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Environmental impact and risk assessments and key factors contributing to the overall uncertainties

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A R T I C L E I N F O

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A B S T R A C T

There is a significant number of nuclear and radiological sources that have contributed, are still contributing, or have the potential to contribute to radioactive contamination of the environment in the future. To protect the environment from radioactive contamination, impact and risk assessments are performed prior to or during a release event, short or long term after deposition or prior and after implementation of countermeasures. When environmental impact and risks are assessed, however, a series of factors will contribute to the overall uncertainties.

To provide environmental impact and risk assessments, information on processes, kinetics and a series of input variables is needed. Adding problems such as variability, questionable assumptions, gaps in knowledge, extrapolations and poor conceptual model structures, a series of factors are contributing to large and often unacceptable uncertainties in impact and risk assessments. Information on the source term and the release scenario is an essential starting point in impact and risk models; the source determines activity concentrations and atom ratios of radionuclides released, while the release scenario determine the physico-chemical forms of released radionuclides such as particle size distribution, structure and density. Releases will most often contain other contaminants such as metals, and due to interactions, contaminated sites should be assessed as a multiple stressor scenario. Following deposition, a series of stressors, interactions and processes will influence the ecosystem transfer of radionuclide species and thereby influence biological uptake (toxicokinetics) and responses (toxicodynamics) in exposed organisms. Due to the variety of biological species, extrapolation is frequently needed to fill gaps in knowledge e.g., from effects to no effects, from effects in one organism to others, from one stressor to mixtures. Most toxtests are, however, performed as short term exposure of adult organisms, ignoring sensitive history life stages of organisms and transgenerational effects.

To link sources, ecosystem transfer and biological effects to future impact and risks, a series of models are usually interfaced, while uncertainty estimates are seldom given. The model predictions are, however, only valid within the boundaries of the overall uncertainties. Furthermore, the model predictions are only useful and relevant when uncertainties are estimated, communicated and understood. Among key factors contributing most to uncertainties, the present paper focuses especially on structure uncertainties (model bias or discrepancies) as aspects such as particle releases, ecosystem dynamics, mixed exposure, sensitive life history stages and transgenerational effects, are usually ignored in assessment models. Research focus on these aspects should significantly reduce the overall uncertainties in the impact and risk assessment of radioactive contaminated ecosystems.

1. Introduction

To assess long-term environmental impact, integrated dynamic models taking into account the source term, transport and deposition, mobility and ecosystem transfer, biological uptake, accumulation and effects are needed. Therefore, model descriptions and parameterization of relevant processes, associated kinetics as well as a series of input variables is required. However, variability, gaps in knowledge, extrapolations, questionable assumptions, poor conceptual model structure such as model bias or discrepancies will contribute to large and often unacceptable uncertainties in impact and risk assessment.

Many sources can contribute to releases of radionuclides and associated contaminants to the environment and affect the same territory (Fig. 1). A series of processes can interact with deposited radionuclides and thereby influence the ecosystem transfer, the

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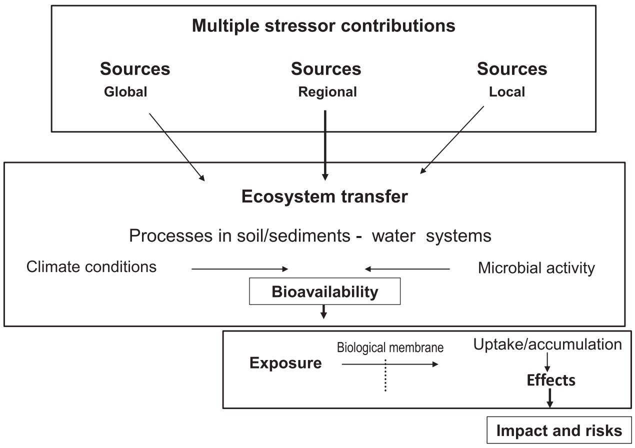

Fig. 1. Environmental impact and risks depend on the source term (many sources and many stressors), interaction and transformation processes, dynamic ecosystem transfer of mobile and bioavailable species, biological uptake and long term effects of sensitive life history stages of exposed organisms.

exposure, uptake and dose received by living organisms, and subsequently the long term effects, impact and risk. As the impact and risk assessments are based on models linking the source term and deposition in different ecosystems to long term effects for various living organisms, the system is complex, simplification is made, and some phenomena are ignored. However, our confidence on the model output depends on the overall uncertainties of the model prediction.

There is a significant number of past, present and future sources of radioactivity that have contributed, are still contributing, or have the potential to contribute to radioactive contamination of the environment. The major sources of artificial radionuclides are associated with the nuclear weapon and fuel cycles. In addition, naturally occurring radionuclides (NORM/TeNORM) are prevalent in environments containing uranium-bearing minerals and additional contributions originate from nuclear as well as non-nuclear industries. Thus, most ecosystems are affected by more than one nuclear or radiological source.

For most historical nuclear events, site-specific information is available, and environmental impact and risk assessments have been performed during the years. In many cases, however, information on the uncertainties is not provided, probably due to the complexity of the systems or due to the urge of making complex problems simple to handle. Experience from historic events could be utilized to better predict the outcome of future similar events, especially if uncertainties are taken into account. To move from impact (consequences) to risk, the probability of a future event must be introduced (risk = probability × consequence). For known localized sources, probability can sometimes be derived from statistics (events/reactor yr). The Three Mile Island accident in USA (1979) demonstrated, however, that low probability nuclear accidents can occur, the Chernobyl accident (1986) showed that the consequences can be more severe than expected, and the Fukushima accident (2011) showed that geohazards can be underestimated. For mobile or orphan sources information on accidental site, time and ecosystem affected is not available, and prognostic environmental impact and risk assessments will hardly be meaningful. For such unforeseen intended event, probability could be replaced with the intention to harm and the capacity/competence to harm. Thus, the risk (risk = intention × capacity × consequences) depends on WHO will do the harm. Accordingly, the World Trade Centre event (2001) showed that extremists have both the intention and capacity to harm. Thus, a paradigm shift has taken place where the risk of nuclear accidents could be higher than earlier anticipated. In these cases, threat assessments focussing on the potential source term and associated impact/consequences, utilizing the experience from past similar events can be more meaningful than evaluating the risks.

To protect man and the environment from radioactive contamination, impact and risk assessments are performed prior to a release, during a release, short or long term after contamination and prior and after the implementation of countermeasures. To cover the area from a releasing source to the long term impact and risk, a comprehensive understanding of the concepts, underlying relevant processes as well as access to relevant input data are required from radioecology, that is assumed to cover all subjects needed. However, expert competence and experience within related scientific disciplines such as analytical/environmental chemistry, geology, limnology, ecology/ecotoxicology/biology, is essential to understand for instance the natural intrinsic variability of the ecosystems. Furthermore, modelling competence is essential due to the complexity of integrating process-based mathematical models developed for specific processes and purposes. Despite major advances made during the last decade in assessing environmental impact of ionizing radiation such as the development of the ERICA tool (e.g., Oughton et al., 2007), there is a number of important gaps and limitations in our knowledge and several phenomena that are ignored. These factors may contribute to orders of magnitude uncertainties in dose and impact reconstructions and in prognostic risk assessments, and thereby limit our ability to determine how radiation levels and risks should best be managed. Thus, utilization of interdisciplinary competence and development of integrated environmental models should be encouraged.

Environmental impact and risk assessment models are based on a set of assumptions, equations, default parameters and experimental input variables aiming at describing the relevant processes. Adding problems such as variability, questionable assumptions, gaps in knowledge, extrapolations, and problems related to biased conceptual model structures, a series of factors can contribute to large and often unacceptable uncertainties in impact and risk assessments. As the overall uncertainty represents a limit on our confidence in the model output, good modelling practice such as performing uncertainty and sensitivity analyses should be applied to characterize, quantify and propagate the uncertainty. Thus, research priorities should be put on key factors i.e., processes, variables, parameters, and conceptual model structures contributing most to the overall uncertainties, to improve the predicting power of assessment models. Therefore, the present paper focuses on conceptual model uncertainties, especially important aspects that are ignored in most impact and risk assessment models such as:

- Source term characteristics, ignoring radionuclide speciation including particle characteristics, with implications for transport, deposition and ecosystem transfer.
- Constant ecosystem transfer parameters, ignoring ecosystem dynamics with implications for pathways, ecological half-live estimates and organisms at risk.
- Single exposure characteristics, ignoring multiple stressors and combined effects in contaminated areas.
- Extrapolation of effects from short time exposed adult test organisms to others, ignoring sensitive life history stages, transgenerational effects and the antioxidant status affecting real life.

2. Uncertainty aspects

Environmental impact and risk assessment models are based on a set of mathematical equations aiming at describing processes of