Radioprotection, vol. **46**, n° 6 (2011) S765–S770
© EDP Sciences, 2011
DOI: 10.1051/radiopro/20116885s

Elaboration on a radiological environmental impact assessment methodology for Northern environments

A. Hosseini[1], J.E. Brown[1], T. Evseeva[2], T. Sazykina[3], D. Oughton[4], E. Bleykh[2] and T. Majstrenko[2]

[1]*Norwegian Radiation Protection Authority, P.O. Box 55, N-1332 Østeras, Norway.*
[2]*Institute of Biology, Komi Scientific Center, Ural Division RAS, Kommunistcheskaya 28, 167982, Syktyvkar, Russia*
[3]*International Academy of Modern Knowledge, 19 Gurianova str., Obninsk, Kaluga region, 249038 Russia*
[4]*University of Life Sciences, 1432 ÅS, Norway*

Abstract. The present work encompasses some key aspects of a 3-year long research project (INTRANOR) where the main focus has been specifically on environmental assessments for radiation exposure through application of existing methodologies and their adaptation to quantify transfer, exposure and effects in Boreal/Arctic ecosystems. Non-parametric statistical methods have been applied in order to estimate the threshold dose rates above which radiation effects can be expected in vertebrate organisms. In addition, industrial areas contaminated by uranium mill tailings and radium production wastes, in the Komi Republic, Russia, were selected as suitable sites to study further the effects of exposure to radiation under boreal conditions. Dose–effect relationships have been established for a few natural populations inhabiting this area. Analyses of data have allowed benchmarks to be established below which no decrease in reproductive capacity could be observed. Other work performed within the project includes the collation of data in relation to naturally occurring radionuclides and application of existing methodologies to characterise background radiation exposures. These dose-rates may be a suitable means of contextualising the exposure attributable to enhanced dose-rates arising from human activities. Finally, combined action of ionizing radiation and low temperature has been analyzed and mathematically modelled.

1. INTRODUCTION

Methodologies to assess the impact of exposure to ionising radiation on flora and fauna in European temperate and Arctic environments have been developed in two European collaborative projects "FASSET - Framework for Assessment of Environmental Impact" [1] and "EPIC - Environmental Protection from Ionizing Contaminants in the Arctic" [2] respectively. These studies were superseded by the project "ERICA - Environmental Risk from Ionising Contaminants: Assessment and Management" wherein risk assessment methodologies have been developed and issues relevant to decision making in the context of the management of environmental impacts of radioactivity have been addressed [3]. Of particular relevance to the Arctic is the project EPIC which provides a number of the foundation stones that are prerequisite in the process of developing a robust assessment methodology. However, the development of the EPIC framework was curtailed at a point that did not incorporate risk characterisation or concomitant management options. With this in mind, the central rationale behind the INTRANOR project was to build upon the recent advances in environmental impact assessments, as detailed in the abovementioned research programmes, with focus on adapting the systems for Arctic/boreal environments, developing the risk characterisation component of the analysis and testing the assessments for actual situations. Some of the activities in the project are presented below.

2. ADAPTATION OF AVAILABLE ENVIRONMENTAL IMPACT ASSESSMENT METHODOLOGIES

The Environmental Impact Assessment methodologies mentioned above are constructed around the concept of Reference Organism [1]. Reference organisms are defined as a series of entities that provide a basis for collation of transfer and dosimetry related data for a range of organisms which are typical of a contaminated environment. It was anticipated that the associated datasets might be used in conjunction with data for ICRP's Reference Animals and Plants [4].

Work conducted in the INTRANOR project has led to the conclusions that: Although the EPIC reference organism suite appear to provide us with a reasonable starting point in selecting region-specific organisms for the estimation of doses and radiation impact on wildlife of the North, there are severe limitations in the practical application of existing organism suite. In particular, the fact that in many cases the reference data either do not exist, as is the case for freshwater reference organisms, or are few (much of the transfer data) means that it is a moot point whether they should be regarded as reference points at all.

There is some evidence which suggests that the in situ physical conditions in the Arctic may hypothetically alter radionuclide transfer to biota and also probably modify the expression of radiation induced effects [5, 6]. However, this sporadic evidence alone does not constitute a dataset which allows a completely Arctic specific environmental risk assessment to be carried out. Several years of additional work leads to the clear observation that the transfer data in ERICA are far superior to those collated in EPIC and, in many cases, the EPIC data have been incorporated into the much larger ERICA datasets. A cursory examination of the dosimetric models for ERICA also suggests that they may be suitably applied to the Arctic. Hence from a practical point of view and until more site specific evidence/ data are available, it seems reasonable to recommend, in relation to conducting environmental impact assessment in the Arctic, replacing the EPIC reference organism suite by those used in ERICA. The proposed simplified system for performing an impact assessment for an Arctic site would therefore involve:

- The use of ICRP Reference Animals and Plants and guidance to allow, inter alia, site specific assessment to be more readily compared to other assessments.
- The use of the ERICA integrated approach [3] supported by the ERICA Tool [7] to provide screening tools and generic data sets to perform the assessment. The ERICA dataset might be regarded as providing data for 'representative organisms'. In this way the approach might be considered as a management tool to be applied for authorisations/compliance, for example, and as providing a pool of information to allow a more comprehensive assessment where clearer links can be made to (and relevant data derived for) actual species of interest.
- If required, to undertake a site specific investigation drawing on tools available in the ERICA Tool, e.g. defining site specific geometries and occupancy factors, conducting probabilistic model runs etc. Furthermore, site specific activity concentration and transfer data should be collated and for the transfer data Bayesian methods might be implemented in refining the information (e.g. see [8]), i.e. allow the assessor to utilise the more comprehensive datasets available from ERICA in tandem with newly acquired site specific information.

In order to appraise the robustness of the selected approach, ERICA was applied and tested at a site discharging authorised levels of liquid radioactive waste [7]. Although the applied assessment methodology generally provided a reasonably robust means of considering environmental impact, a number of weaknesses were identified. Of these, issues related to the application of a single, general screening benchmark and the problem of spatial averaging were thoroughly analysed. While a single benchmark does not allow for differences in the radio-sensitivity of different species, lack of guidance on spatial averaging does not allow for consideration of varied home ranges of different organisms. The former would impact the decision making process and the latter the estimated absorbed dose rates.

Table 1. Total weighted absorbed dose rates (μGy/h) to plants and animals inhabiting areas with elevated levels of naturally occurring radioactivity.

Species	Experimental site		Reference site
	Min.	Max.	
Vicia cracca L.	0.9 ± 0.2	500 ± 35	0.50 ± 0.06
Pinus sylvestris L.	1.2 ± 0.2	374 ± 130	0.62 ± 0.14
Lumbricus sp. and *Dendrobaena* sp.	1.1 ± 0.1	792 ± 57	0.55 ± 0.03
Microtus oeconomus Pall.	32 ± 13	46 ± 21	6.7 ± 4.2

3. EVALUATION OF RADIATION DOSE RATES FOR ORGANISMS INHABITING AREAS OF ENHANCED LEVELS OF RADIOACTIVITY

Samples of soil, plants (*Vicia cracca* L. and *Pinus sylvestris* L.) and animals (*Microtus oeconomus* Pall., *Lumbricus sp.* and *Dendrobaena sp.*) were collected from contaminated sites in proximity to the Vodny settlement in the Komi Republic, Russia. These sites have in the past been contaminated by uranium mill tailings and radium production wastes and currently exhibiting enhanced levels of naturally occurring radionuclides. Measured activity concentrations in the soil samples were generally higher than background for all measured radionuclides but the level of ^{226}Ra, ^{210}Po and ^{210}Pb were particularly enhanced. Based on the activity concentrations measured, the total weighted absorbed dose rates for biota were calculated (Table 1). Radium-226 was found to be the main contributor to the estimated total dose rate.

As part of the INTRANOR project the dose-effect relationships for Scotch pine (*Pinus sylvestris*), Tufted vetch (*Vicia cracca*), earthworms (*Lumbricus* sp., *Dendrobaena* sp.) and tundra vole (*Microtus oeconomus*) were examined. For plants, *Pinus sylvestris* was found to be more sensitive to radioactive exposure than *Vicia cracca*. Significant decrease in reproductive capacity of *Pinus sylvestris* and *Vicia cracca* was observed at 6.4 ± 0.7 μGy/h and 51 ± 10 μGy/h, respectively. Regarding the animals, two different end points were investigated. A decrease in earthworms population number per m^2 and an increase in chromosome aberration frequency in *M. oeconomus* bone marrow cells was observed at $19 \pm 9\mu$Gy/h and $11.4 \pm 0.8\mu$Gy/h, respectively.

Furthermore, the following Effective Dose-Rates 10 % (EDR$_{10}$) were derived: $6.2 \pm 1.9\mu\text{Gy h}^{-1}$, $4.3 \pm 2\mu\text{Gy h}^{-1}$ and $34 \pm 5.5\mu\text{Gy h}^{-1}$ for earthworm, Scots pine and tufted vetch, respectively. In addition, the shapes of dose response relationship for these organisms were elucidated and information relating to no observable effects and lowest observable effects doses were elaborated. By way of example, the lowest dose rate at which an effect was observed is about 9 μGy/h for earthworm. This is almost 450 times lower than that determined by [10]. While the latter value is the result for earthworms exposed to chronic gamma radiation, the former is for earthworms inhabiting areas with enhanced concentrations of radionuclides from the ^{238}U and ^{232}Th decay series. The relatively low predicted no effects dose-rates for the studied sites might be attributed to the combined effects of chemical toxicity and radio-toxicity and the high relative biological effectiveness of alpha emitting radionuclides.

4. DERIVATION OF GENERIC PROTECTIVE BENCHMARKS FOR BIOTA

There have been recent efforts to derive predicted no effects dose-rates for wild-life based on the construction of species sensitivity distributions (SSD) that are in turn constructed from EDR$_{10}$ data from individual experiments [11, 12]. Although such methods are well established in the ecotoxicological sciences (see [13]), their application within the field of radiological protection is relatively new and not without deliberation. One important limitation is the fact that the criteria used in the selection of appropriate data for construction of the SSD are extremely strict which results in the loss of a large dataset that may have great utility in informing the derivation of appropriate dose-rate benchmarks. For this reason alternative methods for analysing dose-effects data have been explored within the INTRANOR project. Non-parametric statistical methods have been applied in order to estimate the threshold dose rates above which radiation effects can be expected in vertebrate organisms by [14]. The effects considered in the analyses include morbidity, reproduction, and life shortening and the approach has drawn upon data collations pertaining to databases on effects of chronic low-LET radiation exposure. Radiation thresholds dose-rates in vertebrate animals subjected to chronic low-LET exposure were estimated to be 2.1×10^{-4} Gy/day, 4.1×10^{-4} Gy/day and 1.1×10^{-3} Gy/day for the endpoints of morbidity, reproduction and life-shortening respectively. This means that the generic screening value of 2.4×10^{-4} Gy/day (10μGy/hr) suggested by [12], based on SSD analysis corresponds to the lowest level for morbidity effects in mammals based on the non-parametric analyses of data proposed in INTRANOR by [14]. Further work may be required to establish whether additional uncertainty factors should be applied to generic benchmarks to account for the (perceived) greater sensitivity of Arctic systems to impacts of radioactivity.

5. COMBINED ACTION OF IONIZING RADIATION AND LOW TEMPERATURE

Upon detailed analysis of world data on the combined action of ionizing radiation and low temperatures it was found that for different groups of animals, manifestations of radiation effects in cold environments differ from radiation responses of animals from warm/temperate environments. The observed differences might be attributed to the radiation-induced imbalance of central thermoregulation, which leads to excess heat losses from animal to the cold environment. The additional heat losses would probably affect the fitness of the irradiated animal and at the end cause a reduction of its survival capacity [15].

A mathematical model was formulated describing the effects of chronic ionizing radiation on fish populations, inhabiting lakes in the cold, temperate and warm climates. Computer simulations of the combined effects of chronic radiation exposure and temperature conditions demonstrate that the overall radiation damage to Arctic/Northern poikilothermic (cold blooded) species is higher than that to temperate/warm climate biota exposed to the same levels of irradiation. This implies that in developing standards for the radiation protection of the Arctic/Northern fauna, temperature effects should be taken into consideration [15].

6. BACKGROUND DOSE RATE CHARACTERISATION

In helping to assess the impacts of radiation exposure on organisms, Pentreath [16] suggested that only two reference points can be utilised in a practicable way, these being natural background dose-rates and dose-rates known to have specific biological effects on individuals/populations. Building on this, the ICRP has suggested that it would be helpful for the decision-making process if information concerning effects on biota was set out in terms of multiples of the natural background dose-rates typically experienced by each type of Reference Animals and Plants [4]. For such a structuring of data to be made, there is clearly a requirement to provide well characterised background dose-rate estimates for the selected Reference Animals and Plants However, whilst data have been collated for terrestrial Reference Animals and Plants [17] information has not been collated with the express purpose of deriving background dose-rates to aquatic Reference Animals and Plants.

In light of these propositions, information on activity concentrations of naturally occurring primordial radionuclides for marine and freshwater ecosystems have been applied and appropriate dosimetry models used to derive absorbed dose-rates for Reference Animals and Plants [18]. Although coverage of activity concentration data is comprehensive for sediment and water, few, or in some cases no, data were found for some organism groups, for most radionuclides. The activity concentrations for

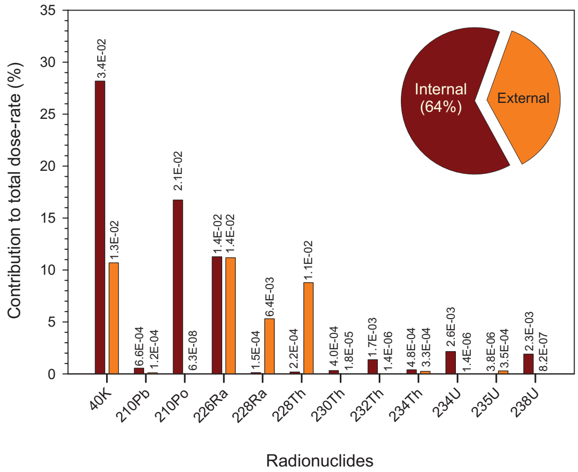

Figure 1. Contributions of different radionuclides to internal, external and the total unweighted dose-rates for Trout. The vertical-orientated values are estimated internal and external dose-rates (μGy/h).

individual radionuclides in both organisms and their habitat often exhibit standard deviations that are substantially greater than arithmetic mean values, reflecting large variability in activity concentrations. The dominating radionuclides contributing to exposure in the aquatic Reference Animals and Plants are ^{40}K, ^{210}Po and ^{226}Ra.

The mean unweighted and weighted dose-rates for aquatic Reference Animals and Plants are in the ranges 0.07–0.39 μGy h^{-1} and 0.37–1.9 μGy h^{-1} respectively. Typical results are shown in Fig. 1.

7. CONCLUSIONS

The INTRANOR project has dealt with many aspects relating to the development of a more robust methodology for assessing the impact of ionising radiation on wild-life. The general methodology itself has been reviewed with particular focus on the applicability of representative organisms in the context of boreal/Arctic systems and how these might relate to the reference animals and plants being developed by the ICRP. Dose response data from published literature has also been investigated by considering the applicability of different statistical methods in the derivation of generic benchmarks for application in protection systems. Due to lack of data, dose-response relationships for many organism types are poorly characterised, especially under field conditions. With this in mind experimental studies have been conducted to investigate the dose response of herbaceous plants to exposure from naturally occurring radionuclides. The combined effect of ionizing radiation and low temperature has been considered and mathematically modelled. Finally work has also been conducted in relation to the characterisation of naturally occurring radionuclides in aquatic ecosystems. Data have been organised around the reference animals and plants considered by the ICRP and thereby should have relevance for the ICRP's development of reference points for contextualising calculated dose-rates for any given impact assessment for ionising radiation.

Acknowledgments

This work was supported by the Norwegian Research Council (NFR) and forms part of the INTRANOR (Impact Assessment of Elevated Levels of Natural/Technogenic Radioactivity on Wildlife of the North) project, contract no.185134. The financial support of the NFR is gratefully acknowledged.

References

[1] Larsson C.M. *J. Radiol. Prot.* **24** (2004) A1-A13.

[2] Brown J.E., Thørring H., Hosseini A. The "EPIC" impact assessment framework – a deliverablereport for EU Funded Project ICA2-CT-2000-10032. Norwegian Radiation Protection Authority,Østerås (2003) 175.

[3] Larsson C.M. *J. Environ. Radioact*. **99** (2008) 1364–1370.

[4] ICRP. Environmental Protection: the Concept and Use of Reference Animals and Plants. ICRP Publication 108. Ann. ICRP 2008; 38 (4-6).

[5] Sazykina, T.G. *Radiat. Prot. Dosimetry*, **75** (1998)219–222.

[6] Sazykina, T.G., Jaworska, A. & Brown, J.E. (Eds.) (2003). Dose-effects relationships for reference (or related) Arctic biota. Deliverable Report 5 for the EPIC project (Contract no. ICA2-CT-200-10032). Norwegian Radiation Protection Authority, Østerås, pp. 119.

[7] Brown J.E., Alfonso B., Avila R., Beresford N.A., Copplestone D., Pröhl G. *J. Environ. Radioact.* **99** (2008) 1371–1383.

[8] Barrera M., Lourdes Romero M., Nuñez-Lagos R., Bernardo J.M. *Analytica Chimica Acta* **604** (2) (2007) 197–202.

[9] Hosseini A., Brown J.E., Dowdall M., Standring W., Strand P., *Environ Monit Assess* **173** (2011) 653–667.

[10] Hertel-Aas T., Oughton D.H., Jaworska A., Bjerke H., Salbu B., Brunborg G. *Radiation Research* **168** (2007) 515–526.

[11] Garnier-Laplace J., Copplestone D., Gilbin R., Alonzo F., Ciffroy P., Gilek M., Agüero A., Björk M., Oughton D.H., Jaworska A., Larsson C.M., Hingston J.L. *J. Environ. Radioact.* **99** (9) (2008) 1474–1483.

[12] Andersson P., Garnier-Laplace J., Beresford N.A., Copplestone D., Howard B.J., Howe P., Oughton D., Whitehouse P. *J. Environ. Radioact.* **100** (2009) 1100–1108.

[13] EC, European Commission. Technical guidance document in support of Commission Directive 93/67/EEC on risk assessment for new notified substances and Commission Regulation (EC) N 1488/94 on risk assessment for existing substances. Office for Official Publication of the European Communities, Luxembourg 2003.

[14] Sazykina T.G., Kryshev A.I., Sanina K.D. *Radiat. Environ. Biophys.* **48** (2009) 391–404

[15] Sazykina T.G., Kryshev A.I. *Radia.t Environ. Biophys.* **50** (2011) 105–114

[16] Pentreath R J. *J. Radiol Prot.* **22** (1) (2002) 45–56.

[17] Beresford N.A., Barnett C.L., Jones D.G., Wood M.D., Appleton J.D., Breward N., Copplestone D. J. Environ. Radioact. **99** (2008) 1430–1439.

[18] Hosseini A., Beresford N.A., Brown J.E., Jones D.G., Phaneuf M., Thørring H., Yankovich T. J. *Radiol. Prot.* **30** (2010) 235–264.