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STRATEGY FOR ALLIED RADIOECOLOGY

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Executive Summary

The aim of the STAR (STrategy for Allied Radioecology) NoE was to facilitate the long term sustainable integration of European radioecological research, with an appropriate governance structure. This was done to ensure an efficient and effective integration of resources and capacities at a European level, and lead to the establishment of a European Research Area in the field of radioecology. The STAR NoE created tools to facilitate integration and contributed to the establishment of mechanisms for long term sustainability under the Radioecology ALLIANCE. The major achievements in joint programming and integration have been:

- the long term Strategic Research Agenda (SRA),
- the inventory of infrastructure including databases and sample archives,
- the virtual laboratory,
- the European Observatory sites for radioecological research,
- to start the process of long term integration.

Additionally, the STAR NoE included dissemination, training and mobility tasks to ensure the objectives of developing and implementing a shared strategy for long term training and mobility and creating advanced tools for knowledge dissemination.

With the help of STAR partners, integration of the European radioecology community is underway. The ALLIANCE, officially formed as an association in September 2012, expanded from the initial eight founding members (BfS, CIEMAT, IRSN, NERC-CEH, NRPA, SCK•CEN, SSM, STUK) to now 21 members from 14 countries. The COMET project (Coordination and iMplementation of a pan-European instrumenT for radioecology) started on 1st June 2013 builds upon the foundations laid by the ALLIANCE and STAR and will continue to strengthen the pan-European research initiative. The work to promote radioecology will also continue under the CONCERT project (European Joint Programme for the Integration of Radiation Protection Research). The research platforms ALLIANCE, MELODI, NERIS and EURADOS are partners in the consortium.

List of Acronyms and Abbreviations

ALLIANCE:	European Radioecological Alliance association. A Research Platform, in accordance with relevant European Union policies which coordinate and promote European research on radioecology
BLM:	Biotic Ligand Model
BSS:	Basic Safety Standards
CEZ:	Chernobyl Exclusion Zone
CINCH-II:	Cooperation in education and training In Nuclear Chemistry – Coordination Action
COMET:	Project Coordination and Implementation of a Pan-European Instrument for Radioecology. An EC-funded project designed to further the work of STAR.
CONCERT:	European Joint Programme for the Integration of Radiation Protection Research. A Co -fund action
CROM:	Screening code for the assessment of the radiological impact of discharges in humans.
CROMERICA:	Computer code implementing an integrated screening model for humans and wildlife (consistent combination of CROM and Tier 2 of the ERICA Assessment Tool)
DEBTox:	Dynamic Energy Budget theory applied to Toxicology
DoReMi:	Low Dose Research towards Multidisciplinary Integration – Network of Excellence
E&T:	Education and Training
EC:	The European Commission
ECTS:	European Credit Transfer and Accumulation System
ECVET:	European Credit system for Vocational Education & Training
EJP:	European Joint Programme
ENRESA:	Empresa Nacional de Residuos Radiactivos SA
ENEN:	European Nuclear Education Network
ERASMUS:	European Region Action Scheme for the Mobility of University Students
ERICA:	FP6 EURATOM funded project “Environmental Risk from Ionising Contaminants: Assessment and Management”
ERICA Tool:	Assessment model resulting from ERICA project
EU:	The European Union
EURADOS:	The European Radiation Dosimetry Group
EURATOM:	The Euratom Treaty officially established the European Atomic Energy Community.
EUTERP:	European Training and Education in Radiation Protection Foundation
FAQ:	Frequently Asked Questions

FP7:	Seventh Framework Programme, European Union research and development funding programme
FRAME:	The impact of recent releases from the Fukushima nuclear accident on the marine environment
HERCA:	Heads of the European Radiological protection Competent Authorities. A voluntary association in which the Heads of Radiation Protection Authorities work together in order to identify common issues and propose practical solutions for these issues
HLEG:	European High Level and Expert Group
IAEA:	International Atomic Energy Agency
ICRP:	International Commission on Radiological Protection
IGDTP:	Implementing Geological Disposal of Radioactive Waste Technology Platform
IRA:	Initial Research Activities
IUR:	International Union of Radioecology
MELODI:	Multidisciplinary European Low Dose Initiative. A European Platform dedicated to low dose radiation risk research
MODARIA:	Modelling and Data for Radiological Impact Assessments
MoU:	Memorandum of Understanding
NCoRE:	National Center for Radioecology of the USA
NEA:	Nuclear Energy Agency
NERIS:	European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery
NGO:	Non-governmental organisation
NoE:	Network of Excellence
NORM:	Naturally Occurring Radioactive Materials
NPP:	Nuclear power plant
OECD:	Organisation for Economic Co-operation and Development
OPERRA:	Open Project for European Radiation Research Area
PREPARE:	Innovative integrated tools and platforms for radiological emergency preparedness and post-accident response in Europe. An EC-funded project
RadEx:	The Radioecology Exchange
RATE:	RAdioactive particle Transformation processes
RL:	Research Line
RTD:	Research and Technological Development
SETAC:	Society of Environmental Toxicology and Chemistry
SRA:	Strategic Research Agenda
SRS 19:	IAEA Safety Reports Series No. 19

STAR:	Strategy for Allied Radioecology. An EC-funded Network of Excellence in radioecology under the Radioecology Alliance framework
UNSCEAR:	United Nations Scientific Committee on the Effects of Atomic Radiation
USCB:	Upper Silesian Coal Basin
WG:	Working Group
WP:	Work Package

Organizations member of the STAR NoE

BfS:	German Federal Office for Radiation Protection, Germany
CIEMAT:	Research Centre in Energy, Environment and Technology, Spain
IRSN:	French Institute of Radiation Protection and Nuclear Safety, France
NERC-CEH:	Natural Environment Research Councils Center for Ecology & Hydrology, United Kingdom
NMBU:	Norwegian University of Life Sciences, Norway
NRPA:	Norwegian Radiation Protection Authority, Norway
SCK•CEN:	Belgian Nuclear Research Centre, Belgium
STUK:	Radiation and Nuclear Safety Authority, Finland
SU:	Stockholm University, Sweden
SUNY:	State University of New York, United States of America
TOKAI:	Tokai University Educational System, Japan

Table of Contents

1 Introduction

The aim of the STAR NoE was to facilitate the long term sustainable integration of European radioecological research, with an appropriate governance structure. This was done to ensure an efficient and effective integration of resources and capacities at a European level, and lead to the establishment of an effective European Research Area in the field of radioecology. The network partners brought together not only radioecology but also leading expertise in biology, ecotoxicology, ecology, radiobiology and modelling. Their wide breadth of expertise facilitated the acknowledged requirement for greater integration of these research areas, enabling the development of improved conceptual and numerical models for increased protection of the environment and man.

The STAR NoE created tools to facilitate integration and contributed to the establishment of mechanisms for long term sustainability under the European Radioecology Alliance (ALLIANCE)[1]. The major achievements in joint programming and integration have been:

- the long term Strategic Research Agenda,
- the inventory of infrastructure including databases and sample archive,
- the virtual laboratory,
- the European Observatory sites for radioecological research,
- to start the process of long term integration.

Additionally, STAR NoE included dissemination, training and mobility tasks to ensure the objectives of developing and implementing a shared strategy for long term training and mobility and creating advanced tools for knowledge dissemination.

This deliverable report provides information on the major achievements in joint programming and integration, how they have been accomplished under the STAR NoE and how they promote the ultimate goal of setting up management structures, procedures, funding plans and legal structures, as well as joint use and development of new infrastructures. The final plan for integration accounts for the new European landscape: some of the issues regarding integration have already been taken in charge by projects (e.g. COMET) or the European platform (the ALLIANCE). This new landscape is presented in section 4. Above all the report describes the way forward, in other words how the work started in the STAR NoE will continue after STAR.

[1]European Radioecology Alliance (ALLIANCE) http://www.er-ALLIANCE.eu/, an association created by 8 organisations in Europe to integrate radioecological research in a sustainable way; In 2015, the ALLIANCE had 21 members from 14 different countries (Belgium, Croatia, Finland, France, Germany, Greece, Ireland, Kazakhstan, Norway, Poland, Portugal, Spain, Sweden and United Kingdom). The ALLIANCE is open to organisations throughout the world with interests in supporting research in radioecology.

2 Strategic Research Agenda - a vision of what can be achieved in the future through a directed effort and collaboration

The Strategic Research Agenda (SRA) in radioecology is a key living document defining the main priorities for research in order to respond to the question: "*What topics, if critically addressed over the next 20 years, would significantly advance the science of radioecology?*"

The first version of the SRA document was prepared by STAR (STAR Deliverable 2.1, May 2012). It was endorsed by the ALLIANCE the members of which recognized that sharing radioecological research could be enhanced by efficiently integrating resources among its partner organisations and prioritising group efforts along common themes of mutual interest. This first SRA was launched to the wider research community for critical review and recommendations through a questionnaire and a dedicated workshop held in November 2012 in Paris. This document received 110 comments from organizations of 36 countries (regulators, industry, research, consultants, NGO) and these comments were considered in the second version of the SRA released in September 2013. This scientific agenda was completed in STAR Deliverable 2.5, released in January 2014, by two additional sections dedicated to Education and Training (E&T) and Infrastructures. The development of the SRA for radioecology has therefore been supported by a large proportion of the radioecological community and by major international organisations (including UNSCEAR, ICRP, IAEA, IUR and NEA). The SRA highlights three scientific challenges, with 15 associated research lines, as a strategic vision of what radioecology can achieve in the future *via* a world-wide prioritization of efforts.

In the European research landscape in general, and in the field of radiation protection in particular, an initiative for coordinating research efforts has become standard. It constitutes the elementary basis to help ensuring efficient use of the limited funds available, avoiding redundancy and enhancing research quality by sharing the most advanced skills and tools. As such, the four major European research platforms in the field of Radiation Protection, namely ALLIANCE, MELODI (Multidisciplinary European Low Dose Initiative), NERIS (Preparedness for Nuclear and Radiological Emergency Response and Recovery), and EURADOS (the European Radiation Dosimetry Group) have all released their SRAs and also examined synergistic topics among them to identify common priorities to advance knowledge in the wider field of radiation protection. In-depth comparative analysis of the SRAs will be run regularly and opened to the wider community as was done in the recent OPERRA e-survey initiative implemented during the second half of 2014 (OPERRA Deliverable 4.5). This information, based on the SRAs developed and regularly updated by the four research platforms (and a yet to be developed platform for radiation protection in medicine), will be the foundation used by CONCERT, the European Joint Programme (EJP) instrument newly established as a consortium with 28 partners, 4 European research platforms, and 20 linked third parties, to develop a sustainable structure for joint programming and open research calls in the field of radiation protection in Europe.

Within the last 4-year period, the Strategic Research Agenda for radioecology has been elaborated by STAR members, commented and updated by various stakeholders and endorsed by the ALLIANCE. This document expresses the needs for radioecology and expected advances from research. The main drivers are listed hereafter (in no particular order):

- the multiple lessons learnt from the Fukushima and the Chernobyl accidents,
- the evolvement of policy in radiological protection at the international and European levels,
- the needs for improving communication with stakeholders,
- the justified requirement to fill gaps in radioecology scientific knowledge as supported by users of our research (industry, regulators, international organisations and/or associations).

Radioecology is a multidisciplinary field, as many environmental sciences are, devoted to the study of radionuclides. Any gain of knowledge and/or methods/tools is driven by the need for improving radioecological expertise for various environmental situations dealing with: the nuclear fuel cycle (from uranium mining to disposal of radioactive wastes; discharges from existing and new nuclear power plants; decommissioning of facilities); remediation of contaminated sites; naturally occurring radionuclides; and nuclear accidents or terrorist events. Radioecology is therefore driven by operational outcomes to gain the capability of assessing the impact and/or the risk to human and non-human biota. This led the STAR consortium to articulate the SRA as any environmental risk assessment, namely developing three major components: exposure analysis (challenge 1), effects analysis (challenge 2) and risk characterization, along with risk management and communication (challenge 3). The SRA was complemented by a preliminary roadmap document (subsequent referred to as a roadmap) produced by the COMET (Coordination and iMplementation of a pan-European instrument for radioecology) project (see section 4.1), with the help of STAR and the endorsement of the ALLIANCE (see section 4.2). The strategy underlying the roadmap construction was driven by the need for improvement of underpinning mechanistic knowledge, for better and more robust models and tools, and fit-for-purpose human and environmental impact assessment for the three types of exposure situations as defined by ICRP (*i.e.*, planned, existing and emergency). Research topics for radioecology were prioritized within this preliminary roadmap to areas relevant for post-emergency management, low-dose effects and dosimetry research, to provide a powerful catalyst to further develop collaboration between the four platforms of radiation protection: ALLIANCE, NERIS, MELODI and EURADOS. On this basis, the ALLIANCE organized a workshop (Madrid, 29-30 April 2014) to identify the on-going research activities and present the fields of excellence of each ALLIANCE member. Alongside research activities funded by the EC under STAR and COMET, this constituted the basic information to identify groups of interest per challenge/research line of the SRA. At present, a number of topical working groups have been launched. The groups have begun to establish 5-year roadmaps for research priorities and started collaborative research activities (in-part through the COMET project, see RadEx). The six topical working groups (WGs) are dealing with: marine radioecology, NORM, forest radioecology, human foodchain, inter- and intra-species radiation sensitivity and transgenerational effects. A 7th topical WG is under development (atmospheric dispersion processes) highlighting that the roadmap development is not a static process.

An overarching roadmap will be established by combining the activities described by the seven topical roadmaps established under the WGs. It is planned to update the roadmap regularly and also to welcome new topical WGs to enlarge the scientific framework and to integrate new priorities. This will include a clear and updated mapping of on-going projects for the radioecology-related activities at the European level and beyond: EC-funded projects and national projects from the ALLIANCE members. Among the key tools for success of integration, open calls under the EJP-CONCERT will play a crucial role to catalyse joint programming across radiation protection.

2.1 Introduction to SRA and associated initiatives

Various stakeholders contributed to the SRA, mainly through two events: the STAR SRA workshop in November 2012 (Paris) which gave rise to significant additions, and the OPERRA e-survey which helped identifying priorities in radioecology when examining the common needs between the SRAs released by the four European platforms dedicated to radiological protection. The e-survey was openly available for all interested responders at http://www.melodi-online.eu/operra_eSurvey.html, and actively announced to members of the four platforms (MELODI, ALLIANCE, EURADOS and NERIS), various European and international organisations, various stakeholders involved in other relevant EC projects and informed members of society. A total of 274 answers allowed the ranking of the common priorities as presented briefly in Table 1 adapted from the final report of the results of the e-survey (OPERRA Deliverable 4.5), and for the 2nd OPERRA call that was to be launched in December 2014. It appeared that almost all research topics received an average score higher than 50 either for feasibility or importance (scores had to range from 1 to 100; the highest the most feasible or important). Two topics were scored with an importance higher than 70: (i) Spatial and temporal environmental modelling and human dose assessment after a nuclear accident and (ii) Biomarkers of exposure and effects in living organisms.

2.2 Challenge 1: To Predict Human and Wildlife Exposure in a Robust Way by Quantifying Key Processes that Influence Radionuclide Transfers and Exposure

One of the fundamental goals of radioecology is to understand and predict the transfers of radionuclides and consequent exposure of humans and wildlife. This is needed for a wide range of sources and release scenarios, exposure situations and assessment contexts in atmospheric, terrestrial (agricultural, semi-natural, natural, urban) and aquatic (marine, freshwater, estuarine) environments. The problem is that the key processes that govern radionuclide behaviour, associated transfers along environmental compartments and resulting exposures are not always well understood, leading to models that have an incomplete (or even inaccurate) representation of the processes. At the same time, scientific knowledge is gradually being accrued through ongoing improvements in our understanding. The challenge faced by radioecologists is to incorporate this knowledge into models capable of representing the behaviour of the radionuclides in a more realistic way. Ideally this should consider the different levels of organisation present in the environment, from small to large scales. However, models need to be proportionate and appropriate to the different scenarios which require assessment.

The SRA (STAR Deliverable 2.1) highlights a number of areas within this topic which require effort: (i) the need to reduce uncertainty and understand variability; (ii) scarcity of data for many radionuclides and parameters; (iii) development of process based models; (iv) better understanding, and incorporation in to models, of spatial and temporal scales.

The strategic vision for Challenge 1 is: *that over the next 20 years radioecology will have achieved a thorough mechanistic conceptualisation of radionuclide transfer processes within major ecosystems (terrestrial, aquatic, urban), and be able to accurately predict exposure to humans and wildlife by incorporating a more profound understanding of environmental processes.*

Table 1: General support for synergistic research topics between the ALLIANCE and the other platforms. Respondents had to score feasibility and importance from 1 to 100 (adapted from OPERRA Deliverable 4.5)

Research topic/identified by		**MEAN (1-100)**	**Standard deviation**	**N of responses**
Identified by ALLIANCE, MELODI and EURADOS				
Multiple stressors and modulation of radiation effects in living organisms	Feasibility	49	22	
	Importance	68	19	235
Identified by ALLIANCE, NERIS and EURADOS				
Spatial and temporal environmental modelling and human dose assessment after a nuclear accident.	Feasibility	65	21	
	Importance	**72**	20	250
Priorities for pre-accident recovery preparedness.	Feasibility	66	19	
	Importance	67	22	247
Decision support based on multi-criteria decision aiding tools in the various phases of an emergency (including the post-emergency remediation phase).	Feasibility	60	19	
	Importance	66	21	252
Identified by ALLIANCE and MELODI				
The roles of genetic and epigenetic changes in heritable/transgenerational and somatic effects relevant to individual and population health.	Feasibility	52	22	
	Importance	69	20	250
Inter- and intra-species differences in radiosensitivity.	Feasibility	50	22	
	Importance	65	23	250
Biomarkers of exposure and effects in living organisms.	Feasibility	55	22	
	Importance	**71**	21	250
Identified by ALLIANCE and NERIS				
Urban radioecological hydrology modelling in (post)-emergency conditions.	Feasibility	62	20	
	Importance	61	22	248

The research lines associated to the strategic vision for Challenge one are:

RL-1. Identify and mathematically represent key processes that make significant contributions to the environmental transfers of radionuclides and resultant exposures of humans and wildlife.

RL-2. Acquire the data necessary for parameterisation of the key processes controlling the transfer of radionuclides.

RL-3. Develop transfer and exposure models that incorporate physical, chemical and biological interactions, and enable predictions to be made spatially and temporally.

RL-4. Represent radionuclide transfer and exposure at a landscape or global environmental level with an indication of the associated uncertainty.

2.2.1 Progress within STAR

The STAR project has contributed to Challenge 1 by:

- Establishing alternative models to the concentration ratio (CR) approach for wildlife (Beresford and Vives i Batlle, 2013; Beresford *et al.*, 2015; STAR Deliverable 3.2).
- Exploring the application of Bayesian approaches in radioecology (Hosseini *et al.*, 2013).
- Investigating extrapolation approaches (Brown *et al.*, 2013; Beresford *et al.*, 2015; STAR Deliverable 3.2).
- Developing a simplified allometric model for wildlife (Beresford and Vives i Batlle, 2013; Beresford and Wood, 2014; Beresford *et al.*, 2015; STAR Deliverable 3.2).
- Investigating process based models (STAR Deliverable 3.4).
- Investigating the influence of co-contaminants on speciation and availability of NORM.
- Consideration of dosimetry methods for wildlife (STAR Deliverable 3.3).

The focus of these activities has largely been on improving wildlife dose assessment. An initial activity funded by STAR is focussing on the transfer of radiocaesium in marine organisms with respect to the Fukushima accident. An overview of progress in the area of Challenge 1 by STAR and the related on-going activities of the COMET project are presented below. The work builds upon advance some of the topical roadmaps developed with the ALLIANCE.

2.2.2 First draft of a 5-year roadmap by COMET/ALLIANCE and subsequent topical working groups

COMET has produced a first roadmap document which highlights synergistic topics with NERIS. Together with the ALLIANCE, it was decided to launch topical roadmap working groups. Of the five existing roadmaps one is focussed on the human foodchain. There is no road map focussed on improving wildlife exposure assessment. However, for certain scenarios/ecosystems three of the road maps include aspects of both human and wildlife exposures (these being the 'Marine Radioecology', 'Forest Radioecology' and 'NORM' roadmaps). Relevant elements of each roadmap are presented below.

2.2.2.1 Human Foodchain WG

The focus over the first 5 years will be the consideration of post-accidental situations in both the short and longer-term, though relevant radionuclides associated with, for instance, waste disposal will also be considered. The WG will consider all terrestrial (focussing on agricultural) and freshwater foodstuffs. The WG will not consider NORM radionuclides nor food products from forest or marine ecosystems as these areas all have dedicated WGs. The broad objectives of the roadmap are to:

1. Improve radiological model parameters: this includes those activities aimed to reduce parameter uncertainty, such as acquiring improved data, and analysing existing data in a novel way.
2. Incorporate the “human-environment” into models: this includes the region-specific parameterisation of, *e.g.*, agricultural or dietary practices.
3. Optimise model complexity: what is the added value from the development of new, processed based, models?

Relevant research lines of the SRA which are addressed by this roadmap are RL1, RL2 and RL3.

The outputs of the roadmap should contribute to:

- Having the models and supporting parameter values and datasets to be able to accurately predict the dose to humans in different European regions over the first year after an accidental release for all relevant pathways.
- Improving the long-term predictions of radionuclide behaviour in terrestrial (agricultural) and freshwater ecosystems.
- Improving the long-term predictions of the effects of remedial measures.
- More efficient soil - plant based remediation measures for different regions (through a greater understanding of the processes controlling plant uptake).

The roadmap also contributes to activities within the NERIS SRA with respect to improvement of decision support systems.

To maximise resources, the activities should be aligned with those of the IAEA’s MODARIA follow-on programme where appropriate.

2.2.2.2 Marine Radioecology WG

The Fukushima accident in 2011 has refocused the vision for marine radioecology by highlighting the importance of post-accidental marine issues and the limited knowledge that we have in that area. The broad objectives of the roadmap on marine radioecology, all of which are relevant to Challenge 1, are:

1. To develop research and studies based on experimental or *in-situ* measurements to improve knowledge on transfer processes for benthic and pelagic organisms.
2. To improve knowledge on radioecological marine transfers in non-equilibrium situations.
3. To consolidate or develop prediction tools usable to characterise and model transport, transfers, ultimate fate and radiation exposure for man and marine wildlife from accidental releases of radioactivity to the marine environment.
4. To provide dynamic models incorporating spatial and temporal processes, for the early- to midterm period after release, before more stable conditions tending to equilibrium are reached.

The work conducted under this WG contributes to the following research lines of the SRA: RL1, RL2 and RL3.

The activities conducted to fulfil the roadmap should allow us to start to:

- Understand the long-term behaviour and fate of radionuclides released from Fukushima, *e.g.* sustained concentrations due to ongoing discharges and land runoff.
- Compare and test robust 'first-generation' dynamic models, and develop a 'second generation' of models incorporating foodweb processes.
- Look at stochastic modelling for biokinetic processes to provide more complete information about bioaccumulation processes in different trophic levels. This approach can be used for evaluation of reliability of sub-model predictions and for testing of Monte-Carlo approach simulations.
- Fill the many data and knowledge gaps, especially concerning benthic organisms and their interplay with sediment compartments.
- Explore potential relationships between biological half-lives in laboratory experiments and ecological half-lives observed in the field.
- Couple biological transfer models with ocean transport and dispersion models (interaction with e.g. PREPARE project, STERNE model).

This roadmap also contributes to the NERIS SRA with respect to aquatic dispersion modelling and improving decision support systems.

2.2.2.3 Forest Radioecology WG

Both the Chernobyl and Fukushima accidents demonstrated that forests can contribute significantly to external and internal (e.g. mushrooms, berries and game animal ingestion) exposure. The objective of this roadmap is to reduce the uncertainties in assessments of short- and long-term impacts of radioactive contamination in forested areas through model sensitivity analysis and parameterisation of key processes controlling the transfer of radionuclides.

The roadmap will contribute to two of the SRA research lines (RL1 and RL3). The outputs of activities within the area of this roadmap will allow us to:

- Gain an ability to predict radionuclide concentrations in trees and forest products after an accident, on timescales of months to a few years.
- Gain an ability to predict radionuclide concentrations in forest on longer timescales (e.g. for waste disposal) based on future climate projections, inevitably involving larger uncertainties.
- Determine likely transfer to humans via wild foods.
- Collect more data, establishing more fully characterised scenarios for model validation.
- Develop the ability (methodology) to assess if the forest ecosystem is adequately protected against radiation (in case of emergency or authorized release) in the context of the new EU Basic Safety Standards (BSS).

2.2.2.4 NORM WG

The main radioecological issue with respect to Naturally-Occurring Radioactive Materials (NORM) is how we assess and regulate the management and clean-up of NORM-impacted sites, such as radium contaminated sites, uranium liabilities and wastes arising from process industries generating NORM as a by product. The broad objective in this roadmap which most relevant to Challenge 1 of the SRA is:

- Development and testing of tools to assess radionuclide migration in the environment, their transfer into biota and into the human foodchain based on a mechanistic understanding of relevant transfer processes in NORM impacted sites (including physico-geochemistry, disequilibria in decay chains, multi-stressors, etc.). This is a complex process that should proceed by achievable goals, i.e., identification of basic processes and interaction matrices, development of conceptual models and eventually of full models.

The roadmap activities will contribute to addressing RL1 and 3, allowing us to:

- Improve our ability to robustly predict NORM behaviour based on mechanistic process understanding. This includes approaches for specific environments and scenarios, e.g., flooding and erosion, where NORM may create environmental pollution of, for instance, groundwater, surface water, and soil contamination.
- Improve our ability to predict radionuclide concentrations in surroundings of NORM disposal sites and assess impact on human and biota exposure for timescales of tens to thousands of years.

2.2.2.5 Atmospheric radionuclides and transfer processes (WG under development)

The development of this WG is currently being discussed. If it goes forward it would contribute to Challenge 1 (with strong links to the NERIS SRA) through an improved understanding of deposition and suspension processes.

2.3 Challenge 2: To Determine Ecological Consequences under Realistic Exposure Conditions

A more recent goal for radioecology than the one of understanding and quantifying transfers of radionuclides in the environment is to predict effects of exposure to ionising radiation on wildlife at various biological/ecological organisation levels. Understanding how toxicants affect wildlife species at various levels of biological organisation (sub-cellular, histological, physiological, organism, population levels) is a major research challenge in both radioecology and ecotoxicology. A mechanistic understanding of the links between the different observed perturbations is necessary to predict consequences for survival, growth and reproduction which are critical for population dynamics. The challenge here is to solve the numerous extrapolation issues needed in view of the vast number of species that exist and their various biological and ecological responses to radiation, in a multiple stressor context. The strategic vision for Challenge 2 is that "*over the next 20 years radioecology will have gained a thorough mechanistic understanding of the processes inducing radiation effects at different levels of biological organisation, including the consequences on ecosystem integrity, and be able to accurately predict effects under realistic conditions*."

Five Research Lines under challenge 2 have been identified, these are:

RL-1. Mechanistically understand how processes link radiation induced effects in wildlife from molecular to individual levels of biological complexity.

RL-2. Understand what causes intra-species and inter-species differences in radiosensitivity (i.e. among cell types, tissues, life stages, among contrasted life histories, influence of ecological characteristics including habitats, behaviour, feeding regime…).

RL-3. In a broader exposure context, understand the interactions between ionising radiation effects and other co-stressors.

RL-4. In a broader ecological context, understand the mechanisms underlying multi-generational responses to long-term ecologically relevant exposures: maternal effects, hereditary effects, adaptive responses, genomic instability, and epigenetic changes/transformations/processes.

RL-5. Understand how radiation effects combine in a broader ecological context at higher levels of biological organisation (population dynamics, trophic interactions, indirect effects at the community level, and consequences for ecosystem functioning).

2.3.1 Progress within STAR

STAR experimental and modelling objectives have explored in various ways implications of protecting ecosystems against radionuclides at the population level. Are populations protected when we protect the most sensitive individual endpoint? Can we find molecular markers which are ecologically relevant, and if so define at which level of response, to use as early warning of specific radiation exposure? Can biology-based mechanistic approaches help understand the metabolic modes of action of radiological toxicity and increase our capacity to predict long-term responses at the individual and population levels?

STAR also invested a lot of effort in the research area of multiple stressors with the main objective to respond to the key question as to if the current wildlife protection standards are robust in a multiple stressor context.

The major contributions of STAR to Challenge 2 are listed below:

- Acquisition of new experimental data on survival, growth and reproduction effects over full life cycles during chronic multigenerational exposure to gamma and alpha radiation in animal and plant species
- Acquisition of new experimental data on molecular and/or cellular responses to chronic radiation in *Arabidopsis thaliana* and the zebrafish *Danio rerio* for alpha and gamma radiation and *D. magna* and *C. elegans* for gamma radiation only;
- Applications of an advanced mechanistic modelling approach (namely the Dynamic Energy Budget theory applied to Toxicology (DEBtox), initially designed to analyse toxicity data of chemical contaminants) to the cases of waterborne radionuclides and ionising radiation; use of the model to mechanistically compare radiotoxicity between gamma and alpha in *D. magna*
- Application of a classic population modelling approach (Leslie matrices) to extrapolate from radiation effects, as measured in the laboratory at the individual level, to population-level endpoints and calculate population risks in 12 species representing four taxonomic groups (including aquatic and soil invertebrates, fish and mammals); use of those matrices to derive radioprotection criteria for a fish group, by exploring the variability in population responses depending on life history among 21 fish species.
- Development of a Uranium Biotic Ligand Model (BLM) for aquatic organisms under mixed contaminant conditions under development for salmon, daphnids and *Lemna minor*. These BLM models allow to model effect of U (and impact of co-stressor) under changing environmental conditions.

- Apply selected approaches developed in ecotoxicology to assess the impact of mixed contaminant conditions on radiation induced effects and improve the understanding of underlying mechanisms and processes
- Binary mixture exposure experiments applying classical ecotoxicological conceptual models (Concentration Addition / Independent Action) for external gamma irradiation + Cd and U(VI) + Cd; some combined exposure experiments were also performed with fluoranthene. Multiple stressor effects assessments were set up for an invertebrate (*C. elegans*), a plant *(L. minor*), a vertebrate (*Salmon salar*), and a simple plankton community. The main general pattern observed has been that in most cases no synergistic effects are observed.
- Development of a Mix-DEBtox for *C.elegans* to explore the underlying mechanism of interaction with the support of DEBtox. Simulations have successfully described the toxicity of U and Cd alone, consistent with previous DEBtox modelling for U and Cd. To describe the combined effects of U and Cd, an interaction term was considered in the various physiological parameters of the model.

At present, the ongoing activities to advance the SRA are implemented by EC funded projects on one hand and by national programmes led by some members of the ALLIANCE on the other hand. Except for Research Line 5, the research lines have a lot in common with MELODI as indicated by the synergistic topics identified by the two platforms (ALLIANCE and MELODI). Partners involved in STAR, and more recently in COMET, have already oriented their research to contribute significantly to the first three lines, by addressing mechanisms underlying molecular modes of action of radiation exposures. For example, STAR initiated a first set of experiments for gaining comparative insights into modes of actions of alpha and gamma radiation types, in plants and animals, by implementing different biomarkers and restricted transcriptomic approaches. Research Line 4 is investigated through experimental strategies designed to study long-term and transgenerational outcome of exposure to ionising radiation within the COMET project, in association with MELODI. Research Line 5 of the SRA, is an overarching one to build upon lessons learnt from the other research lines, it will be developed by joint activities between the radioecology and ecology scientific communities. Collaborations have already started between some COMET members and IUR to this end.

2.3.2 First draft of a 5-year roadmap by COMET/ALLIANCE and subsequent topical working groups.

To specifically advance this challenge, COMET has agreed upon target objectives of the research actions to be planned. A logical sequence of activities was elaborated to advance the basic knowledge of mode of actions and consequences. Two topical working groups named “Transgenerational Effects” and “Species Radiosensitivity” was launched among COMET interested parties and expanded to ALLIANCE members. The work will be based on common technical guidance for research actions dedicated to this topic, focusing on reaching within a 5-year period the broad objectives as follows:

1. To improve our mechanistic understanding of the concepts and drivers governing changes in biological responses of organisms exposed to low-doses of ionising radiation. This includes analysing data in novel ways of meta-analyses (e.g. best use of databases, mathematical and computational approaches).

2. To develop research to characterize molecular or cellular changes driving transgenerational effects and inter- and intra-species differences (between different life-stages within a species)
3. To identify molecular fingerprints that possibly can be used (i) to demonstrate minimal impacts on the environment (e.g. biomarkers of ionising radiation exposure), (ii) to give an indication of potential impact (e.g. biomarkers of ionising radiation-induced effects, possibly related to transgenerational effects) or (iii) to inform understanding (e.g. biomarkers of radiosensitivity)
4. To develop lines of communication with advisory and regulatory bodies to evaluate how the new knowledge being acquired should influence radiation protection standards and criteria.

It is expected that conducting the above research activities will give insight in primary radiation-induced mechanisms involved, and dynamics of biological response. This knowledge is essential to gain power to predict toxicity pathways as it constitutes the primary information to establish the relationships with alterations of physiological functions. This would give insight into the link between toxicity profile, metabolic pathway and adverse consequences at the individual and transgenerational levels. It would help indirectly to tackle the very complex issue of interactions between stressors.

The outcomes should constitute the basis for the development of biologically-based extrapolation models and would be useful for risk assessors as they would help reduce uncertainty in predictions of effects on physiological functions. This is very much needed to support emerging policy in the field of radioprotection of the environment *per se* (*e.g.*, International and European BSS).

2.4 Challenge 3: To Improve Human and Environmental Protection by Integrating Radioecology

The historical development of human radiation protection differs from the one for wildlife. Radiation protection developed in the beginning of the 20th century as a means to protect humans from possible adverse health effects from ionising radiation. It was initially focused on protecting individuals from acute health effects (deterministic effects) and later developed to include protection against possible increased risk of late effects (stochastic effects), mainly cancer.

Though environmental protection frameworks were developed for other toxic substances from the 1970's onwards, they did not include radioactive substances. It was long stated by the radiation protection community that if man was adequately protected from ionising radiation, so was the environment. This was challenged by some scientific communities (in particular the IUR) towards the turn of the millennium and several EC funded projects developed the scientific basis and tools to perform environmental radiation risk assessments (at the same time similar developments were on-going elsewhere in the world. Radiation protection criteria for the environment are gradually being integrated in regulatory frameworks for the environment as a whole, together with other contaminants.

Radioecology is an inherent part of both human and environmental risk assessment as it is the basis for calculating the dispersion and fate of radionuclides that are discharged to the environment. Radioecological dispersion and transport models can be used for existing, planned and emergency situations as a basis for human and environmental risk assessments. They can be coupled with other environmental models, such as those for other contaminants, to address multi-contaminant situations. They can be integrated in decision support systems for nuclear and radiological emergency management. Linked with other scientific disciplines, radioecology can be integrated in evaluation of ecosystem functioning, services and environmental economics.

In the SRA the vision for Challenge 3 is stated as:

Over the next 20 years radioecological research will develop the scientific foundation for the holistic integration of human and environmental protection, as well as their associated management systems.

The associated research lines are:

- RL-1. Integrate uncertainty and variability from transfer modelling, exposure assessment, and effects characterisation into risk characterisation.
- RL-2. Integrate human and environmental protection frameworks.
- RL-3. Integrate the risk assessment frameworks for ionising radiation and chemicals.
- RL-4. Provide a multi-criteria perspective in support of optimised decision-making.
- RL-5. Integrate ecosystem services, ecological economics and ecosystem approaches within radioecology.
- RL-6. Integrate Decision Support Systems.

To achieve this vision, integration must be sought through many pathways:

Integration of radioecology with other scientific disciplines such as chemistry, biology, geology; development of common risk assessment tools for man and the environment and for chemicals and radionuclides; improvement of radioecological modelling for inclusion in Decision Support Systems for nuclear accidents; holistic management of the environment to which humans are an integral part; and valuing the ecosystem services provided. A strong link to the platforms MELODI, NERIS and EURADOS is needed to achieve this, as well as to non-radiological forums such as SETAC.

2.4.1 Progress within STAR

The focus in STAR has been to integrate human and environmental protection frameworks, i.e. addressing RL2. In particular, the development of a combined screening model for both human and non-human biota was targeted. Currently, a new version of the CROM code has been released (CROM8) that addresses this issue. Traditionally, human risk assessment is performed with other tools (e.g. CROM) than those used for environmental risk assessment (e.g. ERICA Tool), yet both kinds of assessment models require contamination levels of environmental media to be measured or calculated.

The generic models described in IAEA Report (2001) have previously been implemented in the computer code CROM for human risk assessment (Robles et al., 2007; CROM, 2011). The dispersion models from the IAEA Safety Report Series 19 (SRS19) (IAEA, 2001) were also implemented in the ERICA Tool computer code for assessing radiation risk to wildlife (Beresford et al., 2007). Coupling both approaches has been accomplished and is recently released as the CROM8 code (STAR Deliverable 3.1). CROM8 can calculate activity concentrations in the environment using the SRS19 dispersion models and then estimate effective doses to humans and absorbed doses to biota, via different modules within the one code. The development was co-sponsored by STAR, the IAEA, CIEMAT and ENRESA. This combined assessment tool will be available on the Radioecology Exchange website (http://www.radioecology-exchange.org).

CROM8 does not include all the features available in the ERICA Tool, nor all the revisions of the SRS19, to which STAR is contributing. A next generation of the CROM code is therefore being developed called the CROMERICA. This code will implement the revised SRS19 models of the IAEA (which will consider both humans and wildlife), the updated version of the STAR milestone report "Integrated Screening Model for Humans and Wildlife" and advances in the parameters in the ERICA Tool. This new tool will implement state-of-the-art approaches for improvements in performance, usability and maintainability.

CROMERICA will maintain all features of CROM8, including the biota and human integration, uncertainties calculations and graphical capabilities, while following a design concept which allows for easy extension, quality control and maintenance. An alpha version of CROMERICA has been presented at the final event of STAR in June 2015. STAR is funding the generation of a Graphical User Interface which contributes to the development of a user friendly tool. The CROMERICA development will continue by CIEMAT beyond the STAR project in cooperation with COMET partners, the IAEA and others.

Plans exist for organizing user and developer courses in a regular way, where basic capabilities for performing impact assessments using CROMERICA and/or information for developers who want to include new modules, will be provided. STAR appreciates the collaboration of the IAEA in these planned activities.

2.4.2 First draft of a 5-year roadmap by COMET/ALLIANCE and subsequent topical working groups.

Research Lines 1 and 6 are partially addressed by the working groups "Marine radioecology", "Forest radioecology" and "Human foodchain" as describe above.

Within the EJP-CONCERT project, a Work Package is devoted to integrate the SRAs of the four European platforms in radiation protection. ALLIANCE is member of the CONCERT consortium, and will actively contribute to the integration of the radioecology SRA with the other radiation protection SRAs. For this purpose ALLIANCE has created a WG, that will be involved in updating the SRA as well as in the development of a joint roadmap for radiation protection.

2.5 Education and training

As is stated in the STAR "Education and Training Strategic Research Agenda in Radioecology" (included in STAR Deliverable 2.5), scientific research in radioecology and application of that knowledge in the radiation protection of man and the environment requires scientists and workers with adequate competence and appropriate skills. Research-based E&T depends on access to relevant infrastructures and facilities.

The strategic vision is to secure a sustainable, integrated European E&T platform in radioecology that attracts top-level graduates and provides a workforce that has the necessary skills to meet future scientific, economic and societal needs within radioecology and other nuclear and environmental sciences.

As laid out in the SRA, to achieve the strategic vision, six action lines will need to be addressed:

1. **Increasing student and teacher mobility.** This is essential, but requires sustainable funding mechanisms within radioecology. Actions such as travel grants for students and guest lecturer fees have a relatively low cost, but need to be maintainable. Inclusion of PhD, postdoc or young researcher positions in EU funded projects should be encouraged. National funding sources to support mobility are often available, as are country-specific, bilateral or European exchange programmes (e.g. Erasmus, Marie Skłodowska-Curie actions).
2. **Exploring joint EU MSc opportunities** through the ERASMUS+ and Erasmus Mundus joint degree programmes and other activities under COMET, OPERRA and Horizon 2020. This would include mechanisms to increase the number of ECTS courses in radioecology that are given by European Universities as well as to stimulate integration within the ALLIANCE. The E&T collaboration between universities and institutes should be formalized by Memoranda of Understanding and possible Joint degrees if the Bologna Model is implemented.
3. **Fostering links with other E&T programmes.** In particular, harmonization of radioecology E&T activities with those in nuclear and environmental sciences (e.g., radiation protection, emergency management, radiochemistry, ecology, environmental chemistry) would maximize use of infrastructure and human resources by ensuring that the courses are compatible between different disciplines. Such E&T initiatives exist both within other EC programmes (EURADOS, MELODI, NERIS, CINCH-II, EUTERP) and in international organizations (such as IAEA, OECD and IUR). Links with environmental sciences (e.g. via lectures on courses) should be made at all educational levels, from schools to postgraduate.
4. **Providing joint courses** for students and professionals with both ECTS (academic credits) and ECVET (vocational credits). This will ensure efficient use of resources and offer important networking opportunities for students, both across countries and disciplines, as well as with potential employees.
5. **Increasing stakeholder and employer involvement** in E&T. This can be done through student placements, joint research projects, summer jobs, sponsored courses or university positions, all of which are very attractive to students. In addition, specialized intensive courses should be developed to meet stakeholder needs. For professional training courses, particular focus should be placed on access to state-of-the-art methods and models.
6. **Development of distance learning courses** where feasible, to increase the recruitment of students. Distance learning, videoconferences, virtual learning environments etc., are also a cost-effective way to teach and involve participants from a wide range of countries.

In addition to these six points, the importance of recruitment for the future of radioecology should be stressed. It is important to attract young people, even undergraduates and school children, as research has shown that their interest in science should be encouraged at this stage. The education of teachers and inclusion of nuclear science teaching in schools is also important. Radioecology should also be promoted through a variety of courses at the BSc level – for example providing lectures to other chemistry, environmental science or nuclear science courses.

The interest in radioecology of students and young scientists is encouraged by promoting student networking and forums, such as websites, conferences, meetings, social media, to stimulate students and facilitate the interaction among them and with experts. These interactions are important not only to discuss the results of the students' research activities, but also to disseminate these results. The multi-disciplinary nature of radioecology is an aspect that could be made attractive to students

– there is both demand and a variety of possible job opportunities available to the candidates. A key factor in the success of long term integration and sustainability of E&T activities is sustainable funding. A range of potential national and European funding sources have been identified that could be used to help sustainability of E&T and mobility within radioecology (STAR Deliverable 6.4) and should be explored further within COMET and the ALLIANCE. In addition, potential funding opportunities from the ALLIANCE need to be discussed, as well as the coordination of the common research resources (platform, virtual laboratory etc.). Provision of in-kind support in the form of personnel in E&T activities and even the possibility to sponsor academics, including professors, at the host universities by the ALLIANCE partners needs to be fostered.

In the short-term, the ALLIANCE will have to actively participate in the CONCERT Work Package on E&T. For this purpose, the ALLIANCE has created a WG on E&T.

2.6 Infrastructure

Adequate infrastructure and capabilities are a necessary resource for state-of-the-art radioecological research, impact assessments and also for education and training activities in radioecology. Infrastructure and capabilities encompass the facilities, equipment, methods, databases and models, and also the expertise required to perform radioecology research. Ideas about how to study and evaluate the behaviour and impacts of radiation and radionuclides on the living world are changing. Consequently the required infrastructure and capabilities are also changing. Therefore it is important to specifically include infrastructure and capabilities in the SRA.

The challenge in coming years is to maintain and acquire the infrastructure and capabilities needed to accomplish the three scientific challenges, as well as to support the education and training challenge of the SRA. *The strategic vision for the next 20 years is that radioecology will develop a sustainable, integrated network of infrastructures and capabilities, to best meet the needs of the radioecology community, both in research and in education and training activities.*

To achieve the strategic vision the requirements for infrastructure and capabilities need to be identified and the partnerships of excellence that bring together these required infrastructure and tools need to be created. To best utilise existing resources, the emphasis will be on promoting the visibility and joint use of existing infrastructures. The sustainability of single, highly-specialised, but essential, facilities should be given priority. Also the Radioecological Observatory sites, an approach to joint research established in STAR, need to be developed further. An effort should be made to avoid duplication of resources through ensuring wider collaboration, not only in the field of radioecology, but also in the broader area of radiation protection and with other related disciplines. Furthermore, an effort will be made to harmonize practices and protocols amongst multiple facilities. This issue is being addressed within the STAR/COMET projects where tools for knowledge management are being developed (e.g. the **Virtual Laboratory**).

In the near future the visibility of the state-of-the-art infrastructure will be promoted e.g. under the EC CONCERT project making them known to the community by helping to get access to them. In addition, thematic working groups have been established within the ALLIANCE. One of these groups is dedicated to infrastructure and capability issues.

3 Tools developed to facilitate integration

3.1 Infrastructure database and joint use of infrastructure

The overarching goal of infrastructure catalogue was to facilitate the long term sustainable integration of European radioecological research, with an appropriate governance structure. This ensures an efficient and effective integration of resources and capacities at a European level. The STAR partners brought together the leading expertise in biology, ecotoxicology, ecology, radiobiology and modelling. The wide breadth of expertise increases protection of the environment and man.

The infrastructure catalogue is now on-line for STAR partners. It is readily available to any current STAR member. The inventory of infrastructure produces an inventory of data bases, sample banks, analysis methods and facilities available within the different STAR partner organisations, with a possibility to enlarge to the other radioecology institutes around the world. The list of the facilities available for others than STAR partners is in the public domain of the Radioecology exchange under "Virtual laboratory, Equipment and facilities".

3.1.1 An inventory of infrastructure

A detailed description of the infrastructure database, as defined by a survey of STAR partners, is given by Ikäheimonen et al. (2012) (STAR Deliverable 2.2). The following aspects are covered in the survey:

- Radioanalytical equipment
- Methods
- Bioinformatic equipment and methods
- Sample archives
- Models
- Expertise
- Facilities for radioecological research

The survey confirmed that STAR partners have expertise in wide-ranging areas of radioecology. There are more than 170 experts employed among STAR institutes operating in 8 different countries. STAR partners have together an impressive array of highly specialized laboratory equipment, essential to perform high quality radioecological research. For instance, there are over 150 gamma spectrometers, over 270 alpha detector and nearly 50 liquid scintillation spectrometers and 30 proportional counter systems needed for radionuclide measurements.

Expertise within STAR partners covers analysis for natural and artificial radionuclides (gamma emitting radionuclides and radiochemically separated radionuclides U-234, U-235, U-238, Th-228, Po-210, Pb-210, Ra-226, Ra-228, Rn-222, Pu-239,240, Pu-238 Am-241, Sr-89, Sr-90, Tc-99m, C-14, H-3) as well as methods for nutrient and ion concentration determination. Partners have expertise in environmental sampling methods that are accredited in four STAR partners' laboratories.

The STAR consortium holds a large variety of samples from terrestrial and aquatic environment as well as air samples. Sample archives contain unique samples at the beginning of the 1900's and samples before and after Chernobyl accident.

STAR partners have expertise in using at least 40 different models that cover fields such as atmospheric dispersion, deposition and transport of radioactivity in the aquatic and terrestrial environment. These models are among others used for calculation of the dose rates, activity concentration and assessment of risk from ionising radiation.

After receiving all data from the partners, a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis for the infrastructure survey was performed to assess strengths, weaknesses, potential and threats of the infrastructure catalogue. Most of the strengths are related to integration, knowing and understanding the perspectives of each partner, a wide range of equipment, methods, analytical capacities, and expertise available for common research. The infrastructure database also needs maintenance and updating. The data in the infrastructure database must be real time if they are to be of value in the future. One of the current weaknesses is the variable quality and quantity of the data and the approach to the entry of information. The other weakness is that the infrastructure catalogue is now open for STAR partners but only small teams are currently involved in the project. The threats are linked to the use of the infrastructure database. What will happen if the database is not updated or used? Also conflicts with national policy about availability of data and internal politics of different organisation are likely.

3.1.2 Use of infrastructure database

The infrastructure survey was used to identify what assets the consortium already have and what need to be improved for integration among the STAR/ALLIANCE partners, i.e. to identify the current lack of know-how among the STAR/ALLIANCE partners. The infrastructure survey shows that STAR partners and the ALLIANCE members have a high-quality infrastructure, extended expertise and competence for radioecological research. No evident lack of know-how was identified in the survey.

The infrastructure catalogue is a useful tool for partners to search for skills that the other partners might have. It is useful for potential new ALLIANCE partners in both directions; new partners will know ALLIANCE capabilities and partners in ALLIANCE can identify which capabilities are missing within the STAR/ALLIANCE. The infrastructure database can also be utilized for training and mobility i.e. by identifying where one partner can send staff to be trained by another partner. The infrastructure database could also be utilized when exploring the potential for collaboration between STAR/ALLIANCE and other research organisations, international organizations (e.g. IAEA, EC) and other platforms (NERIS, HERCA, MELODI, IGDTP). The information in database could also be used for coordination and integration in response to emergencies. The database can be also used to show stakeholders our capabilities and in the standardisation of methods (where appropriate) between the institutes.

In order to be more useful the infrastructure data base needs to be made open to the larger community. Due to technical reasons (e.g. difficulties to keep large amounts of data updated) it was decided that only the most relevant data will be made publicly available. A separate survey was conducted to get a more detailed picture about what facilities are available for others either as commercial services or through research collaboration. A summary table of this survey was placed on the Radioecology Exchange (see section 3.2).

3.2 Virtual laboratory

The Virtual Laboratory is a space within the Radioecology Exchange (www.radioecology-exchange.org) website. The aim of the Virtual Laboratory is to provide openly available information to encourage integration through joint research and joint use of infrastructure. The anticipated audience varies from interested 'members of the public' through to radiation protection specialists.

A brief overview of the space (Figure 1) is provided below. If reading this document online, hyperlinks are available within this section to the relevant pages of the Virtual Laboratory.

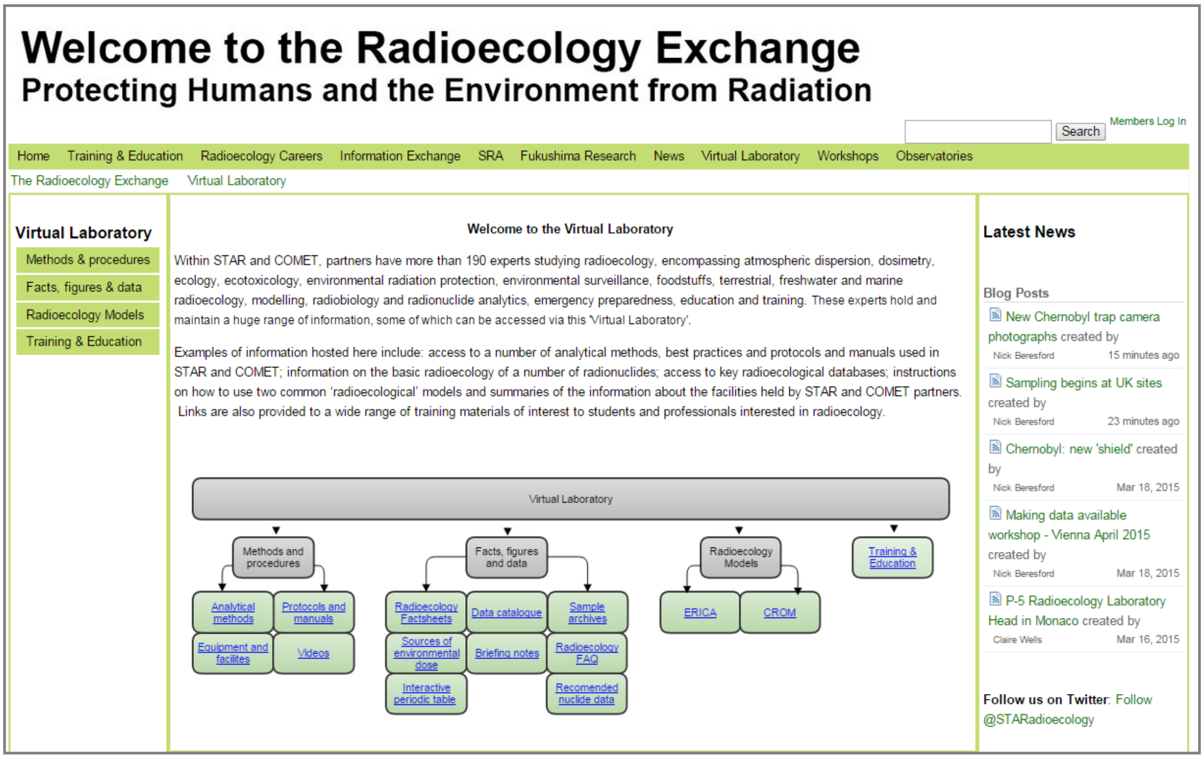

Figure 1. Virtual Laboratory entry page on the Radioecology Exchange website (www.radioecology-exchange.org).

The Virtual Laboratory provides information which has been collated into the following three categories:

- Methods & procedures: this section contains descriptions of many analytical methods commonly used in radioecology studies (some with video); protocols and procedures used in STAR experiments; and a list of equipment and facilities available at a number of STAR institutes with details on how to access them. Information on COMET procedures and facilities will be added in the near future.

- Facts, figures and data: this area contains factsheets on some important radionuclides; examples of absorbed dose estimations (for different wildlife species during different life stages); a catalogue of data made available by STAR partners (which will be expanded to include COMET data); details of sample archives held by STAR partners and how to access them; links to some FAQ's related to radioecology; and a briefing note on the consequences of marine releases after the Fukushima accident.

- Radioecology Models: short descriptions of two models that can be used for human and environmental assessment CROM and the ERICA-Tool respectively are provided. Links to CROMERICA will be added.

These areas of the Virtual Laboratory are outlined below.

3.2.1 Methods & procedures

Analytical methods: The STAR partner survey (STAR Deliverable 2.2) indicated that a wide range of expertise and equipment can be found at partner institutes. Overviews of the analytical procedures used by STAR partners are provided in Deliverable 2.2. More detailed descriptions of some of more than 20 methods and types of equipment are on the Virtual Laboratory.

Equipment & facilities: STAR institutes offer some services to other scientists at commercial rates. A list of these services together with contact information is available on the Virtual Laboratory.

Protocols and manuals: All the protocols used during experiments conducted in STAR work packages 4 and 5 have been made available on the Virtual Laboratory. Summarised information is available for the 18 methods.

Video clips: Short video clips or MS PowerPoint™ presentations describing topics related to radioecology.

3.2.2 Facts, figures and data

Radioecology factsheets and associated datasheets

Factsheets which summarise the radioecological information for twenty elements (Ag, Am, C, Cl, Co, Cs, H, I K, Np, Pb, Po, Pu, Ra, Rn, Sr, Tc, Te, Th and U) which often need to be considered in radiation dose assessments for both humans and biota have been created during STAR. The factsheets are aimed at a readership of age 16+. They contain information on the environmental behaviour of the radionuclides, why the selected radionuclides are of interest, and some commonly used parameters.

Sources of environmental dose

Complementary to the factsheets which summarise the radioecological information element by element, two ‘topical descriptions’ have been prepared which describe absorbed dose estimations for wildlife. The objective of these descriptions is to allow a non-specialist audience to understand the link between environmental contamination with radionuclides and the doses to wildlife.

Key datasets

STAR partners hold many databases from experimental studies and monitoring programmes. Access varies with some datasets being attached to the Radioecology Exchange, others being downloadable from an INSPIRE Directive compliant server or other websites, and other data can be requested.

Nearly 40 datasets have been made available through the STAR project via the Virtual Laboratory. More information and datasets will be added during the COMET project.

Sample archives

The STAR NoE holds a large variety of samples from the terrestrial and aquatic environment which may be available to third parties on request. Details of these sample archives have been collated into six spreadsheets each considering different sample types. Each of the tables contains a summary of each sample archive: stored sample form; nuclides analysed; sample details and sample site; time period samples were collected over and the contact details of the person responsible for the samples.

FAQ

This area of the Virtual Laboratory will be developed during COMET and will provide access to online radioecology related Frequently Asked Questions (FAQs).

Briefing notes

STAR has produced an information sheet, aimed at the general public, on the consequences of marine releases after the Fukushima accident. Fukushima related activities of STAR/COMET partners can be accessed from the Radioecology Exchange.

3.2.3 How to use models

In radioecology, models are used for a wide variety of applications such as the prediction of dose rates and activity concentrations and the associated risk from ionising radiation. STAR partners include both users and developers of such models. Two freely available assessment models, one for human assessment and the other wildlife, which have been developed and maintained by STAR partners, are briefly described on the Virtual Laboratory:

- CROM (human assessment)
- ERICA Tool (wildlife assessment)

3.3 Radioecological Observatories – contaminated field sites for long-term shared field work

One of the opportunities to integrate through common studies, shared data etc. is the creation of Observatories for Radioecological Research. The idea of Observatories was presented in an OECD/NEA report (2007) in which the point was made that:

> *"… efforts … are generally fragmented and involve a range of disciplines, such as radiation biology, radioecology, environmental toxicology, ecotoxicology and ecology. Moreover, environmental data collected over the last half century by the nuclear industry for surveillance purposes has not been utilised in an efficient, co-ordinated manner. Therefore it is proposed that a useful development would be an international network that allowed researchers to co-ordinate and understand research in relevant fields. This "observatory" would be grounded on past and ongoing observations in the real environment and allow them to be linked with laboratory and theoretical developments."*

Radioecological Observatories are contaminated field sites that provide a focus for long term joint field investigations. Research at common sites is expected to create synergistic effects, thus efficiently improving the understanding of the mechanisms and processes affecting radionuclide behaviour and effects. The pooled, consolidated effort will maximize the sharing of data and resources as well as provide excellent training and education sites. All data collected from the

Observatory sites will be made accessible from the Radioecology Exchange and result in a valuable international database.

The collaborative research at Radioecological Observatories will promote a sustainable, efficient, long-term integration of radioecology on an international level. The central demand for a long-term perspective is the most prominent difference between a Radioecological Observatory and a field site chosen to study specific scientific questions for a time span up to several years. In view of this long-term perspective, the Radioecological Observatories are closely linked to the Strategic Research Agenda, the long-term vision of radioecological research needed within the European Community. Research at the Observatory sites is planned by members of the COMET consortium, the radioecology consortium that follows STAR, and the ALLIANCE; we are also starting to try to co-ordinate our research with other programmes.

Suitable field sites for becoming Radioecological Observatories were selected by combining a formal approach (multi-criteria decision analysis), group discussions and recommendations provided by invited external experts. The structured, progressive approach was as transparent and objective as reasonably achievable. The Polish coal mining area in Upper Silesia and the Chernobyl Exclusion Zone (CEZ) performed best with respect to the list of evaluation criteria and hence were selected as Radioecological Observatories. These two sites complement each other. The Polish coal mining area is a typical mixed contaminant situation with moderate dose rates to organisms. The CEZ offers a contamination gradient with high maximum dose rates to organisms. Relevant amounts of non-radioactive pollutants, however, are absent. The complementary characteristics of these two sites were regarded as a promising starting point to address the research lines of the Strategic Research Agenda.

3.3.1 The Radioecological Observatory sites

The characteristics of the Observatory sites in the Upper Silesian Coal Basin (USCB) and in the Chernobyl Exclusion Zone (CEZ) have primarily been derived from scientific literature. They are compiled in STAR Deliverable D2.3. A more detailed document on the Polish Observatory sites has also been produced which includes relevant information from the Polish grey literature. The document will be made available on the Radioecology Exchange.

3.3.1.1 The Upper Silesian Coal Basin (USCB)

The USCB is a post-industrial landscape that has been heavily contaminated by coal mining activities. About fifty underground hard coal mines are still in operation. The daily discharge of mine waters into surface reservoirs exceeds 600,000 m^3. Currently, there are 25 settling ponds in use that contain in total 5,000,000 m^3 of sediment with enhanced levels of radium isotopes and heavy metals. The Radioecological Observatory in the USCB comprises five different sites:

- Site #1: Upper Vistula river, a natural river that is affected by the continuous discharge of mine brines with high activity levels of radium over a length of about 60 km.
- Site #2: Former mine settling pond Rontok Wielki (surface area 32 ha), a natural pond that was adapted in the past as settling and retention pond for mine waters. It is currently disconnected from technological processes and filled with freshwater.
- Site #3: Mine settling pond Kaniów (surface area 4.5 ha), an artificial pond that is currently used for clearing mine waters and discharges saline waters into the Vistula river in a controlled way.

- Site #4: Former natural pond Bojszowy (surface area 16 ha) which was used as mine settling pond for more than 20 years. After technical land reclamation, radium-rich bottom sediments were covered with a layer of an inert material.
- Site #5: Country borough Świerklany where a residential area, arable land and wasteland is contaminated by radium over a length of about 2 km along the former stream bed.

Fish are the dominant vertebrate species in the aquatic ecosystems. Vertebrates are absent in the mine settling pond Kaniów. At the former mine settling pond Bojszowy only small rodents and amphibians form resident populations of vertebrate species. The following ICRP Reference Animals and Plants, as defined in ICRP Publication 108 (ICRP, 2008), are present in the terrestrial ecosystems: Rat, Pine tree, Bee, Frog, Earthworm, Wild grass and Deer.

Radium isotopes and heavy metals originating from mine waters pumped to the surface lead to a mixed contaminant situation. The most important radionuclides are the radium isotopes ^{228}Ra and ^{226}Ra as well as ^{228}Th, ^{222}Rn, ^{210}Pb and ^{210}Po. Usually, the decay chains start with ^{226}Ra and ^{228}Ra, respectively, precipitated from water and deposited in bottom sediments. Radium levels in the sediments of the former mine settling pond Rontok Wielki, for example, amount up to 49,200 Bq kg^{-1} for ^{226}Ra and up to 6,400 Bq kg^{-1} for ^{228}Ra. Highly mineralised formation water is also the source of heavy metal contamination. Heavy metal concentrations in sediments of settling ponds of 10 different coal mines reach 122,000 ppm for Ba, 830 ppm for Pb, 760 ppm for Zn and 270 ppm for Cu. Despite the high mineralization the saline mine waters are often used for technological purposes, resulting in additional contamination with hydrocarbons used as engine oil and lubricants.

The weighted absorbed whole-body dose rates to the default reference organisms of the ERICA Tool may exceed the default screening level of 10 µGy h^{-1}. At the Kaniów site, for example, potential weighted absorbed dose rates to vertebrates of >30 µGy h^{-1} were calculated from the activity concentrations in soil near the pond bank.

To access the USCB negotiations to sign a Memorandum of Understanding (MoU) with the Polish site owners is in process.

3.3.1.2 The Chernobyl Exclusion Zone (CEZ)

The CEZ is one of the most radioactively contaminated sites in the world. Established shortly after the accident in 1986, the CEZ was initially the area within the 30-km radius around the Chernobyl Nuclear Power Plant. Over the last 29 years, the borders have expanded. Predominantly forest and marshland, the area covers an approximately 2,600 km^2 in Ukraine and 2,160 km^2 in Belarus.

The Ukrainian portion contains forests, abandoned farmlands, wetlands, flowing waters, standing waters, deserted villages and abandoned urban areas. The Belarusian portion is a land of swamps, marshes and peat bogs. Here, forest land occupies about one half of the territory. Areas not covered with forest are mostly former reclaimed agricultural lands and meadows. The CEZ is rich in species. More than 400 species of vertebrate animals, including 67 fish, 11 amphibians, 7 reptilians, 251 birds and 73 mammals inhabit the vicinity of the CEZ. More than fifty of them belong to a list of protected species according to national Ukrainian and European Red Books. Species falling within the taxonomic families of all terrestrial and freshwater Reference Animals and Plants, as defined in ICRP Publication 108 (ICRP, 2008), are present in the CEZ.

The most important radionuclides include long-lived ^{137}Cs, ^{90}Sr, plutonium isotopes, ^{241}Am and uranium isotopes, originally present as particles from submicrons to fragments. A key characteristic of the CEZ is the extremely heterogeneous contamination pattern that offers contamination gradients with high maximum dose rates. The CEZ also provides opportunities to study other longer-lived radionuclides released by the accident including ^{99}Tc, ^{14}C and ^{129}I, which have received relatively little attention in the exclusion zone. Appreciable amounts of non-radioactive pollutants are absent.

Estimated weighted absorbed whole-body dose rates to terrestrial reference organisms as calculated using the ERICA Tool exceed 400 µGy h^{-1} for large mammals (deer) and 1,400 µGy h^{-1} for reptiles. Consequently, the CEZ provides the opportunity to study long-term effects of ionising radiation on populations of wildlife.

Access to the CEZ for scientific research is only possible via local research institutes. Some STAR partners, e.g. NERC-CEH and IRSN, have signed MoUs on bilateral collaborations. These MoUs on sampling campaigns and radioecological field studies cover a period of several years. The STAR partner and the local research institute usually agree upon a common research programme on an annual basis. The sampling programme has to be approved by the appropriate authority.

3.3.1.3 Potential further Observatory site: Fukushima area

The area around the Fukushima Daiichi Nuclear Power Station is a potential further Observatory site. Detailed information about the accident and the radiological consequences can be found in the UNSCEAR 2013 Report. The report describes the chronology of the accident, the releases, dispersion and deposition of radionuclides, the assessment of doses to the public and workers as well as the assessment of doses and effects for non-human biota. Unlike the Upper Silesian Coal Basin (USCB) and the CEZ, the Fukushima area also includes marine ecosystems. Fukushima University is a member of the COMET consortium.

3.3.2 Future work

The Polish Observatory sites provide the opportunity to investigate a variety of very specific research questions, e.g. different temporal stages of settling ponds (in operation, post-operational phase, after remediation measures). However, the sites do not provide large-scale terrestrial Observatories with high radium levels as expected. The STAR partners agree that the set of Radioecological Observatories should include a NORM site, preferably located in Europe, since such sites provide mixed contaminant situations (radionuclides and heavy metals). Efforts to identify alternative terrestrial ecosystems that are contaminated with high levels of NORM and suitable for hypothesis-based field investigations have not yet been successful. The major problems are missing long-term perspectives and access restrictions. The ALLIANCE members will be encouraged to suggest terrestrial NORM sites that might be suitable, after applying the criteria used within STAR for the selection of Radioecological Observatories

Concerning the CEZ the next step will be to identify sites that are suitable to address the research lines prioritized in the SRA and the implementation plan currently being developed under COMET. The selection process will also take into account expertise of the Ukrainian partners involved in the COMET project as well as the experience that several STAR partners have gained through collaborations with local research institutes in the CEZ.

The marine ecosystems around the Fukushima Daiichi Nuclear Power Station could complement the range of ecosystems that can be used for hypothesis-based field investigations. Since the Fukushima University is a COMET partner, a strong link to the Fukushima area already exists. Data from the terrestrial, marine and freshwater ecosystems of the Fukushima area will most likely be used to validate and iteratively improve (dynamic) radioecological models within the COMET project.

3.4 Sustainability

The major outputs from STAR will in the short term (24 months) be maintained during the COMET project (see section 4.1.1). In the long-term, the ALLIANCE will sustain the STAR (and COMET) main outputs. To do this, the ALLIANCE has formed a WG on infrastructures and sustainability that will develop and promote the issues related to infrastructure in the future as seen necessary (see section 4.2.1.). Integration of infrastructure will also be addressed and further deepened in the future through the ongoing and recently accepted EU projects COMET, OPERRA and CONCERT.

There is also a need to disseminate data in order to comply with current European legislation and, in some countries, governmental guidance on the management and distribution of environmental information, i.e. the INSPIRE directive, Freedom of Information (FOI), Environmental Information Regulations (EIR). There are currently a variety of ways to disseminate data: as supplementary information to a journal paper, depositing in line with journal requirements, putting data on originators own website, payment to a repository to deposit the data, and use of a data centre. The dissemination options with some example of solutions are discussed in more detail in STAR Deliverable 7.2 Dissemination Plan.

4 The new European context for integration of radioecological research

4.1 COMET- continuation and extension of the work of STAR

COMET (COordination and iMplementation of a pan-European instrumenT for radioecology) (June 2013-May 2017) will strengthen the pan-European research initiative on the impact of radiation on man and the environment by facilitating the integration of radioecological research, including both the human foodchain and the protection of wildlife. The project builds upon, and complements, the foundations laid by the ALLIANCE and STAR. By collaborating with the European platforms on nuclear and radiological emergency response and recovery (NERIS) and low dose radiation risk (MELODI), and relevant training networks (e.g. EUTERP, ENEN) COMET will significantly aid preparation and implementation of an integrated radiation protection programme under Horizon 2020.

The timing of COMET is therefore opportune to further bring together European radioecology and begin working towards achieving the SRA goals in collaboration with allied European platforms which rely upon radioecology for their underpinning science. The COMET consortium expands on the organisations of STAR and the ALLIANCE. In particular, COMET facilitates links with countries which have experienced major nuclear accidents (i.e. former Soviet Union states and Japan). The specific objectives of COMET are:

- Develop innovative mechanisms for joint programming and implementation (JPI) for radioecological research in concert with the mechanisms for JPI developed by OPERRA for the Horizon 2020 proposed Radiation Protection Federating Association.

- Initiate innovative research on the key needs jointly identified by the radioecology community and the (post) emergency management (NERIS) and low-dose research communities (MELODI), and strongly engage with collaborators from countries where major nuclear accidents have occurred.
- Under an enlarged consortium and facilitated by the funds allocated for the Competitive Call further conduct priority research identified following the joint programming mechanisms developed under COMET.
- Develop strong mechanisms for knowledge exchange and dissemination to enhance and maintain European capacity, competence and skills in radioecology.

Within COMET, there are seven different initial research activities (IRAs). Six of them are contributing to Challenge 1 namely Human foodchain modelling, Marine modelling, NORM modelling, Forest modelling and IRA on hot particles. With respect to wildlife COMET (ICRP-IRA) is working with the TREE project (http://www.ceh.ac.uk/tree) to test the hypothesis that radionuclide transfer can be predicted by taxonomic based REML models. The initial research activity related to Challenge 2 is focused on epigenetic changes and their possible role in adaptation and transgenerational effects in organisms experiencing chronic low dose exposure.

There is currently no specific working group to address challenge three in COMET. However, within the IRA of WP3, the Human foodchain modelling group is applying Bayesian statistics to raw datasets to improve parameter values and is as such addressing Research line1. The groups on Marine modelling, Forest modelling and Human foodchain modelling are all addressing Research line 6 as they provide improved radioecological modelling for post-accident situations.

The open call of COMET arranged together with OPERRA was elaborated with the post-accident community NERIS to address their needs for radioecological modelling to be used in Decision Support Systems . As a result of the call two new projects are being funded under COMET, both contributing to Challenge 1: **FRAME** (https://wiki.ceh.ac.uk/x/pwN0DQ) - will investigate the sources, fate, transport, bioaccumulation and associated impact of radionuclides from the Fukushima Dai-ichi NPP accident in the water column, seafloor and marine biota. The concentrations of a suite of contaminant radionuclides (^{137}Cs, ^{134}Cs, ^{90}Sr, plutonium isotopes, ^{236}U and ^{129}I) will be determined and the transfer to marine biota (including fish, macroalgae and plankton) will be assessed. This will be accompanied by measurements of other natural radionuclides (i.e. ^{234}Th, ^{210}Pb, Ra isotopes) in order to quantify groundwater fluxes, residence times in the ocean and accumulation and mixing rates in bottom sediments. Another new project linked to COMET is **RATE**. The proposal “Radioactive particle transformation processes” intends to fill knowledge gaps related to transformation processes influencing weathering of radioactive particles released to different ecosystems and the subsequent release of associated radionuclides in order to reduce the uncertainties in environmental impact assessments of particle contaminated sites.

4.1.1 Sustainability of the outputs of STAR

In close association with STAR (during the ~2 year overlap period) and the ALLIANCE, COMET will take forward the SRA developed under STAR as the basis for developing innovative mechanisms for joint programming and implementation of radioecological research and roadmap development. To facilitate and foster future integration under the common federating structure developed by OPERRA and in the future by CONCERT, the research activities developed within COMET will also be targeted at those research needs from the radioecology SRA that will also address priorities of the emergency management (NERIS) and low dose (MELODI) platforms.

COMET will assure smooth evolvement from STAR & COMET to ALLIANCE by ensuring adequate exchange of information, databases, relevant content and links in websites etc. between STAR, COMET and ALLIANCE in the overlapping period and to draft procedures for access the large infrastructures within the ALLIANCE. Infrastructure catalogues and databases created within STAR will be updated with the information obtained from the new COMET and ALLIANCE partners. COMET will also form an overview on large infrastructures important for radioecological research within Europe and beyond. This will be done in close collaboration with the ALLIANCE and it will build on the work accomplished under STAR. The work includes searching for information on conditions of access to the large facilities and finding the best solutions for the optimal use of the facilities and identification of requirements for new infrastructure and its optimal localization.

4.2 The ALLIANCE - organisation to maintain and enhance radioecological competences

The ALLIANCE initiated the first step towards integrating European Radioecology in 2009, when the directors of eight organisations signed a Memorandum of Understanding (MoU)stating their commitment to the long-term integration of radioecology within Europe. Members of the ALLIANCE bring together parts of their respective research and development programmes into an integrated programme that maintains and enhances radioecological competences and experimental infrastructures, and addresses scientific and educational challenges in assessing the impact of radioactive substances on humans and the environment. The ALLIANCE members recognised that their shared radioecological research could be enhanced by efficiently pooling resources among its partner organizations and prioritising group efforts along common themes of mutual interest.

The ALLIANCE is an Association open to other organisations throughout the world with similar interests in promoting radioecology. Furthermore, with the intention of growth, the ALLIANCE, as a legal entity (an Association under French law), has published details of how to apply for membership (www.er-alliance.eu). In close collaboration with the ALLIANCE, COMET will develop further initiatives to encourage organisations from the European radioecological research community to join the ALLIANCE to help realise the identified priorities for radioecological research. The priorities identified in the SRA developed by the STAR NoE in partnership with the ALLIANCE and COMET can only be realised by an enlarged consortium. At the moment of writing, the ALLIANCE consists of 21 members from 14 countries.

ALLIANCE and COMET unite forces to develop a strategic roadmap of radioecology in interaction with the European Radiation protection community. With OPERRA (section 5.1) and CONCERT (section 5.2), ALLIANCE and sister organisations will optimise research, E&T and infrastructure integration and build up an umbrella coordination structure that has the capacity in a legal and logistical sense to administer future calls for research in radiation protection as a whole. On December 2013, a joint MoU was signed in Brussels, on the premises of the European Commission, between the four major European organisations fostering research in a domain of radiation protection (ALLIANCE, MELODI, NERIS and EURADOS).

Sustainable interaction with international organisations and networks outside of Europe will be pursued by striving towards MoU between the ALLIANCE and those international organisations/networks. The ALLIANCE and the International Union of Radioecology (IUR) have already signed a MoU, and collaborate in several initiatives of both organizations. For example the

ALLIANCE has accepted the IUR invitation to join the IUR FORUM launched in 2014 to develop worldwide harmonization of existing networks in radioecology.

The future of radioecology and the role to be played by the ALLIANCE has been discussed with some international organisations as the IUR or the National Center for Radioecology of the USA (NCoRE).

The IUR is an independent, non-profit and non-governmental association is committed to this spirit of development since the very beginning, with all suitable actions susceptible to assemble the largest community acting in the field. The NCoRE is a network of excellence of the remaining radioecology expertise in the United States, led by the Savannah River National Laboratory. The NCoRE has identified the immediate needs for science-driven research, tool development and the generation of scientific data to adequately protect the human health and the environment.

As IUR states "*Radioecology needs to be tackled at worldwide scale irrespective of the local situations prevailing in terms of political trends, funding, and scientific development*". This is a view shared by the ALLIANCE. Ability to promote joint programming in Europe in self-funded conditions without the further financial support of the EC is regarded as the real challenge for the foreseeable future. If successful, this would perhaps form the strongest added value of the ALLIANCE within the radiation protection perspective of integration in Europe.

Several other challenges have been identified by IUR and NCoRE, including:

- To promote scientific innovation such as to prepare the scientific grounds for moving forward the radiation protection paradigms, and especially the move from a pure anthropocentric view over human risk assessment (past) to a more ecocentric view addressing also ecological risk assessment (future).
- To identify and implement viable solutions to achieve better integration of nuclearized and non-nuclearized countries which may all be submitted to the impact of a potential accident happening in Europe or nearby.
- To seek overall integration also together with non-radiation scientific fields such as ecology, ecotoxicology and biogeochemistry, all similarly committed to environmental/ecological risk assessment of other types of hazards.

4.2.1 Long-term sustainability of STAR (and COMET) outputs

The outputs of the STAR NoE which require consideration for "sustainability" are largely located on the RadEx website (www.radioecology-exchange.org). There are others which although having a website presence are somewhat separate, for instance co-ordination of the work at the Radioecological Observatory sites, the SRA etc.

Some STAR outputs don't need to be further developed, with the only need to keep them in the RadEx. The STAR project has a separate website (www.star-radioecology.org) which only contains STAR deliverables, publications lists and information on the project. At the end of STAR, once all the reports and additional information of STAR are available from it, this site will be 'locked'. This change in the status of the project and the website will be reflected in the home (and potentially other) page of STAR. Other STAR outputs, will require further development in the future years. The major outputs from STAR will be maintained in the short term (next 24 months) within the COMET project, these include: the SRA, Roadmaps, the training pages of the RadEx, Observatories information, social media etc.

Towards the end of the COMET project, the ALLIANCE members will need to consider what aspects of the STAR/COMET outputs need to be further maintained. Some of these will be obvious, e.g. the SRA and Roadmaps. For others (e.g. updating of data catalogues, keeping sample archives available, updating analytical methods, etc.) the ALLIANCE will need to decide and, if needed, will have to develop a work plan for the long-term sustainability of those outputs. The discussion should take place 6-12 months prior to the conclusion of COMET.

5 Integration in the broader area of radiation protection

5.1 OPERRA - continuation and extension of the work of DoReMi in low dose research

In early 2000, concern was raised on the gradual decline of expertise and resources in radiation research in several European Member States. In light of indications that many EU Member States have lost key competences and cannot independently maintain effective radiation research programmes, organised and targeted cooperation in European level was initiated to ensure a solid knowledge base in radiation protection sciences. In 2009, the European High Level and Expert Group (HLEG) identified key policy questions to be addressed by a joint strategic research agenda and initiated the establishment of a European Research Platform, called MELODI (Multidisciplinary European Low Dose Research Initiative). In 2010, a Network of Excellence called DoReMi was launched by the Euratom FP7 programme. DoReMi has acted as an operational tool for the development of the MELODI platform during the first years. Strategic planning of DoReMi activities is carried out in close collaboration with MELODI. The long term Strategic Research Agenda for European low dose radiation risk research was developed by MELODI. DoReMi formulated research priorities in a Transitional Research Agenda that focused on objectives that are feasible to achieve within the six year lifetime of the project and that are in areas where stimulus is needed in order to proceed with the longer term strategic objectives of the SRA.

The experiences of integration of research gained by MELODI and DoReMi have been made use of by other radiation protection research communities. In parallel to the low dose risk research community, other platforms were established for emergency preparedness and response (NERIS in 2010) and radioecology (ALLIANCE in 2012). Similarly to DoReMi, the NoE STAR and Collaborative Project NERIS-TP, followed by COMET and PREPARE projects, have played an important role in establishing the structures and functions of the research platforms by supporting the preparation of Strategic Research Agendas and coordinating activities on infrastructures and training.

The emergence of sustainable research platforms operating through joint research agendas made it possible to bring together all these platforms under one umbrella structure, addressing research on radiation protection. Within the OPERRA project (Open Project for European Radiation Research Area), the MELODI Association, as a well-advanced network, took the lead in establishing the necessary structures able to manage the long-term European research programmes in radiation protection, also taking advantage of the valuable experience gathered through the DoReMi network of excellence. Whilst in fields adjacent to low-dose risk research (radioecology, nuclear emergency management) scientific issues would continue to be hosted by the sister associations, ALLIANCE and NERIS, these associations were encouraged to join MELODI to establish an umbrella structure as equal partners, as were other relevant associations, e.g. EURADOS. EURADOS, the European Dosimetry Group has acted as an important forum for development and training in dosimetry since 1980´s.

OPERRA exploits the synergies of EURATOM and other EC programmes considering the most relevant joint programme areas and mechanisms for funding joint activities. The project will also strengthen the links with national funding programmes as well as the European education and training structures. Also, it will take steps towards a greater involvement of those new Member States who could benefit from increased participation in the radiation research programmes. Finally, OPERRA will take steps to further integrate the joint use of infrastructures in European countries, and to develop and facilitate an easier access to research infrastructures.

The final objective of OPERRA is to build up an umbrella coordination structure that has the capacity in a legal and logistical sense to administer future calls for research in radiation protection as a whole (including low-dose risk, radioecology, nuclear emergency management, and also research activities related to the medical uses of ionising radiation) on behalf of the European Commission. OPERRA launched the first call in the end of 2013 for projects in low-dose risk research and a second call in 2014 for broader projects in radiation protection research. In the second call, synergies between the four SRAs were particularly addressed.

In addition to the research calls, OPERRA has carried out coordination and support activities related to integration of national and EU research and training programs. Besides the more general topics, more specific objectives have included topics that are of interest to radioecology community, in particular identification of experiences and lessons learned from existing exposure situations, including Chernobyl, Fukushima and NORM industry, and exploration of expertise gathered in other fields of research, with the view to strengthening the exchange and integration of knowledge between radiation and non-radiation research communities.

While the OPERRA calls have operated according to general FP7 rules for participation and funding, a longer term objective for the OPERRA project is establishing a joint programming instrument that would be proposed to European Commission as a tool for programming the low-dose risk research in Europe. Joint programming would allow better integration of national and European research activities and co-funding that is expected to be an important element of Horizon 2020.

5.2 Horizon 2020 – European Joint Program Co –fund action CONCERT

Encouraged by the European integration process in radiation protection research, the Euratom Work Programme 2014-2015 included a topic for “Integrating radiation research in the European Union”, to be funded as European Joint Programme Co-fund action, expected to integrate national programmes and EC programme. This has led to the establishment of the CONCERT project – European Joint Programme for the Integration of Radiation Protection Research. National programmes are represented by national Program Owners or Programme Managers nominated by them. The EJP is a co-funding instrument where the ratio of EC funding: National funding is 70:30.

With the OPERRA, COMET and PREPARE projects and the well-advanced organization of the platforms, the time is now ripe for the platforms to jointly prepare the next steps. These steps will be taken within the CONCERT EJP to build a sustainable network of the scientific platforms in Europe covering all relevant sectors in radiation protection research from radiation effects and risks, radioecology, nuclear emergency preparedness and radiation dosimetry to radiation protection in medicine. The platforms develop sectorial SRA’s, set priorities and develop roadmaps, respectively. By joint programming, the CONCERT EJP will set priorities for the entire field of radiation protection research and will develop a joint long-term roadmap.

The integration of national owners and managers of research programmes in the field of radiation protection research in a European joint programme to initiate and administer co-funded research projects and integration activities will strongly support the development of a sustainable radiation protection research area in Europe.

The CONCERT EJP has a clear cyclical workflow from developing strategic research agendas (WP2), defining research priorities and roadmaps by joint programming (WP3) to the initiation and funding of specific projects in radiation protection research (WP4). Integrative activities (WP5: Stakeholder involvement and communication, WP6: Infrastructures and WP7: Education and training) are promoted with the aim to closely interact with funded research projects. Ideally integrative activities will be an integral part of research projects. The general workflow of the CONCERT consortium will be the following:

- Scientific research needs will be gathered in strategic research agendas by each platform, regularly updated in the light of new developments and of multidisciplinary discussions. With the support of the European research platforms MELODI, ALLIANCE, NERIS, and EURADOS which have emerged over the recent years, this will be the mission of WP2. Additional research needs related to for medical radiation, social sciences and supporting the implementation of revised BSS will be explored as well.
- The setting of research priorities tailored to the needs of radiation protection and with a perspective of further integration and sustainability of radiation protection science at the European level will be established with a yearly cyclical approach based on the results from WP2 work. This joint programming will be the mission of WP3.
- The practice of open RTD calls is recognized as the best route to scientific excellence and to the involvement of the wider scientific community in the scientific challenges of radiation protection. It will be the mission of WP4 to organize and administer such co-funded calls, based on the identified priority needs delivered by WP3.

European integration, which is one of the central objectives of the CONCERT EJP, is based not only on the joint organization of open research calls, but also on the increasing convergence between radiation protection institutions across Europe and integrative scientific activities beyond borders. This leads to joint activities in a continuous work flow such as interaction with stakeholders, authorities, the development and access to key research infrastructures in Europe, and joint education and training initiatives. From such an approach, major benefits can be expected on a pan European scale, such as substantial economies of scale, and increased coherence of the scientific basis for radiation protection, and the facilitation of a harmonious implementation of European directives and related basic standards. This convergence will be encouraged by the development of “integration initiatives” to be funded by CONCERT, applying here also the co-fund approach. It will be the mission of WP5 (Stakeholder involvement), WP6 (Infrastructures) and WP7 (E&T), respectively. Via input from WP5, WP6 and WP7 into the work of WP3 integrative activities will become part of CONCERTs research programme such as the facilitation of access to research infrastructure (WP6) or education and training (WP7) or will make sure that the needs of stakeholders will adequately considered (WP5).

CONCERT also aims to continue the ongoing work on identifying key infrastructure for radiation protection research in Europe and beyond and further extend the lists of relevant large infrastructure generated in STAR, OPERRA and other EU funded projects by including infrastructures from non-EU countries. To best meet the needs of the radioprotection community, the listing of large infrastructures may need to go beyond Europe. In CONCERT the quality criteria and lists of recommended infrastructures related for example to irradiation facilities, sample archives and databanks will be further developed and updated. Practices and protocols will be harmonized by focusing on strengthening and expanding databases from radiological experiments (with animals, plants or from the radioecology field) or cohort studies indicating to what extent biological material is available. Furthermore, guidelines will be developed for the carrying out of harmonisation exercises for selected infrastructures.

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