DOSE PREDICTION FOR PLANTS AND ANIMALS — NUCLEAR FUEL WASTE MANAGEMENT PERSPECTIVE

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UN ASPECT DE LA GESTION DES DÉCHETS RADIOACTIFS — L'ESTIMATION DE DOSE POUR LA FLORE ET LA FAUNE

RÉSUMÉ

Nous avons mis au point une méthodologie complète et pratique pour mesurer l'impact écologique des rayonnements ionisants, et nous l'avons appliquée à l'étude d'impact environnemental sur la sécurité du concept canadien de gestion des déchets nucléaires. Cette méthodologie comprend quatre étapes de dépistage; nous nous attardons, dans le présent exposé sur les deux dernières, consacrées à l'évaluation de la dose pour les plantes et les animaux. Nous présentons dix catégories de questions, compilées à partir des commentaires sur notre méthodologie, commentaires présentés par les personnes ayant évalué notre étude d'impact environnemental. Ensuite nous déterminons les besoins futurs, et les améliorations à apporter à notre méthodologie. Les questions soulevées par les évaluateurs, de même que les besoins futurs et les améliorations souhaitables que nous avons définies, nous seront utiles pour orienter nos travaux futurs.

ABSTRACT

We have developed a comprehensive, practical ecological radiation assessment methodology and applied it in the environmental impact statement (EIS) for evaluating the safety of Canada's nuclear fuel waste disposal concept. The methodology has four screening steps, and we focus here on the last two concerned with dose estimation for plants and animals. We present ten classes of issues that were compiled from comments regarding our methodology from EIS review participants. Furthermore, we identify future needs and developments for improving our methodology. The issues raised by EIS participants, and the future needs and developments indicated by us are also of general importance in guiding future work.

1.0 INTRODUCTION

"The EIS should [also] review what is known about the effects of radioactivity on non-human biota. Knowledge about these effects should then be used to evaluate potential short- and long-term impacts on biotic populations and communities, and on ecosystems."

This quotation is from the summary of the final guidelines for the preparation of the environmental impact statement (EIS) for Canada's nuclear fuel waste disposal concept (AECL 1994), issued by the Federal Environmental Assessment Review Panel (FEARP 1992). The detailed guidelines clearly indicate that doses and risks must be assessed for plants and animals. The Panel developed these guidelines with input from public hearings and so they reflect the expectations and needs of Canadians at large. To meet these guidelines, we have developed and applied a practical ecological radiation assessment methodology, consisting of four hierarchical screening steps — (1) humans, (2) abiotic environment, (3) generic organisms and (4) specific species (Amiro and Zach 1993; Davis et al. 1993). Steps 3 and 4 are concerned with estimating doses to plants and animals, and we focus on them here.

Our objectives are to (1) briefly summarize our assessment methodology for estimating doses to plants and animals, (2) present the main relevant issues raised during the EIS review and public hearings by participants, and (3) identify future needs and developments for dose estimation and risk assessment.

2.0 ASSESSMENT METHODOLOGY FOR ESTIMATING DOSES TO PLANTS AND ANIMALS

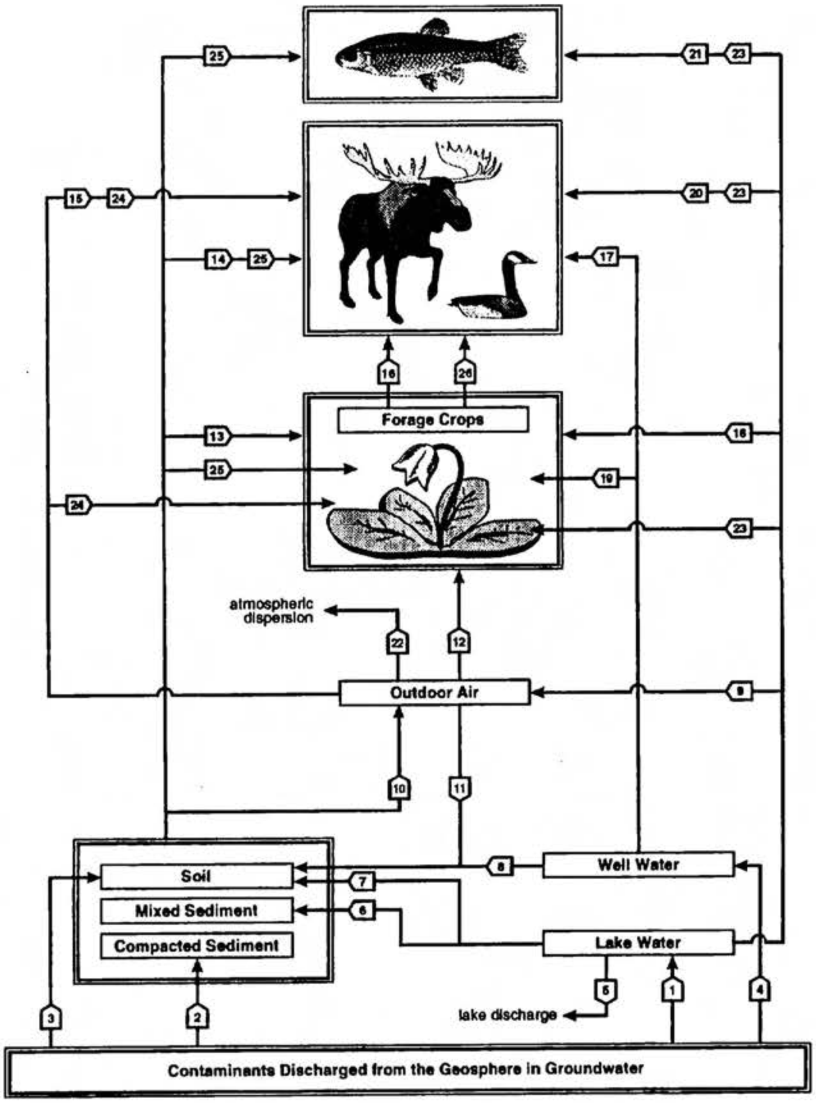
2.1 Generic Organisms

Although the primary aim is to protect populations, our assessment methodology focuses on individual plants and animals (Amiro and Zach 1993). Populations do have unique attributes, such as density, birth rate, death rate, recruitment rate, gene frequency, etc., but there can be no radiation effects on a population without some effects on its individuals. This is also true for communities and ecosystems. Furthermore, dose predictions can be made far more reliably for individuals than for populations with their additional uncertainties. For example, many animal populations undergo natural changes in density and such changes can be accompanied by changes in gene frequencies, but the underlying factors for this remain poorly understood. We also focused on generic organisms because they can include a variety of species and because this allows pooling of the scarce radionuclide transfer and dosimetric databases. Finally, generic organisms are especially useful in long-term assessments where estimates need to be made far into the future and where it is difficult to decide which specific species will be present. We have included in our assessment methodology a generic terrestrial plant, a fish, a mammal and a bird.

We have adapted environmental transfer models used for humans to estimate radionuclide concentrations in the abiotic environment, and in plants and animals (Figure 1). Such models are not necessarily adequate because they largely consider simple, agricultural food chains and ecosystems. In most of these models, food chains are short and higher trophic levels poorly represented. However, there is the advantage of an available, substantial radionuclide transfer database.

Given radionuclide concentrations, doses for plants and animals can be calculated similarly as for humans. However, dose conversion factors (DCFs) for humans include a sophisticated system of radiation and organ weighting factors, and risk conversion factors. Because these are specifically designed for humans, they are not appropriate for other biota. Even so, radiation weighting factors have been commonly used to account for the high biological effectiveness of alpha radiation in the body (IAEA 1992). The dosimetry of plants and animals is not well-developed (Barnthouse 1995) and it is also difficult to translate dose to risk. In response to these challenges, we developed internal DCFs based on radionuclides residing in the body (Amiro 1996), rather than on radionuclide intake rates, as is usually done for humans. Our external DCFs were derived from human values and they are at best rough, conservative estimates for the variety of body sizes and exposure situations of plants and animals.

Figure 1. Transport model for estimating radionuclide concentrations in the abiotic environment and doses to the four generic organisms included in our ecological radiation assessment methodology.



1 Geosphere discharge to lake water
2 Geosphere discharge to compacted sediment
3 Geosphere discharge to bottom of soil profile
4 Geosphere discharge to well water
5 Loss through lake discharge
6 Transfer from lake water to mixed sediment
7 Transfer from lake water to soil (irrigation)
8 Transfer from well water to soil (irrigation)
9 Transfer from lake water to air
10 Transfer from soil/sediment to air
11 Transfer from air to soil (deposition)
12 Transfer from air to plant/forage crops (deposition)
13 Transfer from soil/sediment to plant/forage crops (root uptake)
14 Transfer from soil/sediment to mammal/bird (ingestion)
15 Transfer from air to mammal/bird (inhalation)
16 Transfer from forage crops to mammal/bird (ingestion)
17 Transfer from well water to mammal/bird (ingestion)
18 Transfer from lake water to plant/forage crops (irrigation)
19 Transfer from well water to plant (irrigation)
20 Transfer from lake water to mammal/bird (ingestion)
21 Transfer from lake water to fish
22 Loss through atmospheric dispersion
23 External exposure of target organisms to lake water
24 External exposure of target organisms to air
25 External exposure of target organisms to soil/sediment
26 External exposure of mammal/bird to forage crops

Given dose estimates for plants and animals, a safety criterion is needed to assess potential impacts. Ideally, this criterion should be based on risk, as is the case for human radiation protection. However, because doses for plants and animals cannot be readily converted to risk, a strictly risk-based criterion is difficult to establish. A variety of dose criteria have been used, e.g., the International Atomic Energy Agency has indicated that there is no convincing evidence that dose rates of less that 0.4 Gy/a will harm terrestrial plant or animal populations (IAEA 1992). This value was recently supported by Barnthouse (1995) for representative members of terrestrial and aquatic plant and animal populations, rather than for maximally exposed individuals. However, 0.4 Gy/a is substantially higher than the background dose rate experienced by many organisms. In the EIS, we have used a relatively low criterion of 0.001 Gy/a in order to be fully inclusive of the large diversity of species in Canada, and the uncertainties brought about by predictions far into the future (AECL 1994). From the many laboratory and field studies of plants and animals exposed to radiation (UNSCEAR 1996), we know that the risk of a detrimental impact with this criterion is extremely low.

2.2 Specific Species

Our assessment methodology can be readily extended to specific species, if needed (Davis et al. 1993). However, estimating doses for a specific species can be difficult because there may be few or no reliable radionuclide transfer and dosimetric data (UNSCEAR 1996). Such data might be unattainable, especially for some of the species targeted for protection — threatened, rare or endangered species. Furthermore, it is usually easier to do a credible screening assessment for a generic organism than for a specific species because more data are needed to reflect a species' precise ecological setting and life history. These problems underscore the utility of using generic organisms as a screening tool to guide or avoid further analysis.

3.0 FEEDBACK FROM THE EIS REVIEW PROCESS

A large number of issues concerning the natural environment were raised by various participants during the EIS review and the public hearings. This reflects a genuine concern of Canadians for the natural environment with its plants and animals, and a belief that a healthy environment is essential for human well being. Many of the issues are relevant for our assessment methodology and dose estimation in particular. Furthermore, they also raise expectations regarding such assessment methodologies in general.

Below we have listed ten classes of issues that accommodate many of the individual issues raised. We have also included pertinent comments in each case.

1. *Full supporting data are needed to make an environmental assessment methodology credible.* The database is limited for ecological radiation assessment methodologies in general, particularly for radionuclide transfer, dosimetry and radiation risk.

2. *Physical, chemical and radiological stressors need to be integrated.* The total stress is most important for the well being of an organism than the stress from each individual factor. Furthermore, various stressors may not have simple additive effects — there could be synergism. Most or all the existing environmental assessment methodologies do not take a holistic view with a focus on total stress.

3. *Cumulative impacts need to be addressed.* Many environmental problems have been caused by the cumulative effects over time and space. This means methodologies need to include long-term and spatial effects to fully assess impacts.

4. *Monitoring needs to be considered as part of an environmental assessment methodology.* The estimates made by any assessment methodology must be readily monitorable so remedial action can be taken, if needed.

5. *Specific rather than generic organisms should be used.* When using specific species, there is the problem of which to select from the many possibilities available. This has lead to the idea of selecting the most sensitive species. However, this in itself is a problem because many possibilities need to be investigated before the most sensitive species can be identified and the selection may not stand the test of time. Many participants want to see those species selected that are most important to them in terms of life style, economics, ecology, conservation, hobbies, emotion, etc. The selection of a species is not always a simple scientific/technical matter.

6. *The most sensitive life stages of organisms should be used.* Once a species has been selected, the idea is to focus on its most sensitive life stage. It usually coincides with reproduction or growth when cells rapidly differentiate and proliferate — processes sensitive to radiation exposure.

7. *Model parameters should be based on wild and not on domestic organisms.* This is a serious problem because there is a substantial radionuclide transfer database for domestic organisms, whereas the database for wild organisms is very limited. Furthermore, wild organisms may have lower transfer coefficient values than domestic ones (Macdonald 1996). Thus, the use of such values may not be conservative.

8. *Bioconcentration needs to be fully considered.* The concern here is the concentration and accumulation of a contaminant in organisms, and its potential increase up the food chain. These processes are very important in the assessment of any contaminant and so need to be fully considered in environmental assessment methodologies. Generally speaking, radionuclides do not have a tendency to bioaccumulate, as some other contaminants do.

9. *The environmental understanding and view of aboriginal peoples needs to be included.* Aboriginals have lived for a long time in the natural environment and so have accumulated a vast store of knowledge about it. They have a very holistic, ecological view of the environment that includes all the abiotic and biotic components in an integrated way. This view and knowledge has remained largely untapped in the development and application of ecological radiation assessment methodologies.

10. *Multiple lines of reasoning or evidence are.* When there are large uncertainties in an assessment problem, multiple lines of reasoning should be used rather than relying on any single assessment methodology. Furthermore, some of the lines of reasoning should be simple and intuitive so that everybody can understand them and evaluate the measure of environmental protection they ensure.

4.0 FUTURE NEEDS AND DEVELOPMENTS

Our assessment methodology is very flexible and it can be adapted to various needs (Zach and Amiro 1996). In making recommendations regarding future needs and developments, we focus here on dose estimates for plants and animals. These recommendations grow partly out of our experience gained in developing assessment methodology and the issues indicated in Section 3. The recommendations apply to ecological radiation assessment methodologies in general.

1. *Extension of terrestrial models to secondary consumers.* Most of the existing models include primary consumers only. Inclusion of secondary consumers is important; they are frequently considered most important in environmental protection because they are at the end of the food chain and because they can have a high conservation status.

2. *Expansion of aquatic transfer models.* Most of the aquatic transfer models include fish only. This is not a reflection of ecological reality and, furthermore, radionuclide concentrations in the lower aquatic trophic levels tend to be higher than in fish (Bird et al. 1996). There is also a need to fully recognize food chains in the modelling of the aquatic environment.

3. *Additional organisms.* Our four generic organisms are a poor reflection of the high diversity encountered in Canadian ecosystems. There is a need for more organisms to more fully reflect this diversity and the varied life histories associated with it.

4. *Improved transfer data.* The radionuclide transfer database is dominated by domestic organisms and wild organisms of economic importance to man. More representative data for wild plants and animals are needed.

5. *Improved dosimetry.* Dosimetric data and models for plants and animals are scarce. One of the troublesome issues is how to "weigh" alpha radiation in order to make doses from different radiations additive.

6. *Establishment of risk conversion factors.* Risk is the common denominator for integrating all the environmental stressors — physical, chemical and radiological. This is important because the total stress or risk is most relevant ecologically (Section 3). To establish radiation risk conversion factors, more information on the effects of radiation on plants and animals is needed, particularly on their dose response.

7. *Establishment of dose criteria.* There is a need for a generally accepted dose criterion, preferably based on explicit risk considerations, to evaluate estimated doses for plants and animals.

5.0 CONCLUSIONS

1. Canadians are deeply concerned about the well-being of the environment which they link to their own well-being.

2. We have successfully developed and applied successfully an ecological radiation assessment methodology that includes dose predictions for plants and animals.

3. Canadians have identified a variety of issues regarding our assessment methodology, which can be used as a guide for developing any ecological radiation assessment methodology.

4. We have identified a variety of future needs and developments to improve our assessment methodology, which are also relevant for ecological radiation assessment methodologies in general.

6.0 ACKNOWLEDGEMENTS

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7.0 DISCUSSION

Question No.1: How were the criteria for demonstrating protection of the abiotic environment derived?

Dr. Zach answered that criteria were developed by, and obtained from, various regulatory and international agencies. In the case of the criterion on the degree of variability of natural background concentrations of radionuclides, one standard deviation around natural background was chosen as a criterion.

Question No. 2: Do you have background measurements for ^{129}I or ^{99}Tc?

Dr. Zach replied that they do not have very good information on artificial radionuclides such as these, and that they were not able to demonstrate the safety of the concept on the basis of this criterion.

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