THE REPORT ON "EFFECTS OF RADIATION ON THE ENVIRONMENT" FROM UNSCEAR

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« LES EFFETS DES RAYONNEMENTS IONISANTS SUR L'ENVIRONNEMENT » RAPPORT DE L'UNSCEAR

RÉSUMÉ

Le Comité scientifique des Nations Unies sur les effets des rayonnements ionisants, UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), a conclu, à la suite de certaines inquiétudes exprimées, qu'il serait opportun de faire effectuer une étude indépendante sur :

- la situation actuelle de l'exposition aux rayonnements ionisants de l'environnment naturel; et
- les données disponibles pour évaluer l'impact potentiel sur l'environnement d'une augmentation de cette exposition, suite à des activités humaines.

Le rapport final sera bientôt publié, et le présent exposé fournit un bref résumé des résultats d'importance majeure, et donne ses principales conclusions.

ABSTRACT

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) concluded, in response to some expressions of concern, that it would be opportune to provide an independent examination of:

- the current situation regarding the radiation exposure of the natural environment; and
- the basis available for assessing the potential impact on the environment of incremental exposures from human activities.

The final report is about to be published and this paper gives a brief summary of the important points and conclusions.

1.0 INTRODUCTION

This report [1] has been produced by UNSCEAR in response to the recognition that there was continuing public, and some scientific, concern about the potential effects of increased radiation exposure from human activities on native wild organisms. This was particularly the case for controlled waste disposal to the environment where, although there have been no reports of deleterious effects, the priority given to protecting human health, as distinct from explicitly limiting the potential impact on environment, has been questioned [2,3]. There had been a number of studies of specific situations, e.g. freshwater and terrestrial environments [4-6], the deep ocean [7] and coastal waters [8], and the Committee considered that it would be appropriate to carry out an independent review and produce a summary of the present understanding of the impact of ionizing radiation on plant and animal populations in natural and contaminated environments.

It was accepted that the results of the previous specific studies would provide a part of the source material, as would the Committee's earlier summaries of the radiobiological work carried out over the last 50 years. It was also concluded, however, that an exhaustive review of all the potentially relevant literature would not be possible. An attempt was made, nevertheless, to include rather more of the environmental information available from the former Soviet Union than had hitherto been the case (20% of the references are from the Russian literature) and to take particular account of data that had been collected from the areas contaminated by the accidents in the southeastern Urals in 1957 and at Chernobyl in 1986.

The objectives of the document were to summarize and review information on:

a) the radiation exposures (actual or potential) received by organisms in their natural habitats from the natural background, from radionuclides released to the environment in a controlled manner from industrial activities, and from radionuclides released as a consequence of accidents; and

b) the responses to acute and chronic irradiation of plants and animals, both as individuals and as populations.

The resulting document could, therefore, provide a basis for the development of appropriate criteria for the radiological protection of natural populations, communities and ecosystems.

2.0 DOSIMETRY

Accurate, and reasonably precise, estimates of the radiation dose rate and integrated dose are a necessary requirement for any assessment of the potential or actual impact of increased radiation exposure from contaminant radionuclides in the environment. Such data are also required for the natural background — to provide a context and perspective for the incremental radiation exposures from contamination — and for laboratory studies so that accurate dose-response relationships may be generated. It is rarely possible to acquire these data directly from simple instrumental measurements except in the case that γ- or x-rays are employed in a field or laboratory study; and it is clearly impossible in the pre-operational phase of a proposed disposal practice. Additional difficulties arise if any of the following factors are involved: the dose rate is very low; the organism of interest is small; the dose rate to a specific organ or tissue is required; and α- or β-particles are a major source of dose, from either external or internal contamination. In these circumstances, it is necessary to resort to the use of dosimetric modelling.

The available approaches to dose rate estimation for terrestrial and aquatic plants and animals, and their necessary underlying assumptions, have been summarized. For most approaches, the assumptions arise from the difficulty of obtaining all the required data on the radionuclide distributions, both within, and external to, the organism and their variation over time, the energy distribution of the radiation field incident on the organism, and the geometry of the relevant target, ie the organ, tissue or organism of interest. It was concluded that these factors, rather than the difficulties of developing sufficiently complex dosimetry models, contributed most to the imprecision of dose rate estimates.

In situations where α-particles make a substantial contribution to the absorbed dose, an additional difficulty was identified. The certainty that a given absorbed dose from α-radiation would produce more damage than an equal absorbed dose of either β- or γ-radiation (there was sufficient evidence from animal experiments in the radio-biological literature to support this position) means that some way of combining the absorbed doses from radiations giving different microscopic distributions of ionization density is required. In human radiological protection, where stochastic effects are of concern, this is taken into account through the use of the equivalent dose defined as:

$$\text{equivalent dose (Sv)} = \text{absorbed dose (Gy)} \times \text{radiation weighting factor}$$

and the weighting factor has the value 20 for α-radiation. In many previous assessments of the potential impact of incremental radiation exposure on the environment (eg [7,8]) an identical procedure has been adopted, with estimates of the biologically effective dose rates given in Sv units, although it was recognised that this approach was open to argument. The Committee concluded that it was unlikely that stochastic effects would be of great significance in the environment (see below) as compared with deterministic effects and that the value of 20 for the α-radiation weighting factor would not, therefore, be applicable. A lower α-radiation weighting factor of 5 was suggested as probably being more appropriate for the deterministic effects considered likely to be of importance for wild organisms. In order to avoid any possible confusion, however, the Committee decided to assess and specify the absorbed dose rates (in Gy) from low linear energy transfer (LET) radiations (β -particles, x-rays and γ-rays) and high-LET radiations (α-particles) separately. It was considered advisable to retain this approach until dosimetric concepts and quantities, corresponding to the equivalent dose and the Sv unit that have been specifically defined for human radiation protection, had been developed for wild organisms.

The available data on absorbed dose rates to terrestrial and aquatic, plants and animals, from both the natural background and contaminant radionuclides, have been reviewed and summarized; in certain specific instances, the estimates of absorbed dose rate were developed, *de novo*, by the Committee.

2.1 Radiation exposures from the natural background.

For the natural background, α-radiation was found, in many instances, to make a substantial contribution to the total absorbed dose rate. In the case of terrestrial plants, the major sources were radon taken up, along with water, by the roots, and the daughters subsequently produced in the plant tissue; the estimated total absorbed dose rate, in areas of normal background, amounted to 0.07-0.8 μGy h^{-1}. For freshwater phytoplankton the major source appears to be ^{222}Rn and its decay products in the surrounding water and for marine phytoplankton, ^{238}U, ^{234}U, and ^{228}Th and its decay products accumulated in the cells; for these small organisms, for which the estimated total background absorbed dose rate was less than 0.1 μGy h^{-1}, it was noted that the dose rates must be interpreted with care due to the stochastic nature of the decay process. There are rather few data for terrestrial animals, but ^{222}Rn (plus decay products) and ^{210}Po are significant contributors to the total exposures for burrowing (0.2 μGy h^{-1}) and surface-living species (0.12 μGy h^{-1}), respectively. In local areas of uranium and thorium mineralization the total absorbed dose rates could be up to a factor of 10^3 higher (this would also apply to plants). In the marine environment, the total exposure from the natural background is normally less than 0.33 μGy h^{-1} with benthic organisms at the upper end of the range, but ^{210}Po is frequently a significant contributor to the total radiation dose and certain pelagic species of fish and shrimp can receive several μGy h^{-1} to the gonads from this source.

In summary, the total absorbed dose rate to organisms in their natural habitat normally ranges up to ~1 $\mu Gy\ h^{-1}$, but in some limited terrestrial areas could range as high as 2 10^2 $\mu Gy\ h^{-1}$; in all situations, high-LET α-radiation delivers a substantial proportion of the total absorbed dose rate.

These findings emphasize:

a) the importance of developing an appropriate means of quantifying, in a single measure, the biologically effective dose rate from combinations of low-LET and high-LET radiations (as noted above); and

b) the requirement for detailed information concerning the distribution of the α-emitting radionuclides relative to potential targets for inclusion in realistic dosimetry models.

2.2 Radiation exposures from contamination from controlled waste disposal.

The incremental radiation exposures of wild organisms from the practice of controlled waste disposal to the environment are, inevitably, site specific. In addition to the radionuclide composition of the waste, the nature of the receiving environment, and particularly, the presence and strength of dispersal and reconcentration mechanisms, will influence the potential radiation exposure of wild organisms. Generic assessments have been made for unit releases of noble gas isotopes to the atmosphere and it appears that, under normal routine operating conditions, the incremental radiation exposures of terrestrial plants from this source are unlikely to exceed the variability (and uncertainty) in the estimate for the background exposure. For releases of other radionuclides to the atmosphere such that, for average human use of the local environment for food production, drinking water collection and leisure, the resulting dose rate reaches the limiting value of 1 $mSv\ a^{-1}$, the absorbed dose rates to terrestrial plants and animals have been estimated to range up to 40 $\mu Gy\ h^{-1}$. For releases to aquatic systems from routine operations, the dose rates to phytoplankton and macrophytes can range up to 20 $\mu Gy\ h^{-1}$; for potential inputs leading to a projected human exposure of 1mSv a^{-1} from water and fish consumption, the estimated absorbed dose rates to fish range up to 70 $\mu Gy\ h^{-1}$, and to aquatic macrophytes, up to 10^3 $\mu Gy\ h^{-1}$. In the latter case, the highest exposures were shown to arise from α-radiation; there were, however, considerations that led to the conclusion that these projected dose rates were likely to be over-estimates.

In aquatic environments, it has been consistently shown that benthic organisms are likely to be the most highly exposed due to the accumulation of β- and γ-emitting radionuclides by the under-lying fine sediments. This was the case for the discharge to the northeast Irish Sea from the nuclear fuel reprocessing plant at Sellafield where it was estimated that the dose rate to a benthic fish (the plaice, *Pleuronectes platessa*) from the seabed contributed over 99% of the total exposure from the contaminant radionuclides. With dose rates estimated to be up to 50 $\mu Gy\ h^{-1}$, and above the natural background over an area of approximately 4 10^3 km^2, it was considered feasible to attempt direct measurements with LiF thermoluminescent dosimeters attached to the fish. This approach was successful, and the maximum dose rates measured (~24 $\mu Gy\ h^{-1}$) were of the same order (within a factor of two) as that estimated although it was clear that the natural behaviour of the fish (migration and swimming off the bottom) substantially reduced the average dose rate experienced by the population. The individual dose rates showed a log-normal distribution and the mean dose rate to the gonad was estimated to be ~ 2 $\mu Gy\ h^{-1}$.

In summary, the absorbed dose rates estimated for organisms in contaminated environments are generally less than 10^2 $\mu Gy\ h^{-1}$, but could, exceptionally, reach ~10^3 $\mu Gy\ h^{-1}$.

2.3 Radiation exposures in the environment following accidents.

Each accident is, by its very nature, unique, but the property that distinguishes them from controlled disposal operations is their potential to produce high dose rates in the environment. This was the case for the two accident situations that have received the most intensive study from an environmental viewpoint, ie the explosive release of reprocessing waste in the southeastern Urals in September 1957 and the Chernobyl reactor accident in April 1986.

The release in the southeastern Urals was dominated by the short-lived radionuclides ^{144}Ce-^{144}Pr (~66%; $T_{1/2}$=285d) and ^{95}Zr-^{95}Nb (~25%; $T_{1/2}$=65d) with ^{90}Sr-^{90}Y making up the greater part of the remainder. The deposition density was such that initial dose rates in excess of 10^4 (and up to 8 10^5) µGy h^{-1} could have been received by many plants and animals in a local area of 120 km^2, with total absorbed doses to the dormant buds and seeds of herbaceous plants in the soil surface layer ranging up to 2 10^3 Gy over 100 days in the immediate vicinity of the release point. These dose rates and total doses were effectively acute ie the total doses were delivered in times that were less than, or comparable to, the time taken for severe damage to become apparent. Over time, the radionuclides have become relocated from the forest canopy, initially to the litter layer on the forest floor, and from there to the surface layers of the soil. With the decay of the short-lived radionuclides, ^{90}Sr-^{90}Y became the main source of effectively chronic radiation exposure; this continues to the present day with dose rates less than ~1.5 10^2 µGy h^{-1} to herbaceous plants.

The release from the Chernobyl reactor accident was extended over a period of about 10 days and contained many more radionuclides than was the case in the southeastern Urals including a significant proportion with half-lives less than 15 days. The initial dose rates in the immediate vicinity of the power station were such that total doses up to 10^2 Gy were delivered to trees (and, by inference, to most other organisms in the locality) within a few days, in large part from short-lived radionuclides (^{133}Xe, ^{131}I and ^{99}Mo) in vapour clouds. Again, this phase of the irradiation of the natural environment can be classified as acute and it lasted for 10-20 days after the accident. A second phase extended over about 6 months with dose rates at the soil surface less than ~5 10^4 µGy h^{-1}. In the third, and continuing, phase the major sources of exposure have been ^{134}Cs and ^{137}Cs with chronic irradiation at dose rates now generally less than ~10^2 µGy h^{-1}.

The environmental consequences of the southeastern Urals and Chernobyl accidents have been such that the native organisms have been irradiated at higher chronic dose rates over larger areas than have ever resulted from controlled waste disposal.

2.4 Summary

The ranges of absorbed dose rates to wild plants and animals from the natural background, from contamination following controlled radioactive waste disposal and as a consequence of accidental releases form an overlapping and increasing hierarchy. For the purpose of assessing the impact on the environment of the practice of controlled radioactive waste disposal, information is required on the responses of plants and animals to long-term chronic irradiation at absorbed dose rates up to 10^3 µGy h^{-1}. Such information can be obtained from laboratory and field studies utilising controlled sources of radiation, and from studies in the localities affected by accidental releases of radionuclides.

3.0 The Effects of Radiation on Plants and Animals

All extant species of plants and animals have evolved under the influence of the natural background radiation field and, as is the case for humans, it is to be expected that an increase in the degree of radiation exposure would entail some increased risk of deleterious effects. In human radiological protection it is the incremental individual risk from increased radiation exposure that must be constrained below some level that society judges to be acceptable; this level of acceptable additional risk, while small, is not zero. For the vast majority of non-human organisms, it is the populations that are valued, and protection of these from increased risk from incremental radiation exposure might be an appropriate objective. General exceptions might be made for populations of small size (rare species) and those that reproduce slowly (long generation times and/or low fecundity) where it might be more appropriate to target protective measures at the level of the individual organism. There are, therefore, likely to be differences in the responses that are important for the assessment of actual or potential impact.

If it is accepted that the population is the object of protection, a relevant definition of a population is required so that an assessment of risk and/or impact may be made. The Committee adopted the following as a working definition:

"A population is a biological unit for study, with a number of varying statistics (eg number, density, birth rate, death rate, sex ratio, age distribution), and which derives a biological meaning from the fact that some direct or indirect interactions among its members are more important than those between its members and members of other populations."[9]

Such a population would be (or potentially, could be) a self-sustaining unit that is more or less independent of other, geographically separated, populations of the same species, and protection would be achieved if those attributes (ie those given in the definition) upon which the population depends for maintenance within its normal dynamic range of variation are unaffected by the incremental radiation exposure. Although these attributes can only be defined for populations, they are the integrated outcome (but not the linear sum) of processes that operate at the level of the individual, and it is certain that there can be no radiation-induced effects at the population level (or at the higher community or ecosystem levels) unless there are effects in the individual organisms comprising the different constituent populations. The ultimate objective of protection of the population may be achieved, therefore, by preventing any radiation impact on these processes. This has naturally led to the conclusion that the individual responses to chronic, low dose rate irradiation that are likely to be significant at the population level are effects on:

- mortality (affecting age distribution, death rate and density);
- fertility (birth rate);
- fecundity (birth rate, age distribution, number and density); and
- the induction of mutations (birth rate and death rate);

and it should be noted that these responses are deterministic in nature (except, possibly, for mutations) in contrast to the situation in human radiological protection. In addition to intrinsic factors (eg rapid cell division) affecting radiosensitivity, it was concluded that there could also be extrinsic influences that would modify the response to irradiation; these would include natural factors, eg season,temperature etc, and the presence of other stresses of human origin, eg other, non-radioactive, contaminants.

It may be noted that this conclusion also identifies the relevant targets for which dose rate estimates are required, ie the whole body (and particular tissues if it is known that high accumulations of specific radionuclides can occur), the developing embryo and the gonads.

3.1 The effects of chronic, low-level irradiation on plants.

Although the available data on the effects of acute irradiation on plants are not directly relevant to assessments of the potential impacts of waste disposal, they have been considered in the report for the light that they might shed on the relative radiosensitivities of the different processes identified as being important for the maintenance of populations. For coniferous species, viable seed production and growth inhibition in meristems were more sensitive indicators of radiation damage (at least, in the short term) than mortality. Acute irradiation rendered pine trees susceptible to insect attack and radiosensitivity was increased when other environmental stresses were present. In cultivated and pasture crops the primary measure of effect has been the reduction in yield. On this basis seed crops, eg cereals, are generally more radiosensitive than vegetables, eg onions and radishes, and the purely vegetative pasture and forage crops show the lowest sensitivity.

Many of the data on the effects of long-term irradiation on plants that have been reviewed in the report have been obtained from field experiments in which a large sealed source of γ-radiation has been mounted in a forested area or in open grass-land. Many of the studies have been of long duration (up to 11 years), and the main end point considered has been the loss of viable plants, ie effectively, mortality. Although the ranges of radiosensitivity overlap, the general order of increasing radioresistance is:

coniferous trees, deciduous trees, shrubs, herbaceous species, lichens and fungi.

A few data indicate that the production of viable seed is at least as sensitive an indicator of radiation damage as mortality. Again, it has been observed that irradiation makes trees (white oaks) prone to insect attack and that additional environmental stresses are likely to increase radiosensitivity.

Overall, the Committee concluded that dose rates less than 4 10^2 μGy h^{-1} would have only slight effects on the most radiosensitive plants but would be unlikley to produce significant deleterious effects in the wider range of species present in natural plant communities.

3.2 Effects of chronic low-level irradiation on terrestrial animals.

A more voluminous literature exists for terrestrial animals than for plants. For mammals in particular, the Committee found that there was sufficient information to provide the basis for brief reviews of the effects of irradiation on mortality, reproductive capacity, the developing embryo and the induction of somatic and hereditary mutations.

The available information is consistent in indicating that mortality is the least radiosensitive response to acute irradiation and that continuing protraction of the exposure increases the total dose required to produce a 50% mortality.

Gametogenesis appears to be the most radiosensitive process in a number of mammals. A dose rate of 1.3 10^2 μGy h^{-1} to neonatal mice from tritium produced a 50% reduction in the number of immature oocytes. In juvenile female mice exposed to tritiated water for 10 days, a dose rate of 6.7 10^2 μGy h^{-1} reduced the number of primary oocytes by 80% and a value of 2 was estimated for the RBE value relative to ^{60}Co γ-rays. The resting oocytes in older animals have, however, been found to be less radiosensitive. In long-term experiments, in which mice of four different strains were exposed to absorbed dose rates of 5 10^{-2}-10^3 μGy h^{-1} for ten generations, the fertility, as measured by the average size of the first litter in each generation, was unaffected. This result is not necessarily inconsistent with the apparent radiosensitivity of the immature oocytes noted above because, in most mammals, more immature oocytes are produced than can eventually be utilized for reproduction. In young mice, an α-radiation dose rate of 1 μGy h^{-1} from ^{210}Po accumulated in the ovary produced a significant (21%) reduction in the survival of primary oocytes; a comparison with the effects of γ-radiation gave an estimate of over 370 for the RBE. In male mice, a mean absorbed dose rate of 36 μGy h^{-1} over a period of 5-8 months to the testes from ^{239}Pu α-radiation reduced sperm output by 8%, and an RBE of 10-15 was estimated relative to ^{60}Co γ-rays. In male beagle dogs, a γ-ray dose rate of 1.8 10^2 μGy h^{-1} produced progressive spermatogonial cell depletion and sterility within a few months, but exposure at 36 μGy h^{-1} over the whole life elicited no response.

Although a number of effects can be produced by chronic irradiation during embryonic development, the immature gonads appear to be the most radiosensitive cell system. In the squirrel monkey, absorbed dose rates as low as 2 μGy h^{-1} from tritium exposure from conception to birth produced a 50% reduction in the number of developing oocytes. Female mouse embryos exposed to tritium for 14 days from conception showed significant reductions in the number of primary oocytes at a dose rate of 10 μGy h^{-1}. Although no data were found for embryonic males at such low dose rates, at the higher dose rate of $4.2\ 10^2$ μGy h^{-1} over the whole of the gestation period, the germ cell numbers were reduced by greater percentages in the male pig, guinea pig, rat and mouse than in the females of the species. Differences in the apparent male and female radiosensitivities between species were considered to be a consequence of the differing lengths of the gonocyte life span and the oogenetic period, respectively.

Mutations can be induced by radiation in the cells of both somatic and germinal tissues. In somatic tissues, gross mutations would result in the death of the cell and, at the low incidence likely from low dose rates, deterministic effects at the level of the whole organism would not be expected. For lesser damage, consistent with the continued viability of somatic cells, there is very little evidence for any outcome other than an earlier onset, or increased incidence, of neoplastic disease; at low dose rates this has little effect on the average life expectency. These results are consistent with the conclusion, noted above, that mortality from chronic irradiation is an endpoint of low radiosensitivity. In the germ cells, many of the mutations, eg dominant lethals, produce effects that are subsumed in the radiation impacts on fertility and fecundity discussed above. The potential impact of minor mutational damage is less clear. It would be assumed that these would give rise to a reduction in fitness (even for recessives present in the heterozygous state) and, therefore have an adverse impact on the population. Although these mutations would tend to be lost through natural selection, it is to be expected that a new balance between mutation induction and selective loss would be achieved over time with consequent slight changes in the attributes detailed above for the population. Laboratory studies have not, however, provided unambiguous evidence for an impact from reduced fitness in populations exposed to chronic irradiation. It was cautiously concluded that, at the dose rates likely to be experienced as a consequence of controlled waste disposal, there would be very limited mutational impact on wild populations.

There were many fewer data for other classes of terrestrial organisms. From the available data, however, it was concluded that birds showed a similar radiosensitivity to mammals, while reptiles and amphibians, and insects had progressively lower sensitivities.

Overall, it was concluded that dose rates less than 40 μGy h^{-1} to the most highly exposed individuals in a population would be unlikely to have any damaging impact on the population through effects on the most radiosensitive individual attributes: fertility, fecundity and the production of viable offspring.

3.3 Effects of chronic low-level irradiation on aquatic animals.

It was noted that there had already been a number of reviews of the available information on the impacts of radiation on aquatic organisms and that many had been specifically prepared to assess the potential effects of waste disposal on the aquatic environment. As there did not appear to be any reports of more recent work that could alter the general conclusions, the Committee decided that it would not be necessary to duplicate the reviews. Assessment of the available data produced the conclusions that fish were the most radiosensitive of the non-mammalian aquatic organisms, with reproductive capacity again being the most sensitive attribute, and that maximum dose rates less than $4\ 10^2$ μGy h^{-1} to a small proportion of the individuals in aquatic populations (and, therefore, lower average dose rates to the whole population) would not result in any detrimental effects at the population level.

4.0 EFFECTS OF RADIATION ON POPULATIONS OF PLANTS AND ANIMALS

Due to experimental difficulties and resource constraints there have been few, if any, studies that have definitively examined the effects of radiation on populations (as defined above) under conditions otherwise approaching those experienced in their natural environment. Field studies with large sources of γ-radiation have examined responses in the local environment that are almost entirely confined to changes in community structure that arise from mortality at relatively high dose rates; longer term studies to determine the impact on the populations of the effects on reproductive capacity, that would be expected at lower dose rates to the whole population, have yet to be made. Most of the studies have concentrated on the responses of plants, and where observations of animals have been made the responses are almost invariably the indirect result of direct radiation effects on the vegetation. A study of lizards irradiated in a large enclosure in a desert habitat, has produced some information on reproductive effects. A population of a short-lived species receiving an average dose rate of 8.3 10^2 μGy h^{-1} for a period of 5 years showed an age distribution, a maximal life-span and a sex ratio that were not significantly different from those of the controls: the population numbers were maintained even though an appreciable proportion of the older females were sterile. Two longer-lived species that received differing, and lower, average dose rates of 5.1 10^2 and 2.6 10^2 μGy h^{-1} due to differing behaviour patterns showed impaired fertility after 5.5 and 7.5 years respectively and altered population numbers. These <u>average</u> dose rates to the populations are a factor of ~10 greater than the suggested <u>upper limit</u> of 40 μGy h^{-1} for minimal effects in the most highly exposed individuals in populations of terrestrial animals (see above). Two laboratory studies of small populations of the water flea (*Daphnia pulex*) have shown that the population birth and death rate are relatively insensitive to chronic irradiation, although the additional stress from food limitation in one experiment reduced the threshold for effects on the death rate to ~ 4 10^4 μGy h^{-1}. Of greater significance, sufficient experimental dose rates were used to demonstrate clearly the deterministic nature of the response relationships for the two population attributes.

5.0 EFFECTS OF ACCIDENTS

Studies of the environmental after-effects of accidental releases of radio-nuclides are important for two reasons: first, the irradiation affects an otherwise more or less natural system: and second, the dose rates across individual populations often span the effect/no effect range. For the accidents in the southeastern Urals and at Chernobyl, the initial dose rates close to the release points were sufficiently high that acute effects occurred. These were clearly apparent in the coniferous and deciduous trees and, for the Chernobyl release, were consistent with the expectations from previous studies in terms of dose-response; it may be reasonably presumed that acute effects also occurred in mobile animal species although there appear to be no published data. Of more interest, from the viewpoint of assessing the potential impacts of waste disposal, are the longer-term effects of lower dose rates. Although data are still becoming available, it is clear that populations, generally, have survived the initial damage and are persisting at dose rates greater than those suggested above as upper values for minimal effects in the most highly exposed individuals in terrestrial and aquatic populations of plants and animals. This is not to say that there are not continuing radiation-induced changes in the individual populations and communities in the contaminated areas, but there is evidence that recovery is taking place.

6.0 CONCLUSIONS

A review of the available data has indicated that the radiation dose rates from the natural background, controlled radioactive waste disposal and from accidental releases form an overlapping, and increasing hierarchy. In the majority of situations, individual human activities give rise to a range of dose rates in the contaminated area, and for actual waste disposal practices these have ranged up to a maximum of ~10^2 μGy h^{-1}. It has been concluded that the assessment of the environmental radiation exposures could be improved if:

- more detailed information were available on the temporal and spatial distributions of the radionuclides in the environment: and
- an appropriate method were developed for combining the absorbed dose rates from radiations of high LET (α-particles) and low LET (β-particles and γ-rays).

The Committee identified populations of wild organisms as the appropriate objects of protection in the majority of natural environments. It has been concluded that damage to populations would not be significant if there were minimal radiation effects in those biological functions underlying the maintenance of populations ie mortality rate, fertility, fecundity and mutation rate, all of which are the consequence of processes taking place in individual organisms. The data reviewed have indicated that the populations would be protected if the incremental dose rates to the most highly exposed individuals in the populations (and most probably, therefore, lower average dose rates to the whole population) were below:

- 40 $\mu Gy\ h^{-1}$ for terrestrial animals; and
- 4 10^2 $\mu Gy\ h^{-1}$ for terrestrial plants and aquatic plants and animals.

It is to be understood that these values apply to low LET radiation; where there is an α-particle contribution to the dose rate it should be weighted appropriately and the impact of the total weighted absorbed dose rate considered.

It has been clearly recognised, however, that a very limited number of plants and animals have been studied, and that it would, therefore, be very useful to obtain additional dose-response relationships for both low LET and high LET radiations. As it appears that the relevant responses are deterministic in nature, these studies should employ a sufficiently wide range of dose rates, to span the entire response spectrum.

7.0 DISCUSSION

Question No. 1: ***Having only two categories — terrestrial and aquatic — for guidelines seems very broad. When one examines the range of radiosensitivity that organisms show, are these two categories perhaps too simplistic? Are we being too arbitrary?***

Dr. Woodhead responded that in the aquatic environment, the available data all indicate that fish are the most radiosensitive, if you look at gametogenesis. While there is indeed an enormous range if one looks at LD30 values, this range 'collapses' when gametogenesis is examined. The audience must recognize there is no possibility of doing experimental work to demonstrate the validity of the two-category generalization.

Question No. 2: ***What is the dose rate effect on life-shortening? In 210Po-treated mice, dose rate had no effect. If α-induced damage isn't repaired, dose rate versus RBE graphs can show higher RBE values at low dose rate.***

Dr. Woodhead replied that this apparent situation arose not because α-radiation was more effective at low dose rate, but rather because the low-LET reference radiation became less effective at low dose rates.

Question No. 3: Is this new UNSCEAR document on the effects of radiation on the environment a "one-off," or the first of a series? Are the values of 40 µGy/h (for land animals) and 400 µGy/h (for aquatic plants and animals) dose rates below which further environmental study is not warranted?

In Dr. Woodhead's opinion, given the long gestation period this document had, it was probably a "one-off." He thought some members of the UNSCEAR committee felt somewhat uncomfortable with certain aspects of it. The Committee had chosen not to provide actual recommendations for limits in regard to protecting the environment, saying that some other group, working from the UNSCEAR document, ought to run with the issue of recommendations for environmental protection, just as ICRP does for human radiation protection.

Dr. Woodhead also expressed the opinion that if a level of 1 mSv/d or so [equivalent to 40 µGy/h] is adopted for environmental protection, there indeed is no need to do studies or another report.

8.0 REFERENCES

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