TA2 Radiological Protection Systems and Regulation
(Protection of non-human species and the environment)

COMPARATIVE EVALUATION OF DIFFERENT APPROACHES TO ENVIRONMENTAL PROTECTION AGAINST IONISING RADIATION IN VIEW OF PRACTICABILITY AND CONSISTENCY

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Introduction

International organisations, including ICRP, IAEA and UNSCEAR, and the international scientific community are currently engaged in work on the protection of non-human species against ionising radiation as a complement to the existing framework centred on humans. The basic ideas and conceptual approaches developed during the last decade substantially agree with each other. The EC funded FASSET project (Framework for Assessment of Environmental Impact) summarizes and reviews the current knowledge of radiation effects on biota, provides basic dosimetric models for fauna and flora and suggests an assessment framework [1].

Protection of the environment against ionising radiation, on the one hand, aims to close a conceptual gap in radiation protection. Therefore, current frameworks for environmental protection conceptually follow radiation protection of man. On the other hand, preservation of natural resources, habitats and the biological diversity are common objectives of environmental protection against radioactive as well as chemical pollutants, suggesting an integrated approach based on the fundamental ideas of conventional environmental protection.

In essence, a conceptual framework encompassing protection of man as well as of fauna and flora against chemical and radioactive pollutants would be highly desirable in view of coherence, consistency and transparency. Such an umbrella concept communicates the positive message that similar issues are treated in a conceptually similar manner, thus facilitating scientific justification and public communication and increasing acceptance.

This paper discusses different concepts and approaches to radiation protection of man, radiation protection of non-human biota and environmental protection against chemical pollutants, identifies common principles and differences, addresses conflicting requirements and evaluates the feasibility and limitations of such an encompassing framework.

Conceptual approaches to environmental protection

The current approaches to environmental protection can broadly be grouped in three categories. These are

- *based on concentrations of potentially harmful substances in environmental media with no observable effects on biota,*
- *based on natural background levels of contaminants and their variability or*
- *related to discharges, e.g. pollution prevention or minimisation.*

Since the last category is essential for human protection, adequate strategies and techniques to reduce discharges have been highly developed. Hence, the further discussion is restricted to the first two categories.

It is important to acknowledge that the concepts and methodologies of environmental protection against chemicals and ionising radiation are at markedly different developmental stages. Moreover, radiation protection was centred on humans until recently and biota have only indirectly been protected against radioactive contaminants as far as human needs were concerned [2]. A conceptual framework of radiological protection of the environment should ideally follow the sophisticated strategies in the fields of radiation protection of man and conventional environmental protection against chemicals.

Object of protection

Protection of the environment against harmful substances, both chemicals and radioactive material, clearly applies to biota. Since there are no adverse effects specific on abiotic environmental components, concentration levels of hazardous substances in these media should only be regarded as indicators of potential exposures of animals and plants [3]. Nevertheless, it has been stated that human impact on the abiotic part of the environment should specifically be considered [4]. Although there is no convincing justification to protect the abiotic environment beyond the needs of man and non-human species, the proposed approach may be interesting in order to detect slow increases in general background levels of long-lived radionuclides well before they may reach levels of potential concern.

Level of organisation to be protected

The aim of conventional environmental protection is generally accepted to be achieved, if there are no observable effects on ecosystems at the population level or higher levels of organisation. Nevertheless, the potential harm of a contaminant is often quantified on the basis of adverse effects on individual organisms [5]. This approach was chosen for practical reasons. In most cases ecological stressors influence communities of animals and plants more strongly than potentially harmful substances at low concentrations. The interactions of adverse effects on the individual and population level are very complex and difficult to quantify.

The same strategy has been applied to environmental protection against radioactive contaminants [1, 3, 6]. Since adverse effects due to ionising radiation have mainly been studied for individuals, most conceptual approaches focus on adequate protection of individual organisms. It is virtually impossible to quantify the effects of chronic irradiation at low dose rates on the population or ecosystem level.

Environmental radiation protection is currently based on the hypothesis that adverse effects on higher levels of biological organisation only occur, if effects on individual organisms can be observed. Even if this hypothesis is accepted, there remains a conceptual dilemma. Under unfavourable ecological conditions natural exposure levels may lead to observable effects on individual organisms [7]. The finding that radiation exposures of biota may exceed the range of no observable effects on the individual level, even in ecosystems unaffected by man, should have consequences as to dose rate criteria for environmental protection. This will be the focus of our discussion.

The pristine environment

The pristine environment, although virtually not existent in inhabited areas, conceptually plays a major role for environmental protection. From the point of view of conventional environmental protection there is no call for action, if an ecosystem is unaffected by man, irrespective the type and impact of any potentially harmful substance. Applying this basic principle to radionuclides and ionising radiation in general, any human action to reduce the exposure of living organisms is not justified in an ecosystem with negligible human impact. Such idealised ecosystems have frequently been used as a benchmark for sufficient environmental protection against chemical pollutants as well as ionising radiation.

Suggested and implemented approaches for environmental protection

Environmental protection against chemical and radioactive pollutants primarily aims at protecting populations and/or whole ecosystems. As already discussed, the conservative approach to protect biota on an individual level against ionising radiation has been chosen for practical reasons. Considering the immense diversity of species, adequate protection of non-human biota can only be demonstrated for a limited number of reference organisms which are regarded to be representative for an ecosystem [1, 3, 6, 8]. The selection of reference organisms is based on habitat and feeding habits, bioaccumulation and biomagnification. Using radioecological models and simplified dosimetric models, the potential exposure of reference organisms can be calculated and compared to dose rate levels ('thresholds') below which no observable effects are expected to occur. Relevant endpoints include mortality, morbidity, reproductive success and mutation. The approach based on reference organisms agrees largely with the concept of reference man internationally accepted for human radiation protection. It is important to acknowledge that these 'reference approaches' are based on abstract standardised humans, animals and plants. They do not aim at assessing adverse effects due to ionising radiation on really existing individuals.

The approach to protect non-human species against ionising radiation suggested by FASSET and ICRP is conceptually similar to environmental protection against hazardous chemicals. As an example the guidelines for chemical safety published by OECD will be discussed, since these are internationally agreed standards which have been implemented in assessment procedures and legal regulations in many countries. The chemicals testing *guidelines of OECD consider various aspects of potentially hazardous chemicals, including ecotoxicological effects [5]. These standardised test procedures, in most cases laboratory experiments, aim at deriving acceptable levels of a contaminant in environmental media. The test organisms used as bioindicators cover different levels of the trophic chain (producer, primary consumer, secondary consumer, destruent). These are, for example, algae, water fleas, fish and bacteria for aquatic ecosystems. The ecologically relevant endpoints include growth and growth inhibition, acute and prolonged toxicity and reproduction. Environmental quality in general and critical loads of relevant environmental media are assessed on the basis of the No Observable Effects Concentration (NOEC) for the most sensitive test organism, i.e. the organism with the lowest NOEC. The results of laboratory experiments are often converted to field conditions by applying safety factors.*

Regarding geogenic substances including heavy metals, the approach described above is usually extended. In these cases test data are often compared with natural background levels of the contaminant. The quality objective is then based on both toxicity/ecotoxicity of the substance under consideration and its typical natural levels in an ecosystem.

Numerical criteria for environmental protection against ionising radiation

Current numerical criteria for protecting living organisms against ionising radiation usually relate to dose rates, either explicitly, if based on exposure levels with no observable effects on sensitive animals and plants, or implicitly, if derived from natural radionuclide concentrations in environmental media and their variability.

Dose criteria

The appropriate quantity to address adverse effects of ionising radiation on non-human species is dose or dose rate, more precisely the total dose or dose rate due to all relevant sources. A separate treatment of natural and artificial radionuclides, as sometimes discussed in connection with environmental protection issues, is considered to be inappropriate. However, it might be helpful to distinguish the natural background level of ionising radiation and the exposure increment caused by human activities. As pointed out previously, the chronic low-dose exposure of biota in an ecosystem unaffected by man is a benchmark for exposure levels which do not justify any action from a point of view of radiation protection.

Essentially two conceptually different dose criteria for protecting non-human species against ionising radiation are discussed in literature. The criteria relate either to the total dose to individual organisms or to the dose increment due to human action. The acceptable exposure of biota is usually chosen as the highest dose rate with no observable effects on animals and plants. The available information on the effects of chronic irradiation at low dose rates is reasonable for plants, fish and mammals, but is scarce or not existing for other wildlife groups. The dose rate limits suggested by NCRP [9], IAEA [10] and UNSCEAR [11] are 40 µGy $\cdot$ h^{-1} (350 mGy $\cdot$ a^{-1}) for terrestrial *animals and 400 µGy · h^{-1} (3 500 mGy · a^{-1}) for terrestrial plants and aquatic organisms. Exposure of biota at these dose rates may have detectable effects on some individuals, but detrimental effects at the population level are not expected to occur. It is essential to acknowledge that these derived dose rate limits are not based on risk in contrast to the radiation protection concept of humans.*

At present, the database FRED (FASSET Radiation Effects Database), created within the European research project FASSET, is the most comprehensive collation of information on radiation effects on plants and animals [12]. Entries are grouped according to the endpoints of morbidity, mortality, mutation and reproductive capacity. Based on the available fragmentary information it has been concluded that the threshold for statistically significant effects in most studies is about 100 µGy · h^{-1} (880 mGy · a^{-1}), although minor effects may be seen in the most sensitive species at lower dose rates. It is interesting to note that the FRED data do not clearly support different dose rate thresholds for mammals and other species as previously suggested [13]. For both plants and fish there are occasional observations where effects have been detected at dose rates below 400 µGy · h^{-1} and even a few at tenfold lower dose rates. Moreover, the FRED database does not report adverse effects on non-human mammals arising from chronic irradiation at dose rates lower than 100 µGy · h^{-1}. Based on the present knowledge a dose rate in the order of 40 to 100 µGy · h^{-1} (350 to 880 mGy · a^{-1}) appears to be a reasonable threshold for observable adverse effects due to chronic irradiation of biota.

In most cases radiation exposure due to natural sources is well below the dose rate threshold for observable effects. It is important to recognize that the natural exposure might exceed this level under unfavourable ecological conditions. For small burrowing mammals living in soil with high radon levels lung doses up to 700 mGy · a^{-1} have been reported for an average radon level of 10 000 Bq · m^{-3} in subsurface air [7]. Lung doses were estimated from the dosimetric model for humans which was extrapolated to small mammals taking into account species specific respiration rates and periods of hibernation and activity. Highest lung doses were calculated for a species with a high respiration rate and a high proportion of activity time in the burrow [7]. The whole-body dose due to radon inhalation was estimated from the mass of the lung and the mass of the whole body, assuming that dose to lung is the major contributor to whole-body dose in the small mammals investigated. It was concluded that whole-body doses exceeding 100 mGy · a^{-1} may be common for small mammals [7].
Average radon levels of 10 000 Bq · m^{-3} in subsurface air have been reported to be representative for some areas in Canada, but can easily be exceeded in other regions. In Germany, for example, 1.6% of the surface area exhibits radon levels in soil at a depth of 1 m higher than 150 000 Bq · m^{-3}, corresponding to a whole-body dose to small burrowing mammals of more than 1.5 Gy · a^{-1}. The whole-body dose is expected to surpass 1 Gy · a^{-1} on about 6% of the German territory. Such high exposures exceed the threshold for observable effects as derived from the FRED database. Radiation exposure arising from natural sources may lead to observable effects on individuals, even if the ecosystem is not affected by human activities. Obviously, in such

situations the threshold of no observable effects for the whole-body dose rate is not a suitable criterion to demonstrate the protection of the biotic environment.

Some approaches, e.g. [6], do not consider radiation exposure of biota arising from natural sources but use the increment resulting from human activity. It has repeatedly been pointed out that the natural background of radiation exposure is no argument to justify an additional anthropogenic exposure. Nevertheless, the mere existence of a stable population in an ecosystem demonstrates that potentially adverse effects due to ionising radiation play only a minor role compared to other environmental stressors. An acceptable anthropogenic dose rate increment has been inferred from the small-scale variation of natural exposure, but can also be derived from the standards of radiation protection of man. Radiation protection of individuals of the general population usually considers only the enhancement of radiation exposure arising from practices or other human activities, an exception being the WHO drinking water guideline [14]. In most exposure situations a dose increment of 1 mSv · a^{-1} is accepted to adequately protect individuals of the public. As long as there is evidence that humans are the most radiosensitive mammals, the acceptable incremental dose to biota due to human activity should not be chosen lower than 1 mGy · a^{-1}. The criterion of 1 mGy · a^{-1} for environmental protection was used, for example, in the concept for the disposal of spent nuclear fuel in Canada [6].

In summary, a two-step dose criterion might be appealing, combining the concept of total whole-body dose rate with no observable effects on biota and an acceptable anthropogenic increment. If the whole-body dose rate to biota is below a threshold above which observable effects on living organisms are expected to occur on the individual level, non-human species are considered to be adequately protected according to the current knowledge of the dose-effect relationship of animals and plants. If the whole-body dose exceeds this threshold, the dose increment arising from human activity should not exceed a pre-defined level of 1 mGy · a^{-1} or higher.
As discussed earlier, present information will indicate a value of 40 to 100 µGy · h^{-1} (350 to 880 mGy · a^{-1}) for such a threshold. It is essential, however, to acknowledge the limited quality of the data basis. The available information on the effects of chronic irradiation at low dose rates is scarce or not existing for wildlife groups other than plants, fish and mammals [13]. Most results for animals have been obtained from laboratory experiments with moderate exposure times. Moreover, minor effects on animals and plants have been observed in the most sensitive species at dose rates below the threshold mentioned above [13]. In view of the fragmentary nature of data and the numerous knowledge gaps identified by the scientific community, it seems to be adequate at present to apply safety factors for assessment purposes, resulting in a lower allowable whole-body dose rate to living organisms.

Natural variability of radionuclide concentrations

The pristine environment, although virtually not existent in inhabited areas, conceptually plays a major role for environmental protection, since such an ecosystem does not warrant any human action to reduce radiation exposure of *biota. Natural levels of radionuclides, more general the resulting chronic exposure of living organisms, have been proposed as a criterion for adequate environmental protection. Such an approach seems to be obvious in situations where the levels of naturally occurring radionuclides are modified by human action. ICRP proposed to derive consideration levels based on average background levels of dose rate to reference organisms and their ranges [3]. An incremental annual dose in the range of natural exposure levels or lower is suggested to indicate low concern with no human action being considered. If the anthropogenic dose rate increment exceeds ten times the natural background, concern should arise dependent upon various factors, such as nature of effects, spatial and temporal aspects, numbers and types of individuals affected etc.*

As has already been pointed out, dose rates due to natural levels of radionuclides may already lead to observable effects on biota under unfavourable ecological conditions. The mere existence of stable populations in such an ecosystem demonstrates that potentially adverse effects due to ionising radiation play only a minor role compared to other environmental stressors. However, it is in no way evident that a tenfold increase without considering any remedial efforts is justified. The local small-scale variation of natural radiation exposure of biota might be a more appropriate measure of acceptable anthropogenic exposure increments. From a practical point of view, however, it should be emphasised that any criterion based on local natural exposure levels of living organisms and their variability would probably require substantial efforts to obtain the relevant data.

Conclusions

Although still at a developmental stage, radiation protection of living organisms conceptually agrees in many respects with radiation protection of man and environmental protection against hazardous chemicals. A conceptual framework encompassing protection of man as well as of fauna and flora against chemical and radioactive pollutants is highly desirable in view of coherence, consistency and transparency, communicating the positive message that similar issues are treated in a conceptually similar manner. ICRP has formed the new Committee 5 to further develop principles for the radiological protection of the environment. This committee will particularly aim to ensure that the development and application of approaches to environmental protection are compatible with those for radiological protection of man and with those for protection of the environment from other potential hazards.

Environmental protection against ionising radiation currently suffers from many gaps in scientific knowledge, including dosimetry of biota, impact of ionising radiation on living organisms and the fate of many radionuclides in the environment. The efforts of the ERICA consortium to check the practical applicability of the assessment framework in a road test at an early developmental stage is well appreciated. However, a dose rate criterion solely based on exposure levels with no observable effects on individual organisms is not convincing. It may be exceeded even in ecosystems unaffected by man under unfavourable ecological conditions. It is therefore suggested to apply a *two-step dose rate criterion, combining both exposure levels with no observable effects and acceptable anthropogenic dose rate increments.*

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