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Is Radioecology mature enough to cope with long term environmental consequences of nuclear accidents?

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Twenty five years ago, the Chernobyl accident considerably boosted R&D in radioecology. Facing the urgency, radioecologists were solicited primarily to assess the risks to humans from living in contaminated territories where agricultural products were grown to feed the population, but also to work out countermeasure strategies and techniques capable of mitigating such risks. Especially in Europe most impacted, important budgets have been committed for about 15 years by the European Commission to stimulate R&D and the advancement of scientific knowledge. However, during the decade which followed, this substantial financial support vanished out together with the post-Chernobyl political movement of several western countries to withdraw from nuclear energy production, except in a few countries. Some detractors of radioecology gained stronger voice arguing that the scientific knowledge accumulated so far was good enough to adequately deal with any radio-contamination of the environment, and that public money would be more appropriately spent elsewhere. As a consequence, a number of radioecology laboratories did not survive, and several unique research facilities and large scale programs were cancelled out within less than a decade. During the more recent years finally, until the accident at Fukushima Daiichi promoted by a tsunami's intensity beyond any prior expectation, a worldwide ambiance of nuclear renaissance prevailed, as a meaningful response to solving the growing needs for energy and the concomitant rarefaction of petroleum stocks, the burning of which being recognized to yield deleterious climatic impact.

Within this context, irrespective of the national or regional positions and initiatives, and keeping in mind that any major environmental contamination would not be kept within any such kind of national or regional borders, IUR concentrated its efforts on strengthening its worldwide network of scientists such as to maintain high level expertise in all country members (currently 56 countries). Meanwhile, the Union also prompted a scientific evolution of radioecology, moving from an exclusive focus on protection of the human species (anthropocentric view) towards a more holistic scope (Bréchignac et al.[1], 2003) targeting the structure and functions of ecosystems where all life forms are concerned (ecocentric view). A first step is currently under development where protection of non human species (biocentric view) is afforded at organism level (ICRP[2], 2008). Having started to be recommended one decade ago (Bréchignac[3], 2002) but also noticeably questioned with respect to its pertinence (Stone[4],

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[1] Bréchignac F., Polikarpov G., Oughton D., Hunter G., Alexakhin R., Zhu Y., Hilton J., Strand P. (2003) Protection of the environment in the 21st century: radiation protection of the biosphere including humankind – Statement of the International Union of Radioecology. *Journal of Environmental Radioactivity* **70(3)**: 155-159.

[2] ICRP Publication 108. Environment protection: the concept and use of reference animals and plants. *Annals of the ICRP*, 38(4-6), 242 pages.

[3] Bréchignac F. (2002) Environment versus man radioprotection: the need for a new conceptual approach? *Radioprotection Colloques* **37** C1:161-166

2002), it is worthwhile mentioning that this evolution has led now to one of the most active R&D direction currently tackled at international level.

Given this historical background, and facing now the environment contamination issues promoted by the accident at the Fukushima nuclear power plant in Japan, it is of much relevance to analyze what is the current status of radioecology, first in terms of its recognition at political level (and associated funding), and second in terms of its scientific maturity. The accident in Japan prompts important drivers to orient this brain storming. Do we have the right and optimal answers to the many immediate questions raised by our Japanese colleagues dealing with the contamination spread over the territories and affecting the population? Is our scientific understanding mature enough to anticipate what will the long term impact of the contamination on the environment be (land and sea)?

Ensuring a continuous rate of funding to master the risks: an industrial duty

As long as nuclear activities are going on, radioecology is required to make sure that the associated risks are tackled and properly mastered, an objective which can only be fulfilled with a long-term and continuous rate of funding. As mentioned above in more details, short-term funding variations are very deleterious to research efficiency: a good research team and the related expertise takes more than one decade to be constructed and led to excellence; radioactivity specialized experimental facility are complex and often large-scale and they need long-term exploitation to be brought about to data production and therefore knowledge advancement. As a consequence, even a short-term decline in funding is much destructive of both, the research brain power and the experimental capabilities. It is important to stress here that the same situation applies to the scientific fields contributing to mastering the risk associated to other industrial activities (agro-chemical, pharmaceutical, mining, etc…), and a mechanism that would subordinate the funding of research on risks to the development of an industrial activity promoting such risks is highly desirable.

Advancing radioecology to maturity: expand the scientific scope to ecological risks mastering

With respect to the maturity of radioecology in advancing the appropriate scientific understanding to cope with radiological problems and solutions in the environment, several initial reflections can be made along the historical evolution of radioecology.

Along the traditional <u>anthropocentric view</u>, targeting exclusively human health via the transfer of radioactivity through the environment, the problems linked to urban contamination have not been fully resolved yet, an issue of crucial relevance given the density of the population at risk. This is not only a question of decontamination techniques of urban surfaces (roofs, concrete walls, asphalt, …) but also of managing risks in conditions of dense population. For the long-term impact on agriculture lands, decontamination still remains a challenge, the most efficient solution often proving to be too expensive for any practical application on large surfaces. Here, the potential of phytoremediation to remove radionuclides from soil has usually been rejected a priori given the typical orders of magnitude known for soil-to-plant transfer factors (around $10^{-2} – 10^{-1}$). This is most probably out of scope for cesium, but it may be worth re-examining the issue for other contaminant radionuclides bearing in mind that such values were primarily derived for species of agronomical value (i.e. a very small portion of the plant kingdom biodiversity). Another area generating much uncertainties is the approach to estimating radionuclides transfer still largely relying on the simple partition coefficient between water and soil/sediment. This method assumes equilibrium, a quite theoretical condition which tends to never being met in the real conditions (large hysteresis of sorption/desorption processes are now well documented). The bias introduced by such an approximation within the data bases compiling radioecological transfer parameters certainly deserves more attention.

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[4] Stone R. (2002) Radioecology's coming of age, or its last gasp. *Science* **13**:1800-1801.

Following the intermediate biocentric view, targeting fauna and flora, dose-effect relationships for individual test organisms of some species are currently developed in view of deriving safe levels of radiation which could be used in a regulatory framework for environmental protection. Primarily driven by operational goals, on-going developments expand from the radio-toxicological methods in use for the radioprotection of man on one hand (concept of reference person, radio-toxicological data used to identify dose-response relationships, focus on individual organisms, etc.), and from the classical eco-toxicological methods based on individual organisms of test species for chemical toxicants, on the other hand. As a consequence, they all follow a philosophy of reducing biodiversity down to some sorts of "reference organisms" designed to exploit dose-response relationships at the level of individual organisms. Without being useless, such an approach, however, hardly can meet the real environment protection objectives which have been set, in the vast majority of situations, at population and ecosystem levels. Indeed, the ecological and long-term consequences of low radiation doses to populations and ecosystem fitness, as derived from observations in contaminated territories, are still much controversial pointing the need for more experimental work to test hypothesis along a continuum integrating controlled conditions, field investigations and modeling.

Facing the above limitation, finally, a number of professionals have called for a more holistic approach to ecological risk assessment (see IUR "Ecosystem approach" Task Group, www.iur-uir.org). Following a similar evolution as in other fields of environment protection (dealing with biological diversity, fish stocks, climate change), an ecocentric view based upon an ecosystem centered approach has been proposed (Bréchignac and Doi[5], 2009), which would address the long-term maintenance of ecosystem-related attributes such as structure and functions which are key to life support and services. The keywords here are "linkage" and "integration". Linkage (Hinton and Bréchignac[6], 2005): because the research focus remains fragmented over some parts of the system which tend to restrain scientific knowledge. Integration: because the system behavior cannot be obtained from simply summing up the behaviors of its parts. Expanding to mastering ecological risk requires implementing better linkage and integration of effects in several dimensions: on fauna, flora and man, at scales including levels above individual organisms, for multiple stressor mixtures, over the long-term with successive generations. All such dimensions define a priority direction for research.

3d May 2011

[5] Bréchignac F., Doi M. (2009) Challenging the current system of radiological protection of the environment: arguments for an ecosystem approach. *Journal of Environmental Radioactivity* **100**:1125-1134.

[6] Hinton T.G., Bréchignac F. (2005) A Case Against Biomarkers As They Are Currently Used In Radioecological Risk Analyses: A Problem Of Linkage. In *"The scientific basis for radiological protection of the environment"*, F. Bréchignac & B.J. Howard, eds., Lavoisier Tec & Doc, Paris, France, 123-135.