

Current challenges to the radiological protection of the environment: arguments for an ecosystem approach

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INTRODUCTION

Today, the approach towards radiological protection of the environment most considered by various national and international bodies, including ICRP, is favouring a focus on the concept of “reference organisms” (IUR, 2002; ICRP, 2007; Larsson, 2004). Evolving from traditional toxicology, this bottom-up approach is emphasizing individual organisms for several immediate considerations: 1) the requirement from environmental risk assessors to be pragmatic, therefore aiming at a straightforward practical approach for rapid and easy use, 2) ensuring consistency with the existing system for human radiological protection (also focused on the individual), and 3) the recognition that most scientific data available to date on radiation dose-effect relationships concern individual animal and plant organisms (UNSCEAR, 1996; Real *et al.*, 2004). This has the merit of optimising the exploitation of the largest basic knowledge existing on the biological effects of radiation on life and ensuring consistency of protection approaches between man and other plant and animal species.

However, the reductionism of this approach deserves critical attention because information on individuals only partially covers potential environmental effects, especially system level effects. Such shortcomings have already been recognized and discussed (Tannenbaum, 2004) in other fields of environmental protection, and have also been stressed in radiological protection (Bréchignac, 2003; Hinton *et al.*, 2005; Fuma *et al.*, 2003; Doi *et al.*, 2005).

THE REFERENCE ORGANISM CONCEPT

Current rationale

There is a high complexity in the environment: a range of abiotic components (soils, waters, gaseous atmospheres), a vast biodiversity of species interconnected within hierarchical space and temporal structures which support ecosystem functioning, a broad diversity of potential pathways and conditions of exposure to radioactivity (acute/chronic exposure, high/low doses). Today, this complexity is putting quite a challenge on the conception of practical tools of ecological risk assessment that would ensure high level trust in subsequent measures taken for the protection of ecosystems. Simplification therefore has been one main driver to the bottom-up current conceptual approach that has been grounded on the Reference organism concept. This concept takes a limited set of reference individual organisms, chosen along various scientific and practical criteria, and meant to serve as points of comparison in ecological risk assessments.

Consequently, research is oriented today towards gathering relevant data on dose-effect relationships in such reference animals and plants, at individual level, through four umbrella endpoints recognised as most pertinent: mortality, morbidity, reproductive success and

mutation. In addition, environmental exposure pathways and transfers are related to the dose received by these individual organisms based on the development of simple dosimetric calculation models.

Advantages of the reference organism concept

Reference organisms are generically defined based on a limited set of widely spread living entities. The reference organism approach therefore allows to derive a scale of risk that is also generic in nature, offering a good basis for comparison purposes within an assessment. This aspect has been especially exploited by ICRP in its proposal for constructing an assessment scale of risk along “bands of consideration levels” (ICRP, 2007).

Being designed with similitude to the principles of human radiological protection, the reference organism approach ensures an overall coherence that allows integration within one single system of the protection of humans and non-human biota. Both are thus rooted in a common focus on individuals, and on the use of references (reference man and reference animals and plants). This is an attractive feature because it fulfils a high level policy goal that aims at protecting at the same time man and the environment.

Traditional Ecological Risk Assessment for chemicals is also using some references which have been developed as standardised ecotoxicological test organisms for which extensive toxicological data have been explored and documented (microalgae, daphnia, barley root, worms, zebra fish...). This is still a widely used approach, especially for regulatory purposes, although its reductionism tends now to be more and more acknowledged, pushing for the development of additional approaches that would be both better integrated and more realistic.

Conceptual limitations arising from the need for simplification

As acknowledged by ICRP in drafting its last report on the use of reference animals and plants (ICRP, 2007), the approach “...cannot provide a general assessment of the effects of radiation on the environment as a whole, but ... could provide a useful basis for judgments about the probability and severity of the likely effects of radiation ...”. Hence, it is of interest to examine in more details what are the consequences of the simplifications in terms of limiting the ability of the assessment methodology to demonstrate that the environment is being protected. The main limitations can be summarized as follows:

The Reference organism approach is: 1) restricted to the biotic part of the environment that carries on radiosensitivity, therefore largely ignoring the abiotic part of the environment, both components deserving ideally equal attention, 2) designed on a quite limited corpus of knowledge on chronic radiation effects in biota, essentially at individual level, missing therefore the higher levels of biological organisations that are widely thought to be more environmentally relevant (population, community and ecosystem), 3) designed around a limited set (12-30) of Reference organisms to cope with a complexity level difficult to grasp and the necessity to design an easily accessible assessment methodology, 4) focused, as arising from primary consideration of individuals, on mortality, morbidity, reproduction and mutation, all being individual level endpoints considered as most relevant with respect to population fitness, although system level endpoints as measures of ecosystem structure preservation (biodiversity,...) and function fitness (life support,...) are more and more advocated, 5) considers dose rather than concentration as a key quantity to assess risk, in contrast to traditional existing methods in use for chemical toxicants.

ECOLOGICAL CRITICALITIES OF THE REFERENCE ORGANISM APPROACH

Abiotic components not explicitly considered

Concentration/activity of toxicants in abiotic compartments has most often been used as a metrics for assessing environmental risk, especially within regulatory contexts. Although arising from radioecology, a discipline that has for a long time promoted better description and understanding of environmental radioactivity within the various abiotic compartments, environment radiological protection is currently evolving with an almost exclusive focus on living matter. This is indeed the radiosensitive part of ecosystems, and radionuclides activities in abiotic compartments are used to support dose calculation to biota within a source-to-sink unidirectional understanding. However, ecosystems feature a bidirectional relationship that link abiotic and biotic components together, and one must realize that biota may also change the concentration/dispersion of radionuclides in abiotic compartments based on ecologically relevant processes (biomagnification, migration, accumulation of waste,...).

Uncertainties driven by an extrapolation-based philosophy

For the assessment methodology, simplification is leading to the requirement to introduce a range of extrapolations, the robustness of which needing therefore to be proven and justified. Extrapolations currently considered include : 1) from acute and high doses to chronic exposures and effects at low doses, 2) from external to internal irradiation, 3) from single radionuclides to multiple contaminants, 4) from one species to another, 5) from individual to population, community and ecosystem (Garnier-Laplace *et al.*, 2004). All such extrapolations carry on their respective uncertainties that ultimately all sum up and therefore drive to reducing the level of trust in assessment conclusions.

Indirect and ecosystem level effects not captured

A weak point requiring further attention comes from the recognition that if the endpoint for human radioprotection is very clear – reducing stochastic effects of radiation in individuals (cancer induction) – this is not as simple for the environment. Here, there is a range of protection goals, from individuals (of endangered species, for example) up to full ecosystems, habitats and landscapes, that would deserve to be endorsed in parallel with a range of potential endpoints. It is questionable if assessment endpoints developed for individuals will appropriately do the job for protecting habitats and ecosystems. In particular, the potential for radiation to induce indirect effects through interaction with community and ecosystem-level processes, such as trophic and competitive relationships, will not be addressed (Bréchignac, 2003; Fuma *et al.*, 2003; Doi *et al.*, 2005) although this is a very common feature driving inter-population dynamic stability and the very concept of ecosystem health.

Furthermore, a key concern remains that there may still be ecosystem effects from long term exposures, since the complexity and non-linearity of the ecosystem can lead to unexpected consequences from apparently innocuous activities (Bréchignac, 2003).

THE NEED TO ALSO ADDRESS AN ECOSYSTEM APPROACH

Tackling the shortcomings mentioned above for the reference organism approach strongly suggests the need to develop in parallel an ecosystem approach in order to strengthen the overall credibility of the system of protection. Forming perhaps the most fundamental environmental unit, the ecosystem concept reconciles many views over the environment, biotic and abiotic components, human and non-human related components interlinked through the provision of life support and services. Such an approach has already been called for by

risk assessment users and environmental managers, and it arises now within a growing number of international legislations. One can mention the Convention on Biological Diversity, and also the European Water Framework Directive which includes targets reflecting the ecological integrity of water bodies and emphasizes their ecological status defined as the quality of the structure and functioning of ecosystems (Apitz *et al.*, 2006).

Today, many authors stress that traditional ecotoxicological methods are inadequate to found decisions aimed at planetary sustainable development, maintaining ecosystems services and life support, and their health (Cairns *et al.*, 1996). They pursue efforts to design measurable ecological indexes (biotic, biodiversity, trophic, energy/element cycling) to support top-down environmental risk assessments. In the world of environmental protection, the protection system against radiation is no exception and its future credibility depends on its ability to address ecosystem-level as well as organism-level potential radiation-induced hazards.

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