Radiation & the environment: Assessing effects on plants and animals

An overview of a recent report issued by the United Nations Scientific Committee on the Effects of Atomic Radiation

by Gordon Linsley

The international body known as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) periodically reviews the effects of ionizing radiation on the environment. Last year, the Committee, for the first time, issued a report that contained a review specifically focused on the effects of ionizing radiation on plants and animals.* While the review contained no surprising findings, it does serve to focus attention on the changing nature of the scientific community's assessment of radiation's potential environmental effects.

Previously, scientific assessments had considered plants, animals, and other living organisms as part of the environment in which radionuclides become dispersed. They were further seen as resources which, when contaminated, may contribute to human radiation exposures since some plants and animals are elements of food chains and represent pathways for the transfer of radionuclides to humans. In brief, the assessments reflected the generally accepted position that priority should be given to evaluating the potential consequences for humans — which are among the most radiosensitive mammalian species — and to providing a sound basis for protecting human health.

This position, however, has been questioned recently. It has been shown that there is at least one situation — namely in deep-sea sediments, an environment very remote from humans — where the above accepted priority could be incorrect.** Detrimental effects on the environment also have been observed in localized areas as a consequence of plants and animals having received short-term, very high radiation doses following major accidental releases of radionuclides. This has been the case, for example, in areas affected by the 1957 accident in the southeastern Urals and by the Chernobyl accident in 1986.

UNSCEAR's latest review was done in response to such concerns, and to demonstrate explicitly that full account can be, and is being, taken of the potential effects of radiation on the environment. It recognizes that the world's plants, animals, and organisms are themselves exposed to internal irradiation from accumulated radionuclides and to external exposure from contamination of their respective environments. This article highlights the main conclusions of UNSCEAR's review.

The context of environmental impact assessments

The presence in our environment of cosmic radiation and natural and artificial radionuclides implies a consequential radiation exposure of the indigenous populations of all organisms. For humans, it is expected that the probability of adverse effects are greater where exposures are higher than the range of natural background radiation dose rates. This also is to be expected for other organisms.

However, there is a fundamental difference in the viewpoint adopted for the evaluation of the risk. For humans, ethical considerations make the *individual* the principle object of protection. In actual practice, this means that the incremental risk to a person arising from increased radiation

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*United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) *Sources and Effects of Ionizing Radiation*, UNSCEAR 1996 Report to the General Assembly, with Scientific Annex, United Nations sales publication E.96.IX.3 (1996).

***Assessing the impact of deep-sea disposal of low-level radioactive waste on living marine resources*, Technical Reports Series No. 288, IAEA, Vienna (1988).

exposure must be constrained below some level which society judges to be acceptable. This level of risk, although small, is not zero.

In the case of other organisms, the case is less clear. Humans display an enormous range of attitudes towards the other species that share this planet — consider, for example, a population of mosquitoes at one extreme and an individual giant panda at the other. For the vast majority of organisms, we consider the *population* to be important, and we set as an appropriate objective the protection of each population from any increased risk attributed to radiation. Exceptions might be populations of small size (rare species) or those reproducing slowly (long generation times and/or low fecundity) for which it might be more appropriate to target protective measures at the level of the individual organism.

Whether we are interested in the protection of one or many, the responses are likely to be significantly different when it comes to the assessment of environmental impacts. One point undoubtedly is self-evident — namely, that there cannot be any effect at the population level (or at the higher levels of community and ecosystem) if there are not effects in the individual organisms constituting the different populations. This does not mean, however, that detectable radiation-induced effects in some members of a population necessarily would have any significant consequences for the population as a whole.

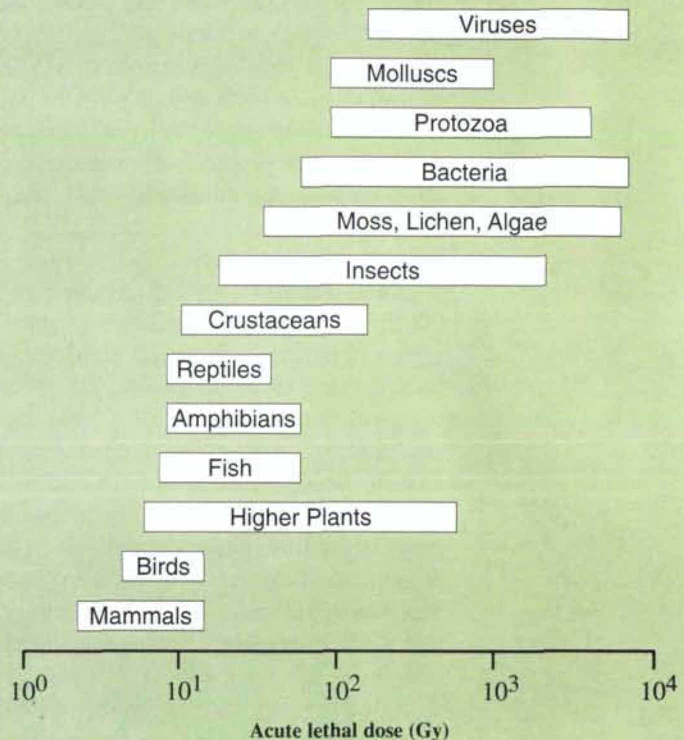
There are other factors to keep in mind as well when considering the assessment of environmental impacts. For one, natural populations of organisms exist in a state of dynamic equilibrium within their communities and environments and ionizing radiation is only one of the stresses that may influence this equilibrium. The incremental radiation exposure from human activities cannot, therefore, be considered in isolation from other sources of stress. This includes those that are either natural (e.g. climate, altitude, volcanic activity) or of human origin (e.g. synthetic chemical toxins, oil discharges, exploitation for food or sport, habitat destruction). When, as is not uncommon, ionizing radiation and chemicals, both from human activities, are acting together on a population, the difficult problem arises of correctly attributing any observed response to a specific cause.

Conclusions of the UNSCEAR Review

All living organisms exist and survive in environments where they are subject, to a greater or lesser degree, to radiation from both natural and anthropogenic sources, including the contamination from global fallout which followed atmospheric nuclear weapons tests. At times, and generally in restricted areas, there are additional increments of radiation exposures either from authorized (controlled) discharges of radioactive wastes to the air, ground, or aquatic systems or from accidental releases. In the majority of cases there have been no apparent effects in wild plants and animals from these additional exposures. Following severe accidents, however, damage has been observed in individual organisms and populations, and long-term effects could develop in communities and ecosystems from the continuing increased chronic irradiation.

The available data on the exposure of wild organisms to radiation from the natural background and from contaminant radionuclides are relatively limited. They relate to a very restricted variety or organisms, although for the marine environment they do provide a reasonably representative picture of the range of dose-rate regimes likely to be experienced. Because the estimates are largely derived either from localized measurements of the concentrations of radionuclides within the organism and in its immediate external environment or from models that assume an equilibrium state, there is very little information on the temporal variation in dose rates to be expected from short-term fluctuations in discharge rates, differing stages in the life cycle, changes in behaviour and short-term environmental factors such as seasonality. It is thus very difficult to estimate from the available data the total doses that are likely to be accumulated over specific stages of the life cycle, e.g. during embryonic development or up to reproductive age.

For both terrestrial and aquatic environments, there appears to be a significant contribution to the natural background dose rate from alpha radiation. For the former the main source appears to be radon-222 and its short-lived decay products, and for the latter the main source is polonium-210. Owing to the short range of alpha particles, the absorbed dose rates are tissue-specific, and the results underline the crucial need for more detailed information on the distribution of the radionuclides relative to the biological targets that might be considered important (e.g. the developing embryo or the gonads) if accurate estimates of background radiation exposure are to be made. The usual range for the background radiation exposure is



The graphs show the approximate lethal dose ranges for various taxonomic groups, an indication of the comparative radiosensitivity.

Comparative radiosensitivity among organisms

up to a few microgray per hour, but in exceptional cases (e.g. the hepatopancreas of a small pelagic marine shrimp) the absorbed dose rate may be as high as 150 microgray per hour.

Radioactive wastes. It is accepted that the release of radioactive wastes to the environment is likely to increase the radiation exposure of wild organisms. For discharges to the atmosphere, to a landfill or to surface waters, the published assessments reviewed indicate that the radiation exposures to some (but not all) individuals in endemic wild populations could reach about 100 microgray per hour in general; in exceptional cases, depending on the quantities of specific radionuclides in the wastes, absorbed dose rates might reach several thousand micorgray per hour. In a very limited number of instances the dose rates estimated from measured concentrations of radionuclides in the contaminated environment have been broadly confirmed by *in situ* measurements employing dosimeters attached to the animals.

Accidental releases. The dose rates in the environment following an accidental release clearly depend on the quantities of specific radionuclides involved, the time-scale of the release, the initial dispersal and deposition patterns, and their subsequent redistribution by environmental processes over time. It is equally clear that these accidental releases have the potential to generate much higher dose rates and higher total doses in the environment than do normal operations. Such was the case following the accidents in the southeastern Urals and at Chernobyl, where numerous studies have indicated that trees (and, by reasonable extension, other organisms) close to the release points could have accumulated doses up to 2000 gray and 100 gray at the two accident sites, respectively, over relatively short periods of time. At both sites, longer-term chronic exposures from the deposit of longer-lived radionuclides have continued to be significantly higher than exposures from controlled waste disposal.

From these data it may be concluded that it is the responses of plants and animals to chronic radiation exposures up to a maximum absorbed dose rate of 1000 microgray per hour that are of interest from the viewpoint of providing a basis for assessing the environmental impact of controlled radioactive waste releases; in practice, information at lower dose rates, up to 100 microgray per hour would probably be sufficient in the great majority of cases.

For accident situations, experience has clearly demonstrated that initial dose rates can be high enough to allow accumulating lethal doses in relatively short periods (days). In light of this, data are needed to provide the basis for predicting the progress of environmental recovery at generally lower, long-term chronic dose rates, down to the upper end (1000 microgray per hour) of the range of interest for assessing waste disposal practices.

Radiosensitivity. There is a wide range over which organisms are sensitive to the lethal effects of radiation. A general classification has been devised based on the interphase chromosome volume of sensitive cells. These and other results of experimental irradiations show mammals to be most sensitive, followed by birds, fish, reptiles, and insects. Plants show a wide range of sensitivity that generally overlaps that of animals. Least sensitive to acute radiation exposures are mosses, lichens, algae and micro-organisms, such as bacteria and viruses. *(See figure, previous page.)*

Sensitivity of the organism to radiation depends on the life stage at exposure. Embryos and juvenile forms are more sensitive than adults. Fish embryos, for example, have been shown to be quite sensitive. The various developmental stages of insects are quite remarkable for the range of sensitivities they present. Overall, the available data indicate that the production of viable offspring through gametogenesis and reproduction is a more radiosensitive population attribute than the induction of individual mortality.

In the most sensitive plant species, the effects of chronic irradiation were noted at dose rates of 1000 to 3000 microgray per hour. It was suggested that chronic dose rates less than 400 microgray per hour (10 milligray per day) would have effects, although slight, in sensitive plants. They would be unlikely, however, to have significant deleterious effects in the wider range of plants present in natural plant communities.

For the most sensitive animal species, mammals, there is little indication that dose rates of 400 microgray per hour to the most exposed individual would seriously affect mortality in the population. For dose rates up to an order of magnitude less (40-100 microgray per hour), the same statement could be made with respect to reproductive effects. For aquatic organisms, the general conclusion was that maximum dose rates of 400 microgray per hour to a small proportion of the individuals and, therefore, a lower average rate to the remaining organisms would not have any detrimental effects at the population level. The radiation doses necessary to produce a significant deleterious effect are very difficult to estimate because of long-term recovery (including natural regeneration and the migration of individuals from surrounding areas that are less affected), compensatory behaviour, and the many confounding factors present in natural plant and animal communities in both terrestrial and aquatic environments.

IAEA activities and plans related to environmental protection

The results of the UNSCEAR review of the effects of radiation on the environment generally confirm the conclusions reached in an IAEA study issued in 1992. * They further support the general view of the International Commission on Radiological Protection (ICRP) that the "standard of environmental control needed to protect man to the degree currently thought desirable will ensure that other species are not put at risk".**

However, it is recognized in both the UNSCEAR and IAEA reviews that there are circumstances where this general conclusion may not be valid. Moreover, there is a view that the ICRP statement could be misinterpreted as indicating a lack of concern for the environment. For these and other reasons, there is a movement in some countries towards the establishment of specific standards for the protection of the environment. There were discussions on this theme at an IAEA symposium in 1996.*** In recognition of this ongoing debate, the Agency will hold a series of expert consultations during 1997 and 1998 with a view to determining the prevailing view in its Member States on these issues. Depending upon the outcome of these discussions, one possible objective is the development of a Safety Standard that incorporates international consensus on this important subject. ❒

* *Effects of ionizing radiation on plants and animals at levels implied by current radiation protection standards*, Technical Reports Series No. 332, IAEA, Vienna (1992).

**International Commission on Radiological Protection, 1990. *Recommendations of the International Commission on Radiological Protection, ICRP Publication 60*, Annals of the ICRP 21 (1-3) Pergamon Press, Oxford (1991).

***See "Environmental impact of radioactive releases: Addressing global issues", *IAEA Bulletin*, Vol. 38, No. 1 (1996).