Challenges in Radiation Protection for the Environment and non-human Biota

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Abstract- ICRP publication 108 introduced the concept of Reference Animals and Plants (RAPs) for environmental radiation protection. This was in analogy to the use of a Reference Person in radiation protection for human individuals and makes use of endpoints such as mortality and reproductive success of these reference organisms to evaluate the potential negative effects of radiation on an ecosystem. However, it is widely recognized that an ecosystem cannot be completely described as a simple collection of organisms, and complex properties emerge from the interaction of its individuals. Therefore, the individual organism approach based on the human model might not be enough for radiation protection of ecosystems. A more holistic approach might be warranted, with more appropriate endpoints such as diversity and changes in ecosystem balance.

Bacteria and other unicellular organisms were not included among the reference organisms due to their high resistance to radiation. However recent studies have shown that low radiation doses can have a wide range of effects on bacteria, from inducing stress to enhancing growth and changing composition of bacterial communities, and potentially inducing resistance to antibiotics. This suggests that smaller organisms should not be ignored when considering environmental radiation protection, and on the contrary, could even serve as a tool to monitor ecosystem health and response to radiation.

Moreover, the 12 Reference Animals and Plants chosen came mainly from temperate climates in northern regions and might not be representative for other types of ecosystems. Information on more reference organisms might be necessary for other types of ecosystems but not readily available for quick reference. The environmental radiation protection community could benefit from a collaborative database with curated information on different organisms, as is already done in several fields in biology and life sciences. A document could then be developed with guidance on how to decide local dose criteria based on key radiobiological data of representative organisms in a local ecosystem. An open database that aggregates relevant data would additionally facilitate application of machine learning techniques to the highly complex problem of evaluating the potential impact of radiation in an ecosystem.

Keywords: environmental radiation protection, non-human biota, bacteria.

1. Introduction

ICRP publication 108 introduced the concept of Reference Animals and Plants (RAPs) for environmental radiation protection [1]. A set of twelve different RAPs were chosen as reference organisms, each representing a family of species. These were chosen to represent organisms with a wide array of characteristics, and named after one of the most known members of each represented family, namely: deer, rat, duck, frog, trout, flatfish, bee, crab, earthworm, pine tree, wild grass and brown seaweed. The main biological endpoints used to evaluate negative effects of ionizing radiation in this model were mortality, morbidity and reduced reproductive success.

The idea to use reference organisms to simplify the task of evaluating the potential negative effects of ionizing radiation in the environment comes from the approach used in human radiation protection, where previously a *Reference Man* and currently, *a Reference Person*, is used as a tool to set dose limits, constraints and reference levels. This approach is much more complicated to apply for environmental protection due to the immense diversity of the organisms present in different ecosystems. Additionally, an ecosystem consists not only of the organisms that live within it, but also of the physical and chemical characteristic of their environment and the interactions between them. Therefore, many authors have questioned whether this individual organism approach is enough for environmental radiation, and propose a more holistic *ecosystem approach* [2-4]. More appropriate endpoints have been suggested, such as species diversity, ecosystem network metrics such as connectedness and link density, nutrient cycling, among many others [4].

2. Radiation Effects on Bacteria

In the context of environmental radiation protection, potential effects on bacteria have not been of particular concern partly due to their high resistance to radiation. The dose needed to kill 80% of a population of common bacteria (*Escherichia coli*) is around 800 Gy, though it goes from 40 Gy for radiosensitive bacteria (*Shewanella oneidensis*) to 8000 Gy for the radioresistant *Deinococcus radiodurans* [5]. These doses are much higher than the dose levels of around 10 Gy that are considered lethal for mammals and birds [1].

Nevertheless, several studies show that low radiation doses can have a wide range of effects on bacteria, and suggest that they should not be ignored in discussions of environmental radiation protection. Bacteria are already used to test and monitor toxicity of several pollutants, and could serve as a tool to monitor ecosystem response to radiation [6, 7].

Stress induced by low doses

Even though they doses required to kill them are quite high, doses as low as a few mSv were shown to induce stress and increased mutation frequency in Escherichia coli and Salmonella typhimurium, in experiments with maximum dose rates of 67.8 uGy/hour and maximum absorbed doses of 4.88 mSv over a few days [6]. In another study with *E. Coli* and *Pseudomonas aeruginosa*, reduced growth rate and number of viable cells was observed after irradiation to doses of 7.2 mGy over 30 mins [7]. *P. aeruginosa* was found to be particularly sensitive to radiation, and therefore suggested to be potentially useful for developing monitoring tools on radiation toxicity.

Even a lack of ionizing radiation can induce stress in bacteria, as shown in a study that measured growth and expression of stress-related genes in bacteria cultured in an environment with dose rates up to 79 times lower than background radiation [8].

Effects on Bacterial communities

Recent studies have looked at how relatively low doses of ionizing radiation could impact bacterial communities. A study looking at the effect of a total dose of 5 Gy in a rice paddy ecosystem found changes in the composition of the bacterial community and ion concentrations in water from the sample [9]. Samples were irradiated with Cesium-137 at a rate of 1 Gy/day, which is a realistic dose rate for an accident scenario. Loss of sulphate reduction bacteria has also been observed in communities exposed to uranium in mines [10]. The results suggest chronic gamma radiation can destroy the balance in bacterial community composition and nutrient cycles. The potential interaction between ionizing radiation and other toxic agents should also be considered [11].

No phylum and class percentage changes were observed in a study looking at bacterial communities in cesium-137 contaminated soil from the Fukushima accident, with contamination levels ranging from 10 to 563,000 Bq/kg dry soil [12]. However, a higher abundance of some species of radio-resistant and non-radio-resistant bacteria were found in contaminated soil.

Effects on Antibiotic Resistance

Bacteria exposed to non-lethal levels of radiation could develop resistance to antibiotics through adaptive response, in which an organism is better able to resist damage after being exposed to other stressors. Studies have shown that bacteria can become either more resistant or more susceptible to antibiotics after being exposed to different environmental stressors [13].

Bacteria from the Ramsar region, a region in Iran with a background radiation of around 10 mSv per year, have been suggested to be more resistant to antibiotics through this adaptive response mechanism [14]. On the other hand, an increase in bacterial susceptibility was observed after irradiation to doses 0.5-2 Gy in a study with antibiotic resistant bacteria isolated from human skin [15]. Gamma radiation contamination due to the Fukushima accident was studied for this effect and it was concluded that it will not lead to antibiotic-resistance in Gram-positive bacteria, and may lead to a decrease in antibiotic-resistance in Gram-negative bacteria in 100 years (dose levels ~ 15 mGy to 1.5 Gy) [16].

3. Radiobiology databases

The 12 Reference Animals and Plants from ICRP publication 108 came mainly from temperate climates in northern regions and might not be representative for other types of ecosystems. Information on the radiobiology of different organisms might be needed in order to properly evaluate the potential impact of radiation in an ecosystem. Different databases exist that contain radiobiology data [17], such as the European Radiobiological Archives [18] and the FREDERICA radiation effects database [19]. The information in the FREDERICA database, in particular, can be used through the ERICA (Environmental Risk from Ionising Contaminants) Assessment tool to estimate radiological risk to selected animal and plants.

Although the information contained on these databases is highly valuable, the importance of open, easily accessible and up-to-date data is also very clear [20]. A more coordinated effort to make this data readily available and reusable following FAIR principles [21] would make it easier for machine learning applications to be developed on this data.

Current databases aggregate data at the experiment or article level. A database could be curated to combine information from different sources at the organism-level, which would provide a quick-reference resource to assess radiological risk to different species (and other taxonomic levels) based on currently available information. A document could then be developed with guidance on how to decide local dose criteria based on key radiobiological data of representative organisms in a local ecosystem, instead of relying on reference organisms that might not be representative in certain regions.

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