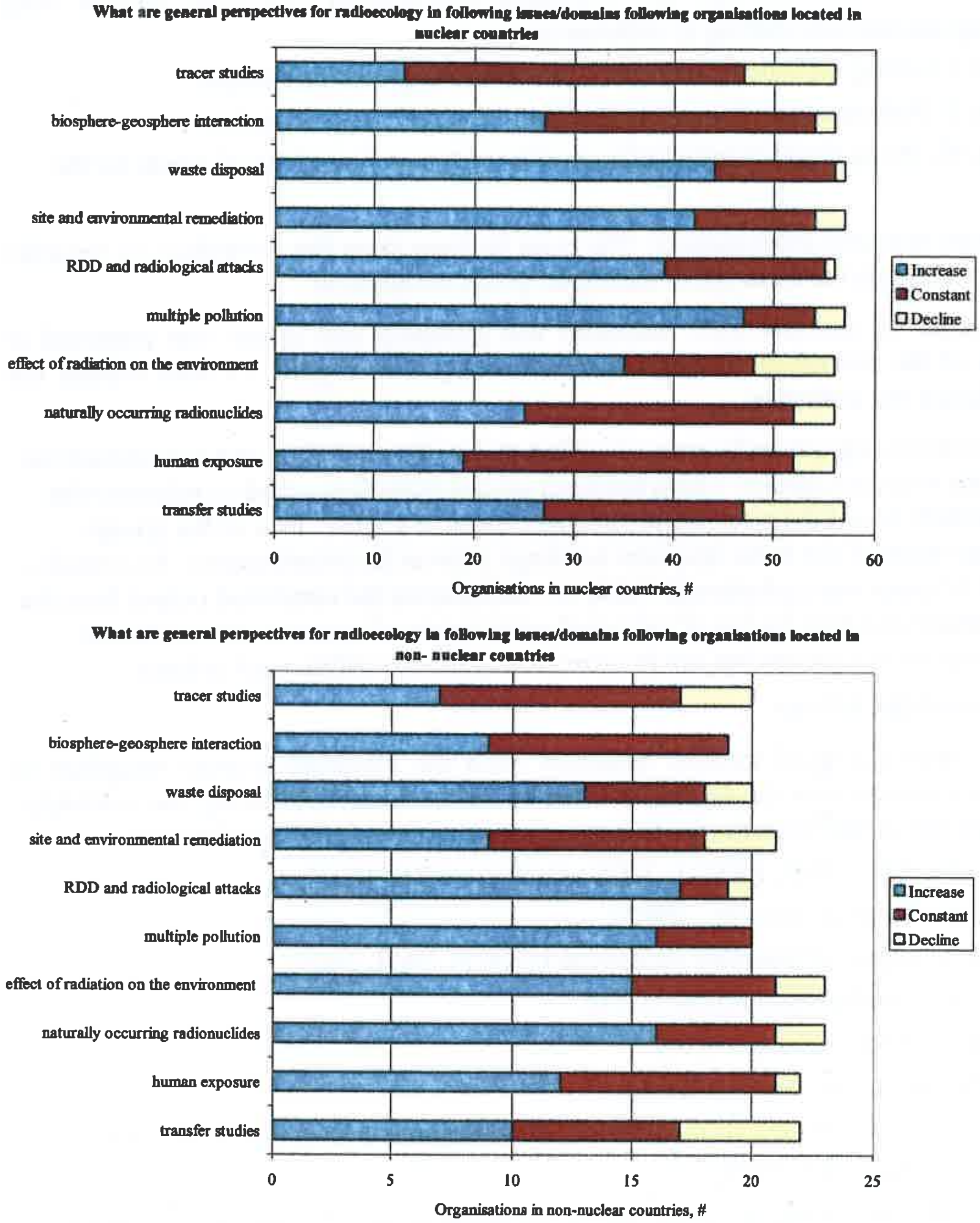


Figure 3.2: General perspectives of the future for specific domains/issues in radioecology within the research community. Evaluation for organisations in nuclear (top) and non-nuclear countries (bottom) [Vandenhove *et al.*, 2007].

4 Discussion

4.1 The FUTURAE Workshop on radioecological needs

The FUTURAE WP2 one and half day workshop was divided into three sessions with associated group discussions relating to different issues:

- Session I. Setting the broad perspective of radioecology within Europe;
- Session II. Radioecological needs identified in the WP2 questionnaire;
- Session III. Bring together information and formulate radioecological needs for the future.

All sessions were recorded anonymously. The main findings from the workshop are reported here and Annex 1 details the notes taken during all group discussions.

A number of areas of interests were discussed and grouping into issues was proposed at various stages of the workshop. The illustration developed in Figure 3.1 also reflects the issues raised during the workshop.

More detailed radioecological needs were identified during the workshop and a combined list of all suggestions was put together. Three breakout groups were then asked to prioritise the items and, if needed, re-word the statements and add items to the list. Two of the groups decided to merge some of the items into new headings prior to the prioritisation. As a result a greater number of items were prioritised. Table 4.1 summarises the combined output from the three groups, identifying thus the list of radioecological needs of common interest for all groups or only one or two groups but not in order of importance within each column.

4.2 Other considerations

Many areas of radioecological interest identified from the literature sources described in Chapter 3, are consistent with the topics listed in Table 4.1 identified during the workshop. Additional topics not identified at the workshop include (not in order of importance):

- extrapolation [EC, 2003; ERICA, 2004 and 2005 ; GRS, 2003],
- knowledge of source-term [EC, 2003],
- radiological impact of transient conditions [ERICA, 2004, 2005],
- radon/ natural background [GRS, 2003],
- cost-benefit analysis [GRS, 2003],
- dose-response curves [Section 2.2.2],
- coordination of efforts as a mechanism to addressing research needs [IUR, 2003],
- bioaccumulation [GRS, 2003],
- advanced statistical analysis [GRS, 2003], including sensitivity analysis to quantify uncertainties [Annex 1].

Emergency preparedness for nuclear accidents is partly addressed in "Human exposure", and "malevolent use of radioactive materials". Furthermore, emergency management (real-time dose assessment, exposure analysis, exposure evaluation, decision, implementation of countermeasures) in case of large-scale accidents is a key issue because the societal and economic costs related to such events are enormous. Therefore, the potential for mitigation of radiological consequences and saving money are also enormous. All areas of radioecology requires educated and well-trained people with a sound radioecological and radiological background as well as specialists from other disciplines and this is particularly true for mitigating the consequences after a large release of radioactive material to the environment.

Table 4.1: Radioecological needs identified by the groups during the Stockholm workshop.

Common to all three groups	Common to two groups	One group	Not chosen (from the list)
- Radionuclides migration as biosphere changes with time - Design monitoring to demonstrate changes (decreases) in concentrations in the environment		- Lack of understanding of long-term decrease of radionuclide concentrations in semi-natural system - Long-term monitoring of environmental system	- Effect of seasonal variation in radionuclide transfer and risk assessment - Dynamics of radionuclide concentrations in *e.g.* animal feedstuffs and food, animal and human exposure
- Modelling applicable to both human and biota exposure - Classical radioecological models to be improved to take into account their chemical properties - Validation of models using existing data, inter-comparison - Develop and implement more ecosystem models instead of transfer factor models - Understand the underlying assumptions behind transfer factors - Model developments for specific radionuclides in the nuclear field (e.g. Cl-36, I-129)	- Real-time monitoring coupled to dynamic modelling - Development of realistic models for management of releases - Determining the radioecological impact of decommissioning waste due to its complexity	- Inter-comparison of assessment results. - The importance of speciation in transfer processes - Remediation	
- Develop methodologies that combine radionuclides and chemicals to demonstrate where the problem may lie - Integrating/harmonising radioactive substances with other types of contaminants and stressors in risk assessment	- Effect on biota of chronic exposure	- Interact with other disciplines - Vulnerable ecosystems	

Common to all three groups	Common to two groups	One group	Not chosen (from the list)
- How to deal with dispersion and impact in urban areas in post-emergency situation	- Radiecology of potential malevolent use of radioactive materials	- Transport and security issues (mainly related to possible accidental releases) and implications for the environment	
- Risk assessment of natural radionuclides from various sources (terrestrial, marine, etc) or other under-researched ecosystems	- Standardisation of how to deal with NORM across Europe		
	- Social perspective: communication of radioecological risk to stakeholders - Education - training	- Use a list of radionuclides as the basis to build-up knowledge	

5 Conclusions

Within FUTURAE, the overall objective of work package 2 (WP2) was to "assess the present and future needs of end-users, and the related requirements with respect to the assessment and management of the impact of radionuclides on man and the environment". To achieve this, WP2 collated information on future needs and requirements from end-users of radioecological research/expertise within Europe, including regulators, industry, international and non-governmental organisations.

The evaluation shows that the need for radioecology revolved around the same themes, whether within regulators, industry, academia or other groups (Figure 5.1). More detailed radioecological needs identified by stakeholders participating in a workshop in Stockholm are summarised in Table 4.1.

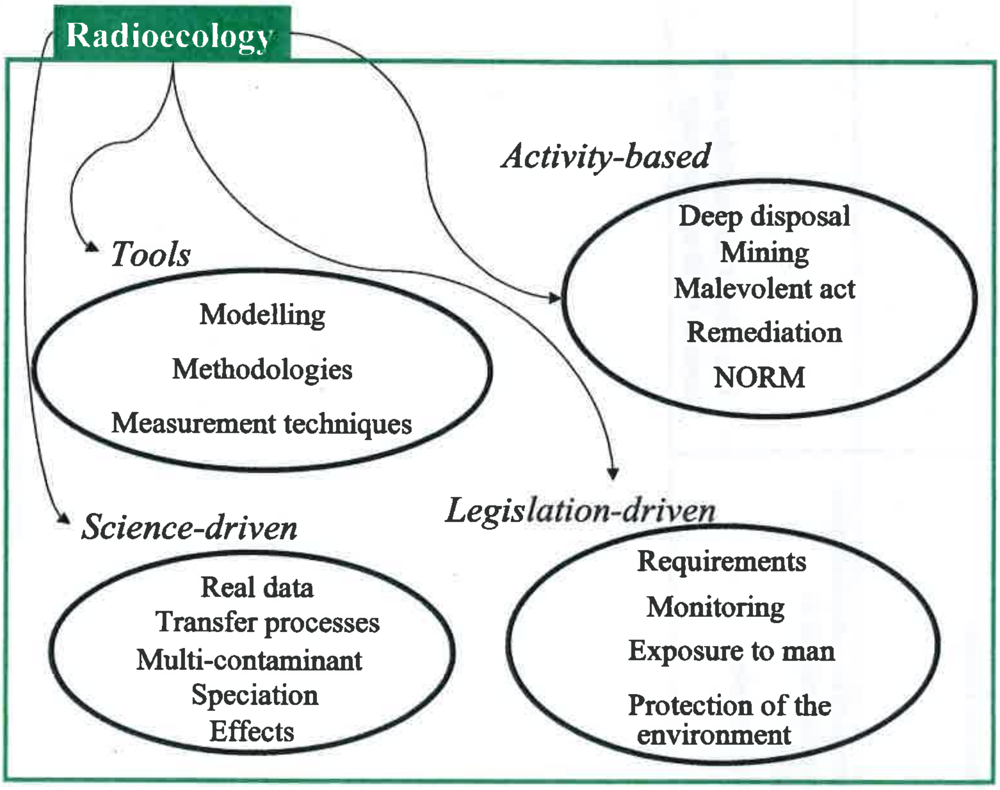


Figure 5.1: Illustration of radiological needs identified in the survey. (Same as Figure 3.1.)

From the outputs of the FUTURAE WP1 and WP2 questionnaires, the WP2 workshop and other work reviewed above it is apparent that there are common requirements for radioecological research within Europe. Within Work Packages 3 and 4, FUTURAE will take these findings forward to suggest over-arching topic areas, which would benefit from research at a European level. However, it should be noted that whilst FUTURAE will use the outcomes of the WP2 workshop (and WP1 and 2 deliverables) there will need to be critical evaluation and justification of specific topic areas for consideration.

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