Terms of Reference for Radioecology WG

Title and acronym:

Naturally-Occurring Radioactive Materials (NORM)

Topical area

The main issue in view of NORM-impacted sites[1] is how such sites, e.g. radium contaminated sites, uranium liabilities, sites exploited for the mining of metals associated with NORM and wastes arising from industries processing or generating other kinds of NORM, are assessed and regulated. In view of the implementation of the new Basic Safety Standards (BSS), the regulations apply to the management and clean-up of existing sites as well as to the licensing of future discharges and large quantities of NORM waste. This necessitates a better understanding of key routes involved in the migration and bioavailability of radionuclides at NORM sites, i.e. to develop (i) sampling strategies to characterize NORM-contaminated sites, (ii) the practical use of hydrogeological and hydrogeochemical mechanistic modelling together with a process-based understanding of radionuclide migration in abiotic and biologically influenced environments, radionuclide transfer into biota and finally into the human food chain, and (iii) projective modelling for existing sites as well as generic modelling for licensing procedures on timescales from years to millennia. Research in these directions will foster science based advice on the classification of NORM and NORM affected sites according to the recommendation and requirements set in the BSS and on the opportunity to undertake innovative and long-term effective remediation actions. It will also support the development of advanced generic radioecological models with a lower degree of conservatism, thus avoiding unnecessary restrictions in licensing procedures. Due to the complexity of NORM sites, which are characterized, for instance, by complex mixtures of different chemicals and minerals as well as disequilibria in radionuclide decay chains, challenges arise not only from the lack of comprehensive scientific data, but also from existing model concepts themselves, which do not adequately describe the interplay between simultaneously occurring processes at a NORM site. Therefore, a promising strategy is to reduce modelling uncertainties by identifying and parametrizing the key processes that influence the radionuclide behaviour and to transfer this knowledge into a mechanistic model sufficiently complex to describe the radionuclide behaviour in the environment, however, simultaneously simple enough to be practical and applicable to different NORM sites. In view of potential hazards associated with the radioactive source term of NORM sites related to former, current or future human activities, as well as the need for developing preventive methods at different stages of a technological process in a NORM industry, this is an important task.

WG group NORM currently is composed of 14 organisations from 10 European countries which contributed to the preparation of the current version of the WG NORM roadmap document. It contributes to Challenge 1 of the radioecology Strategic Research Agenda (SRA), research lines 1 to 3, by (i) identification and parameterization of key processes relevant for the environmental transfer of naturally occurring radionuclides and the resultant exposure of humans and wildlife, (ii) acquiring data necessary for the parameterization of key processes controlling the behaviour of radionuclides

[1] The expression NORM in the document below denotes NORM (naturally occurring radioactive materials) sites as well as TENORM (technologically enhanced naturally occurring radioactive materials) sites.

in the environment, and (iii) by improving existing models or developing parametric models linking observed accumulation, mobility (K_d), and transfer (TF and fluxes) with environmental parameters and processes to enable spatial and temporal predictions. The resulting knowledge is needed for a more reliable description and prediction of the behaviour of natural radionuclides in environmental compartments, including dynamic processes. This WG will generate new knowledge necessary to assess NORM resulting exposures of both humans and non-human populations with substantially reduced uncertainty.

Leadership

Susanne Sachs and Thuro Arnold (HZDR, Germany)

Partners with a brief description of their institutes

BfS: BfS (Federal Office for Radiation Protection; www.bfs.de) is an independent scientific-technical national authority in the portfolio of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety. It pools the national expertise in the entire field of radiation protection, nuclear safety and radioactive waste management. BfS pursues, conducts and initiates application-oriented research in these fields. BfS is strongly involved in the radiation research platforms MELODI, ALLIANCE, NERIS, EURADOS and the medical field and co-ordinates CONCERT. A key issue in the radioecological research at BfS is to reduce the predictive uncertainty of radioecological models by identifying and explicitly modelling key processes. Here, the focus is on replacing highly uncertain empirical parameters by robust radioecological sub-models. BfS has extensive expertise in characterization, risk assessment and clean-up strategies of NORM legacy sites that resulted from uranium mining in Eastern Germany. In view of the implementation of the Basic Safety Standards, BfS aims at decreasing the degree of conservatism in generic assessment models, thus avoiding unjustified restrictions in licensing procedures, especially of NORM industries.

CEA: Different teams of the CEA (French Atomic Agency) study molecular mechanisms of radionuclide interaction with living organisms and toxicity, in link with their speciation. This involves the complementary expertise of chemists, biophysicists and biologists and concerns molecular studies on simple organic and inorganic model compounds, proteins, cell lines, and a variety of organisms including plants and soil bacteria. A transverse program “Toxicology” supports interdisciplinary projects in this field. We study NORM interactions with soil bacteria populations as well as mechanisms of interaction at the molecular level, to assess speciation, transfer, bioconversion or accumulation, and to identify protein targets, and markers of exposure, with a specific focus on uranium. In a context of integrative plant biology, using omics approaches combined with genetics and biochemistry, we evaluate the impact of NORM (notably uranium) on cell function and study biochemical and physiological defence mechanisms, as extracellular immobilization, active exclusion into the apoplast, chelation in the cytosol and sequestration in the vacuoles. Better understanding the molecular mechanisms controlling these processes, metal toxicity and accumulation in plants, will enable to identify biomarkers of exposure and to design new strategies of phytoremediation via engineered plants, natural hyperaccumulators, or the selection of crops with low radionuclide accumulation.

CIEMAT: The CIEMAT is a Public Research Institution belonging to the Spanish Ministry of Economy (within the secretary of research and development). It promotes and carries out research and technological development projects in the field of energy, keeping as far as possible close connections with other national and international research groups with similar objectives. Likewise,

it is the link between basic research and the national industry, acting when requested as an adviser of our national authorities in the fields of technology and energy strategy. The CIEMAT acts as technical supporter for regulators and operators, providing methodologies, tools, analytical services and performing radiological impact assessments for solid waste disposal, effluent releases and "ad hoc" situations of environmental contamination. Its activities in radiological protection extend to the public and the environment through studies on radioecology, evaluation and reduction of radiological impacts, environmental radioactivity measurement, as well as personal and environmental dosimetry. The CIEMAT has an important activity in training/education of professionals (radiation protection, radioactive waste management, nuclear safety), and a wide experience in organizing workshops, conferences and other events (www.ciemat.es).

CLOR: Central Laboratory for Radiological Protection (Centralne Laboratorium Ochrony Radiologicznej) is a research institute situated in Warsaw, Poland. Our primary activities are monitoring of radioactive contamination in foodstuff, environmental components and building materials, calibration of dosimetric instruments and monitoring of occupationally exposed workers as well as the general population. We conduct research on matters dealing with radiation protection, radiobiology and radioecology. CLOR perform dose assessments both for humans and wildlife exposed to artificial and natural ionizing radiation. Our recent projects related to NORM were connected with phosphogypsum waste dumps and also former uranium mining sites located in Poland. CLOR serves as a centre for training in radiation protection, scientific and technical information and developer of high-sensitive stations for detection of radioactive contamination in air. Furthermore, from 2012 CLOR became Technical Support Organization by bilateral agreement with the President of the National Atomic Energy Agency.

GIG: Główny Instytut Górnictawa (GIG; Central Mining Institute) is located in Katowice, the administrative centre of Silesia, a mining and industrial region in southern Poland. GIG is a research and development institute, working for mining industries, local authorities, environment protection businesses and other customers. The tasks, related to radioprotection and radioecology, are run by the Silesian Centre for Environmental Radioactivity (SCRS), the modern, well equipped GIG's department. The SCRS' team has been involved in the problems caused by NORM at industrial and post-industrial areas for many years. It results in extensive experience in radiation measurements, occupational risk assessment and monitoring of the environmental impact related to natural radioactivity (NORM). Besides mining industry the main scientific activity of SCRS is currently directed into protection of widely comprehended environments against ionising radiation, including, e.g. non-human biota, effects related to the simultaneous presence of other toxic metals and different environmental conditions or radon and radon progenies in homes. During the last few years SCRS participated in EU projects mainly focused on radiation protection and environmental effects related to activities of the non-nuclear industry. SCRS has experience in training in radiation protection and NORM waste management and can provide excellent conditions for trainings and exercises focused on radiation protection and radioecology. SCRS provides almost all measurement techniques useful in radiation protection and radioecology.

HZDR: The Institute of Resource Ecology (IRE) is part of the Helmholtz-Zentrum Dresden-Rossendorf (HZDR). Research activities of the IRE are focused on the assessment and reduction of risks related to the nuclear fuel cycle and the migration of radionuclides in natural environments, based on a profound knowledge of molecular processes at the interface between geo- and biosystems. The IRE combines earth sciences, biochemistry, chemistry, and biology. It has ample experience with the characterization of environmental problems (mostly in connection with former uranium mining). These activities include low level nuclear radiation measurements, sophisticated spectroscopies, modelling of thermodynamic equilibria and migration processes, interactions of microbes or plants with radionuclides, sorption phenomena, colloid chemistry, and solubility and speciation studies. IRE

combines spectroscopic, microscopic, and biological methods in controlled areas allowing studies that can only be performed at a few places in Europe. IRE runs the X-Ray absorption spectroscopy station for radiochemistry, the Rossendorf Beamline, at the European Synchrotron Radiation Facility in Grenoble (France). In addition, a number of different chemical speciation codes are in use. HZDR is the leader of WG NORM. More information is provided at www.hzdr.de.

IRSN: The Institute for Radiological Protection and Nuclear Safety (IRSN) provides expertise and research in nuclear safety and radioprotection of human health and the environment. IRSN has a strong experience in the field of risk associated to uranium mining, NORM activities and contaminated sites management. IRSN contributes to the development of technical and regulatory documents on uranium mining and NORM activities in support to the French national authorities and at the international level. IRSN experts are regular contributors to IAEA activities. IRSN also performs its own environmental and human impact assessment of radionuclides, alone or combined with other stressors, and contributes to the development and the implementation of national and local environmental monitoring programs around uranium mining and milling sites. IRSN conducts R&D works devoted to a better understanding of radionuclides transfer and impact in the environment and develops its own transfer modelling tools. IRSN has several laboratories, particularly to perform radiological analyses on effluent releases and environmental samples for all radionuclides of interests (e.g. uranium and thorium), in support of monitoring and R&D related activities.

IST: IST is the largest and most reputed school of engineering, S&T in Portugal. Its mission is to provide top quality higher education in the areas of engineering, S&T and architecture, as well as developing RD&I activities that meet the highest international standards. The IST has expertise, among others, in nuclear physics&engineering, radiological protection and nuclear safety, nuclear techniques, environment&cultural heritage and runs specialized equipment and infrastructures, unique in the country. IST combines nuclear analytical techniques (INAA), spectrometric methods (gamma spectrometry, LSC, etc.), microscopic techniques (SEM-EDS), luminescence measurements, Mössbauer spectroscopy (MS), X-ray diffraction and mineralogical and granulometric methods for the precise and accurate determination of NORM sites, their distribution in different size fractions of soils and sediments, and the identification of the host phases in NORM materials. More information is provided at http://c2tn.tecnico.ulisboa.pt/.

LRA-UAB: The Laboratory of Environmental Radioactivity (LRA) at the Universitat Autònoma de Barcelona (UAB) is a research group specialized in natural and artificial environmental radioactivity at different fields (oceanography, radiochronology, NORM industries, radioecology, …). LRA-UAB has been worked in several NORM environmental areas focused on the determination and distribution of radioactive elements and their effects related to dose assessments of the human health and environment. These NORM studies have been mainly dedicated to the phosphate industry and water characterization in several water management processes. The LRA-UAB has an environmental radioactivity laboratory, sampling equipment's and radionuclide detectors for radionuclide spectrometry.

NCSR"D": The National Centre for Scientific Research "Demokritos" (NCSR"D") is the largest multidisciplinary research centre in Greece, with critical mass in expertise and infrastructure in the fields of nanotechnology, energy&environment, biosciences, particle and nuclear science, informatics and telecommunications. Research activities are currently coordinated by five research institutes; one of them is the Institute of Nuclear&Radiological Sciences&Technology, Energy&Safety (INRASTES). INRASTES is an interdisciplinary institute with a large part of its scientific activities centred around nuclear technology, energy/environmental technologies and radiation protection, molecular radiopharmacy and biodiagnostics. It is a multidisciplinary research institution pursuing basic, translational and applied research to address challenges of great scientific and socioeconomic

impact in a broad spectrum of scientific and technological fields. The various activities have been organized in four thematic areas (divisions): (1) energy/environmental technologies&safety, (2) nuclear technology, (3) biodiagnostics, (4) radiological sciences and radiopharmaceutics. All these thematic areas share a common background in physical sciences and are in line with both the Horizon 2020 priorities and the national smart specialization areas.

NERC-CEH: The Natural Environment Research Council (NERC) employs over 450 staff at four sites. The Centre for Ecology and Hydrology (CEH) is the UK's Centre for Excellence for integrated research in terrestrial and freshwater ecosystems and their interaction with the atmosphere. Our science is organised within three programmes, Biodiversity, Water and Biogeochemistry with an overarching Environmental Informatics Data Centre. The Radioecology group has extensive experience in the development and testing of approaches to demonstrate radiological protection of the environment (e.g. ERICA, PROTECT, IAEA EMRAS chairs, ICRP TGs), spatial transfer model development (e.g. SAVE), farm animal radioecology, and countermeasure development and strategies (e.g. STRATEGY). The group (together with IRSN, SCK•CEN and the University of Stirling) developed training packages in radiological environmental assessment. NERC-CEH currently co-ordinates the TREE consortium (http://www.ceh.ac.uk/tree). The chemical and radiochemical laboratories of CEH in Lancaster are UKAS accredited (ISO17025).

NMBU: The Centre of Environmental Radioactivity (CERAD CoE) at Norwegian University for Life Sciences (NMBU) is established to perform fundamental long term research to improve the ability to accurately assess the radiological risks from environmental radioactivity combined with other stressors. By focusing on key factors contributing to the uncertainties, CERAD represents a state-of-the-art research foundation for the advancement of tools and methods needed for better management of those risks. The scope includes both man-made and naturally occurring radionuclides that were released in the past, those presently released as well as those that potentially can be released in the future from the nuclear fuel cycle and non-nuclear industries. For more information, see https://cerad.nmbu.no.

SCK•CEN: The Biosphere Impact Unit (BIS) is part of the Institute for Environment, Health and Safety (EHS) of the Belgian Nuclear Research Centre (SCK•CEN). Our major objectives are (1) to enhance competence in the understanding and process-based modelling of the behaviour of radionuclides in the biosphere, (2) to develop a groundwater-soil-vegetation interaction model to assess the long-term impact of perennial vegetation systems on the dispersion of radionuclides and contamination of the food chain, (3) to study biological effects induced in plants by radiation, radionuclide uptake and mixed contaminant conditions at different levels of biological organization and (4) to develop and improve our tools and models for assessing the radiological impact on man and environment. To better understand and predict the processes that determine radionuclide mobility, transfer, etc. in the terrestrial, freshwater and marine environment, we use dedicated laboratory set-ups, greenhouse experiments and field studies as well as develop modelling tools calibrated and validated with the available data sets.

STUK: Radiation and Nuclear Safety Authority (STUK) of Finland operates in the regulation of ionising and non-ionising radiation, e.g. regulation of nuclear energy and reducing radon exposure, and in emergency preparedness. One of the official duties is to monitor the radioactivity in the environment using various methods. The main goal of the environmental radiation monitoring is to get detailed information on the radiation exposure of the Finnish population, whether it is from natural or artificial radiation sources. Another goal is to detect all significant changes in the levels of environmental radiation and radioactivity to identify foreign substances and provide information for protection procedures. The running of an environmental surveillance programme on a continuous basis maintains and develops competence and readiness to respond to radiological emergencies.

Specifically for NORM, through changes in legislation in 2015 the role of STUK in the regulation of the mining industry has been strengthened. In the near future the focus related to NORM will be on the implementation of the BSS as well as carrying out radiological baseline studies. In addition, small-scale investigations might be carried out in the former and existing mine sites in order to gain knowledge on the local radiological situations to support the implementation of the BSS.

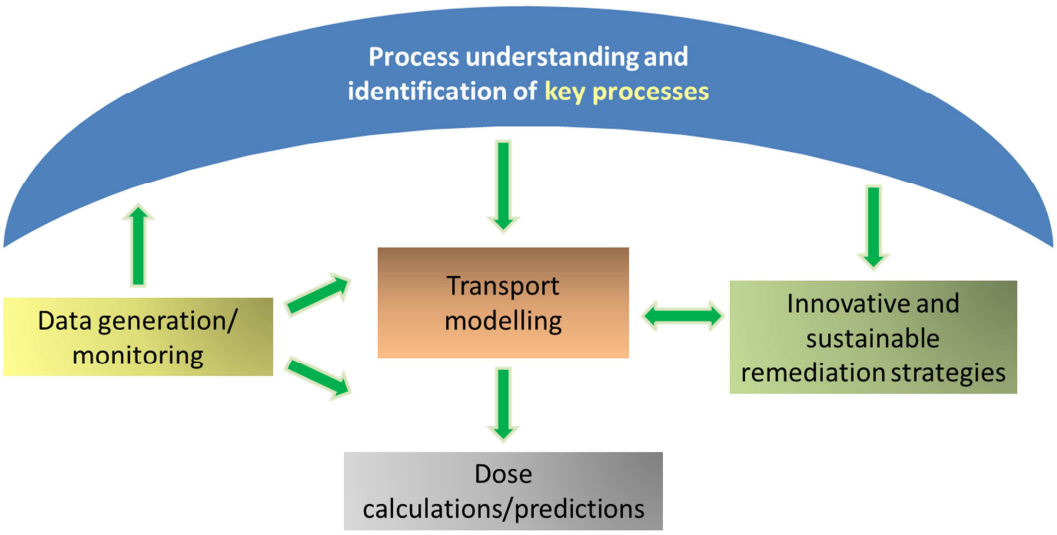
Intended activities (task, approach, steps to accomplish, expected outcomes)

This roadmap covers a time frame of five years; however, we are aware that there are important activities in future R&D that are beyond our immediate scope. But, the here described roadmap is part of a prolonged vision aiming at continuously incorporating new knowledge, when it becomes available, to progressively improve risk assessments of NORM contaminated sites and thereby help to reduce the risk for humans and wildlife.

The **main objectives** of the WG NORM can be summarized as follows:

1. Improve risk assessment for existing and future NORM sites.
2. Extend transport modelling of radionuclides into the uncontaminated environments by including chemical/geochemical, biological/microbiological, and mobilization/immobilization processes, i.e. by to identify and mathematically describe processes that make significant contributions to the environmental transfer of radionuclides resulting in extended exposure of humans and wildlife.
3. Develop a mechanistic understanding of chemical and biological processes on a molecular scale and translate this knowledge into robust sub-models thus paving the way for new strategies for a sustainable rehabilitation and remediation of NORM sites.

To be able to achieve these objectives a multidisciplinary approach is required. The power of multidisciplinary teams working jointly together on environmental issues in Europe should result in synergies, from which the radioecological community will benefit, and helps to achieve such a goal in an efficient way. Based on these objectives and the expertise of the contributing partners, a general structure of WG NORM was developed, which shows its main tasks and their respective relationships.



Main working tasks of WG NORM.

There is a strong link between all tasks of WG NORM. For example, knowledge generated in task "Process understanding and identification of key processes" will feed into task "Transport modelling". Both tasks will feed into task "Dose calculations/predictions". In turn, with this task major uncertainties will be identified which will feed back into new requirements on process understanding and transport modelling.

The starting situation of WG NORM is the following: in a number of European countries there are NORM sites of interest, resulting from mining activities (e.g., U, Zn, Cu mining, Upper Silesian Observatory Site) and phosphate industry (e.g., phosphogypsum stock pile, phosphate production plant, pine forest on a sludge heap from the phosphate industry), which may cause health hazards for humans and the environment. These NORM sites are already under investigation, however, predominantly on a national level. Due to the fact, that there is no EU funding for WG NORM and no foreseeable funding at the moment, each partner currently contributes to the tasks of WG NORM with their own data, skills, knowledge, and financing from national and international sources (projects, grants, funds).

The work of WG NORM will create a research platform for NORM interested scientists for sharing and exchanging knowledge on radionuclide behaviour in the environment. Thereby, studies made by the European platform EAN-NORM (European Alara Network for Natural Occurring Radioactive Materials) will be considered to make sure that activities are not duplicated. It aims at reducing the uncertainty of human and environmental risk assessment for NORM via an improved mechanistic process-based transport modelling and by integrating chemical process understanding (e.g. multidimensional K_d) as well as biological/microbiological processes in transport codes. The **added value for the society** can be found in: (i) improved transport models for radionuclides with reduced model uncertainties, (ii) more reliable and less conservative assessments of the radionuclide transfer, (iii) new innovative, cost-effective and sustainable remediation measures of NORM sites, and (iv) licensing procedures of NORM industries that provide adequate protection of humans and the environment without unnecessary restrictions.

The planned research in WG NORM offers the possibility to link its efforts with other topical roadmap WGs within the ALLIANCE and it is also linked to other radiation protection research platforms in Europe, especially with MELODI.

Starting date and estimated duration of the WG to accomplish its plan

Starting date: October 1, 2015

Duration of the WG: 5 years

Work plan

Based on the strong expertise and the comprehensive topical contributions of our different partners the following tasks will be studied in the next five years in order to reach the objectives of WG NORM. Currently, all partners work or relate their laboratory work to different European NORM sites and for their research they use their own funding (national/international). Radionuclides of interest include, among others U, Th, Ra, Rn, ^{210}Pb, ^{210}Po.

<u>Task 1:</u> Data generation/monitoring

- Compilation of hypotheses and research questions that guide data generation and monitoring

- Radionuclide fluxes in NORM sites → Determination of radionuclide activities (e.g., U, Th, Ra, Rn, ^{210}Pb, ^{210}Po)
- Physicochemical characterization of soils → Determination of simple TF and K_d values and correlation with the physicochemical parameters of the NORM site
- Identification of interaction constants between radionuclides and inorganic/organic compounds to be integrated in transfer models

Task 2: Process understanding and identification of key processes

- Identification and parameterization of radionuclide transfer in plants and microorganisms including the prevailing radionuclide speciation
- Molecular understanding of the radionuclide interactions with simple inorganic and organic model compounds, proteins, cells, bacteria and plants considering their different organs, cell types, and sub-cellular compartments
- Soil-to-plant radionuclide transfer
- Influence of co-contaminants, e.g., heavy metals, on the transport behaviour of radionuclides
- Radionuclide transfer considering redox processes and reactive transport processes
- Use of geochemical speciation databases and codes to support the interpretation of results (such as BASSIST, DACTARI, WHAM, JCHESS, PHREEQC, Geochemical Workbench, …)

Task 3: Transport modelling

- Development of modules for transfer and exposure models that incorporate physical, chemical and biological interactions

Task 4: Dose calculations/predictions

- Calculation and modelling of total doses related to external and/or internal exposures depending on radionuclides and scenarios, e.g., (i) a solid waste disposal site with a vegetation cover, (ii) a natural site contaminated by the release of NORM waste into the environment, and (iii) a natural enhanced site

Task 5: Innovative and sustainable remediation strategies

- Engineering of affine and specific binding sites in proteins and in simple model compounds such as peptides
- Water decontamination using selected hyper-resistant and/or hyper-accumulating microorganisms (bacteria, microalgae) at micro-pilot scale and high-affinity chemicals, peptide derivatives or proteins
- Purification of radium rich water released from fossil fuel mining industry into terrestrial and aquatic ecosystems

Milestones

The following milestones have to be accomplished in order to reach the main objectives:

1. Define, select and generate data necessary for (i) building up a mechanistic understanding, (ii) needed as input in transport codes

2. Development of chemical modules suitable to be included in NORM related transport models (e.g., compartment models)

3. Identify and parameterize mobilization and immobilization processes of NORM radionuclides with plants and microorganisms considering radionuclide speciation

4. Development of a first concept for microbiological/botanic modules suitable to include in transport models (e.g., compartment models)

5. Publication on a process-based modelling approach describing the migration behaviour of radionuclides from NORM sites to uncontaminated environments by including chemical and biological processes

Partners with a brief description of their assigned role (contributions of NORM partners in alphabetic order)

BfS: BfS is mainly interested in identifying and modelling key processes that affect the transport of natural radionuclides in the environment, especially in large quantities of NORM waste (Tasks 2, 3). Here, the focus is on the potential contamination of groundwater and the resulting dose to humans (Task 4). BfS will apply state-of-the-art codes for the water-bound transport of radionuclides (e.g. HYDRUS) in combination with hydrogeochemical speciation modelling (e.g. PHREEQC). BfS is also interested in the further development of generic radioecological models for large quantities of NORM waste with the aim of reducing the predictive uncertainty. These advanced generic models are intended to provide the basis for licensing procedures as well as reference levels for the release of NORM sites from regulatory control. The results will be used to implement the EURATOM Basic Safety Standards. In summary, BfS will mainly contribute to Tasks 2, 3, and 4.

CEA: - Molecular mechanisms governing the interaction of uranium with model compounds, peptides and proteins, soil and water bacteria, microalgae, and plants.

- Molecular origin of resistance, accumulation, and transport mechanisms (including translocation and subcellular distribution in plants and in the microalgae *Coccomyxa actinabiotis and* the role of post-translational modifications PTMs in plant response to uranium) to better describe uranium bioavailability and transfer in ecosystems.

- NORM soil-plant transfer characterization with a selection of mutants or transporter-overexpressing plants, effect of speciation and soil bacteria.

- Isolation of radioresistant microorganisms able to live in various conditions and possessing radionuclides accumulation capacities for the development of bioremediation processes. Decontamination of environmental water with NORM using *Coccomyxa actinabiotis* at micro-pilot scale using a micro-pilot process. Assessment of peptide/protein-derived water-remediation properties.

- Contribution to the databases BASSIST (base applied to speciation in solution, at interfaces and solubility, https://inis.iaea.org/search/search.aspx?orig_q=RN:35016056) and DACTARI for chemical toxicity and radiotoxicity assessment of radionuclides (http://www.dactari.toxcea.org/)

CIEMAT: The CIEMAT is interested in the identification, modelling and parameterization of key processes affecting the behaviour of natural radionuclides transfer. The group has experience and knowledge in the implementation and application of soil-to-plant natural radionuclide transfer models. The CIEMAT is also interested in the development of conceptual and mathematical models for the assessment of natural radionuclides transport, transfer and exposure, looking for processes where uncertainties can be reduced (Task 3). By using key examples to demonstrate the importance of key processes in the doses (effective or absorbed) to biota and humans, the group can contribute to the validation of models (Task 4). CIEMAT can prepare dose scenarios for the derivation of clearance or guidance levels, for remediation or clearance of NORM contaminated sites from the regulatory control. Also following MARSSIM methodology (Multi-Agency Radiation Survey and Site

Investigation Manual), the group can contribute in the design of sampling strategies for NORM sites (Task 1). Therefore, the CIEMAT will mainly contribute to Tasks 2, 3, and 4. If appropriate, it can also contribute to Task 1, in the design of the sampling strategies.

CLOR: CLORs recent projects were related to dose assessments of human and wildlife in the vicinity of phosphogypsum waste dumps and former uranium mining industry located in Poland. These work as well as our current interest include measurements and sampling methods (Task 1), calculation of soil-to-plant radionuclide transfer (Task 2), modelling with the use of ERICA tool, RESRAD family codes etc. (Task 5) and long term monitoring strategies. Regarding NORM, our experience and statutory activity is mainly focused on dose assessments and environmental monitoring.

GIG: GIG is interested in the investigation of all aspects related to an assessment of the impact caused by radium rich waters released into terrestrial and aquatic environment from coal mining industry, oil and gas industry including shale gas exploitation; the identification of processes leading finally either to accumulation or dilution of radionuclides in particular compartments of the environment; the classification of NORM affected sites according to the requirements of the new BSS; identification and development of well scientifically justified methods of NORM effects on environment assessment founded on genotoxicity and cytotoxicity of radionuclides that can be easily applicable in routine monitoring of NORM affected sites.

HZDR: HZDR is interested in the identification and quantification of key processes that play an important role in the transfer of radionuclides in the environment. Fields of applications are related to uranium mining and possibly phosphate industry, and geothermic work places. This includes studies on the interactions and the mobility of radionuclides at the interface between geo- and biosystems. It is intended to investigate the uptake of radionuclides by microorganisms (e.g., bacteria, archaea, and eukaryotic microorganisms) and plants on a molecular level. The radionuclide uptake will be studied as a function of the radionuclide speciation, which will be identified by state-of-the-art spectroscopic techniques and geochemical modelling. Key processes of the interaction of radionuclides with microorganisms and plants will be identified and parameterized. These new data will then be used as basis for the development of basic concepts for modelling of the radionuclide transfer by considering biological processes.

IRSN: IRSN is interested in a better understanding of the geochemical mechanisms that control radionuclide mobility through the aqueous pathway in the environment of mine sites. In that context, IRSN will mainly contribute to Tasks 1 and 2. For Task 1, IRSN currently uses and develops tools, such as diffusive gradient in thin films (DGT) associated with isotopic analyses, to identify sources of radionuclides that mix through aquatic interfaces (*e.g.* discrimination between mine waters, treated waters, ground waters, surface waters, etc.). Such DGT are used for uranium and under development for radium and thallium. Concerning Task 2, IRSN can contribute to a better understanding of the redox processes in the transfer of NORM. Effectively, IRSN currently studies the redox interface sediment/water and develops solution extraction devices for sediment cores under anoxic conditions. IRSN is also interested in the study of NORM speciation in the presence of natural organic matter. For this, IRSN develops methods to study NORM interaction with natural organic matter through fluorescence spectroscopy. In support of these studies, IRSN uses regularly different codes for reactive transport in soils and underground waters (Hytec, Modflow) or geochemical speciation modelling (Chess, Phreeqc, Visual Minteq, WHAM). Finally, IRSN can also provide expertise on the understanding of the key processes that control uranium bioavailability, uptake and accumulation in biota (plants, bacteria, fishes), internal speciation, biological effects as well as on the ecological risk assessment. IRSN has developed an integrated approach to take into account chemical and radiological toxicity, bioavailability, multi-pollutants, disequilibrium in decay chain, as well as natural background. This method has already been applied to former uranium mining areas in

France. IRSN can also contribute to Task 4, with the use of its own tool for dose calculation to biota (EDEN).

IST: IST will contribute to setup sampling strategy and methods, to the chemical, physical and radiological characterization of NORM samples resulting from current and past Zn, Cu and U mining activities as well as historical phosphogypsum tailings. This part of the work will be supported by the use of a robotized sampling vehicle-Introbot Sampler, built by a Portuguese company in collaboration with IST. This equipment has already been tested in previous projects but it will be tested for the first time in phosphogypsum tailings and in the inter-tidal sediments area surrounding the phosphogypsum tailings to collect samples. Studies following up sampling will also be developed by IST such as: the distribution of the radionuclides concentration in host phases in phosphogypsum residues; the evaluation of phosphogypsum influence in the surrounding environment (soils, sediments, water, salt marsh plants, estuarine seaweeds and bivalves); the soil-plant radionuclide transfer in different phosphogypsum/soils ratios; and the identification of the vegetal species that can act as bioindicators for trace metals and radionuclides. The development of new methodologies and measurement devices for measurement of natural radionuclides (expected outcome of IST participation in other NORM related international projects) as well as new reference materials adapted in an appropriate manner to the real composition and geometry of measured samples, assuring the traceability to national standards will also be performed.

LRA-UAB: The Laboratory of Environmental Radioactivity (LRA) is interested in: (i) developing radiochemical techniques to measure radionuclides from different biological or geological matrices, as well as contributing to the design of sampling strategies (Task 1); (ii) quantification of radionuclides derived from NORM activities in different industrial, natural and biological environments (Task 1); (iii) understanding the transfer mechanisms of radionuclides from NORM production plants to the environment (Task 2); (iv) understanding the accumulation factors of radionuclides in biota (Task 2); and (v) evaluating the potential external and internal doses for human and animals (Task 4).

NCSR"D": In terms of radioecology/environmental radioactivity the current research and technological activities in NCSR"D"are focused on: (ii) development of a user-friendly, ready-to-use by stakeholders, commercial organism-kit for environmental quality assessment purposes based on the impact level, (ii) providing an innovative tool for the remote control of the radioactive releases in the marine environment from local and/or regional/global radiological events, (iii) pursuing improvement in modelling by introducing further biological parameters for more accurate estimations of doses to non-human organisms and model inter-comparison and validation. Considering NORM, NCSR"D" is interested in: radiological impact assessment and natural radionuclide transfer in NORM sites (areas of elevated natural radioactivity in the vicinity of geothermal mineral springs), effects on non-humans by the protracted exposure to elevated ionizing radiation (but non-intervention levels), dose rate estimations from natural radionuclides especially of ^{222}Rn through different pathways for various groups of exposed humans (e.g. spa installations) and as it is reported above, use of models for dose rate calculation and risk prediction. Besides, innovation is focused on the use of cytogenetic tools for field observations of the effects of protracted low levels of ionizing radiation and the synergistic action of various pollutants on natural population in NORM sites (areas of geothermal mineral springs).

NERC-CEH: NERC-CEH will only have a minor contribution to this WG. We will be developing alternative transfer (REML) models which will include some NORM radionuclides (including U). NERC-CEH will also provide a link to the TREE project in which other organisations are focusing on uranium biogeochemistry and also application of DGT (diffusive gradient in thin films; NERC-CEH co-supervised PhD) to predict plant uptake of a range of radionuclides (including NORM elements).

NMBU: NMBU will contribute to the identification and mathematical representation of key processes that play a role in the environmental transfers of radionuclides. Data necessary for the parameterisation of key processes controlling the transfer of radionuclides will be acquired. We will contribute to the development of transfer and exposure models that incorporate physical, chemical and biological interactions. By making the models more realistic and process-based, it is expected to more accurately assess radionuclide transfer between and within environmental compartments and as such assure more robust human and ecological impact assessments. To achieve this, time dependent K_d values for NORM contaminated soils from different origin will be determined and linked with soil characteristics. Also, soil-to-plant TF for NORM contaminated soils will be determined and linked with soil characteristics and radionuclide speciation. We also want to look into if the presence of co-contaminants changes the mobility and uptake of NORM by terrestrial plants.

SCK•CEN: SCK•CEN is interested in the identification, modelling and parameterisation of key processes controlling the mobility and transfer of natural radionuclides and radiological impact assessment of releases from NORM sites (Tasks 1, 2, 3 and 4). We will determine K_d and TF values for ^{232}Th, ^{210}Po and ^{210}Pb on fully characterised (i.e. particle size distribution, organic and mineral content, CEC, etc.) spiked soils and soils from NORM contaminated sites (Tasks 1 and 2). For the monitoring part of Task 1, SCK•CEN will take samples of a 20 year old pine forest present on a sludge heap from the phosphate industry in Tessenderlo, Belgium. The data generated will allow to identify what soil properties control radionuclide mobility and soil-to-plant transfer in the environment. We can contribute to Tasks 3 and 4 by applying hydrological and reactive transport models, mainly HP1 code which combines the water flow and solute transport simulator HYDRUS-1D and the geochemical modelling code PHREEQC to assess the performance of reactive transport modules developed in this WG and to provide activity concentrations in environmental media as inputs into radiological impact assessments. For the radiological impact assessment we will apply our biosphere code to calculate doses received by humans of different age groups arising from different exposure pathways.

STUK: STUK regulates and monitors mines and industrial facilities that produce, intend to produce or have radiological issues with NORM. The monitoring data from e.g. a nickel mine which has issues with soluble uranium (and also intends to produce uranium) is public and is therefore available for use for transport modelling or other studies related to transport of NORM in the environment. Also if any NORM-contaminated site in Finland becomes regulated by STUK, the monitoring data will be public and can be used for other studies, if external funding is secured.

EC Calls

Within this WG NORM there are important R&D activities in future, so that there is a basis for the development of a call for proposals under CONCERT.

- January 2016 and January 2017 first and second CONCERT open call, respectively
- Identification of upcoming calls within HORIZON 2020

Major elements of the communication plan

Continuing professional development

- PhD students (HZDR, IRSN, NMBU, SCK•CEN each with one PhD student)
- Shared supervision of PhD students?

Workshops

- September 2015: presentation of the ALLIANCE and especially WG NORM took place at the Nordic NORM workshop in Helsinki, Finland by Maarit Muikku (STUK)
- Presentation of NORM topics at the radiation protection week 2016 in Oxford, UK and at the ICRER conference 2017 in Berlin, Germany
- NORM session within the ALLIANCE workshop in 2017 (to be confirmed)
- Financial support and collaboration in organisational issues by the ALLIANCE is required in order to organize the above mentioned activities

Knowledge dissemination

- Publications of the participating institutes (peer-reviewed journals, contributions to national and international conferences)
- PhD theses
- Joint publication of WG NORM members after two years and at the end of the 5 years period
- Popular scientific presentations (lectures, posters), e.g., at travelling exhibitions of Kompetenzverbund Strahlenforschung, Dresden Long Night of the Science, Open Laboratory Days

Links with other activities identified at the national and the international levels (contributions of all partners in alphabetic order)

BfS: BfS is strongly involved in the radiation research platforms MELODI, ALLIANCE, NERIS, EURADOS and the medical field. It coordinates the project CONCERT and participates in the project COMET. At the national level, BfS cooperates with the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, for which BfS provides the scientific-technical basis of legal regulations.

CEA: TOXICOLOGY, the French *'CEA Transversal Programme of Toxicology'*

CIEMAT: CIEMAT has participated in many relevant international projects related with modelling, specifically in NORM (BIOMOVS-II; BIOMASS; BIOPROTA; FUTURAE; FASSET; ERICA; EMRAS-II; MODARIA; EAN-NORM; NORM4BUILDING, METRONORM...). The organization was partner of the European NoE STAR, and is one of the founding members of the ALLIANCE. Their experts are member of many international committees (as ICRP, ICRU, IRPA, UNSCEAR, EAN-NORM...). On a national scale CIEMAT collaborates with the regulatory authority in projects related with NORM (pilot projects for NORM industries, coal-fired power plants), ENRESA which is the national company for the management of radioactive waste (NORMIMA project, devoted to the reduction of NORM wastes) or the electrical companies (UNESA), among other.

CLOR: At the moment, there are no ongoing research projects concerning directly aspects of NORM. However, there is the possibility of carrying out tasks within the frame of future international cooperation programs.

GIG: RAMSES: „Monitoring of radium and thallium in the in the vicinity of Mining Sites" bilateral project with IRSN; GIG statutory activity; possible other projects with France and Germany in frame of bilateral cooperation programs

HZDR: TRANSAQUA (national project funded by the Federal Ministry of Education and Research); Research Programme of the Helmholtz Association: Nuclear Waste Management, Safety and Research

IRSN: RAMSES: "Monitoring of radium and thallium in the vicinity of Mining Sites" bilateral project with GIG. Within the framework of the RAMSES project, a PhD has been launched in September 2014 by IPGP, IRSN, CEA and BRGM. This project aims at developing DGT sensors for assessing radium and thallium activities in surface and pore waters along the aquatic continuum (aquifer, rivers and hyporheic zone) together with $^{226}Ra/^{228}Ra$ and $^{205}Tl/^{203}Tl$ isotopic ratios by HR-ICP-MS measurements. These developments will be used for assessing radium and thallium sources in the vicinity of mining sites (including the Polish Observatory sites) and to study the fate of radium through aquatic interfaces (e.g. water/sediment interface, ground and surface water).

IST: ENVIREE (Environmentally friendly and efficient methods for extraction of rare earths elements from secondary sources), ERAMIN international Project: 2015-2017.

- MetroNORM: Metrology for processing materials with high natural radioactivity. EMRP international Project: 2014-2016.

- ROBOSAMPLER- Development of a Terrestrial Robotic System as a Tool for Radiological and Heavy Metal Monitoring in Estuarine Environments funding by QREN/IAPMEI (PORLisboa): 2013-2014.

- COST Action: ES1407 - "European network for innovative recovery strategies of rare earth and other critical metals from electric and electronic waste (ReCreew)", 2015-2017.
- Radiological environmental monitoring programme under Art 35 EURATOM Treaty.

LRA-UAB: The task can be carried out within the frame of a collaboration project that UAB has with phosphate industry and the COST project NORM4Building.

NERC-CEH: UK TREE project has uranium as one of the priority radionuclides (http://www.ceh.ac.uk/tree)

NCSR"D": The task can be carried out in the frame of the program "Preparation and evaluation of environmental studies", a technological research program (NCSR"D" EE 10950) self-funded under contracts, in compliance with the Decision of the Greek Ministry of Tourism, No. 17414/02-10-2009, on the identification process of thermal natural resources (Official Gazette 2215/02-10-2009). Our participation in MODARIA activities can support the program activities. Besides, a candidacy for a MSc work is being carried out focused on dose rate modelling.

NMBU: There are at present ongoing several national and international projects at CERAD/NMBU addressing NORM both in field and in laboratory studies. The results from these studies will also be made available for the COMET NORM IRA. These projects are funded by Norwegian Research Council, Norwegian Foreign Affairs and also Norwegian Road Construction Authority.

SCK•CEN: The experiments on NORM mobility and availability will be performed within the frame of a PhD project (partially linked with COMET) and by own R&D. Leaching tests will be performed within the frame of the COST project NORM4Building, for FANC (Federal Agency of Nuclear Control) and by own R&D. Soil-vegetation-atmosphere transfer modelling will be performed within a PhD project. The study on gaseous NORM will be performed by own R&D and for NIRAS-Ondraf (national institute for radioactive waste).

STUK: There are no major research projects ongoing at the moment with NORM-related topics, but some information on occurrence and transfer of NORM is gained via environmental surveillance programme and the regulation and monitoring of mine sites. STUK has participated in IAEA-programs e.g. MODARIA, but at the moment the level of participation is rather low. STUK takes part in MetroNORM.

Expected problems, gaps/lack of knowledge, etc. that might prevent the accomplishment of the research

GIG: Lack of financial support.

IST: Lack of national/international financial support to develop the proposed work.

NCSR"D": Lack of financial support (end of contracts).

SCK•CEN: Lack of financial support.

STUK: Reduction of research budget and researchers, which has also lead to reduction in the level of achieved external funding for research.