Executive Summary

The scientific analysis which is developed in this document results from the need, after nearly one decade of development, to review in a broad context, beyond the radiation protection circles, the trends, views and methods currently exploited to set up a system of radiological protection of the environment. Indeed, the International Commission on Radiological Protection (ICRP) expressed its objective as to propose a system of radiological protection of the environment which would be compatible not only with the current system of protection for humans, but also more generally with other systems of environment protection such as those for protecting biodiversity or protecting against chemical stressors. The International Union of Radioecology (IUR), therefore, committed a broad team of experts to tackle the issue by setting up a dedicated Task Group gathering radioecologists together with experts from various areas such as risk assessment of chemicals, biodiversity, systems ecology and fisheries. The IUR "Ecosystem approach" Task Group membership therefore included : Clare Bradshaw (Department of Systems Ecology, Stockholm University, Sweden), François Bréchignac (Institute for Radioprotection and Nuclear Safety, IRSN, France), Simon Carroll (Center for Biological Diversity, Sweden), Soichi Fuma (National Institute of Radiological Sciences, Japan), Lars Håkanson (Uppsala University, Sweden), Alicja Jaworska (Norwegian Radiation Protection Authority, NRPA, Norway), Larry Kapustka (SLR Consulting, Canada), Isao Kawaguchi (National Institute of Radiological Sciences, Japan), Luigi Monte (National Agency for New technologies, Energy and the Environment, ENEA, Italy), Deborah Oughton (Norwegian University of Life Sciences, Ås, Norway), Tatiana Sazykina (Typhoon, Obninsk, Russia) and Per Strand (Norwegian Radiation Protection Authority, NRPA, Norway).

Starting from the acknowledgement that there is a number of definitions for "environment protection" depending on the context where protection is to be applied, or from where it is evolving, an attempt is first made to identify a possible common overarching objective of protection that would be general enough to encapsulate all specific goals expressed in various particular contexts. This is achieved through analysing why environment protection became a concern and how its various objectives have evolved from various perceptions including ethical, philosophical, moral, socio-economic and legal considerations. This is also pursued by briefly reviewing the issue of environment protection in the particular context of radiation, mentioning recent undertakings and achievements from the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the International Union of Radioecology (IUR), the International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection (ICRP). It is concluded that the ecosystem concept, the structural and functional entity defined in ecology[1], best captures all the perceptions, and that the field of environment protection against radiation would gain from considering further an ecosystem approach to better fulfil the general goals of protection.

In the context of environmental impact assessment, the ecosystem approach is conceived as a holistic strategy which integrates toxicological knowledge with ecological understanding. One of its major justifications stems from the mismatch between current methodologies which are largely based upon toxicological data gathered for individual organisms and recognition that the most widely accepted goal of protection generally sits at the population and ecosystem levels of organisation. Toxicological knowledge in organisms is indeed needed, but this is not enough to adequately meet the protection goal as ecosystem responses to stress will also be governed by interactions between populations of such organisms. How ionising radiation impacts ecosystems has been widely reported from a number of empirical studies conducted in contaminated areas. Also, ecological theories featuring ecosystems as complex systems demonstrate the importance of taking such interactions in consideration especially in view of assessing ecosystem stability and resilience. Another justification to considering an ecosystem approach for radiation protection comes from the observation that the concept is already applied in other fields of environment protection, such as those dealing with protection of biodiversity, under the noticeable pressure of environmental managers and users.

[1] Ecology defines an ecosystem as an assembly consisting of an association or community of living beings (biocenose) and its abiotic i.e. geological, edaphic, hydrological, climatic, etc… environment (biotope), (see section 1.6). The constituting elements of an ecosystem develop a network of energy and matter exchanges allowing the development and sustainability of life. This terminology was initiated by A.G. Tansley (1935) to identify the basic unit of nature.

In radiation protection, ongoing developments are based upon a concept of reference organisms[2], or reference fauna and flora, for which a dosimetric approach to individual organisms together with associated radio-toxicological data allow to rate the potential risk of harm through some organism-level effect endpoints. Primarily driven by operational goals for practical application, this approach necessarily features some inherent reductionism. The pros and contras of this approach are discussed especially in the light of the approach which is currently used to assess toxicity of chemicals. In order to promote an ability for suitable comparisons, the current method in use for assessment of toxicity of chemicals is first widely reviewed and discussed. Secondly, the approach developed for the protection of biodiversity is also presented in details as it is the most advanced international concerted effort having particularly advanced the concept of an "ecosystem approach", with underlying principles, objectives and practical tools to support it. Finally, a third example is provided with the protection of fish stocks in use to support adequate management in fisheries, where more and more efforts are devoted to include modelling of ecological complexity. Given this wide context depicted above, research priorities that would help to move on beyond the reference organism concept are discussed, especially in terms of addressing the various extrapolations required and the important need to also address (eco)systems level effects. One key conclusion from the discussion leads to acknowledging that the reference organism and ecosystem approaches are complementary and part of a continuum. The concept of reference fauna and flora has been devised for the purpose of radiological protection and does not improve our understanding of the ecosystem, but considering ecosystem processes and interactions can improve the reference fauna and flora approach to radiological protection.

An extensive review of legislation about environment protection as a whole, undertaken with particular emphasis on the ecosystem approach, illustrates the wide current spread of the concept, and how it is being applied in various fields (marine environment, fisheries, OSPAR, European Union Marine Strategy Framework Directive, RAMSAR Convention on Coastal Wetlands, Convention on Biological Diversity, European Union Habitat Directive, Canadian Environment Protection Act, Forest Management). Several methods to implement ecosystem approaches are already existing, or emerging, even in the field of radiation, and their use demonstrates that this field of development is both active and promising.

The general overview and analysis made above on how does the current "reference organism" based approach developed for radiation protection fits within the overall context of environment protection drives to support the additional development of an ecosystem approach to improve future radiation protection. In view of promoting such an improvement, and of contributing to the development of relevant international strategic research agendas, this overall discussion drives to identifying Research & Development needs to support the ecosystem approach. Featuring ecosystem-level issues, enhancement of organism-level studies that could be used more effectively in modelling ecological systems interactions and, cross-cutting field studies of radiation contaminated areas from, for example, accident areas or mine sites, the research priorities fall in three categories:

- Areas of emphasis for the systems-level research include detailing interactive responses to radiation exposure, propagation of effects, delayed effects, and resistance/resilience of ecosystems. Each of these could be designed to examine effects at a) population-, guild-, or community-levels, or b) systems functions such as primary productivity, decomposition, energy transfer, or nutrient flow.

- Additional research at the organism-level should be expanded to include representatives of trophic groups not currently included or understudied (e.g., decomposers). There should also be efforts to expand representation of taxa from multiple geographic regions to supplement the current dominance of data from northern temperate systems. Topical research that would be useful would be to develop better understanding of radiation effects that result in adaptation, acclimation, hormesis, and epigenetic effects.

- Field studies are needed to calibrate laboratory studies from both the systems- and organism-levels. In addition to the opportunities at Chernobyl and Fukushima (decidedly different in terms of

[2] ICRP (2008) defines a "reference organism" as "a hypothetical entity, with the assumed basic biological characteristics of a particular type of animal or plant, as described to the generality of the taxonomic level of family, with defined anatomical, physiological, and life-history properties, that can be used for the purposes of relating exposure to dose, and dose to effects, for that type of living organism."

ecological systems), studies should be undertaken in radionuclide mining areas. In each of these potential study areas, the investigative designs should preferably be based on gradient analyses approaches and not some attempt to compare to "reference sites[3]."

In concluding, recommendations with respect to radiation protection are finally drawn. Recognizing that the ecosystem concept has been adopted in an increasing number of other situations, it is believed appropriate for radiation protection to move in the direction of an ecosystem-based approach in order to improve the relevance of information coming to decision-makers. To that end, the following points should be considered:

- Promote the dialogue between environmental assessors and environmental managers (facilities operators, contaminated site managers, and other regulators) to increase the chances of improving the value of information flow (two-way dialogue).

- More integrated and functional endpoints to expand beyond the organism-level. This could also include consideration of additional indices that embed the existing and new endpoints (decomposition, primary productivity, etc.).

- Reference organism approach–improve to incorporate ecological functionalities, other ecological criteria, and reference species versus reference organisms, all aimed to facilitate an ecosystem approach. Better consideration of taxonomy such as insects, bacteria, fungi to cover ecological functionality and to make it more accessible to people within different geographical areas, biomes[4].

[3] The "reference site" terminology is often confusing as regional data sets are nothing else than a collection of sites in the landscape that share some similarity allowing comparisons. Both, clean and dirty reference sites can lead to good effect in site specific causal assessment (Gerritsen et al., 2010).

[4] An additional concept of "representative organisms" is currently being worked out by ICRP, contributing to address this point.