1.1c Doses and Effects in Non-human Systems

Summary of the work of the action group of UIR

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1. Introduction and Objectives

This action describes a strategy for developing a framework for the assessment of the impact of increased radiation exposure on the native biota in the environment. Traditionally, in the field of radiation protection, the focus has been on man; it is only occasionally that the potential effects of increased radiation exposure on the environment, excluding man, have been explicitly assessed. The need to address this topic has recently grown in order to increase scientific understanding and to improve the knowledge base in such a way that decisions concerning environmental protection are more transparent. The objective for the IUR within the IUR/EULEP/EURADOS concerted action was to address the topic of doses and effect on non-human systems. This objective was achieved by dealing with three major tasks :

I. I. a review of the available literature and an assessment of present knowledge;

II. II. an examination of possible approaches including the need for a framework for assessing the consequences of exposure of biota to radiation, and

III. III. the identification of gaps in present knowledge and propose directions for future research.

2. Progress and Results

2.1. Present knowledge concerning doses and effects in non-human systems.

The Concerted Action was initiated in 1998. During the first period, the task involved the collation and evaluation of existing data on the effects of exposure of plants and animals to ionising radiation and on methods for assessing the doses resulting from environmental contamination. A number of participants were involved, both EC and non-EC, in the formation of a core expert group chaired by Arrigo Cigna. Correspondence was maintained remotely (by e-mail etc.) over this initial period with the aim of collating relevant information and providing a forum for the discussion of relevant topics. The Mol Topical Meeting (Mol, 1-5th June 1998) provided the first opportunity for the group to meet and discuss progress. Seven papers were presented that were relevant to the task, and included a study on the genetic effects in plants growing in areas affected by Kyshtym and Chernobyl (Shevchenko *et al*., 1998) and research on doses and effects in the Chernobyl NPP Cooling pond (Kryshev, 1998). An open discussion was also held where a number of themes were considered. One discussion related to whether the individual or populations should be the target of concern when considering radiation impact assessments for biota. Earlier data, also presented at the meeting, demonstrated that the biological effects of acute irradiation show a very large range of sensitivities between species and also within species.

In the initial part of the concerted action, dose rate conversion factors for organisms were also considered. Attention was drawn to a number of limitations that exist with the calculation of dose rates. The first limitation relates to the differential distribution of dose-forming radio-nuclides within the plant or animal. The lack of specific data often leads to the assumption that radionuclides are accumulated uniformly within the organism. This can result in a serious underestimation of doses to specific organs. In addition to this, the Relative Biological Effectiveness (RBE) of radiations is not considered during normal dose calculations for biota. For human radiation protection this phenomenon is taken into account by applying a radiation weighting factor of 20 for high LET radiations and 1 for low LET radiations. It should be noted that these weighting-factors are associated with the induction of stochastic effects (principally cancer, but also germ cell mutations) in humans and may not, therefore, be directly applicable to the effects that are potentially of interest in wild organisms (e.g., reductions in fertility and fecundity). Nonetheless, a consistent dose calculation approach, involving the integration of exposures from a large range of radiation types and subsequent comparison between cases, necessitates the adoption of some form of radiation weighting factor for biota. The problem may be circumvented by applying a radiation weighting factor of 20 to ?-particles to account for RBE (this is a preliminary position; the available information needs to be reviewed to extract a radiation weighting factor for the detrimental effects and absorbed dose rates of interest). The dose conversion factors reported by Amiro (1997), which can be used to convert units of Bq per unit mass of matter (organism or habitat) to a dose rate (Gy per year), were modified for this purpose and produced in tabulated form. For the calculation of internal dose, Amiro's model conservatively assumes that all energies emitted by radionuclides within the organism are absorbed by the organism. It should be noted that this model is only one of a number of approaches that can be adopted. The effects of radiation on plants and animals have been examined in a number of earlier reviews (e.g. NCRP, 1991; IAEA, 1988; IAEA, 1992; UNSCEAR, 1996; Woodhead, 1998), and these were used as a basis of discussion.

One of the main conclusions to emerge from the first phase of the task was that a more coherent approach was required with respect to the assessment of doses to biota and the protection of the environment from ionising radiation. It was agreed that the time was right to place the *ad hoc* research data and exhaustive reviews into a structured framework thereby providing the necessary conditions for an evolution in our understanding of the problem and a basis for the development of transparent, scientifically-based environmental protection criteria. Two working Groups were convened in quick succession (Oslo, April 1999; Stockholm, June 1999) with the aim of assessing the work conducted up to that point, both within the Concerted Action and externally, and exploring the need for further research within this scientific discipline. An outline framework plan was presented by Jan Pentreath at the Oslo Meeting as a basis for development. It was generally agreed that this provided a significant step forward in the attempts within the scientific community to structure the available information for use in environmental impact assessments for radioactive materials in contaminated areas.

2.2. The need to consider impacts of radiation on the environment explicitly.

Traditionally, radiological protection frameworks have been firmly focused on the protection of man. This has arisen, primarily, because the advisory body on such matters - the International Commission on Radiological Protection (ICRP) - has maintained a strong bias towards human health issues stating the view that "if man is adequately protected then other living things are also likely to be sufficiently protected" (ICRP, 1977). More recently a caveat has been added (ICRP, 1991) that "individual members of non-human species might be harmed but not to the extent of endangering whole species or creating imbalance between species." In most cases this tenet appears to have sufficed in protecting the environment from observable harm. This is largely due to the fact that dose limits for man are set at a low level such that the corresponding concentrations of radionuclides in the environmental pathways leading to man would be unlikely to produce effects at even the most vulnerable part of a food web. However, no evidence is given to support the ICRP statements and there is no *a priori* reason to suppose that it should always be true. This results in the regulatory bodies in many countries being left in a difficult position every time the subject of environmental protection is raised. Not only is environmental protection from radiation based on a limited number of unsupported statements, but it has been shown that the ICRP statements could be invalid in certain situations. This could happen, for example, in a situation where pathways to man do not exist, i.e., man makes little or no use of the area being contaminated, or in the case of deep sea disposal (although no longer practised) where biota could be exposed to harmful doses whilst still maintaining doses to man well below the recommended dose limits (Pentreath, 1998).

In recent years, there has been increasing pressure to explicitly demonstrate environmental protection from radiation. Internationally, the problems of radiation and/or radioactive waste are addressed in conventions on environmental protection. For example, management of radioactive substances has recently been the subject for formulation of a specific strategy within the OSPAR Convention for Protection of the Marine Environment of the Northeast Atlantic (OSPAR, 1998) and the subject is specifically addressed in conventions on waste safety, e.g. the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste

Management. The second principle of the IAEA Safety Fundamentals for the Management of Radioactive Waste (IAEA, 1995) states that, ”Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment”, applies directly to environmental protection. Several relevant documents have emerged from the 1992 UNCED Earth Summit in which a number of general principles for environmental protection have been laid down. An example is The Rio Declaration (UNCED, 1992) which emphasises in Principle 4 the issue of sustainable development , stating that ”development should take place with proper consideration of the use and maintenance of resources. Environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it.” At present, there is no internationally-accepted methodology for performing an environmental impact assessment *sensu stricto* for radioactivity and, thus, there are no means of demonstrating that the environment is, in fact, being protected from ionising radiation. This is clearly not good practice and leads to an undermining of public confidence. Finally, there is inconsistency with the environmental standards in place for other hazardous materials, such as heavy metals and organic chemicals. For these substances, specific environmental protection criteria are applied, e.g., concentration standards in specified vulnerable biota. A more consistent, integrated approach is required, whereby the total environmental impact from a site discharging both radioactive and non-radioactive substances can be assessed.

2.3. Development of a framework for assessing the impact of radionuclides in the environment.

In order to develop a coherent and logical environmental impact assessment methodology for ionising radiation, a framework, within which models can be applied and results analysed, is prerequisite. A number of components, which could form the basis of such a system, have been considered by Pentreath (1999). These include :

I. I. a set of reference organisms - clearly not all the species of organisms native to the area around a radionuclide release point can be considered; this necessitates an informed selection procedure.

II. II. a set of quantities and units to express a dose to biota. In current practice, doses are expressed in Grays per unit time. This approach clearly excludes the relativity of the biological effects arising from equal absorbed doses of different radiation types.

III. III. a reference set of dose models for a number of reference flora and fauna. Existing calculation methodologies allow the estimation of dose rates to organisms with varying geometries, e.g. (Woodhead, 1979). Consensus is required in adapting these algorithms for use within an environmental protection framework.

IV. IV. a set of dose rate-effects relationships for real examples of the reference organisms. These could include data from situations of both low exposure, e.g., cytogenetic effects, and high exposure, e.g., lethal or other deterministic effects.

Further discussions in conjunction with the International Union of Radioecology have led to the adoption of these criteria into a proposed strategy.

The choice of reference organisms could be based, amongst others, on criteria such as (a) organisms which, by virtue of environmental transfer and concentration factors, have the greatest potential for exposure; (b) organisms which have a high radiosensitivity; (c) organisms which are important to the healthy functioning of the community or ecosystem; and, (d) organisms which are common.

The proposed strategy includes 3 key components :

(a) (a) ***Exposure pathways and retention of radionuclides by biota***

The study of exposure pathways should be based on the acquisition and synthesis of information concerning the characteristics of selected ecosystems, particularly those that could be expected to influence the behaviour of radionuclides and their uptake by the biological components. Expert judgement can then be applied to the available information and knowledge of the environmental behaviour of radionuclides in the chosen ecosystems. Combined with modelling studies, e.g., the currently available equilibrium and dynamic models, the organisms likely to experience enhanced exposure can be identified. Integrating these findings with a selection based on other relevant criteria, e.g., radiosensitivity, would allow reference organisms to be defined. Finally, simple reference models can be developed for the simulation of radionuclide migration and uptake to the whole organism (and organs if applicable) for these reference species living in representative terrestrial and aquatic ecosystems.

(b) (b) ***Dose calculation***

For these defined reference organisms, corresponding radiation dosimetry models can then be developed. These could be designed to permit the estimation of the actual or potential absorbed dose-rates to the organisms, from internal and external sources of α-, β- and γ-radiation, given information on the distributions of natural and contaminant radionuclides in their local environment. The final output could be a tabulation of absorbed dose rate coefficients (Gy s^{-1} per unit radionuclide concentration in the relevant environmental compartment) for each reference organism for the radionuclides of concern in radioactive waste management. A review could be made of the approaches that have already been adopted for the estimation of radiation dose to non-human biota (largely, but not exclusively, for the marine environment) to determine if these are appropriate or can form a basis for development. If the approaches are acceptable, then they can be applied to other aquatic ecosystems in a fairly straightforward manner. Work in terrestrial environments has been less extensive than for aquatic environments. Several problems require a solution, including the development of models to account for density differences between the organism and the surrounding atmosphere. Monte Carlo methods may be required to derive dose coefficients. The requirement for additional target organs and tissues in some species could also be considered. It is to be expected that the gametogenic organs will be important targets for inclusion in the dosimetry models. The output from the dosimetry models can be given in terms of absorbed dose rate. It is recognised, however, that α-particles (high LET) are likely to be more effective in causing damage than β- and γ-radiation (low LET) for equal absorbed doses. The available information on the relative effects of these radiation types on the endpoints of concern in the natural environment could be reviewed to determine whether a sufficient basis exists to develop a dosimetric quantity corresponding to the ”equivalent dose” (absorbed dose x radiation weighting factor) employed in human radiological protection practice.

(c) (c) ***Dose (rate)-effect relationships***

Endpoints of concern in individual generic organisms could be defined and dose rate/response relationships for the chosen endpoints tabulated. This would involve the integration of data from earlier reviews and assessments of the potential impacts of radiation in the environment, of the wider radiobiological literature, and of newly-available information from Eastern Europe, e.g., papers reporting the impacts on the environment of the Kyshtym and Chernobyl accidents can be included as they become available. It is probable that the effects of radiation of interest will include, but not be restricted to, changes in morbidity, mortality, fertility, fecundity, mutation rate. The available information can be organised into a format that will indicate the approximate dose rate - response relationships and, therefore, the threshold dose rates at which minor radiation effects can currently be expected to become apparent in the defined biological processes in the selected generic organisms. An attempt could be made to quantify the intrinsic (i.e., the radiobiological) uncertainty in these threshold dose-rates (e.g., due to the extrapolation of laboratory data to natural conditions) and to indicate possible modifying influences (e.g., the influence of natural environmental variables, or interactions with other, non-radioactive, contaminants). Because it is known that ionising radiation primarily induces damage in cellular DNA (although it is not unique in this respect), and that this can be quantified as chromosome aberrations, an attempt could be made to correlate such cytogenetic damage with the degree of response in other endpoints of interest. This could then provide an indicator of radiation damage that is relatively easy to measure and monitor. The information on dose rate-response relationships will also form an input to the definition of the reference organisms.

As a result of this work, it will be possible to recommend the appropriate level in the biological hierarchy (over the range from cell to ecosystem) at which protective action should be directed. It will also be possible to propose minimum/threshold dose rates at which effects in the environment would be expected to be minimal with a high degree of confidence. Any assessment should include the sources of uncertainty in the proposed dose rates and the effects that this might have on the degree of assurance that the desired level of environmental protection could be achieved.

2.4. Present knowledge and information gaps related to the construction of an environmental protection framework for radiation

(a) (a) ***Available dosimetric models***

A selection of dosimetry models is available for the aquatic and terrestrial environments, although these are not necessarily comprehensive for the purpose of developing a framework for environmental protection. In the aquatic environment, the generic models relate to: phytoplankton, small and large, pelagic and benthic crustacea, benthic molluscs and pelagic and benthic fish. These have been developed to the point at which dose rate factors have been tabulated for a range of radionuclides at a unit concentration in seawater (Pentreath and Woodhead, 1988). Additional, more or less generic, dosimetry models in the literature relate to a seal, a whale, and a gull and its developing egg, but these have only been applied for a very limited range of radionuclides, and have not been generalised for unit radionuclide concentrations in water. In the terrestrial environment, dose conversion factors have been developed for generic exposure situations and are based on unit radionuclide concentrations in the organisms, and on unit radionuclide concentrations in the surrounding air, water, soil/sediment, or vegetation (Amiro, 1997). The assumptions and geometries adopted in this approach were deliberately set to be conservative. It is envisaged that future work would be in the development of the dosimetry models, and the associated dose conversion factors, that relate directly to the reference organisms (and their local environment) chosen as indicated above.

(b) (b) ***Effects of radiation on native wild plants and animals***

The effects of radiation on plants and animals have been reviewed many times from the perspective of assessing the potential impacts of radioactive waste disposal (e.g., IAEA, 1976, 1988,1992; NCRP, 1991; UNSCEAR, 1996) and there is no requirement to repeat this exercise. The present need is to structure this information so as to identify the levels of dose rate at which different degrees of damage might be produced in the endpoints of interest (e.g., mortality, fertility, fecundity, mutation rate, etc.) in the chosen reference organisms.

3. Conclusion

The extensive literature review and evaluation conducted in the first part of this action led to the conclusion that a framework was urgently required in order to structure the knowledge derived from earlier studies. The second part of the action has therefore involved a preliminary development of an environmental radiation protection system, which could be adopted in order to direct future scientific research. The key components of the framework include the derivation/development of relevant quantities and units, reference organisms, environmental transfer models, reference dosimetric models and tabulated dose rate/effects information for reference organisms. The final system would allow regulators to explicitly and transparently demonstrate a commitment to environmental protection and provide a basis for developing standards against which to test for compliance for current and future radioactive waste management practices.

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