1 Publishable summary

1.1 Summary description of project context and objectives

Radioecology is the science concerned with how radioactive substances released to or present in the environment are dispersed by various transfer processes and retained by different environmental components. The quantification of these processes allows determination of radiation exposures. From exposure, radioecologists estimate the absorbed dose, potential biological/ecological effects, and ultimately assess the risks to humans and the environment.

With the scientific challenges related to the nuclear fuel cycle, the need for radioecological expertise is increasing world-wide. Concurrently, education related to radioecology has declined, leading experts are approaching retirement, and funding for radioecological research is at a minimum in many European countries.

To face these challenges and avoid further fragmentation, nine leading organisations (further expanding to eleven organisations)*, dedicated to strengthening the science of radioecology in Europe, were funded under the EC's 7th Framework to establish a Network of Excellence (NoE) in radioecology. *The goal of the NoE, called STAR (Strategy for Allied Radioecology), is to efficiently integrate important organisations, infrastructures, and research efforts into a sustainable network that contributes to a European Research Area in radioecology.* To achieve this, a Joint Programme of Activities was implemented that concentrates on integration and sharing of infrastructures; training, education and mobility; knowledge management and dissemination; as well as collaborative research in three key areas: (1) integrating human and non-human radiological risk assessments; (2) radiation protection in a multi-contaminant context; and (3) ecologically relevant low-dose effects.

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1.2 A description of the work performed since the beginning of the project and the main results achieved so far

STAR made considerable progress in enhancing the long term stability and sustainability of radioecology in Europe. The main outcomes of the project include:

- the implementation of tools to promote data sharing and dissemination, with the creation of a dedicated website (www.radioecology-exchange.org);
- the integration of the radioecology community into an ever-evolving European landscape, including the production of a Strategic Research Agenda (SRA) dedicated to radioecology, tools that facilitate effective collaboration and integration (infrastructure catalogue, virtual laboratory and radioecological observatories) and the

establishment of process insuring the long-term stability and sustainability of radioecology in Europe

- the reinforcement and development of radioecology training programmes at the European level;
- the integration of methods for assessing radiological risk to human health and the environment, with the development of a new tool dedicated to integrated risk assessment (CROMERICA);
- an examination of the adequacy of current environmental radiation protection criteria in more complex and realistic exposure situations such as multi-pollutant contexts and chronic low doses of ionising radiation, along with proposal of endpoints relevant from an ecological point of view.

STAR increased the visibility and dissemination of radioecology worldwide by creating a reference website for radioecology: the Radioecology Exchange website (www.radioecology-exchange.org) (termed RadEx). It is now established as the gateway for accessing on-line radioecological resources. Europe now has a single website giving freely available and good quality information on environmental radioactivity radioecology. Through RadEx, STAR made their research protocols and data available to increase transparency and support future radioecology research in Europe. In addition, STAR created an active social media site for radioecology: with a frequently updated blog on RadEx and Twitter and Facebook accounts.

STAR produced the first Strategic Research Agenda (SRA) (last update D2.5, Feb. 2014). Endorsed by the ALLIANCE, it is a key living document providing a long-term vision (15-20 years) of radioecological research needs. It highlights three scientific challenges, with 15 associated research lines, as a strategic vision of what radioecology can achieve in the future via a world-wide prioritization of efforts. It also includes two sections dedicated to Education and Training and Infrastucture, both with an associated vision and key action lines. The SRA benefited from the comments of a large proportion of the radioecological community and of major international organisations (including UNSCEAR, ICRP, IAEA, IUR and NEA).

The Virtual Laboratory is a space within RadEx that provides openly available information to encourage integration through joint research and joint use of infrastructure. The Virtual Laboratory provides information on methods and procedures, facts and datasheets, radioecology models as well as lectures and videos. It has also begun to establish the integrated use of data and sample materials within the network and by the wider community.

To best utilise existing resources, STAR developed the infrastructure catalogue in RadEx, which is an inventory of equipment, methods, bioinformatic equipment and methods, sample archives, models, expertise and facilities that are available in each STAR partners for others to access.

One novel idea for integration was the creation of Observatories for Radioecological Research, which are contaminated field sites that provide a focus for long-term joint field investigations. Three contaminated sites were selected as the most promising options for Radioecological Observatories sites: areas near Chernobyl contamination exclusion zone, a previous coal mining and processing site in Poland and a forest in the Fukushima prefecture in Japan, contaminated by the accident at the Fukushima Dai-ichi NPP (under the EC COMET project). Despite some difficulties, the observatory sites have enhanced collaboration between the partners, and confidence in the potential value of observatory sites.

The STAR Mobility, Education and Training (E&T) program made a significant contribution to help address the identified shortage of academic programmes in radioecology and the

number of radioecologists in Europe. The STAR consortium held several courses ranging from MSc and PhD courses to workshops and professional development, including refresher courses given at international conferences. The majority of the courses were open to participants outside of the STAR project. An Education and Training Platform was established on RadEx as a website focal point for students and professionals interested in the educational aspects of radioecology. The platform presents an overview of education and training course modules on environmental radioactivity presently offered by the STAR consortium, information on course curriculums and learning outcomes, as well as links to other E&T platforms, such as those within Radiochemistry, Radiobiology and Radiation Protection. The STAR courses have attracted increasing number of students each year.

STAR promoted the sharing and mutualisation of personnel/infrastructure through the use of a mobility budget for (i) student or researcher exchanges between partners for joint research or courses and (ii) senior personnel travel to other partner institutions for teaching purposes.

STAR responded to the newly emerging system of environmental radiation protection, by developing a joint screening model for humans and biota: initially in CROM8 (released for public use in April 2015) and further in CROMERICA (α version presented in June 2015). These codes allow human and environmental risk assessment via different modules within the same tool. They are based on a revision of earlier versions of CROM for human risk assessment , and the most recent revision of the ERICA Tool for environmental risk assessment. Thus, CROMERICA implement revised models of the IAEA (i.e. replacement to SRS19) and advances in the parameters in the ERICA Tool. The final product will be a tool that can be further expanded by community developers, for including their own models and creating new user interfaces. This creates a flexible dose assessment platform that can be further expanded by new users for addressing their specific problems.

Fukushima research was introduced in the STAR project following an open call on this issue. Research on “fluxes and trophic transfer of radiocaesium in marine ecosystems off Fukushima” has brought new insight into marine radioecology, in particular the role of sediments as a sink and a secondary source of contamination of fish.

Regarding the adequacy of current environmental radiation protection criteria in multi-pollutant contexts, STAR demonstrated that the joint toxicity of mixture, including radionuclides or radiation, is predictable from single substance toxicity data, according to the additivity concepts established in the literature for stable contaminants (namely the CA-concentration addition or IA-independent action concepts). In all cases accounting for the combined effects of the mixture provided a better prediction of observed hazard than considering one of the single stressor in isolation. However, data demonstrated possible deviations from the CA/IA reference concepts, highlighting for interactions (either antagonist or synergetic ones). A mechanistic understanding of interactions at different process levels (interactions in the exposure media, interactions at uptake sites, toxicokinetic, or toxicodynamic interactions) is needed. STAR research highlighted the importance of obtaining information about speciation in exposure media and bioaccumulation when linking exposure to effects. Biotic Ligand Models for contaminant in mixture, including radionuclides, are helpful to explain mixture toxicity. Using consensual concepts like CA and IA for the developments of an Ecological Risk Assessment (ERA) framework for mixtures including radionuclides is consistent with the general ERA framework. However, Cumulative Risk Assessment concept which is based on additivity can be used properly only where there are no interactive effects between radionuclides and other stressors (especially if synergistic). When any interactions occur, quantifying its amplitude and identifying its origins is a

required-step to improve risk assessment. The development of alternative mechanistic models (*e.g.* PBTK and dynamic models) could help in this field.

For the robustness of ecological risk assessment of ionizing radiation, STAR brought new knowledge of greater relevance by enhancing the (i) range of addressed endpoints in each species; (ii) range of tested species to cover biodiversity; (iii) range of tested life stages; and (iv) by considering multigenerational exposure rather than that of a single generation. Concomitantly STAR evaluated toxic effects at various levels of biological organisation (molecular, cellular, histological, physiological, organism), bringing valuable information to understand the mechanisms of (chemical and radiological) toxicity and to test biomarkers relevance for both ecotoxicology and radioecology.

Finally, the integration of the European radioecology community is underway with the help of STAR partners to strengthen the long term stability and sustainability of radioecology in Europe. The ALLIANCE, officially formed as an association in September 2012, expanded from the initial eight founding members to 21 members from 14 countries. The sustainability of STAR outputs will be maintained by COMET and further by the ALLIANCE. The work to promote radioecology will continue under the CONCERT project.

1.3 The expected final results and their potential impact and use (including the socio-economic impact and the wider societal implications of the project so far)

STAR made considerable progress in enhancing the long-term stability and sustainability of radioecology in Europe. The collaborative work and joint research done in STAR strengthens radioecology and enables partners to achieve their mutual goals. The STAR partners managed to integrate further than was originally envisaged at the beginning of the project.

The creation of RadEx as a reference website for radioecology, clearly enhanced the visibility and improved the dissemination of radioecology worldwide. It is now presented with a simple structure so users do not have to click too many links etc., provides useful information and is frequently updated. Today, it often has 100 unique daily visits. We firmly believe this will increase further given the enhanced effort to improve the site prior to the dissemination event at the end of the project. One key impact of the site is that it provides authoritative information on issues which are of current interest, such as Fukushima, a highlight being the Fukushima Research page. The Information Exchange page also provides access to much underpinning information on a wide range of relevant topics. RadEx is getting requests to post advertisements, job opportunities and meetings/conferences in and of interest to radioecologists. Other European and International organizations are now following and participating, which further establishes Europe as an important partner in advancing radioecology. RadEx will continue to be enhanced during COMET. Furthermore, STAR (and COMET) partners and the ALLIANCE have discussed approaches to the sustainability of the web site with other EC platforms. The ALLIANCE has also formed a working group to consider the sustainability of RadEx after the COMET project finishes.

The STAR consortium reversed the decline in interest in radioecology through education, stakeholder participation and integration in support of the radioecological needs of industry, national authorities, and the public. The STAR E&T programme also retained a high international profile by interacting with other EU E&T networks (DoReMi, CINCH, EUTRAP, NERIS, etc) that will be essential for ensuring the integration of radioecology in

future EU projects, networks and is an important component within the CONCERT EJP. This is also fundamental for the future sustainability of radioecology E&T.

The integration of the radiation protection frameworks for humans and biota will serve as a useful, practical input to the larger radiation protection community in responding to the development of new recommendations for protection. Considerations within STAR on the possible integration of radiation protection frameworks have highlighted the possibilities and challenges to such an approach. In short, using the same dispersion and transfer models is justified whereas challenges remain for aspects such as protection endpoints, availability of transfer data, sophistication needed for dosimetry, spatial and temporal variability influencing transfer and exposure, and availability of relevant data on dose-effect relationships. The CROMERICA development will continue after STAR ends, with cooperation between several institutes and the IAEA, led by CIEMAT. STAR partners expect this to continue for CROMERICA, in particular because the ERICA Tool developers are now well integrated with the CROM developers as an outcome of STAR. Of course, the need for some future funding is clear, mainly for arranging users and developers courses or if specific developmental needs arise. However, the benefits are clear in that a risk assessment tool that combines human and biota calculations in the same code gives more coherence to risk assessment for a given scenario. Furthermore, for regulators, a combined tool would be more resource-efficient than to perform assessments for humans and biota separately with two different tools for the same site.

The Strategic Research Agenda (SRA) will continue to be valuable for both the radioecology research groups as well as stakeholders to formalize priorities for radiation protection research. The existence of the SRA will prevent fragmentation and non-optimal use of resources within radioecological research. It was originally planned that STAR would prepare the roadmap associated to this SRA. However this task is now being completed by the ALLIANCE with the help of the COMET project. At present, seven working groups (WGs) have been launched aiming to build a five-year roadmap. Currently, six topical WGs are dealing with: marine radioecology, NORMs sites, forest radioecology, human food chains modelling, inter- and intra-species radiation sensitivity and transgenerational effects. A 7th topical WG is under development (atmospheric radionuclides transfer processes). The SRA and the roadmap are essential documents needed for the inclusion of radioecological research within CONCERT.

During these last 18 month, STAR gradually merged the functions of STAR with that of the ALLIANCE by providing a clear transnational structure with accountabilities. A transition plan was developed that mapped the road to sustainability of radioecology research in Europe. The ALLIANCE agreed to provide a permanent management structure and implementation for long term international radioecological research that would go beyond the short term funding period of STAR. The step-wise phased integration programme was intended to permit the ALLIANCE to maximize integration of its radioecological infrastructures, research, training and education programmes. A dissemination plan was developed which ensures the sustainable application of network outputs within the ALLIANCE. The impacts of the STAR NoE were intended to include:

- facilitating the integration process of partner organisations and their research agendas
- reversing the trend of fragmentation of radioecology in Europe;

- enabling consultation and dissemination activities that broaden membership to the ALLIANCE, and aid in the development of a Strategic Research Agenda (SRA) in radioecology.

1.4 The address of the project public website

STAR has restructured the initial project website beginning in spring 2014. STAR and COMET were provided with 'project' websites (www.star-radioecology.org and www.comet-radioecology.org) containing: project descriptions, deliverable reports and a news blog. All other information, such as the 'virtual laboratory' and the 'training and education platform' (both developed by STAR and enhanced by COMET) are located on www.radioecology-exchange.org, which is now a 'hub' website for information related to radioecology.