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Commentary

When a duck is not a duck; a new interdisciplinary synthesis for environmental radiation protection

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ABSTRACT

This consensus paper presents the results of a workshop held in Essen, Germany in September 2017, called to examine critically the current approach to radiological environmental protection. The meeting brought together participants from the field of low dose radiobiology and those working in radioecology. Both groups have a common aim of identifying radiation exposures and protecting populations and individuals from harmful effects of ionising radiation exposure, but rarely work closely together. A key question in radiobiology is to understand mechanisms triggered by low doses or dose rates, leading to adverse outcomes of individuals while in radioecology a key objective is to recognise when harm is occurring at the level of the ecosystem. The discussion provided a total of six strategic recommendations which would help to address these questions.

1. Introduction

Radiobiology as a sub-division of Radioecology is often neglected. However moves over the last few years to protect the natural environment from harmful effects of ionising radiation, rather than assuming protecting humans also protects other species, has led to a need for radioecologists and radiobiologists to establish a closer and more meaningful dialog. Cross-fertilization in science resulting from bringing the fields together has often proven to be very effective in promoting new theories and innovation (Jones, 2009; Van Noorden, 2015).

Radiobiology has essentially been developed in the context of understanding how radiation affects living tissues, and is aimed at helping to protect humans from deleterious effects of radiation such as cancer. It has therefore been focussed on biological materials derived from humans or from a few species considered as human surrogates.

Radioecology in turn, has been dominated in the decades since the accident at Chernobyl (Smith and Beresford, 2005) by a consideration of the environment as a simple mediator of transfer of radiation towards

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Abbreviations: IAEA, International Atomic Energy Authority; ICRP, International Commission on Radiological Protection; RAP, reference animals and plants; CAP, contextualised animals and plants; NTE, non-targeted effects; OECD NEA CRPPH, Organisation on Economic Cooperation and Development Nuclear Energy Agency Committee on Radiological Protection and Public Health; PCR, polymerase chain reaction; CpG, cytosine- guanine dinucleotides

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man, therefore largely ignoring radiation effects on animals and plants and their related ecosystems, and the potential of these environmental perturbations to impact on humans indirectly (Caffrey et al., 2014; Salbu, 2009).

Responsibility for protection of the environment from anthropogenic ionising radiation has been a universally accepted principle since radiation safety was first put on an international and institutional footing. From both an anthropocentric point of view and from an ethical point of view, the imperative to protect the environment has been accepted and formalised in, for example recently, IAEA GSR Part 3 published in 2014 (European_Commission_and_others, 2014). In this set of recommendations, protection of the environment is broadly defined as follows:

"include(s) the protection and conservation of: non-human species, both animal and plant, and their biodiversity; environmental goods and services, such as the production of food and feed; resources used in agriculture, forestry, fisheries and tourism; amenities used in spiritual, cultural and recreational activities; media, such as soil, water and air; and natural processes, such as carbon, nitrogen and water cycles."

This definition provides a more complex articulation of environmental protection than just the sustainability and complexity of ecosystems, in that it also takes an anthropocentric view of the utility of the natural environment to humans. Thus it supports the main thrust of radiation protection legislation for which the primary purpose is protection of humans. The question addressed in the workshop was whether the current approach to environmental protection is sufficient to meet these aspirations, and whether in the light of more recent developments in our understanding of the action of low-dose ionizing radiation on the biosphere the approach currently adopted, that of using key indicator or "reference" species (RAPs) (ICRP, 2008) as surrogates for the effect of radiation on humans in the contaminated environment, is any longer adequate, especially in the case of chronic low dose exposure. The currently used RAPs are deer, rat, duck, frog, bee, earthworm, crab, trout, flat fish, pine tree, grass, seaweed. There is concern not only that the list is limited to 12 undefined organism types but about the fact that no number of organisms can represent the complexity and diversity of the ecosystem.

The recent move towards consideration of effects on wildlife presents new opportunities in radiobiology, since it has been known for many years that biodiversity presents a large spectrum of radiosensitivities within and between a wide range of species (Bowen, 1961) including humans (Bouffler, 2016). Unravelling the mechanistic reasons for these varied radiosensitivities has been quite poorly addressed so far. However, understanding these mechanisms should provide new insights that may prove to be very useful in better understanding human radiobiology, and may aid the development of a more holistic understanding of the impact of radiation on the ecosphere.

The workshop on which this paper reports represented an interdisciplinary attempt to address some of the key issues relevant to both fields, and to assess what changes in approach might be desirable to better realise the aspirations already articulated through international regulatory and advisory bodies; specifically the International Atomic Energy Authority (IAEA) and the International Commission on Radiological Protection (ICRP).

1.1. Key questions

In order to structure the discussion a key question was identified in each discipline and subdivided yielding topics for discussion. The key question in radioecology was identified as "how do we protect biodiverse ecosystems to the benefit of humans and other living organisms"? While in radiobiology the key question was "what are the risks to human and non-human animal health associated with low/chronic dose exposures"? From these overarching questions, the topics for discussion were as follows:

1. Development of big data approaches to gathering and analysing large scale complex ecosystem data: informatics, citizen scientists and ecological observatories
2. Segmentation of the ecosystem to provide niche and landscape data to facilitate integrated analysis
3. The impact of new knowledge concerning multiple stressors and synergistic interactions between radiation, other noxious agents and natural environmental challenges, such as climate change.
4. The impact of historic dose in the light of our new understanding of non- targeted effects (NTE)
5. The opportunity to exploit and validate new biomarkers coming from radiation biology, while recognising that population and ecosystem level biomarkers for fitness are required.
6. Impact of radiation induced epigenetic changes on individual organism and population fitness, adaptation and population genetic structure.

2. The discussions on these topics are summarised in the following sections

2.1. Development of big data approaches to gathering and analysing large-scale complex ecosystem data: informatics, citizen scientists and ecological observatories

A prominent challenge to gathering data from exposed ecosystems is the level at which data needs to be collected and consequently the scale and depth of that collection. While a known deficiency of human radiological protection studies is the inability to introduce existing knowledge about individual sensitivity into exposure limits and damage assessment, we know hardly anything about the radiation sensitivity of most species of animals and plants or its individual variation. Moreover the health issues of concern in human radiation protection, which are used to set endpoints for damage assessment such as cancer or cardiovascular disease are rarely concerns in non-human species. A third challenge is that human radiation protection objectives are set at individual organism level of one single species, leading to a fit-for-purpose methodology of risk assessment. Since environmental protection objectives are set at population and ecosystem levels, associated methods of risk assessment that would address these levels are required (Bradshaw et al., 2014; Brechignac and Doi, 2009; Brechignac et al., 2016). This means that human radiation protection approaches should not be repurposed to deal with environment protection.

The initial approach recommended by the ICRP includes the use of a small set of reference animals and plants (RAPs) which we discuss later. However these are difficult to justify given the range of biodiversity and the complexity of ecosystems. In fact, this approach is broadly speaking a simple extension from human radiation protection methods, involving the "reference man" concept (ICRP, 2008). As such, it does not take due account of the fact, stated above, that the object of protection is different, i.e. populations of interacting species and their ecosystems. It is therefore difficult to demonstrate that this meets the objectives asserted for protection of the environment (Bradshaw et al., 2014; Brechignac et al., 2016). While integration of human and other species in one same system of radiation protection may seem a laudable goal, it is currently more methodology-driven than conceptually-driven and does not capture the relative positions of human and other species within the ecosystem and how these interact with each other (Brechignac, 2017).

Ten years ago, an Expert Group created by the NEA CRPPH (Committee on Radiation Protection and Public Health) acknowledged that efforts were generally fragmented and involved a range of disciplines (radiation biology, radioecology, environmental toxicology, ecotoxicology and ecology). They also accepted that environmental data collected over the last half century by the nuclear industry for surveillance purposes had not been utilised in an efficient, coordinated, manner and recommended the development of an international network or "Observatory" (NEA/OECD 2007). This international network