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D 2.1 - Annual SRA Statements from MELODI, ALLIANCE, NERIS and EURADOS

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Abstract

D 2.1 - Annual SRA Statements from MELODI, ALLIANCE, NERIS and EURADOS

Annual SRA Statements from MELODI, ALLIANCE, NERIS and EURADOS have been compiled by collecting the SRA Statements from the platforms. This material serves as input for Joint Programming (WP3). Each platform considered the same criteria for prioritization and provided a ranked list of priorities as summarized below.

Four priorities on radioecology were identified by ALLIANCE. The first two concern reducing the uncertainty in exposure and dose assessment for human and wildlife and the last two effects on wildlife.

- Environmental availability and impact of radionuclides in terrestrial and freshwater ecosystems (including human food chain) and their interactions with atmosphere, incorporating physical, chemical and/or biological processes. Validated process-based model parameterisation, characterisation of variability and uncertainty, and guidance for fit-for-purpose models (ranked as priority 1)
- Development of models/tools, and datasets for their calibration and validation and guidance to select and evaluate the effectiveness of different remediation strategies in long-lasting exposure situations (*e.g.* nuclear accidents and/or NORM/TeNORM) (ranked as priority 3)
- Biomarkers of exposure and effects to living organisms as operational outcomes of a mechanistic understanding of intra- and inter-species variation of radiosensitivity to chronic low dose exposure situations (ranked as priority 2)
- Multiple stressors and modulation of radiation effects in living organisms (ranked as priority 4).

EURADOS identified the following six priorities for the RTD on dosimetry:

- To quantify correlations between track structure and radiation damage
- To improve neutron dosimetry techniques
- To quantify doses after accidental internal contamination
- To develop accurate and on-line personal dosimetry for workers
- To improve the measurement and combination of out-of-field radiotherapy and imaging doses in photon and particle radiotherapy, for input to epidemiological studies
- To improve dosimetry in modern external beam radiotherapy

MELODI identified five priorities in the area of low dose risk:

- To explore the shape of the dose-response relationship for radiation induced health effects at low doses/dose-rates based on key informative epidemiological studies (including where appropriate, molecular or other biomarkers) for internal and/or external emitters, incorporating detailed dosimetric assessment.
- To explore and define the role of epigenetic modifications in radiation-induced health effects following exposure to low doses/low dose rates.
- To identify, develop and validate biomarkers for exposure, early and late effects for cancer or/and non-cancer diseases in relation to low doses/low-dose rates and to integrate them in molecular epidemiological studies.
- To explore the roles of specific target cells for low dose/dose-rate radiation-induced late developing health effects such as cancers, circulatory diseases and cataract.

- To understand the potential impact of individual susceptibility on radiation risk using cohorts and/or systems models with variations in sensitivity to low doses of radiation, so that differences in the response pathways can be detected and biomarkers validated.

NERIS identified six priorities on RTD concerning emergency preparedness and response:

- **Assessment of and communication of uncertainties**. Investigation of data uncertainties (model or monitoring results) and how they can be communicated, e.g. in model results and in Decision Support Systems (DSS) to help decision-makers to understand the radiological situation. This includes also work on model sensitivity, validity of model results and inter-comparisons of models and measurements.
- **Robust decision-making.** Structuring the decision processes and the protective strategies at national, regional and local levels with the help of formal decision aid tools, such as multi---criteria analysis and on the basis of feedback from stakeholder processes. Development of guidance on the use of DSS in the various phases of an event based on feedback from stakeholder processes and from Fukushima experience in emergency response and recovery.
- **Countermeasure strategy preparedness.** Development of sustainable preparedness strategy at Local, National and European level, based on the analysis of countermeasures for relevant accident scenarios. Ensuring that parameters governing the radiological consequences can be identified in time to enable optimized remediation and contribute to the elaboration of robust recovery strategies.
- **Atmospheric dispersion modelling.** To make more reliable forecasts of atmospheric dispersion, including data assimilation and improved inverse modelling (to determine source term and/or source location) in different environments (e.g. urban areas) and/or at different spatial scales (near range to global scale).
- **Local radio-ecological models.** Development and integration in general DSS of local radio-ecological models interlinked with monitoring information and the more global and food chain dose models. Investigate the capability of such models to be operated by local stakeholders as farmers or local communities. Link with ALLIANCE.
- **Monitoring strategies.** Optimised use of monitoring resources, including mobile units and trans-border issues. Integration of new monitoring technologies (e.g.; drones). Development of processes and tools for integrating the monitoring results from experts and lay people into a common operational picture (monitoring crowdsourcing). Information fusion (radiological and non-radiological). Link with EURADOS but focus on strategy and integration, less on the improvement or development of new measurement methods/techniques.

<End of abstract>

EUROPEAN RADIOECOLOGY ALLIANCE

ALLIANCE SRA-Statement 2015

The ALLIANCE, the radioecology Strategic Research Agenda and the onset of the Roadmap

The European Radioecology Alliance (ALLIANCE) was founded in 2009 to coordinate and promote European research on radioecology. The ALLIANCE acts as a research platform, defining priorities for research programmes and integrating human and infrastructure resources to advance research in the field of radioecology. It promotes maintenance, updating and mutual use of suitable infrastructures, education and training and communication with stakeholders.

The present statement based on the Strategic Research Agenda[1] (SRA) was produced to serve as an input to those responsible for defining EU research call topics. It provides and justifies research priorities for radioecology at the short- and medium-term consistently with the major outcomes from recent and ongoing projects and with the ALLIANCE SRA, which constitutes the reference document shared by stakeholders and researchers. The strategy underlying the ongoing roadmap development associated to this SRA is driven by the need for improvement of mechanistic understanding across radioecology such that robust fit-for-purpose human and environmental impact/risk assessment can be provided in support of protection of man and the environment in interaction with society (connecting science, communication, economy) and for the three exposure situations defined by the International Commission on Radiological Protection (*i.e.*, planned, existing and emergency). Several topical working groups[1] each dealing with specific scientific areas and/or complex environmental issues are in progress: 1) atmospheric transfer processes, 2) marine radioecology, 3) human food chains modelling, 4) Naturally-Occurring Radioactive Materials (NORM), 5) inter- and intra-species radiation sensitivity, 6) transgenerational effects. Topics 1-3 are mainly linked with NERIS and topics 5-6 with MELODI. Topics 2-6 are also developed as initial research activities within COMET[2]. The COMET call (2013) supported research in marine radioecology and hot particle environmental behavior. Topics 1 and 3 are also partly covered in the HARMONE project recently granted under the OPERRA 2nd call[3]. Some of the research areas hence provide a powerful catalyst to further develop collaboration between the four European platforms of radiation protection, ALLIANCE, NERIS, MELODI and EURADOS.

Outcomes of recent past activities and OPERRA e-survey

STAR Network of Excellence[4] has contributed to promote the establishment of various alternative transfer models (*e.g.* allometric, process-based models, Bayesian approaches) and has successfully explored the issue of the importance of the multiple stressors context in radiological risk assessment, using the situation of NORM contamination. STAR advanced the integration of human and environmental protection frameworks with the development of a combined screening model for both human and non-human biota (CROMERICA tool). Mechanistic models developed (*e.g.* DEBtox) proved to provide important insights in the causes of effects observed and tools to develop more robust ecological protection benchmarks. By implementing different biomarkers and transcriptomic approaches, comparative insights into modes of actions of alpha and gamma radiation types in plants and animals were obtained. Additionally, the STAR External Advisory Board final report[4] pointed out that the Fukushima accident has once again demonstrated the importance of having robust national and international programs in radioecology to make scientifically sound decisions for the protection of man and the environment. Moreover, Europe is in an excellent position to build upon the momentum and synergies created by the STAR project to lead advances in radioecology.

The OPERRA e-Survey[5] helped to evaluate the importance of the research priorities suggested by the different European platforms by engaging with a wide panel of stakeholders. For the ALLIANCE SRA,

[1] https://wiki.ceh.ac.uk/x/YoFsD
[2] COMET: COordination and iMplementation of a pan-Europe instrumenT for radioecology. www.comet-radioecology.org
[3] http://www.melodi-online.eu/operra.html
[4] https://wiki.ceh.ac.uk/display/star/STAR+Radioecology; see the SRA ; see STAR D1.12 with the External Advisory Board report
[5] http://www.melodi-online.eu/doc/operra_esurvey2014/OPERRA%20D4-5%20Analysis%20of%20stakeholder%20questionnaire%20responses%202015-07-06.pdf

all the 15 research lines received high scores for importance/feasibility, suggesting their relevancy for improving radiation protection. The following three lines were considered as the most important to accomplish the long-term vision of radioecology, in agreement with the ranking from the STAR questionnaire released in 2012[1]:

- Identify and mathematically represent key processes that make significant contributions to the environmental transfers of radionuclides and resultant exposures of humans and wildlife.
- Acquire the data necessary for parameterization of the key processes controlling the transfer of radionuclides.
- Develop transfer and exposure models that incorporate physical, chemical and biological interactions and enable predictions to be made spatially and temporally.

According to the ALLIANCE respondents to the OPERRA e-Survey, exposure situations that should receive priority to develop those three research lines were accident/post-accident situations, followed by existing NORM-TeNORM situations. Among the synergistic topics identified by the ALLIANCE and at least one other platform, the highest importance/feasibility scores were given to:

- Spatial and temporal environmental modelling and human dose assessment after a nuclear accident (identified with NERIS, EURADOS).
- Priorities for pre-accident recovery preparedness (identified with NERIS, EURADOS).
- Biomarkers of exposure and effects in living organisms (identified with MELODI).
- Multiple stressors and modulation of radiation effects in living organisms (identified with MELODI, EURADOS).

Selection of priorities for the years to come and ranking (for details see Annex)

Combining the conclusions of the e-Survey, the research progress in the recent past and on-going EC-funded projects and consolidation by the ALLIANCE SRA/Roadmap Working Group and ALLIANCE members, priorities were grouped into two categories reflecting expected impact on radiation protection increase.

Two priorities with impact expected mainly in terms of reduced uncertainty in exposure and dose assessment and increased human and wildlife radiation protection:

- Environmental availability and impact of radionuclides in terrestrial and freshwater ecosystems (including human food chain) and their interactions with atmosphere, incorporating physical, chemical and/or biological processes. Validated process-based model parameterisation, characterisation of variability and uncertainty, and guidance for fit-for-purpose models **(ranked as priority 1)**
- Development of models/tools, and datasets for their calibration and validation and guidance to select and evaluate the effectiveness of different remediation strategies in long-lasting exposure situations (*e.g.* nuclear accidents and/or NORM/TeNORM) **(ranked as priority 3)**

Two priorities with impact expected mainly in terms of reduced uncertainty in effect assessment and increased wildlife radiation protection:

- Biomarkers of exposure and effects to living organisms as operational outcomes of a mechanistic understanding of intra- and inter-species variation of radiosensitivity to chronic low dose exposure situations **(ranked as priority 2)**
- Multiple stressors and modulation of radiation effects in living organisms **(ranked as priority 4)**.

The ALLIANCE encourages where relevant openness to other disciplines to integrate their skills and knowledge into radioecology, and capitalisation of best practices, tools and data in the various fields of research needed. Additionally, research combining “lab-field-modelling” approach and fit-for-purpose applications will be appreciated.

ANNEX: Description of ALLIANCE 2015 priorities

Priority title	**Environmental availability and impact of radionuclides in terrestrial and freshwater ecosystems (including human food chain) and their interactions with atmosphere, incorporating physical, chemical and/or biological processes. Validated process-based model parameterization, characterisation of variability and uncertainty, and guidance for fit-for-purpose models** (**ranked as first priority**).
Priority description	A key goal of radioecology is to understand and predict the transfers of radionuclides and consequent exposure of humans and wildlife. More specifically, this is needed for a wide range of sources and release scenarios, exposure situations and assessment contexts in continental environments, including interactions with atmosphere. Although considerable advances have been made since the Chernobyl accident in predictive modelling, the Fukushima accident in Japan has highlighted the need of improved transfer and exposure models. The new models should represent the behaviour of the radionuclides in a more realistic way, ideally considering the different levels of organisation present in the environment. The key physical, chemical and biological processes that govern radionuclide transfers, and how transfers and exposure of humans and wildlife vary spatially, temporally and with the source term, should also be taken into account. Research should contribute to an improved process-based understanding of radionuclide transport and transfers in various radioactively contaminated areas and eventually into the human food chain. Major physical and biogeochemical processes should be identified, conceptualised and mathematically translated into models (from empirical to mechanistic, depending on the requirement) taking into account spatial heterogeneity and temporal variability of the environment under study. One of the expected outcomes is to provide guidance for selecting the level of refinement for models according to the targeted uncertainty. Another is to obtain calibrated and validated models which are fit for purpose.
European relevance	This topic is highly relevant for European radioecology in view of substantial advances in improving process-based understanding of radioecology in Europe, which needs to be supported by adequate funding, allowing European scientists to be leaders in the field. This topic has synergies with NERIS and EURADOS, and indirectly with MELODI, since dose assessment is a key step in the radiological impact/risk characterisation. This synergistic topic was highly scored by the OPERRA e-Survey. The radioecology research lines related with this topic (Challenge 1) also received a high score in the OPERRA e-Survey.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	This topic is multidisciplinary because it connects radioecology, radiation protection, dosimetry, ecotoxicology, physics and biogeochemistry. The topic has links with European research platforms: -ALLIANCE (Sep 2013): p.14-22; Challenge 1; research lines: 3.1.2.1; 3.1.2.2.; 3.1.2.3; and 3.1.2.4; p.32, Challenge 3, research line 3.3.2.1. - NERIS (April 2014): p. 12; Key topic 1.6; p. 13; Key topic 2.1; p. 16; Key topic 3.4; p. 18; Key topic 5.1; p.24 cross cutting issues -EURADOS (May 2014): p.6; Vision 3 and 5
Impact: decreased uncertainty	A deeper scientific understanding of the environmental processes involved in the transport and transfer of radionuclides will reduce uncertainties and hence robustly support decision making in various exposure situations. The knowledge gained will allow providing guidance for selecting the level of refinement for models according to the targeted uncertainty.
Impact: increased radiation protection	The topic will contribute to improve the radiation protection system, since it will allow to accurately predict exposure to humans and wildlife in planned, existing and emergency exposure situations, within two major ecosystems (terrestrial and freshwater).
Impact: increased acceptability	Uncertainties and lack of predictive power in risk assessments are major contributors to the public's reduced credibility of radiological sciences. Therefore, the acquisition of new scientific knowledge to reduce the uncertainties of the dose assessments, allowing more robust predictions and improved human and wildlife impact/risk assessments, will improve credibility with stakeholders.
Feasibility	There is a strong European radioecology research base with access to modelling, international databases, long-term collaborations with international organisations and first-class facilities. A thorough study for research in the domain proposed is estimated to last 4 years requiring a budget of 2-4 M€.

Priority title	**Development of models/tools, and datasets for their calibration and validation and guidance to select and evaluate the effectiveness of different remediation strategies in long-lasting exposure situations (*e.g.* nuclear accidents and/or NORM/TeNORM)** (**ranked as third priority**).
Priority description	Management approaches in emergency and existing exposure situations can range widely in complexity. Although a significant knowledge exists for a wide range of exposure situations, it tends to be fragmentary rather than forming an integrated strategy capable of dealing with complex, dynamically changing conditions. The need for integrated and graded management approaches and the appropriate tools to implement them over the entire spectrum of possible exposure scenarios, and thus ensuring socio-economic facets are taken into account in the rehabilitation of the impact areas, are primary drivers for radioecological research in the coming decades. The recent events at Fukushima exemplify these problems and the existing deficiencies. There is a need for sound, fundamental and progressive science to yield maximum benefits from these efforts. Research is needed to guide the development/selection of models and assessment tools for medium to long-term predictions. There is a parallel need to generate and make available field data for their validation. Appropriate models (from empirical to process-based) should be developed to help compare radiological effects from various remediation measures, including those reducing radionuclide transfers into the food chain and/or those improving ecosystem services. For relevant radionuclides, models need to be applied to design remediation strategies to the major components of the ecosystems. Regarding more specifically post-accident exposure situations, the research to be done ought to complement the OPERRA-2014 HARMONE project activities, mainly dealing with the early phase of an emergency situation. Regarding NORM/TeNORM sites research is needed to give answers to the specific requirements of the EURATOM Basic Safety Standards.
European relevance	This topic has synergies with NERIS and EURADOS, in the establishment of priorities for pre-accident recovery preparedness, which was highly scored by OPERRA e-Survey. The topic defined by ALLIANCE will complement the expected outcomes from OPERA-2014 HARMONE, by dealing with medium- to long-term transfer processes and by tackling remediation issues. The topic is relevant to implement the requirements from the EURATOM BSS in relation to NORM/TeNORM. The priority is designed up-front to address specific BSS requirements for long-lasting exposure situations / remediation strategies.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	Multidisciplinarity is assured through topical links between radioecology, radiation protection/dosimetry, ecotoxicology, physics and biogeochemistry. -ALLIANCE (Sept 2013): p. 30-37- challenge 3- research lines 1 to 6; p.15-22: challenge 1- research lines 1 to 4. -NERIS (Apr 2014): p. 12; Key topic 1.6; p. 16; Key topic 3.4; p. 19; Key topic 5.7; p.24 cross cutting issues -EURADOS (May 2014): Vision 3 and 5
Impact: decreased uncertainty	Scarcity of data is one of the major sources of uncertainty. The databases developed will contribute to the reduction of uncertainties in the impact/risk characterization in long-term radiological assessment, making remediation strategies more credible and robust, and offering the possibilities of comparing a range of strategies. The use of calibrated and validated models will also contribute to reduce uncertainties.
Impact: increased radiation protection	The predictions obtained in the assessment models are often key constituents in decisions made about emergency response, waste management, environmental remediation, and mitigation. The availability of more accurate validated models will increase the confidence in the radiological impact/risk assessment process, and therefore will contribute to the improvement of the radiation protection system through robust evaluation of the best remediation strategies to minimise exposures to the public and the environment.
Impact: increased acceptability	The use of validated models will improve the predictive accuracy and precision of the radiological impact assessments, with a greater confidence in the results. Moreover, justification of nuclear industry activities is increased if robust remediation approaches exist and are well evaluated before things go wrong.
Feasibility	The expertise and technological resources needed exist and are well consolidated at the European level to make this research highly feasible. A thorough study is estimated to last 4 years requiring a budget of 2-3 M€.

Priority title	**Biomarkers of exposure and effects to living organisms as operational outcomes of a mechanistic understanding of intra- and inter-species variation of radiosensitivity to chronic low dose exposure situations** (**ranked as second priority**)
Priority description	The issue of biological effects of low doses of ionising radiation is still of major concern for both human and environmental radiation protection, as highlighted recently after the Fukushima accident, especially with the aim of quantifying (and reducing if needed) the magnitude of risk to individual (human and endangered species) and population (human and biota) health at low doses/dose rates. We need urgently to complement the system of radiation protection to be able to face the wide biodiversity and biological responses to radiation (from molecules to ecosystems) in a credible and robust way. A key for success is to explore intra- and inter-species causes of radiosensitivity variation. This will help to screen out candidates for biomarkers to be used as early warning tools after *ad hoc* validation. Research is required to contribute to the identification of the primary mechanisms of radiation induced effects at the molecular level and their propagation up to the individual level, including consequences for physiological functions (*e.g.* reproduction). This will be evidenced by evaluating suitable biomarkers of exposure and biomarkers of effects. A comparative and "lab-field-model"-combined approach for a number of exposure conditions and/or a number of species will enhance the understanding of the toxicity profiles as a response to exposure conditions. Dose-response relationships will be established making the best use of "omics" analytical methods, possibly combined with the use of a system biology approach, to provide evidence of linkage between metabolic pathways and associated biomarkers of effects. Research could expand to the use of genetic and epigenetic changes as biomarkers by implementing innovative approaches to test changes in the genome (*e.g.* mutation rates and types) and the epigenome (*e.g.* epigenetic tags) through generations.
European relevance	This topic, synergistic with MELODI, was highly scored in the OPERRA e-survey. It presents a high potential for multidisciplinarity beyond the radiological protection community since it highlights similarities that radioecology has with ecotoxicology, stress ecology and human radiation biology. The topic is indirectly relevant to NERIS in that biomarkers potentially also useful in health surveillance, are looked for. The research is also relevant to EURADOS as accurate dosimetry is a prerequisite for any robust dose-response relationships. Impact on risk communication is expected by providing answers to burning questions emerging from public perception of the consequences of the Fukushima and the Chernobyl accidents. Outcomes will support emerging policy in the field of radioprotection of the environment, explicitly mentioned in the EURATOM BSS.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	This topic will complement human and environmental radiation protection frameworks in a consistent way and will contribute to an improved and efficient integration of both protection frameworks. -MELODI (Aug 2015): p.12-17: chapter 4.2, 4.3, p.18 -ALLIANCE (Sept 2013): p.23-29: challenge 2 – research lines 2.1, 2.2; 2.4; p.33: challenge 3-research line 3.2 -NERIS (Apr 2014): p.18 key topic 5.1; p.20 key topic 5.8; p.24 cross cutting issues -EURADOS (May 2014): p.5-11: vision 1 topics 1, 2, 3; p.20-23: vision 3 topic 1
Impact: decreased uncertainty	This research should provide the basis for the development of biologically-based extrapolation models which are the key to tackle the wide species diversity and would be useful for risk assessors by helping reducing uncertainty in predictions of effects (and ultimately risk).
Impact: increased radiation protection	Identification of such biomarkers will be relevant to humans or non-human species radioprotection. Acquired knowledge will highlight and feed the various extrapolations needed when assessing radiological risk to humans or non-human species, and will provide robustness in effects predictions and decision taking.
Impact: increased acceptability	By encouraging openness to other disciplines and innovative hypothesis-driven approach to understand underlying mechanisms, this research topic will contribute to increasing acceptability of the radiation protection system and aid in risk prediction, management and communication.
Feasibility	A wide range of methods and approaches exists to make this research highly feasible, along with effect database (*e.g.* FREDERICA). A thorough study is estimated to last 4 years requiring a budget of 2-4 M€.

Priority title	**Multiple stressors and modulation of radiation effects in living organisms** (**ranked as fourth priority**)
Priority description	Exposure to multiple stressors may directly or indirectly modulate radiation effects in living organisms. Even though studying a contaminant in isolation is necessary to understand the underlying mechanisms resulting in the observed effects, this does not allow to predict potential interactions among the many stressors to which organisms are actually exposed and the resulting effects. Interactions can reduce overall damage or augment single stressor effects. Hence, the presence of co-stressors may alter the level at which organisms are likely to show radiation effects. From a risk point of view, knowing how co-contaminants/stressors might influence the radiosensitivity of organisms is therefore a pressing need. Research is required to contribute to the mechanistic understanding of how radiation effects in living organisms are modulated in the context of multiple stressors. Emphasis is on environmentally relevant combinations of stressors that interact such that synergistic effects are likely to occur with exposure to radiation or radionuclides. The occurrence of synergisms will have to be investigated at realistic radiation levels and realistic concentrations/conditions of other stressors. Given the multitude of potential stressors and combinations that exists in real exposure conditions, the approach to prioritise hypotheses, select stressor combinations and conditions is quintessential. Projects should be directed to the mechanistic understanding of the site where interactions occur: at the level of exposure, where interactions can take place in various processes (*e.g* uptake, internal distribution of the radionuclides), or at the level of effect (where interactions could be observed at the primary site(s) of disturbance or in regulation and signal transduction of the response of the organism following exposure). Dynamic and biology-based methods and approaches (*e.g.* DEBtox, gene expression pathways) could contribute to mechanistic understanding. Multiple stressor research will benefit from field based studies and the evaluation of the results in a risk assessment context. The question of the robustness of screening values in a multiple stressor context should be considered.
European relevance	This multidisciplinary complex topic can build on the achievements of the STAR Network of Excellence and was selected as a high importance synergistic topic by ALLIANCE, MELODI and EURADOS. The research on this topic will help reduce uncertainties by taking into account environmentally relevant exposure conditions. The research is relevant to EURADOS as accurate dosimetry is a prerequisite for any robust dose-response relationships. Impact in communication to the public is expected by improving the capability of demonstrating the impact of ionising radiation in comparison to other environmental stressors.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	This topic will support chemical and radiological environmental protection frameworks in a consistent way and will improve consistency for any environmental impact assessment. This research is highly multidisciplinary in nature and will benefit from interacting with ecotoxicology and biochemistry. -MELODI (Aug 2015): p.17 – synergistic topic 1 -ALLIANCE (Sept 2013): p.27 challenge 2 – research line 3; p.34: challenge 3-research line 3 -NERIS (Apr 2014): p. 16 key topic 3.6; p.24 cross cutting issues -EURADOS (May 2014):): p.5-11: vision 1 topics 1, 2, 3; p.20-23: vision 3 topic 1
Impact: decreased uncertainty	This research will complete the scientific foundation for fully integrating environmental and human protection frameworks under one generalised system (*i.e.* consistent between radiation and chemicals on one hand and human and environment on the other hand), which would be of much interest to regulators, industry and the public.
Impact: increased radiation protection	This research will demonstrate if radiation protection standards are robust and protective enough will provide robustness to any risk assessment, associated decisions and communication.
Impact: increased acceptability	Gaining knowledge on low dose effects under realistic exposure conditions and explaining clearly important and relevant results obtained to the public are needed to give people the power of informed choice and of making decisions knowing the level of risks associated to their living conditions for them and the future generations. Being able to clearly demonstrate the role of ionising radiation in comparison to any other environmental stressor is a must for being successful.
Feasibility	This research needs to implement an innovative approach and as such, is risky. A thorough study is estimated to last 4 years requiring a budget of 3-4 M€.

EURADOS SRA Statement – September 7, 2015

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History of SRA development

In 2012, the EURADOS Council recognized the need to actively contribute to the identification of future research needs in radiation dosimetry in Europe and encouraged all eight EURADOS working groups (WGs) to collect the required information, depending on their field of expertise. In February 2013, the Council established a dedicated Task Group (TG) to collect this information and draft a first version of a EURADOS Strategic Research Agenda (SRA) for dosimetry. An advanced version of the SRA was distributed in January 2014 among the EURADOS Voting Members and Working Group Chairs, for discussion. This version was produced with major input from all EURADOS WGs and the Voting Members. It included what – according to the EURADOS community – should be done to improve dosimetry during the next decades and be funded in future calls issued by the European Commission. Already at this stage it was acknowledged, however, that this version would need continuous further improvement.

The SRA was published as EURADOS Report 2014/01, which can be downloaded from the EURADOS website (www.eurados.org). It was presented to the scientific community on various occasions, including at an OPERRA meeting in January 2014 in Rome, Italy, at a meeting of the German Radiation Protection Association in April 2014 in Munich, Germany, at the 4th European Regional IRPA Congress in May 2014 in Geneva, Switzerland, at the 6th MELODI workshop in October 2014 in Barcelona, Spain, and at the 60th AM Health Physics Society Meeting, Indianapolis, US, in July 2015. In early 2015, a condensed version of the EURADOS SRA was published in *Radiation Protection Dosimetry* ("Radiation Protection Dosimetry Advance Access published March 9, 2015"), to reach a broader scientific audience and add the SRA to the peer-reviewed international literature.

Brief summary of SRA content

The current EURADOS SRA describes five visions in dosimetry. For each vision, key challenges in dosimetry research are identified that are considered important for the next decades. These visions will also be used to steer the EURADOS research programs and the working group activities.

The first vision describes scientific developments required towards updated fundamental dose concepts and quantities. Within this vision the following five scientific challenges were identified: a) to update fundamental dose concepts and quantities, b) to improve understanding of spatial correlations of radiation interaction events, c) to establish

correlations between track structure and radiation damage, d) to improve understanding of radiation-induced effects from internal emitters, and e) to update operational quantities for external exposure.

The second vision describes scientific developments needed towards improved radiation risk estimates deduced from epidemiological cohorts. This vision includes the following two scientific challenges: a) to improve exposure pathways not yet considered or validated, and b) to improve retrospective dosimetry for exposure pathways already considered.

The third vision deals with an efficient dose assessment for radiological emergencies. This vision includes the following three challenges: a) to identify and characterize new markers of exposure, b) to develop strategies and methods to increase measurement capacity, and c) to quantify doses after accidental internal contamination.

The fourth vision identifies work towards integrated personalized dosimetry in medical applications. This vision includes the following five scientific challenges: a) to improve the measurement and combination of out-of-field radiotherapy and imaging doses in photon and particle radiotherapy, for input to epidemiological studies, b) to develop micro-dosimetric models for imaging and radiotherapy, c) to improve dosimetry in modern external beam radiotherapy, d) to optimize dose and risk estimations in interventional radiology, and e) to establish reliable patient dosimetry in CT examinations.

Finally, the fifth vision identifies efforts needed towards improved radiation protection of workers and the public. This vision includes the following five challenges: a) to implement new biokinetic models for intake of radionuclides, b) to develop calibration procedures for partial body counters, c) to develop accurate and on-line personal dosimetry for workers, d) to improve neutron dosimetry techniques, and e) to include nuclide-specific information in dose rate measurements in the environment.

The published EURADOS SRA also includes chapters on Monte Carlo computational dosimetry, infrastructure, and education and training actions important in the future.

EURADOS ranking list

In spring 2014, EURADOS initiated an email survey among the EURADOS Voting Members and Council Members, based on the published SRA. All participants were asked to identify and rank what they believed are the five most important challenges (the most important challenges got 5 points, the second important 4 points, and so on). The participation was high, 11 out of 12 Council Members and 40 out of 61 Voting Members answered to this request. In a final evaluation all scores were added and in this way a ranking list of the 18 challenges was obtained (see Table 1 in Annex). The first 6 challenges are described below in more detail. Some of these challenges were edited slightly, compared to the previous wording, based on intense discussions within the EURADOS Council.

- To quantify correlations between track structure and radiation damage

  The comprehensive multi-scale characterization of the physical aspects of particle track structure should be investigated, to allow for a quantitative investigation of the impact of

particle track structure in terms of biological effects at the subcellular and cellular level. To this end, radiobiological experiments and radiobiological modelling need to be included. In order to obtain a quantitative and comprehensive characterization of the correlation between microscopic particle track structure and radiation damage to biological cells, the latter need to be exposed to single particle tracks (link to MELODI).

- To improve neutron dosimetry techniques

  Neutrons are a major source of dose from secondary cosmic radiation in the atmosphere. Moreover, neutron sources are intentionally used and/or incidentally created in various scientific areas and technical applications (e.g. electricity generation, radiography and tomography, materials research, activation analysis, fundamental research, military activities, production of radioisotopes/radiopharmaceuticals, and radiotherapy). Some of the fields represent new challenges due to strongly pulsed radiation or very high energy ranges, i.e. radiation fields around high-energy particle accelerators including particle therapy facilities, and during flights at high altitudes or space missions. On the other hand, external dosimetry for neutron radiation, which is inevitably accompanied by a photon component, still presents challenges despite many years of development of neutron personal dosimeters (link to MELODI (epidemiology), medical associations, occupational radiation protection).

- To quantify doses after accidental internal contamination

  The current method of choice for estimating internal doses is based on biokinetic modelling and radionuclide measurements in the body or in urine and faeces. However, in case of an emergency with suspected incorporation of radioactive materials of a large number of individuals, specific emergency bioassay methods may be needed that have not yet been developed. Dose estimation in cases of mixed external and internal exposure presents a particularly complex challenge. Furthermore, not much work has been done so far to link internal dosimetry from incorporated radionuclides with biological dosimetry methods, although biological dosimetry is well established and validated for providing dose estimations following external radiation exposures (link to NERIS).

- To develop accurate and on-line personal dosimetry for workers

  The challenge is to provide reliable, accurate and on-line personal dosimetry for occupationally exposed workers. This requires monitoring the workers in real time for all limiting quantities (whole body, eye lens, extremities, brain, heart), regardless of the protection methods used, and to provide input for the optimal application of the ALARA principle. Dosimetric research for personal dosimetry should deliver good characterized active and passive dosimeters for all relevant dosimetric quantities, and good computational tools using advanced tracking technology (link to medical associations, occupational radiation protection).

- To improve the measurement and combination of out-of-field radiotherapy and imaging doses in photon and particle radiotherapy, for input to epidemiological studies

  In order to estimate and quantify the risk of second cancers that may occur even decades after treatment of the primary tumour, an overall assessment of patient dose is required. However, a complete picture of the out-of-field (i.e. outside the target volume) dose distribution following radiotherapy is still lacking, because it is necessary to estimate and combine the dose contributions from a) the primary beam to regions outside the target volume, for photons, electrons and hadrons; b) scattered photons from the patient and linear accelerator leakage; c) neutron production at higher photon energies, and for hadron therapy; and d) imaging exposures used as part of the radiotherapy process. In addition to second cancer risk estimate, out-of-field dosimetry data will be also important for estimating (i) risks of deterministic effects, (ii) potential foetal doses and risks, (iii) risks of non-cancer stochastic effects, (iv) risks of cardiac pacemaker malfunction, and (v) genetic risks (link to MELODI (epidemiology), medical associations).

- To improve dosimetry in modern external beam radiotherapy

  Radiation therapy plays a major role in treating about half the number of cancer patients. It is very important to be able to measure the dose distribution given to the tumor, in an effort to check if this agrees with the treatment plan. However, *in vivo* dosimetry during external beam therapy could benefit from the development of improved dosimetry techniques. Next to this, the rapid development in new radiotherapy techniques (flattening filter free (FFF) fields, volumetric arc therapy, small fields, proton and heavy ion therapy, microdosimeric characterization for hadrons, etc.) requires a continuous effort in dosimetry research, not only to develop on-line dosimetry techniques, but also to improve calibration procedures (link to medical associations, radiation protection).

ANNEX

Table 1: Ranking list of 18 challenges. Note that two challenges were added to the SRA after the survey ("To identify and characterize new markers of exposure" and "To develop calibration procedures for partial body counters"); these challenges could therefore not be included in the ranking list. The challenges ranked "8" and "16" ("To rapidly identify individuals with highest doses" and "To handle a large number of dosimetric samples in a short time") were later combined and reformulated in the SRA as "To develop strategies and methods to increase measurement capacity".

1. To quantify correlations between track structure and radiation damage
2. To improve neutron dosimetry techniques
3. To quantify doses after accidental internal contamination
4. To develop accurate and on-line personal dosimetry for workers
5. To improve out-of-field dosimetry for photon and particle therapy
6. To improve dosimetry in modern external beam radiotherapy
7. To optimize dose estimations in interventional radiology
8. To rapidly identify individuals with highest doses
9. To establish reliable patient dosimetry in CT examinations
10. To Update Operational Quantities for External Exposure
11. To improve understanding of dosimetry and biokinetics of internal emitters
12. To improve understanding of spatial correlations of radiation interaction events
13. To explore exposure pathways not yet considered or validated
14. To improve retrospective dosimetry for exposure pathways already considered
15. To improve internal microdosimetry in radiotherapy and medical imaging
16. To handle a large number of dosimetric samples in a short time
17. To include nuclide-specific information in environmental monitoring
18. To improve, validate and implement new biokinetic models

EURADOS - Rank 1	**To quantify correlations between track structure and radiation damage**
Priority description	Dose quantities currently used to estimate stochastic risks and tissue reactions are based on crude radiation weighting factors or the quality factor. These weightings rely on limited biological data from animal experiments and exposures of human samples such as blood. They do not directly relate to damage within cells. The goal of this topic is to produce data that relate radiation exposures to biological damage by computer modelling of biological structures that are realistic on the atomic scale. This is the cutting edge of modelling for radiation protection. Primary radiation-induced biological effects, which will determine the outcome at the cellular and tissue scale, originate from the energy deposited by ionising radiation in critical biological targets such as the nuclear DNA. These initial interactions, their number and distribution at the nanometric scale, form the track structure that is specific to each irradiation type (particle and energy). It is well known that the biological effects (e.g. double-strand breaks of the DNA or the kinematics of the clonogenic curves) show a qualitative correlation with the track structure of the incident ionizing radiations. To quantify this, simulation codes (PATRAC, Kurbuc, Geant-DNA and others) have been developed to predict these biological effects using a mechanistic approach. The multiplicity of factors involved in this mechanistic approach compromise each of these codes and currently lead to the need to "calibrate" the results for different biological endpoints or cell types. Further research in this field is thus still needed so that each of the stages contributing to the production of the initial biological effects can be more accurately simulated: from the description of the physical track (charge changing cross sections, very low energy electron cross-sections for biomaterials, role of excitations, etc), the chemical stage (reaction rate constants, scavenging factors in the cells, etc), the role and description of the chromatin folding, the description and quantification of the repair mechanisms, etc. For medical applications or radiation protection, this approach must result in new measurable quantities common to different radiation qualities that will link the initial track structure description at nanometric scale with a given biological outcome, independent of other biological parameters.
European relevance	Deeper comprehension of the mechanisms and the important factors in the origin of radioinduced biological effects can have a direct application in radiation therapy, especially concerning hadrontherapy, by replacing the "biological dose" with physical quantities better adapted to quantify the biological impact of the radiation.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	• MELODI: Page 1, Paragraph 3, Ranked list of priorities 1-4. • ALLIANCE: Page 2, Priority 2. • NERIS: Page 2, Assessment and communication of uncertainties. • Medical: Research Topics 3.1.1 and 3.2.4.
Impact: decreased uncertainty	This knowledge will decrease the uncertainty in RBE values used in radiotherapy, by replacing them with more universal quantities: not a relative quantity nor one dependent on the dose level, dose rate, cell type/cycle, etc.
Impact: increased radiation protection	The outcomes of this topic will help to define the next generation of radiation protection quantities and to make them more reliable predictors of radiation effects.
Impact: increased acceptability	Increased acceptability of new radiation therapies such as hadrontherapy or the use of nanoparticles, and more reliable quantities for radiation protection.
Feasibility	For successful outcomes, reference European infrastructure is needed for the calibration of new quantities using nanodosemeters. There is a need for reference radiobiological experiments and associated protocols. A total budget of 3 M € is proposed for 4 years.
Other justifications	This work is of fundamental importance in radiation protection: successful outcomes will impact on the recommendations of the ICRP and ICRU, thereby

	influencing international radiation protection legislation and practice.

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EURADOS - Rank 2	**To improve neutron dosimetry techniques**
Priority description	In Europe, neutrons are a major source of occupational exposure, in terms of annual collective effective dose. They dominate air crew exposure (secondary cosmic radiation), and they contribute to exposures in industry (e.g. production of radioisotopes/radiopharmaceuticals, nuclear industry, radiography and tomography, fundamental research) and particle radiotherapy where they add to staff and patient exposures. Research: High-energy neutrons, above 20 MeV essentially, contribute to doses of patients at particle therapy facilities, and to doses of air crew. Due to the shortage of experimental data, however, precise measurement or simulation of these neutrons is still difficult: calibrations of suitable instrumentation include large uncertainties, and available Monte Carlo simulation codes lack experimentally validated interaction cross sections. Moreover, the presence of neutrons always implies production of photons, which makes correct dose determination difficult. Further, complications arise in all workplaces, especially in pulsed fields, where the application of electronic neutron detectors is still challenging. Even widely used passive methods show strong energy/angle dependence and poor low dose performance: improved accuracy and lower dose thresholds are required for all workplaces.
European relevance	Wherever neutrons are involved in the exposure of individuals (examples are given above), improved detection and dosimetry is of importance in European radiation protection. The increased number of proton/ion therapy facilities that are currently being constructed or planned in Europe highlight the need for careful quantification of radiation detriment due to neutrons, as well as emerging new technologies such as laser-driven proton sources for radiotherapy that involve pulsed high-energy neutron fields.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	This topic is of relevance in all cases where exposures to humans include a neutron component and where a complete dose assessment is required, for example, for cancer and non-cancer risk assessment of exposed cohorts, for a complete assessment of patient doses that include diagnostic and therapeutic exposures, or for systematic dose quantification of occupational exposures. Moreover, in radio-biological studies on the effects of high-LET radiation, neutrons are important. -MELODI (August 2015): page 12, 4.1.3; page 16, 4.3.3 -EURADOS (May 2014): pages 28-30, 3.4.1; pages 38-39, 3.5.4; -Medical (August 2015): page 8, 3.1.1, page 9, 3.1.2, pages 10-11, 3.1.4
Impact: decreased uncertainty	Improved measurement and simulation techniques will reduce the current uncertainties which remain important in the dosimetry of high-energy neutrons above 20 MeV and of neutrons in pulsed fields.
Impact: increased radiation protection	Neutrons can contribute to planned, existing and emergency exposure situations. Exposures include workers, patients and the public. By definition, improved neutron individual dosimetry, in particular with active electronic devices, will contribute to improved radiation protection of these groups.
Impact: increased acceptability	Improved dosimetry of neutron exposures, together with improved assessment of the corresponding uncertainties, will strengthen the solidity of present radiation protection. For example, if reliable dose assessment can be performed online by means of electronic devices, allowing for immediate action in varying exposure conditions, the acceptability of individuals working in such environments can be improved (e.g., nuclear industry, medical applications, nuclear emergencies).
Feasibility	With regard to neutron dosimetry, the scientific and technological competences in Europe are still available, but are at risk. For example, the last European facility that allows calibration of instruments in high-energy neutron fields will be shut down in 2015. Support for this priority is seen as a strategic European

	decision that would also include support for access to facilities outside of Europe. A thorough study is estimated to require 4 ys duration and a budget of about 3 M €.

EURADOS - Rank 3	**To quantify doses after accidental internal contamination**
Priority description	Vision 3 of the EURADOS SRA deals with efficient dose assessment for radiological emergencies. One of the challenges is to quantify doses after accidental internal contamination. The current method of choice for estimating internal doses is based on biokinetic modelling and radionuclide measurements in the body, or in urine and faeces. However, in case of an emergency with suspected incorporation of radioactive materials by a large number of individuals, specific emergency bioassay and dose assessment methods may be needed that have not yet been developed for adults and/or children. Dose estimation in cases of mixed external and internal exposure presents a particularly complex challenge. A combination of internal dosimetry, biomarkers affected and bio- and physical dosimetry not affected by incorporation would give the best multiparametric approach of properly separating the two components. Furthermore, not much work has been done so far to link internal dosimetry from incorporated radionuclides with biological dosimetry methods, although biological dosimetry is well established and validated for dose estimations following external radiation exposures. In cases of high levels of internal exposure, bioligands or chelators are administered as decorporation therapy after intakes of radionuclides of high radiotoxicity (e.g. actinides), to enhance excretion and to reduce the dose. This action makes it difficult to interpret bioassay monitoring data which don't follow regular human biokinetics. Further research is need to understand the mechanisms of chelating agents like DTPA and to provide appropriate modelling descriptions of the metabolic behaviour of contaminants affected by decorporation.
European relevance	The topic is of high priority for EURADOS and the links with NERIS and RENEB are especially relevant. Social sciences and humanities issues are also considered in the management of an emergency situation and in the post-accidental frame. The actual risk and the perception of the risk by populations should converge with the calculation of reliable doses, using appropriate and unambiguous communication channels to inform exposed individuals.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	The priority is linked to SRAs of EURADOS and NERIS, but also refers to MELODI's: - EURADOS 3.3.3 To quantify doses after accidental internal contamination - NERIS: key topic 5, subtopic 5.9 Monitoring strategies - MELODI: 2.3.3. individual radiation sensitivity
Impact: decreased uncertainty	This topic will contribute to an improved system of radiation protection by decreasing dose uncertainty, especially in case of accidental internal exposures of children. This will require appropriate strategies and capabilities for monitoring and dose assessment in scenarios of radiological or nuclear emergency Another important challenge is the proper interpretation of monitoring data using new rapid bioassay methods, biodosimetry methods or in decorporation therapy.
Impact: increased radiation protection	This topic will contribute to improving the system of radiation protection for better protection of workers and the public in emergency internal exposure situations. Areas to investigate are the definition of reliable biological end-points, which are suitable especially for chronic internal exposures, and the definition of proper dosimetric quantities to be compared to the biological end-point. Special models must be developed for reliable blood dosimetry, to determine the blood dose and to know how this quantity correlates with the information provided by biological assays. The experiments can be conducted in cooperation with nuclear medicine units using different radiopharmaceuticals.
Impact: increased acceptability	This topic will contribute to improve the acceptability of the system of radiation protection in terms of reduced and more realistic risk perception.
Feasibility	Scientific and technological competences needed for this topic are available in Europe regarding equipment, methodology and strategies for monitoring in case of emergency (EURADOS and NERIS). The expertise required in biokinetics

	and in biological dosimetry is also guaranteed (EURADOS and RENEB). A budget of 2 M€ for 4 years is proposed for this topic.
Other justifications	Lessons learned from Fukushima Daiichi and Chernobyl NPP accidents

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EURADOS - Rank 4	**To develop accurate and on-line personal dosimetry for workers**
Priority description	Provision of reliable, accurate and on-line personal dosimetry for occupationally exposed individuals requires monitoring the workers in real time for all limiting quantities (whole body, eye lens, extremities, and perhaps brain, heart), regardless of the protection methods used, and to provide input for the optimal application of the ALARA principle. Research: Dosimetric research for personal dosimetry should deliver good characterized active dosimeters for all relevant radiation fields, and reliable computational tools. Many devices exist already, but they are not suited for all of these fields. These active dosimeters should be developed in a way that they can also be used for official dose records. For fields that are used in medical applications, and in particular for pulsed fields, improvements are still needed, and, for example, the dependence of active dosimeter response on dose rate must be investigated. Besides that, all existing devices must be tested for all relevant fields in which they are used. Active dosimeters should also be developed for eye lenses and extremities. Improvement of active dosimeters is also needed so that the measured dose is visible to the operator on-line and that the results can be easily implemented in advanced staff databases.
European relevance	Applications of ionizing radiation in Europe are characterized by a vast variety of different radiation fields, including static and pulsed fields, fields with different radiation qualities (e.g. photons, protons, electrons, neutrons), fields of mono-energetic particles or involving a large range of particle energies and directions, with doses ranging from µGy to Gy and more, and different dose rates. The standard of radiation protection in Europe would be significantly improved if existing passive dosimeters could be complemented by suitable electronic dosimeters that allow reliable on-line detection of doses in the various fields mentioned above.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	This topic is of general relevance for radiation protection, and accurate individual real-time dosimetry is of importance in many research areas. - MELODI (August 2015): page 11, 4.1.2; page 14, 4.2.1 - EURADOS (May 2014): pages 37-38, 3.5.3 - ALLIANCE (Sept 2013): pages 25, 3.2.2 - NERIS (April 2014): page 20, 5.8 and 5.9 - Medical (August 2015): page 8, 3.1.1
Impact: decreased uncertainty	A time-resolved assessment of radiation doses to workers will improve the current dose assessment which is mainly based on passive dosimeters integrating dose typically over a month. Exposure scenarios can therefore be more accurately described and unclear dose contributions quantified. This will contribute to a significant reduction in dose uncertainties and by changing practice can lead to an overall reduction in doses received.
Impact: increased radiation protection	Improved measurement techniques involving electronic devices, that allow measurement of doses in real-time, will significantly improve individual radiation protection because any unwanted high exposures can be immediately be detected and therefore avoided.
Impact: increased acceptability	Reliable dose assessment performed online by means of electronic devices allows for immediate action in varying exposure conditions, which in turn will increase the acceptability of individuals working in various radiation fields.
Feasibility	In Europe, a number of active electronic dosimeters for different radiation fields are already on the market. The feasibility of the project is high because any of the improvements discussed above can be achieved on the basis of current technology, and need not be started from scratch. A thorough study is estimated to require 4 ys duration and a budget of 2 M €

EURADOS – Rank 5	**To improve the measurement and combination of out-of-field radiotherapy and imaging doses in photon and particle radiotherapy, for input to epidemiological studies**
Priority description	Radiotherapy plays a major role in the treatment of cancer. There are approximately 14 million new cancer cases per year worldwide. In the developed world, approximately half of all cancer treatments will involve radiotherapy. Radiotherapy target doses are accurately calculated and delivered with rigorous supporting quality assurance (QA), and are well documented, although there is a need for the development of in-vivo dosimetry (see EURADOS topic 6). However, combined out-of-field doses to organs and tissues at risk, from both radiotherapy and imaging procedures associated with treatment planning, verification and image-guided radiotherapy (IGRT) (the "complete dose description") are not so extensively measured or calculated. The development and harmonisation of dosimetry techniques for out-of-field measurements from therapy and imaging is important in providing input to risk models and epidemiological studies of: (i) second cancer induction (ii) cardiovascular disease (e.g. pericardial & myocardial disease, valvular defects, coronary artery disease) (iii) other radiation-induced organ damage (digestive, lung, eye, thyroid, liver, kidney, cognitive/neurological effects) (iv) risks to the irradiated foetus
European relevance	There are approximately 1.3 million radiotherapy treatments per year in EU, so that this research priority will have a major impact on the lives of many European citizens, especially children and young adults for whom prognoses are good.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	- MELODI: This EURADOS proposal is strongly linked to, and underpins, MELODI proposals for research into dose-risk relationships and epidemiological studies, for which the "complete dose description" from radiotherapy and associated imaging is a pre-requisite. (specifically, 4.1 Dose and dose rate dependence of cancer risk, 4.2 Non-cancer effects, 4.3 Individual radiation sensitivity) - Medical: 3.1.1. Measurement of exposure; 3.1.3. Quality metrics for imaging and therapy; 3.3. Optimisation of radiation exposure and harmonisation of practices (specifically 3.3.1. Patient-tailored diagnosis and treatment)
Impact: decreased uncertainty	Improved knowledge of the complete dose description from both radiotherapy and associated imaging will form a solid foundation for input to epidemiological studies. More accurate and extensive measurements of organ and tissue doses will reduce dosimetric uncertainties in such studies.
Impact: increased radiation protection	More accurate estimates of doses to patients will allow better protection of the patient in terms of balancing the benefits of radiotherapy with the risk of possible adverse late effects.
Impact: increased acceptability	This topic will contribute to improved acceptability of the radiation protection system for protection of the patient in radiotherapy, by underpinning risk assessments through more extensive and accurate dosimetry of organ and tissue doses.
Feasibility	Many European radiotherapy centres and research institutions are active, or potentially active, in the collaborative dosimetry developments needed for this topic. A total budget of 3 M € for 4 years is proposed.
Other justifications	As the Japanese Life Span Study eventually comes to a close, there will be a need to study other large cohorts of irradiated humans to improve our understanding of the effects of ionising radiation. Notwithstanding many potential difficulties (e.g. genetic predisposition of cancer patients), the worldwide radiotherapy patient population provides a very large cohort of people irradiated over a wide range of doses (tens of Gy down to tens of mGy) which are accurately delivered and recorded in detail. Further development and harmonisation of techniques for the measurement of the complete dose description in radiotherapy is an essential pre-requisite to future robust epidemiological studies.

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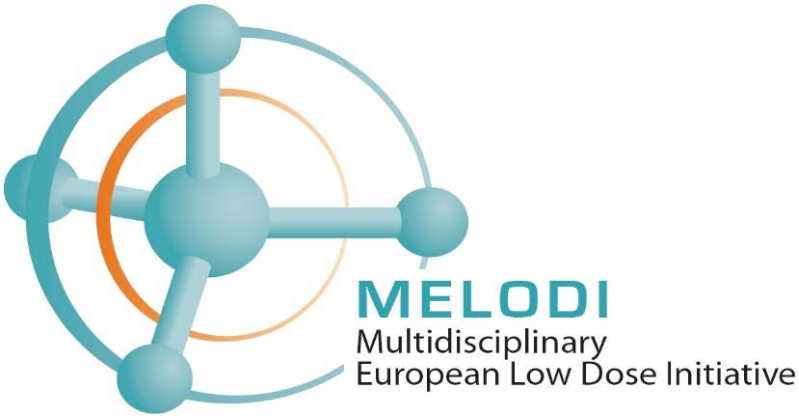
EURADOS - Rank 6	**To improve dosimetry in modern external beam radiotherapy**
Priority description	Radiation therapy plays a major role in treating about half the number of cancer patients. It is very important to be able to measure the dose distribution given to the tumour, in an effort to check whether this agrees with the treatment plan. However, in vivo dosimetry during external beam therapy could benefit from the development of improved dosimetry techniques. Next to this, the rapid development in new radiotherapy techniques (flattening filter free (FFF) fields, volumetric arc therapy, small fields, proton and heavy ion therapy, microdosimeric characterization for hadrons, etc.) requires a continuous effort in dosimetry research, not only to develop on-line dosimetry techniques, but also to improve calibration procedures (links to medical associations, radiation protection).
European relevance	In European countries a considerable fraction of the population will face a cancer diagnosis at a certain time in life, and radiotherapy represents one of the major methods of treatment. Approximately half of all cancer patients will receive radiotherapy at some point in their illness. This research priority will have a major impact on the lives of many European citizens. The topic is obviously oriented towards the medical society.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	This topic is literally mentioned in the draft medical SRA. 3.1.1. Measurement of exposure 3.1.3. Quality metrics for imaging and therapy
Impact: decreased uncertainty	Currently the actual dose given to the tumour is not measured. By developing methods for in-vivo measurements, the uncertainty in the tumour dose can be reduced. This will lead to an improved outcome from the radiation therapy treatment, and an improved quality control (QC) in radiotherapy.
Impact: increased radiation protection	Better knowledge of the actual dose given will improve the accuracy of dose delivery, reducing doses to healthy tissues and ensuring that the dose to the tumour is high enough for therapeutic benefit.
Impact: increased acceptability	Better QC will reduce the probability of accidents in radiation therapy. Improved QC will allow better, and thus more effective, radiotherapy to be delivered.
Feasibility	There are many different techniques being tried for in-vivo dosimetry. None of them have achieved sufficient accuracy and applicability. The rapid evolution of different treatment modalities also requires a continuous effort to develop in-vivo measurement techniques that can be applied to all therapies. A total budget of 3 M € for 4 years is proposed.
Other justifications	



MELODI statement 2015

Approved by the MELODI Bureau: 10 Aug 2015

MELODI (Multidisciplinary European Low Dose Initiative) is a European Platform dedicated to low dose ionizing radiation risk research. The purpose of the MELODI Association is to integrate national and European activities in low dose and low dose rate radiation research, to define priority scientific goals and to facilitate effective implementation of research. The Strategic Research Agenda (SRA) of MELODI identifies these priority goals and the specific resources, infrastructures and training capabilities needed to further develop low-dose risk research.

Prior to EU research funding calls, MELODI develops a short statement indicating its view on current research priorities, which serves as an input to those responsible for defining call topics. The research priorities were identified from the MELODI SRA, which is gradually enriched by the contributions of its members, ongoing and completed research projects and the findings of the MELODI workshops organized annually since 2009. The 6th draft of the MELODI SRA for 2015 has been opened for consultation and can be downloaded from http://www.melodi-online.eu/sra.html. It forms the basis for the definition of the priorities.

The system of radiation protection has developed and evolved on the basis of an understanding of the magnitude of the health risks associated with radiation exposure and knowledge of the mechanisms of radiogenic disease pathogenesis to inform risk extrapolation. Accurate health risk assessment is fundamental to striking an appropriate and acceptable balance between the benefits of use/exposure to radiation and the associated health risks. Today the main uncertainties in radiation health risk assessment are in the magnitude of cancer risk at low and protracted doses, the magnitude of circulatory disease, cataract and other tissue injury below 500 mSv, and the variation in disease risk between individuals in the population. More information on these and associated issues is required to ensure adequate protection is afforded to populations and individuals in all situations – occupational, medical, emergency and in the course of normal life.

Criteria for prioritization

- Feasibility (research to be done within the next coming years)
- Importance in terms of improved radiation protection system
- Relevance for operational radiation protection (BSS implementation)
- Multidisciplinarity (biology, epidemiology, dosimetry)
- Synergy with other radiation research platforms (ALLIANCE, EURADOS, NERIS, medical field)
- Timeliness
- Avoidance of overlap of topics with other calls or topics that have been recently funded and outcome from projects that have recently ended.

Ranked list of priorities (for detailed description see Annex):

1. To explore the shape of the dose-response relationship for radiation induced health effects at low doses/dose-rates based on key informative epidemiological studies (including where appropriate, molecular or other biomarkers) for internal and/or external emitters, incorporating detailed dosimetric assessment.

2. To explore and define the role of epigenetic modifications in radiation-induced health effects following exposure to low doses/low dose rates.

3. To identify, develop and validate biomarkers for exposure, early and late effects for cancer or/and non-cancer diseases in relation to low doses/low-dose rates and to integrate them in molecular epidemiological studies.

4. To explore the roles of specific target cells for low dose/dose-rate radiation-induced late developing health effects such as cancers, circulatory diseases and cataract.

5. To understand the potential impact of individual susceptibility on radiation risk using cohorts and/or systems models with variations in sensitivity to low doses of radiation, so that differences in the response pathways can be detected and biomarkers validated.

MELODI encourages, where appropriate, (1) the use of archived biological materials from prior EU funded research, (2) the integration of experienced laboratory networks (such as e.g. RENEB), (3) the integration of expertise from outside the conventional fields of radiation research, in particular expertise from the medical research field where appropriate.

ANNEX: Description of MELODI 2015 priorities

Priority title	**To explore the shape of the dose-response relationship for radiation induced health effects at low doses/dose-rates based on key informative epidemiological studies (including where appropriate, molecular or other biomarkers) for internal and/or external emitters, incorporating detailed dosimetric assessment**
Priority description	Risk of all solid cancer combined due to whole body exposure with ionizing radiation is fairly well understood for doses of about 100 mSv. In this dose range there is, however, an urgent need for an understanding of health effects of internal exposures or inhomogeneous external exposures and of risks of site-specific cancer. Another major uncertainty is related to the magnitude of risk of non-cancer diseases at doses below about 500 mSv. Research: Large (molecular-) epidemiological studies with precise dosimetry and information on important confounders shall be further developed or established. Omics and system biology approaches to biological samples from study members should aim at exploring markers for radiation-induced disease and understanding the disease processes. Health risks shall be derived taking into account a multitude of models based on biological and epidemiological data.
European relevance	Per definition, the priority is of top importance for **MELODI**. By the need of improved dosimetry for key epidemiological cohorts the priority is linked to **EURADOS**. The implications of improved risk estimates for emergency management link the priority to **NERIS**. The enhanced risk characterizations may link the priority to **ALLIANCE**. Improved knowledge of health risk will also be of importance for the optimization of ionizing radiation applications in **medical** diagnostics and therapy, and for the **BSS** implementation in the future, as evidence can be expected to be taken in to account in ICRP recommendations.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	This priority needs intensive collaboration of epidemiology, dosimetry, radiation biology, systems biology, experts of pathogenesis, mathematical modelling, statistics, radiation protection and emergency measurement. Expertise outside of the traditional fields of radiation research needs to be integrated. -MELODI (Aug 2015): p.9-14; chapter 4.1 and 4.2 -ALLIANCE (Sept 2013): p.6; Challenge 3; topic 3 -NERIS (April 2014): p.20, Topic 5.8 Health surveillance -EURADOS (May 2014): p.11-19; 3.2; p.35; 3.5.1
Impact: decreased uncertainty	The research will decrease uncertainty with respect to the shape of the dose-response-relationship for cancer and non-cancer diseases in the low dose range.
Impact: increased radiation protection	Improved health risk estimates together with an improved assessment of uncertainties will strengthen the solidity of present radiation protection. This will especially be the case for i) regulating occupational exposures; ii) optimizing radiation therapy for patients with good prognosis (long time risks of diseases in relatively low exposed tissues); iii) deciding about appropriate diagnostic applications of radiation in medicine (especially for procedures causing in total several tens of mSv; and iv) regulating emergency situations (involving reference levels from a few tens to 100 mSv); and v) better understanding of epidemiological findings and health effects of internal emitters.
Impact: increased acceptability	Presently, radiation protection is based on uncertain risk estimates, for which the full size of uncertainty has not even been addressed. This priority focusses on a more realistic assessment of the shape of the dose-response relationship for cancer and non-cancer diseases. The resulting robustness of the risk estimates will improve the public reliance on an important basis of radiation protection.
Feasibility	The priority is feasible in terms of scientific and technological competences available in Europe. Key informative cohorts with the potential for access to biological samples have been identified in DOREMI. The priority will need a large scale integrative action. A thorough study is estimated to require 4 ys duration and a budget of **5-7M €**

Priority title	**To explore and define the role of epigenetic modifications in radiation-induced health effects following exposure to low doses/low dose rates**
Priority description	In recent years, biological research has identified a range of processes that can modify cellular, tissue and whole organism phenotypes that do not require DNA mutation. Collectively these are termed epigenetic effects and these include modified DNA methylation, microRNA expression and histone acetylation. While there are indications in the literature that radiation can affect epigenetic endpoints, there remains a lack of understanding of dose- and dose-rate responses, and the relationship of the changes to radiogenic disease, although epigenetic phenomena have been linked to cancers and transgenerational effects. Research is required to define radiation dose-/dose-rate responses for individual epigenetic endpoints, determine radiation quality dependence and the relationship of such changes to radiogenic cancers, non-cancer diseases and hereditary/transgenerational effects
European relevance	The proposed research is relevant to (i) **MELODI** in that it requires consideration of low dose/dose-rate response and relevance for radiogenic disease and may identify biomarkers of exposure or effect (ii) **ALLIANCE** in that it will explore the relevance to transgenerational effects and population health (iii) **EURADOS** in that it will require a high standard of radiation dosimetry for cell culture systems, model organisms and a range of radiation qualities (iv) **NERIS** in that it may identify biomarkers of exposure or effect (v) **medical** applications in that biomarkers may be identified and through mechanistic understanding of effects, novel radio-protectors may be identified (vi) **BSS** implementation in the future, as evidence taken in to account in ICRP recommendations.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	The research topic is of European and wider relevance in that it will help to determine the appropriate risk-benefit assessment for radiation use in all sectors, in this way, by informing the system of protection the research will ensure that the population and non-human biota are neither under nor over protected; and this ensures effective and efficient resource usage -MELODI (Aug 2015): p.10 (and others); 4.1.1, 4.1.2, 4.1.3, 4.3.1 -ALLIANCE (Sept 2013): p.6; Challenge2, topics 1 & 4 -NERIS (April 2014): p.20; Topic 5.8, Health surveillance -EURADOS (May 2014): p.17; 3.2.2 and p.21; 3.3.1
Impact: decreased uncertainty	The research will improve the scientific evidence base for judgements in radiation protection. It will address the question, whether endpoints in addition to DNA mutation need to be considered in selection of risk extrapolation models for cancer, and if epigenetic effects are important for judgements on risk extrapolation for non-cancer diseases. Detailed dose-/dose-rate response information will be generated.
Impact: increased radiation protection	The proposed research will provide evidence to inform judgements on one of the most fundamental aspects of the system of protection, namely, which is the best model for risk extrapolation for cancer and non-cancer diseases. The research thus informs judgements on dose limits and emergency reference levels.
Impact: increased acceptability	The understanding gained from carrying out this research will contribute to increasing acceptability of the radiation protection system as it will provide supporting evidence for judgements on the model used for risk extrapolation for all health endpoints. The research may provide evidence either to support or contradict the currently adopted approaches.
Feasibility	The proposed research topic is feasible; many methods have been developed that can carry out high-throughput epigenetic analyses and there is a growing body of technical competence in Europe. It may be necessary to consider funding projects that focus on one or a limited range of epigenetic endpoints. A thorough study is estimated to require 4 years duration (especially to address transgenerational issues) and a budget of **1-2 M Euro**

	To identify, develop and validate biomarkers for exposure, early and late effects for cancer or/and non-cancer diseases in relation to low doses/low-dose rates and to integrate them in molecular epidemiological studies
Priority description	In recent years, the rapid development of technologies for "omics" research has opened up for a detailed biochemical analysis of cellular responses at each regulatory level in the cell machinery. Understanding interactions at the molecular levels and the use of new software's for pathway analysis has provided new insights in the mechanisms that regulate the cellular responses to different stressors. Identifying biomarkers for radiation induced stress responses, as well as for early and late stages of diseases induced by radiation will provide a platform for a mechanistic understanding of the cellular responses to ionizing radiation, from the primary target through the repair/defence processes and the outcome of these. If persistent biomarkers for exposure and radiation-induced diseases can be identified, the integration of them in epidemiological studies will have significant implications for risk estimates of low dose/dose rate exposures. Research is required to define radiation dose/dose-rate responses for biomarkers of exposure, to determine their radiation quality dependence and the relationship of such changes to radiogenic cancers and non-cancer diseases.
European relevance	The proposed research is relevant to (i) **MELODI** in that it requires consideration of low dose/dose-rate response and relevance for radiogenic disease and may identify biomarkers of exposure or effect (ii) **ALLIANCE** in that biomarkers of exposure from the human model systems may be of relevance for the studies of other types of species and help to explore the relevance to transgenerational effects and population health (iii) **EURADOS** in that it will require a high standard of radiation dosimetry for cell culture systems, model organisms and a range of radiation qualities (iv) **NERIS** in that it may identify biomarkers of exposure or effect (v) **medical** applications in that biomarkers may be identified that can be used for diagnosis of individual sensitivity to radiotherapy and early detection of cancer and non-cancer diseases (vi) **BSS** implementation in the future, as evidence taken in to account in ICRP recommendations.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	The research topic is of European and wider relevance in that it will help to determine the appropriate risk-benefit assessment for radiation use in all sectors, in this way, by informing the system of protection the research will ensure that the population and non-human biota are neither under nor over protected; and this ensures effective and efficient resource usage -MELODI (Aug 2015): Chapters 4.1, 4.2 and 4.3. -ALLIANCE (Sept 2013): p.6; Challenge2, topics 1 & 4 -NERIS (April 2014): p.20; Topic 5.8, Health surveillance -EURADOS (May 2014): p.17; 3.2.2 and 21; 3.3.1
Impact: decreased uncertainty	The research is expected to be of significance for the development of better risk estimates for other types of genotoxic stressors that are challenging the health of humans and other species. Biomarkers of exposure and diseases applied in epidemiology will significantly reduce the uncertainties of the present risk estimates in the low dose/dose rate range as detailed dose-/dose-rate response information will be generated. Precise dosimetry of internal emitters may also significantly decrease uncertainty.
Impact: increased radiation protection	The proposed research will provide evidence to inform judgements on one of the most fundamental aspects of the system of protection, namely, which is the best model for risk extrapolation for cancer and non-cancer diseases. The research thus informs judgements on dose limits and emergency reference levels.
Impact: increased acceptability	The understanding gained from carrying out this research will contribute to increasing acceptability of the RP system as it will provide supporting evidence for judgements on the model used for risk extrapolation for all health endpoints.
Feasibility	The proposed research topic is feasible; many methods have been developed that can carry out high-throughput "omic" analyses and the bioinformatics needed for the transfer of this results into a mechanistic understanding is at hand. A thorough study is estimated to require 4 ys duration and a budget of **2-4 M €**

Priority title	**To explore the roles of specific target cells for low dose/low dose rate radiation-induced late developing health effects such as cancers, circulatory diseases and cataract**
Priority description	Currently, radiation risk extrapolation does not specifically include mechanistic considerations, but is more a statistical curve-fitting approach. To improve mechanistic understanding of radiogenic disease processes that can inform mechanistic approaches to cancer risk extrapolation several key pieces of information will be required. Most fundamentally, it is important to identify the cells at risk of conversion into the disease state, and enumerate these. For the case of cancer it is generally assumed that stem and early progenitor cell populations are relevant, but these are not generally well characterised, understood in their responses to low dose/dose-rate radiation or enumerated. Research is required to clarify these aspects, and similarly to identify, enumerate and define radiation responses of target cell populations for other late-developing diseases such as circulatory disease and cataract.
European relevance	The proposed research is relevant to (i) **MELODI** in that it requires consideration of target cells relevant for radiogenic diseases and low dose/dose-rate response, providing important input for mechanistic models for risk extrapolation (ii) **EURADOS** in that it will require a high standard of radiation dosimetry for cell culture systems, model organisms and a range of radiation qualities (iii) **NERIS** in that in the longer term it will strengthen and improve risk estimation and thus exposure threshold for emergency action (iv) **BSS** implementation in the future, as evidence can be expected to be taken in to account in ICRP recommendations.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	The research topic is of European and wider relevance in that it will help to determine the best approaches to risk extrapolation for all late developing diseases, in this way , by informing the system of protection, the research will ensure that the population are neither under nor over protected; and this ensures effective and efficient resource usage -MELODI (Aug 2015): p.10 (and others); 4.1.1, 4.2.1, 4.3.3 -ALLIANCE (Sept 2013): p.26; Challenge 2, 3.2.2.1 -NERIS (April 2014): p.18; Topic 5.1 -EURADOS (May 2014): p.17, 3.2.2
Impact: decreased uncertainty	The research will improve the scientific evidence base for judgements in radiation protection. It will address the issue of the improvement of risk extrapolation and strengthening the scientific evidence base for risk extrapolation.
Impact: increased radiation protection	The proposed research will provide evidence to inform judgements on a fundamental aspect of the system of protection, namely, which is the best approach for risk extrapolation for cancer and non-cancer diseases. The research thus in the long term informs judgements on dose limits and emergency reference levels.
Impact: increased acceptability	The understanding gained from carrying out this research will contribute to increasing acceptability of the radiation protection system as it will provide supporting evidence for judgements on the approach used for risk extrapolation for all health endpoints. The research may provide evidence either to support or contradict the currently adopted approaches.
Feasibility	The proposed research topic is feasible; many methods have been developed that can identify stem cells *in vivo* and *in vitro,* fundamental research in stem cell biology has developed an impressive range of methods for cell manipulation and imaging that can be utilised and there is a growing body of technical competence in Europe It may be necessary to consider funding projects that focus on a specific disease/target cell population. A potentially useful study is estimated to require 4 years duration and a budget of **2-3M Euro**

Priority title	**To understand the potential impact of individual susceptibility on radiation risk using cohorts and/or systems models with variations in sensitivity to low doses of radiation, so that differences in the response pathways can be detected and biomarkers validated.**
Priority description	Studies of carriers of BRCA1/2 mutations and studies of cancer patients have shown that single nucleotide polymorphisms (SNPs) in a number of genes can modify the radiation responses – either in the long term (risk of cancer) or in the short to medium term (adverse reaction to radiotherapy). Differences in sensitivity have also been observed in relation to gender, age at exposure, state of health, genetic and epigenetic make-up, lifestyle, and age attained. At present, there is insufficient information on the influence of individual radiation sensitivity on health risk estimates at low doses/dose-rates. Research is required on the extent of variation of individual sensitivity in the population, on the factors contributing to this variation, as well as integration of mechanistic studies in the quantitative evaluation of health risk.
European relevance	Individual sensitivity is one of the three key policy questions in the **MELODI** SRA and one of the main research priorities in the HLEG. It is also important for **NERIS** in emergency response and surveillance after accidents – children, pregnant women and elderly/ill persons being priority groups for radiation protection in the case of an accident - ; for **ALLIANCE** in protection of non-human biota. Studies of radiation sensitivity obviously need adequate dosimetry, including biological dosimetry, and hence there is an important role for **EURADOS**. -Individual sensitivity is extremely relevant for radiation protection of **patients** undergoing both diagnostic and therapeutic irradiations, where the possibility of using other medical procedures (MRI for imaging, surgery/chemotherapy/ hormone therapy/immune therapy for treatment) exist.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	A multidisciplinary approach is needed to address this topic, including epidemiologists, biologists, clinicians, dosimetrists and modellers, as well as –for aspects related to response to radiation accidents – social scientists, ethicists and psychologists. -MELODI (Aug 2015): p.15-17; 4.3 (Individual Radiation Sensitivity) -ALLIANCE (Sept 2013): p.26; Challenge 2, topics 1 & 2 -NERIS (April 2014): p.20; Topic 5.8, Health surveillance -EURADOS (May 2014): p.17; 3.2.2 and p.21; 3.3.1
Impact: decreased uncertainty	Individual differences in sensitivity raises ethical and policy question as to whether some individuals or groups are inadequately protected by the present system and regulations. Answers to this question are therefore urgently needed.
Impact: increased radiation protection	Identification of sensitive persons in the population can lead to better RP –in medicine (where approaches not involving IR can be used), in occupational settings as well as in the general population after, for example, accidents
Impact: increased acceptability	Understanding the potential impact of individual susceptibility will contribute to a more realistic assessment of radiation health risks increasing the acceptability of the radiation protection system.
Feasibility	Scientific / technological competences needed for this topic are available in Europe. Different approaches can be considered, including (molecular) epidemiological studies of cancer patients (e.g. WECARE study) or cohorts of genetically predisposed individuals (carriers of specific mutations, AT heterozygotes,...), system modelling, studies of biomarkers, animal models. A thorough study is estimated to require 4 years duration (especially to address transgenerational issues) and a budget of **2-4M Euro**

European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery

NERIS statement – August 2015 (DRAFT)

NERIS is a European Platform on preparedness for nuclear and radiological emergency response and recovery, founded in June 2010. The mission of the NERIS Platform is to establish a forum for dialogue and methodological development between all European organisations and associations taking part in decision making of protective actions in nuclear and radiological emergencies and recovery in Europe. 55 institutions are currently member of the NERIS platform from which 28 supporting organizations.

An integral part of the mission of NERIS is to identify gaps and needs for further research and developments and addressing new and emerging challenges in the field of preparedness for nuclear or radiological emergency response and recovery. The Strategic Research Agenda (SRA) of NERIS, coordinated by the NERIS R&D Committee, identifies these research needs.

In the context of future EU research calls, NERIS has identified current research priorities which can serve as input for defining call topics. The definition of the research priorities proposed here is based on the following elements:

- The priorities identified in the current SRA of NERIS: http://www.eu-neris.net/;
- The input from the members of the NERIS R&D Committee;
- The recently organized NERIS workshop (Milano, April 2015) and especially the conclusions from the session rapporteurs;
- A consultation of all NERIS members related to the identified priorities (July 2015);
- The Operra survey;
- The realizations in past and current EU funded projects and especially from the Fukushima experience.

Research and development in the field of emergency management and recovery at the European level calls for co-operation between authorities, emergency centres, research organisations and the academic community in different countries, as well as interactions with key concerned stakeholders with the goal to enhance adequate and coherent response throughout Europe in case of a nuclear and or a radiological event. To reach this goal, apart from advances in the development of models, research improving the decision-making processes is crucial (NERIS SRA key topic 5). Four out of the six priority subjects proposed here are falling within this key-topic and include uncertainty handling in emergency response and recovery, robust decision making, countermeasure preparedness strategy and

monitoring strategies. This research requires a highly multidisciplinary approach and should include societal and ethical aspects. The identified priority research needs related to advances in modelling are in the domain of atmospheric dispersion modelling and local radio-ecological modelling. Based on the exchange of ideas with other radiation protection platforms (MELODI, ALLIANCE, EURADOS) a link with potential common research priorities was identified.

A short description of the current ranked research priorities identified by NERIS are given below. A more detailed description can be found in the annex.

1. **Assessment of and communication of uncertainties**. Investigation of data uncertainties (model or monitoring results) and how they can be communicated, e.g. in model results and in Decision Support Systems (DSS) to help decision-makers to understand the radiological situation. This includes also work on model sensitivity, validity of model results and inter-comparisons of models and measurements.
2. **Robust decision-making.** Structuring the decision processes and the protective strategies at national, regional and local levels with the help of formal decision aid tools, such as multi-criteria analysis and on the basis of feedback from stakeholder processes. Development of guidance on the use of DSS in the various phases of an event based on feedback from stakeholder processes and from Fukushima experience in emergency response and recovery.
3. **Countermeasure strategy preparedness.** Development of sustainable preparedness strategy at Local, National and European level, based on the analysis of countermeasures for relevant accident scenarios. Ensuring that parameters governing the radiological consequences can be identified in time to enable optimized remediation and contribute to the elaboration of robust recovery strategies.
4. **Atmospheric dispersion modelling.** To make more reliable forecasts of atmospheric dispersion, including data assimilation and improved inverse modelling (to determine source term and/or source location) in different environments (e.g. urban areas) and/or at different spatial scales (near range to global scale).
5. **Local radio-ecological models.** Development and integration in general DSS of local radio-ecological models interlinked with monitoring information and the more global and food chain dose models. Investigate the capability of such models to be operated by local stakeholders as farmers or local communities. Link with ALLIANCE.
6. **Monitoring strategies.** Optimised use of monitoring resources, including mobile units and trans-border issues. Integration of new monitoring technologies (e.g.; drones). Development of processes and tools for integrating the monitoring results from experts and lay people into a common operational picture (monitoring crowdsourcing). Information fusion (radiological and non-radiological). Link with EURADOS but focus on strategy and integration, less on the improvement or development of new measurement methods/techniques.

Priority 1	**Assessment of and communication on uncertainties**
Priority description	Important advances have been made in the last decades in the development of models and monitoring methods for evaluating the impact of nuclear/radiological events or assist in the recovery phase after such an accident. Examples are the validation of food chain and hydrological models, validation of the RODOS model for the Hanford scenario, use of models & monitoring methods in the aftermath of the Fukushima accident. However, uncertainty in these assessments has never been addressed in detail. Both, uncertainty arising from limited information, especially in the early phase of an accident, as well as inherent model or monitoring uncertainties have to be addressed and communicated properly. The research needs identified are: - The investigation of data uncertainties on model or monitoring results and how to propagate uncertainty through simulation models; - How to communicate uncertainty to decision-makers. Key research questions are: - Identify the need of decision makers: how to include uncertain information from simulation and modelling in their decision making process, helping them to avoid rigid schemes with the likely difficulties for implementation and social acceptance? - Define the level of uncertainty for the key simulation areas of a DSS; - How to include/visualise uncertainty in the results of simulations & measurements and how to propagate them between simulations (e.g. source term – dispersion – dose assessment)? - Is there a methodology for uncertainty handling and sensitivity analysis applicable for all? - How to communicate uncertainty – legal, social and ethical aspects?
European relevance	The topic is part of the NERIS Strategic Research Agenda (Key Topic 5, sub-topic 5.1). Especially in European context, in which accidents have a high probability to have cross border consequences, having better insight in the uncertainty of evaluations based on models or monitoring and how to communicate and visualize these uncertainties is of key importance to come to common European decisions on protective actions and for the harmonization of intervention levels across Europe.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	Uncertainty handling is crucial in all aspects of radiation protection and of importance in several disciplines: apart from assessments in nuclear emergency response and recovery it is of importance e.g. in radio-ecological modelling (ALLIANCE), dosimetry (EURADOS) and studying dose-effect relationships (MELODI).
Impact: decreased uncertainty	Better understanding and quantification of the sources of uncertainty will result in efforts to reduce the main sources of uncertainty.
Impact: increased radiation protection	Taking into account the uncertainty of model calculations and monitoring results makes it possible to elaborate better scientifically sound decisions, as well as more acceptable from the social and ethical points of view.
Impact: increased acceptability	One of the main challenges of communication of uncertainties is to improve the decision-making processes (DMP).
Feasibility	The propagation of the uncertainty between simulations is a scientific challenge. However, model developers are the key scientists to address this topic. Estimation of the budget: 1-2 M€, duration 3 years.
Other justifications	The topic has a high scientific relevance because by identification of the uncertainties new research priorities will be identified. In addition, it has a very societal relevance by addressing uncertainties to improve DMP and favour the communication with the public.

Priority 2	**Robust decision-making**
Priority description	Further developments in decision-making are currently required to clearly address i) the structure of the different levels of decision-making and the needs of different tools and ii) how to make best use of existing Decision Support Systems (DSS). The work proposed entails: • Structuring the decision processes and the protective strategies at national, regional and local levels with the help of formal decision aid tools, such as multi-criteria analysis and on the basis of feedback from stakeholder processes. • Development of guidance on the use of DSS in the various phases of an event based on feedback from stakeholder processes and from Fukushima experience in emergency response and recovery. The work proposed will investigate: how are DSS used today and if this complies with their existing structure and robustness; the potential added value of using formal decision-aiding tools in the decision-making process; the adequacy of decision support tools at different levels of decision-making, including all possible stakeholder groups; stakeholder involvement in the preparedness phase: the use of predefined strategies in emergency and recovery management and inclusion of social resources (crowd sourcing, stakeholder participation,…) in the Decision-Making Processes (DMP).
European relevance	The topic is part of the NERIS Strategic Research Agenda (Key Topic 5, sub-topic 5.3). Moreover, the work proposed will help evaluating if pre-defined protective strategies are sufficient to manage the early phase of an emergency and if yes, how to define and use them in an emergency. It is thus relevant to the implementation of the BSS, namely recommendations regarding emergency planning and recovery strategies. Finally, the work is grounded on strong stakeholder involvement and will entail establishing legal, social and ethical guidelines; it will thus require input from social sciences and humanities and contribution from stakeholder engagement processes in Europe.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	The topic is highly relevant at European level, since it will lead to the identification of criteria for the “optimal” use of European DSS and the development of additional guidance material to support their usage. The topic is related to the priorities described in the SRA of European platforms: - NERIS: Key Topic 5, sub-topic 5.3 -ALLIANCE: Challenge 3
Impact: decreased uncertainty	By helping to develop appropriate tools to support the decision-making process at the various levels, the topic will contribute to decreased uncertainty concerning the efficiency of the protection and thus to the health effects for people in emergency and recovery situations.
Impact: increased radiation protection	By contributing to an improved decision-making process on protective actions in case of a nuclear or radiological accident, it will contribute to better protection of workers, people living in affected area and the general public in emergency and recovery situations.
Impact: increased acceptability	A better structured and more efficient decision-making process will bring increased transparency and grounds for justification of protective actions in case of an emergency and recovery situations. It will thus also contribute to increased social participation in the DMP and thus improve efficiency of protection and favour reassurance.
Feasibility	The scientific/technological competences needed for this topic are available in Europe. Estimation of the budget: 1-2 M€, duration 3 years.
Other justifications	The topic has a high societal relevance since it aims at a better protection of the population in case of a nuclear or radiological situation.

Priority 3	**Countermeasure strategy preparedness**
Priority description	Several European projects in past Framework Programmes have addressed the multiple dimensions (radiological effectiveness, technical feasibility, stakeholder involvement, economic impact, legal issues, etc.) of management options for agricultural and urban areas in the aftermath of a nuclear accident (FARMING, SAGE, EURANOS, NERIS TP, PREPARE (on-going project)). The accident in Fukushima highlighted however, the need for further work in the area of emergency and recovery preparedness and response as regards the development of countermeasure and recovery strategies, by: ▪ Drawing the lessons on the applicability, efficiency and sustainability of countermeasures strategies from the emergency and recovery responses following the Fukushima accident; ▪ Improving the adequacy of existing decision-making processes and tools at national/regional/local levels to favour the preparedness of efficient countermeasure and recovery strategies; ▪ Achieving sustainable engagement of local stakeholders in emergency and recovery preparedness and response. The work proposed under this topic entails: • The development of sustainable preparedness strategy at Local, National and European level, based on the analysis of countermeasures for relevant accident scenarios and recovery strategies; • Ensuring that parameters governing the radiological consequences can be identified in time to enable optimized remediation; • Ensuring that countermeasures preserve territorial resilience.
European relevance	The topic is part of the NERIS Strategic Research Agenda (Key Topic 5, sub-topic 5.7). Inputs from social sciences and humanities are required concerning the social and ethical dimensions of countermeasure and recovery strategies.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	The accidents in Chernobyl and Fukushima demonstrated that consequences of nuclear accidents exceed by far national boundaries and last over several decades. The topic proposed will contribute to improved preparedness and response to nuclear and radiological emergency and recovery situations. It is highly relevant at European level, since it entails the development of sustainable preparedness strategies at both local and European level and will allow to draw the lessons from the long-term management of the consequences of the Fukushima accident. The topic is related to the priorities described in the SRA of European platforms: NERIS: Key Topic 5, sub-topic 5.7 & ALLIANCE: Challenge 1.
Impact: decreased uncertainty	Optimized remediation contributes to decreasing uncertainty concerning the effects on people and the environment in emergency and recovery situations and to improve the stakeholder engagement in the strategies.
Impact: increased radiation protection	By developing sustainable countermeasure and recovery strategies and ensuring that parameters governing the radiological consequences are identified in time to enable optimized remediation, the topic contributes to improved protection of the population in emergency and recovery situations.
Impact: increased acceptability	Stakeholder involvement at different levels of preparedness and response will reinforce the efficiency of decisions taken in case of emergency and recovery situations and will lead to increased acceptability of countermeasures strategies. It will also increase the capability of resilience in case of an accident.
Feasibility	The scientific / technological competences needed for this topic are available in Europe. Estimation of the budget: 0.7-1.5 M€, duration 3 years.
Other justifications	The topic has a high societal relevance since it aims at a better protection of the population in case of a nuclear or radiological situation. It will also allow to draw the lessons from the management of the consequences of the Fukushima accident.

Priority 4	**Atmospheric dispersion modelling**
Priority description	Atmospheric dispersion models are the key tools to study the impact of atmospheric releases of radioactive material to humans and the environment. Although a long history exists in the development of atmospheric dispersion models and recent improvements such as worldwide applicability of the JRODOS system (FP7 project NERIS-TP), the use of higher spatial and temporal resolution meteorological data (FP7 project PREPARE) and source term estimation based on monitoring have been achieved, several improvements are still required. Important steps can still be made to improve reliable forecasts of atmospheric dispersion, including data assimilation and inverse modelling to determine source term and/or source location. Especially in specific environments e.g. urban areas and specific ranges (e.g. the near-range) room for improvement is possible. Specifically highly interesting research questions are: • Model improvements responding to the needs of decision-makers in specific areas: e.g., near-range, urban areas, confined spaces; • Inverse modelling and data assimilation techniques related to dispersion modelling from near-range to global scales; • Multi-scale modelling: how to integrate model calculations from local to global scale to allow coordinated use of ADM; • Better understanding of the complex interplay between time-varying release characteristics and meteorological conditions (e.g. use of ensembles, impact of precipitation, …); • Statistical analysis and graphical representation of multiple model simulations (using different source terms and meteorological analyses), including use of below-threshold data (null measurements); • Model validation, robust uncertainty handling and visualization in ADM.
European relevance	The topic is part of the NERIS Strategic Research Agenda (Key Topic 1). Improved and validated modelling tools will help harmonization of emergency countermeasures across Europe.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	Atmospheric dispersion modelling is of particular interest, apart from assessing the impact of emergency exposures, in the impact analysis of routine emissions in planned exposures (planned exposure situations, …).
Impact: decreased uncertainty	Improved and validated models will reduce the uncertainty in the output generated by the models and in all further assessments of the radiological evaluation and improve advice to the decision-makers.
Impact: increased radiation protection	Improved and validated models for different ranges and environments will contribute to better protection strategies and increase in this way radiation protection.
Impact: increased acceptability	More confidence in model calculations will result in more confidence in protection strategies and increase the acceptability of advised countermeasures.
Feasibility	Atmospheric dispersion modelling is a key research theme within the emergency and NERIS community for many years. Improvements are linked to the access to better meteorological data, increasing computer power and the continuous development of dispersion and transport methodologies (e.g. Computational Fluid Dynamics). Estimation of the budget: 1-2 M€, duration 3 years.
Other justifications	The continuous improvements in meteorological forecasts and calculation methods allow the improvement of dispersion models for specific ranges and environments. Also very specific situations require new, more advanced modelling techniques.

Priority 5	**Local radio-ecological models**
Priority description	Past and on-going European projects (FUTURAE, EURANOS, NERIS-TP, COMET, PREPARE) have contributed to the development and integration in Decision Support Systems (DSS) of models for the estimation of the radiological spatial-temporal situation in different environments (terrestrial and aquatic) and the impact on population. Such models have been applied for remediation purpose in both emergency and recovery situations. Furthermore, generic regionalisation has been done for different European climatic regions of the radiological parameters and other socio-economic factors. However, there is a need to: ▪ Develop / adapt the radio-ecological models used in DSS for the preparedness and management of the emergency and recovery to the complex local specificity; ▪ Apply the radio-ecological models to establish feasible and efficient site-specific remediation and monitoring strategies; ▪ Improve the operability and the understanding of the dose assessment and countermeasures models by potential users, including non-expert stakeholders. The work proposed under this topic entails: • Development and integration in general DSS of local radio-ecological models interlinked with monitoring information and the more global and food chain dose models; • Estimation of the efficiency and spatial-temporal evolution of the protective /remediation actions in relation to site-specific characteristics; • Investigation of the capability of locally customised models to be operated by local stakeholders as farmers or local communities especially for the recovery situation; • Identification/classification of vulnerable areas in European environments with the implication of stakeholders.
European relevance	The topic is highly relevant at European level since it involved further developments of European DSS, such that they can be used at local level in order to allow enhanced preparedness and optimised response. The topic is part of the NERIS Strategic Research Agenda (Key Topic 5, sub-topic 5.6). Inputs from social sciences and humanities are required concerning stakeholder involvement at local level.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	The topic proposed will contribute to improved preparedness and response to nuclear and radiological emergency and recovery situations. The topic is related to the priorities described in the SRA of European platforms: NERIS: Key Topic 5, sub-topic 5.6 & ALLIANCE: Challenge 1 and Challenge 3.
Impact: decreased uncertainty	Adaptation of generic models to the specificity of the local areas affected by a nuclear or radiological accident will lead to an improvement in the estimation of radiological transfer and impact on population. This in turns leads to decreased uncertainty in the estimation concerning the effects on people and the environment in emergency and recovery situations.
Impact: increased radiation protection	The topic will contribute to optimised decision-support and thus to increased protection of the population in emergency and recovery situations.
Impact: increased acceptability	Empowering local stakeholder and communities with tools adapted to the specificity of the local context will contribute to increased preparedness and higher efficiency and acceptability of countermeasures strategies.
Feasibility	The scientific / technological competences needed for this topic are available in Europe. Estimation of the budget: 0.5 - 1 M€, duration 3 years.
Other justifications	The topic has a high societal relevance since it aims at a better protection of the population and the environment in case of a nuclear or radiological situation.

Priority 6	**Monitoring Strategies**
Priority description	Decisions in the aftermath of or recovery from a nuclear or radiological accident are largely based on monitoring efforts. Although most countries installed monitoring capacity for nuclear and radiological accidents, important challenges still exist, such as: - The optimization of the monitoring strategy in function of the decision support; - The integration of different monitoring techniques in one strategy, including new technologies (drones, measurement by the public, …). Research questions are: • How to optimize the measurement strategy taking into account radiological, societal and ethical factors in case of a nuclear accident, especially addressing accidents with cross border impact; • Evaluation of new technologies and how they can be integrated in nuclear emergency and long term monitoring: e.g., drones, smartphone apps, …; • How to integrate and support monitoring by the public; • How can monitoring be linked with nuclear emergency and recovery reference levels (e.g. related to contaminated goods); • How can monitoring (strategies) be linked with advanced modelling (source term calculations); • How to combine monitoring data, including non-radiological data (data fusion); • How does monitoring uncertainty impact decision support and how to visualize monitoring uncertainty; • How to use monitoring efficiently in optimization recovery countermeasures; • What are the specific differences needed in monitoring in the different phases of an accident.
European relevance	The topic is part of the NERIS Strategic Research Agenda (Key Topic 5, subtopic 5.9). Currently all European countries have developed their own monitoring capacity. A sound scientific basis, taking into account local differences, for developing a robust monitoring methodology, considering technical as well as societal factors is missing.
Multidisciplinarity; Reference to the strategic research agendas (SRA)	Apart from NERIS, monitoring is strongly linked to research related to the European platform for dosimetry (EURADOS). However, it should be noted that this topic doesn't focus on the development or optimization of new measurement techniques, but addresses the integration of existing and new technologies in a robust monitoring strategy to support decision-making. The set-up of monitoring strategies should also include stakeholder involvement.
Impact: decreased uncertainty	A robust monitoring strategy will allow a much faster assessment of the situation. It will also improve the efficiency of countermeasures.
Impact: increased radiation protection	This topic aims at optimizing monitoring strategies, which should result in acquiring a clear picture of the radiological situation in a limited timeframe. In this way better and faster protective actions can be taken.
Impact: increased acceptability	A clear, stable picture of the radiological situation will enhance trust in decisions related to protective actions and consequently increase acceptability of countermeasures. In addition capabilities will be developed for stakeholders.
Feasibility	The main challenges are to connect monitoring experts with radiological emergency and recovery experts (advisors to the decision makers) and integrate societal/ethical aspects. Estimation of the budget: 1-2 M€, duration 3 years.
Other justifications	The Fukushima accident demonstrated that the involvement of the public in measurements is essential. Research in this context should be the basis for any preparedness actions in this respect.