apportioned for the source being considered, that is, the waste repository).

Principle No. 6 (risk upper bound). This principle is appropriate to disruptive events not covered by the previous principle. It requires that there be a limit to the risk to individuals in the future as a result of the existence of the repository. In this context, risk is taken to be the probability of a health effect for an individual or his descendants. It is equal to the product of the probability of radiation exposure as a result of an event and the probability of a health effect arising from that exposure.

The risk limit is based on the limit to risk implied by the dose upper bound in Principle No. 5. For example, the full dose limit for members of the public of 1 millisievert per year currently recommended by ICRP, when averaged over a lifetime implies an average annual risk of a serious health effect of about 1 in 100 000 per year. The risk upper bound is some fraction of this to be determined by national authorities.

Principle No. 7 (additional radiological safety). While the specification of upper bounds to dose and risk serves to ensure the required level of safety to an individual it is recommended that all exposures should be as-low-as-reasonably achievable (ALARA).

Technical criteria

The basic safety principles are supplemented by technical criteria. These provide guidance on the practical means for complying with the safety principles. Important among these are the requirements for a multi-barrier approach to achieving isolation of the wastes, for appropriate choice of site geology, and for consideration of natural mineral resources when choosing underground disposal sites.

Summary

The IAEA report sets out an internationally agreed set of principles and criteria for the design of repositories for the underground disposal of HLW.

To the extent possible at this stage in the development of HLW repositories, and recognizing the technical differences of approach in Member States, the aim is towards achieving harmonization on the philosophical basis for their design.

The safety principles and technical criteria are intended to form a common basis for the subsequent development of more detailed and quantitative performance standards, some of which may need to be site-specific in nature.

Protection of natural ecosystems: Impact of radiation from waste disposal practices

Several review studies and assessments have been prepared recently

by Gordon Linsley

The prime concern in regulating activities involving the release of radioactive materials into the environment is ensuring the protection of human individuals and populations. It is assumed that if this is achieved then other non-human species will automatically be protected, although not necessarily individual members of those species.* In almost all situations, the need to limit radiation doses to low levels is expected to ensure that radiation doses to other organisms will also be small and below the levels at which ecological changes could occur.** These assumptions have not been seriously challenged in 30 years of nuclear power operations. Nevertheless, the issue is regularly discussed and recently it has been the subject of several review studies and assessments.

In this review, three possible exposure scenarios (or cases) for man and for non-human organisms are considered. *(See accompanying figure.)*

Case A. The general assertion that non-human species will be adequately protected seems, at first sight, to be reasonable for practices in which radionuclides are released into the biosphere in close proximity to human habitation. At these locations environmental concentrations are maintained at very low levels in order to keep radiation doses to humans well below dose limits.

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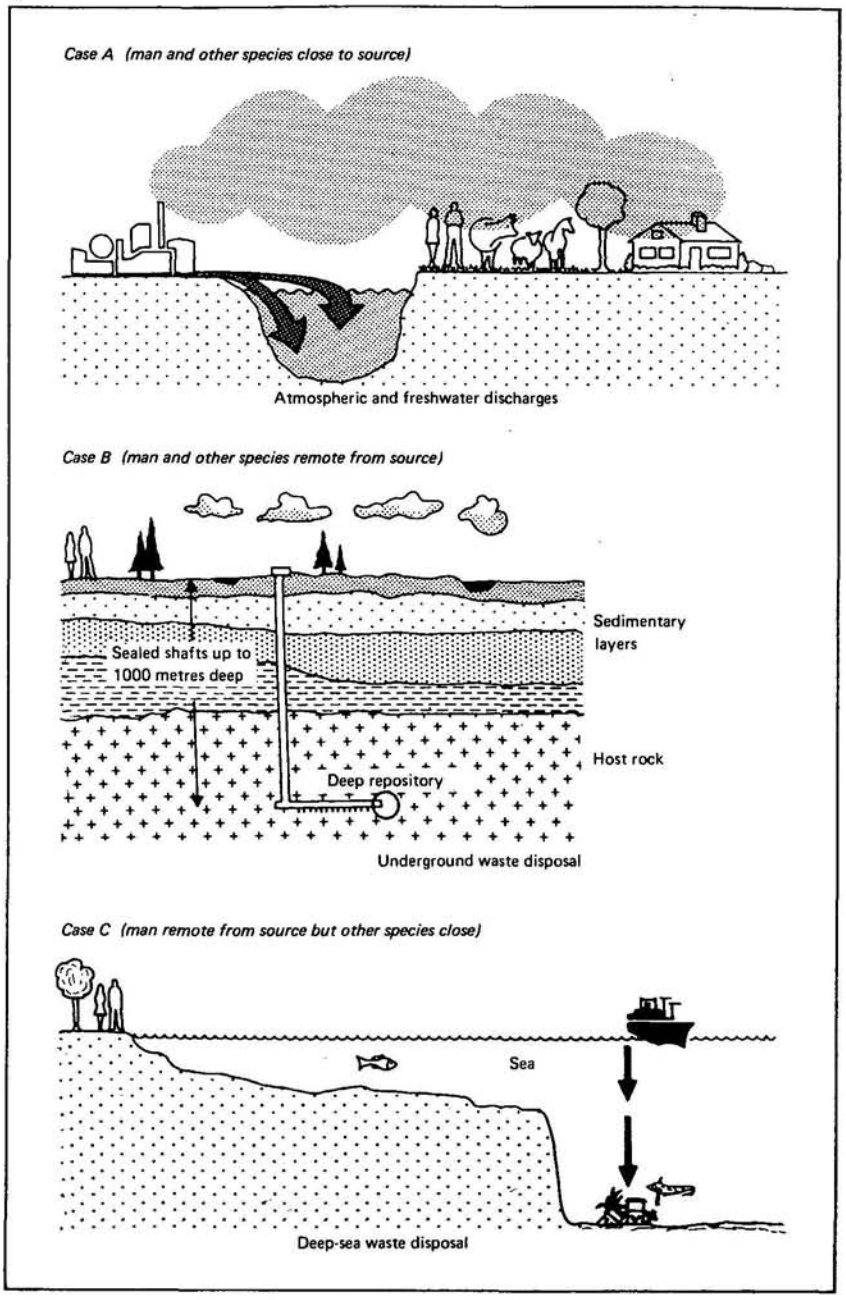
* *Recommendations of the International Commission on Radiological Protection*, ICRP Publication 26 (1977).

** *Radionuclide Release into the Environment: Assessment of Doses to Man*, ICRP Publication 29 (1978).

However, when we consider that the sensitivity to radiation of plants and animals varies markedly and that they may be exposed to higher radiation doses than man when living in the same environment, then a more thorough examination of the issue may be seen to be justified. Higher radiation doses could occur because of soil-to-plant transfer processes. These processes could lead to accumulation of radionuclides by plants and animals. Higher doses could also result from the special dietary habits of some animals leading to elevated intakes of certain radionuclides. In some cases, the greater proximity of plants and some animals to radionuclides dispersed in soil and water could give rise to higher external radiation doses than man would be exposed to when living in the same environment.



Case B. In the case of solid radioactive waste disposal in deep geological formations, the disposal is to essentially abiotic (lifeless) environments. A series of impermeable barriers surround the waste to prevent the migration of radionuclides back to man. The situation for near-surface disposal facilities is different since many are located in environments accessible to higher plants and animals.

Case C. For the disposal of low-level packaged wastes into the deep sea, there is likely to be more need to question the assumption about protection of non-human species. Because of the large depths at which the wastes are dumped and the long distances back to man, it is possible to have significant radiation doses delivered to deep sea organisms while doses to humans are kept at acceptable levels.

It is clear that in Case C, at least, the risk of effects can be higher for natural biota than for humans. However, it should be noted at this point that there is a basic difference in the way that we, as humans, view risk to our own species as compared to other species. When considering risk to man, our values are strongly focused upon the individual, since individuals are considered to have great value and importance. In contrast, most other species are viewed and valued by us more as a population than as identifiable individuals.

This article reviews recent and on-going Agency and some national studies on the impact of radiation from waste disposal practices. It is stressed that the studies relate to environmental protection afforded by controlled radioactive waste disposal practices and not to environmental impacts which might be caused by accidental releases of radionuclides or due to uncontrolled waste disposal.

Assessment approach

The basic approach adopted in the main studies considered is as follows: (a) information on the effects of ionizing radiation on natural organisms is reviewed; (b) the radiation dose and/or dose rate above which there are deleterious effects on populations of different types of plants and animals is determined; (c) the radiation dose and/or dose rate to plants and animals, which

results when releases of radionuclides are controlled on the basis of the standards for the protection of man, are estimated; and (d) the radiation doses and dose rates in steps (b) and (c) are compared to establish whether or not plant and animal populations are afforded adequate protection under radiation protection standards for man.

Case A: Releases to atmosphere and surface waters

A study sponsored by the IAEA that assesses the impact on plants and animals of controlled releases of radionuclides to the atmosphere and to the aquatic (freshwater) environments is nearing completion.* On the basis of a review of the available literature on radiation effects on terrestrial and freshwater aquatic ecosystems, it is concluded that chronic radiation dose rates of 1 milligray/day (mGy d^{-1}) or less to species in terrestrial ecosystems and 10 mGy d^{-1} in freshwater ecosystems are unlikely to cause measurable, detrimental effects on populations. This conclusion for the aquatic environment was reached in other previous Agency reviews and a recent US review.**

In the latest study sponsored by the IAEA, the maximum radiation dose rates which could be delivered to terrestrial and freshwater organisms as a result of controlled releases of radionuclides were evaluated by means of simplified and conservative calculations. For the evaluation of the impact of controlled releases, the release rates were chosen such that radiation doses to the most exposed human individuals would be equivalent to the annual dose limit for members of the public (1 millisievert/year). Actual releases to the environment are only small fractions of these values due to application of the principle of reducing radiation exposure to as-low-as-reasonably achievable (ALARA). The maximizing approach adopted in the calculations (both in terms of the assumptions regarding release rates and the dose assessment methodology) produces estimates of radiation dose to plants and animals which are at the upper end of the range of the doses which could conceivably be delivered from controlled releases.

The estimated doses to plants and animals from controlled releases are below the levels at which detrimental effects on populations would be expected. Furthermore, in most conceivable release scenarios, only a small fraction of the total animal or plant populations would be likely to receive the estimated doses.

It is, however, stressed that the available information on the effects of radiation on non-human species is limited and that the results of these assessments must be treated with caution since they may not be applicable to all conceivable situations.

In a separate study, in response to questions concerning the possible effects on trees and forests of gaseous releases of radionuclides from nuclear power stations, it was shown that the radiation doses could only be very small fractions of those due to natural background radiations.*

Case B: Deep underground radioactive waste disposal

In disposing of radioactive wastes deep underground, the objective is to isolate them from man's environment. Natural barriers are provided by the deep geological location, and the wastes are isolated by a series of man-made barriers. These include the waste form or matrix, which may be an insoluble material such as glass; the waste container, which, for high-level wastes, may be designed to last for thousands of years; and the surrounding buffer material, typically a form of clay, designed to exclude water ingress and to retard radionuclide migration. If migration of radionuclides does eventually occur it would be at some time in the far future; any activity reaching the biosphere would be at very low levels, due to radioactive decay and also due to dilution and retention on surfaces during groundwater transport. It is most unlikely that any resulting activity levels would be high enough to cause harm to man or to plants and animals.

Near-surface radioactive waste disposal

Near-surface disposal in the terrestrial environment is the preferred option in many countries for short-lived wastes of low-to-medium activity. A lesser degree of isolation is provided than for disposal in deep geological formations and there is the possibility for some types of shallow disposal sites of intrusion into the wastes by plants and animals. Early experiences of simple trench disposal of unpackaged wastes have shown that in certain circumstances, for example, as a result of trench flooding due to improper siting or to inadequate drainage, radionuclides can be spread laterally beyond the zone of the disposal trench, downwards into the soil profile and in some cases into local streams and groundwater.** In modern near-surface disposal facilities, the risk of intrusion by plants, animals, and man is considerably reduced because the wastes are encapsulated and stored within concrete barriers. The possibility of radionuclide migration from the wastes is reduced by encapsulation and by proper siting and repository design.

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* *Effects of Ionizing Radiation on Plants and Animals at Levels Implied by Current Radiation Protection Standards*, Draft Report.

** *Effects of Ionizing Radiation on Aquatic Organisms and Ecosystems*, IAEA Technical Reports Series No. 172, Vienna (1976); *Assessing the Impact of Deep Sea Disposal of Low Level Radioactive Waste on Living Marine Resources*, IAEA Technical Reports Series No. 288, Vienna (1988); *Effects of Ionizing Radiation on Aquatic Organisms*, US National Council on Radiation Protection and Measurements, Draft Report.

* *Betrachtungen zur Strahlenexposition von Bäumen durch natürliche und künstliche Strahlenquellen*, by W. Jacobi, and H.G. Paretzke, GSF-Bericht 5/86 (1986).

** Shallow land burial of low-level radioactive wastes in the USA, IAEA-SM-243/152 (1980).

In the IAEA's latest study, calculations of the radiation doses to plants and animals intruding into a shallow repository have been performed, assuming that the radioactive contents of the repository have been previously controlled based on limiting the radiation dose to man. Conclusions similar to those for controlled releases to the atmosphere and freshwater were reached, although it is recognized that in some older disposal sites greater radionuclide concentrations than those considered may exist. However, for modern engineered disposal sites containing wastes in encapsulated forms, any effects on plants and animals can only be very localized in space and only a small fraction of any animal or plant population could conceivably be exposed to radiation from such a source.

Case C: Sea disposal

An Agency report on the impact of the dumping of low-level packaged wastes on marine organisms in the deep ocean was published recently and reported in the *IAEA Bulletin*.* Briefly, the study showed that because, on the one hand, some marine species live in close proximity to the hypothetical dump-site while human populations are isolated from it, comparatively large radiation doses may be delivered to these marine species while doses to man remain very low. At the maximum release rates for the dumping of low-level packaged wastes permitted under the existing IAEA definition for the London Dumping Convention, it does seem possible that some environmental impact could result.** This is one of the factors which would have to be taken into account in any future revisions of the Agency guidance on the practice of sea dumping. It is stressed, however, that the dumping practices which took place in the North Atlantic until the voluntary moratorium agreed by Member States to the London Dumping Convention in 1983 were at rates which are small fractions of those permitted by the current definition. It has been concluded in a review by the Nuclear Energy Agency that no discernible environmental damage would result from past dumping practices.*

Conclusion

The studies lend general support to the assumption of the International Commission on Radiological Protection regarding the radiation protection of populations of living species other than man.

In situations where man is living in close proximity to other exposed species, the available evidence on the radiosensitivity of living species suggests that protecting man will also be effective in protecting the other species. However, the database is far from complete and the radiosensitivity of many populations of plants and animals has never been investigated.** Furthermore the question of synergistic effects due to the presence of other environmental pollutants has not been properly addressed. The above conclusion, therefore, is not sufficiently firm to justify any lack of concern for possible radiation effects on plant and animal populations.

There are special circumstances where man may be located farther from the point of release of radionuclides than other non-human species and where it is necessary to give separate consideration to the protection of populations of plants and animals.

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* "Deep Sea Disposal — Protecting Fish ... and Man," by A. Hagen, IAEA Bulletin, Vol. 30, No. 4 (1988), a feature article based on the IAEA technical report *Assessing the Impact of Deep Sea Disposal of Low-Level Radioactive Waste on Living Marine Resources*, Technical Reports Series No. 288 (1988).

** *Definition and Recommendations for the Convention on the Prevention of Marine Pollution by Dumping Wastes and Other Matter 1972, 1986 Edition*, IAEA Safety Series No. 78, Vienna (1986).

* "Review of the Continued Suitability of the Dumping Site for Radioactive Waste in the North-East Atlantic", Nuclear Energy Agency of the Organisation for Economic Co-operation and Development, Paris (1985).

** "Environmental Monitoring for Radionuclides in Marine Ecosystems: Are Species Other Than Man Protected Adequately?" by P.M. Thompson, *Journal of Environmental Radioactivity 7* (1988) 275–283.