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MANAGEMENT OF OCEAN DISPOSAL OF RADIOACTIVE WASTES: A BASIS FOR THE CONTROL OF OTHER POLLUTANTS

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ABSTRACT

To manage, on a scientific basis, the quantities of all kinds of waste disposal to coastal waters and open oceans, it is necessary to assess the environmental or assimilative capacity for these materials which will not result in an unacceptable biological impact upon the components of the ecosystem nor on man who uses its resources. One approach available is that which has been demonstrated for the management of the disposal of radioactive wastes to the oceans. Methodologies have been developed, both generic and site-specific, which allow the relationship between discharge or release rate and the radiation dose to be established. Guidelines and recommendations which govern acceptable radiation exposed to man have been developed by the International Commission on Radiological Protection (ICRP). These methodologies developed for the control of radioactive wastes can be applied directly for public health protection for non-radioactive wastes such as metals and organochlorine pesticides. ICRP recommendations on justification and optimization can be integrated into an overall management philosophy in order to quantify alternative waste disposal options.

1. INTRODUCTION

The oceans have been used since time immemorial as a repository for man's wastes. In the last century, and before, the majority of the wastes were natural products which when degraded entered the natural biogeochemical cycles of the oceans with little or no apparent detriment to the system.

However, in the present century the quantities have not only increased as functions of population and production but the composition has changed and now include complex anthropogenic chemical materials which can cause detriment to ecosystems, including man at extremely low concentrations. In some situations man has continued to load the system to the stage that natural processes are so reduced that ecosystems operate with reduced efficiency. In other cases the quantities of inorganic and organic toxic materials are so great as to result in debilitation or death of the marine resources. Sometimes the toxic materials are transferred through the food web resulting in these materials being incorporated in the diets of high trophic organisms, including man.

While there are no doubt local areas of our coastal waters that have suffered from unlimited disposal of our waste products the currently legislated solutions do not appear to have scientific justification. The alternatives to zero discharges and "clean water" can only result in disposal on land.

Yet the regulators and the scientific community have not developed a management philosophy to the alternatives as regards environmental capacity, the detriments and the financial costs of these options. A first step in this direction was made when it was concluded that the waste capacity of US waters is not now fully used; based upon an endpoint of unacceptable disturbance to the community of organisms (NOAA 1979). Goldberg (1981) and Osterberg (1981) have both recently criticized our philosophy of overprotecting the oceans and have called for a reexamination of our waste disposal options in order that the proper choices can be made on defensible scientific grounds. The basis for these arguments is that coastal waters and the oceans have a definable capacity to receive these wastes without unacceptable risk of harm either to the ecosystem, the marine resources harvested by man or to man himself. Clearly there is some evidence available today that while the capacity for some materials is very close to zero, there is also ample evidence that the capacity for other materials is large enough to take care of a large proportion of the arisings.

One example of a management philosophy that has proven successful over the last four decades is that applied to the disposal of liquid and dumping of solid low-level radioactive wastes.

2. RADIOLOGICAL PRINCIPLES FOR THE DISPOSAL OF RADIOACTIVE WASTES

The basic guidelines which have been developed are the recommendations of the International Commission on Radiological Protection (ICRP) on the exposure of man and his progeny to ionizing radiation.

It should be pointed out, however, that merely recommending upper limits which should not be exceeded is not particularly helpful when it is known that the limits will not be exceeded and yet there is still a lower probability of some form of health detriment occurring. Obviously risks should not be taken unless there is some benefit to be gained, and some guidance needs to be provided as to where the line should be drawn. ICRP (1977) therefore goes further than merely proposing exposure limits and recommends that: (a) no practice shall be adopted unless its introduction produces a positive net benefit, (b) that all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account, and (c) that the dose equivalent to individuals shall not exceed the limits recommended for the appropriate circumstances by the Commission.

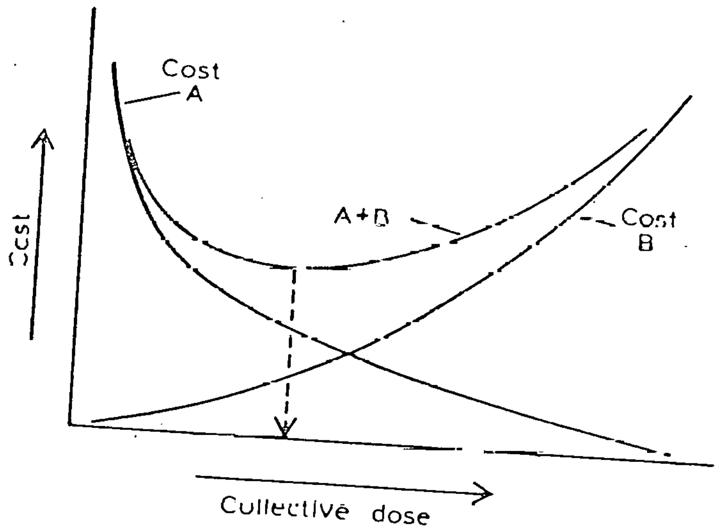
It is important to state here that, for a number of reasons, separate lower limits are recommended for the public as a whole compared to workers who are routinely exposed to ionizing radiations occupationally. Yet for both categories the same three basic principles apply. The first of these (a) is referred to as justification. It may be assumed that the use of nuclear power, or the use of radioisotopes in other forms, has been considered justifiable at a national level in those countries where they are used because of the benefits they bring to members of their population. The second principle (b) is referred to as optimization and this is perhaps the more difficult to resolve. It is a principle which has continually evolved within the ICRP recommendations, the current expression cited above being referred to by the phrase 'as low as reasonably achievable' (ALARA). Inevitably it involves what are commonly known as cost/risk and cost/benefit factors, subjects which evoke considerable debate, but nevertheless these factors are used continually in other everyday practices, particularly in those involving safety features.

In optimization calculations the term "cost" comprises the sum total of all negative aspects of the equation, and the "benefits" include all of the benefits gained by society as a whole. The concept of "risk" and its acceptance is a much debated subject and will not be discussed here. However, there is no reason in principle why such approaches should not be used in radiation protection practices as they are used in other fields of risk assessment, especially when it is realized that zero risk and absolute safety are illusions. In fact, the effects of radiation lend themselves, to some extent, to such calculations because they are already evaluated in terms of detrimental risk per unit dose.

ICRP does not recommend any dose limits for populations as opposed to individuals which are expressed in rem or mSv per year. Nevertheless it is important for optimization to estimate the exposure of the general public in a collective manner (collective dose equivalent), and the doses to which populations will be committed in the future (collective dose equivalent commitment), in order to justify a particular choice of waste disposal. One should note that the collective quantities are expressed as man-rem or man-Sv to distinguish them from individual doses.

Essentially the optimization procedure attempts to assess the level of expenditure on protection at which the total cost of the waste disposal is least. There are, in fact, two sets of "costs" (Figure 1). One set is the direct monetary cost of storing or handling and packaging the waste and minimizing its introduction into the environment (Set 1). The greater the effort spent on this aspect the lower the collective dose to the general population. The second set is primarily that of radiological detriment (Set 2). So far, this second set has largely been dominated by attempting to put a monetary value on the health detriment, but quite clearly other "detrimental" factors need to be considered. At present, therefore, monetary values based on health detriment represent the minimum values which can be used. The optimization technique attempts to determine the level of expenditure at which the combined

Figure 1.



costs are at a minimum. From an administrative point of view, therefore, it is not simply a question of balancing a straightforward cost/benefit or cost/risk equation but of solving a differential equation which attempts to maximize the net benefit in relation to the collective dose. It should be stressed that the objective of this philosophy, as recommended by the ICRP, is not to retain all of the waste forever, even if it were technically feasible, because this would not achieve the optimum level of protection (Pentreath, 1980).

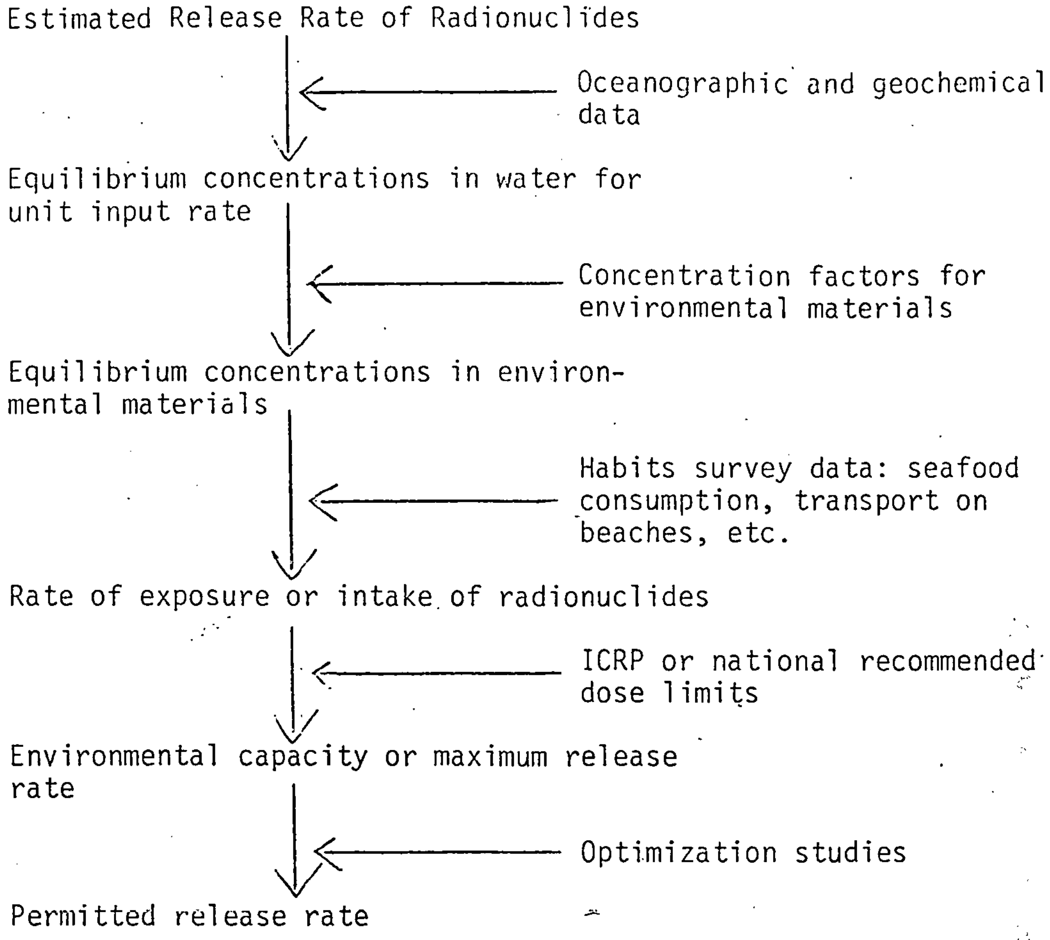
The role of radiation protection with regard to justification procedures is therefore to ensure that the radiation detriment is taken into consideration and that the comparisons between different practices are made after applying the optimization procedures on as realistic a basis as possible, as discussed above. The actual acceptance of any one practice, choosing between different practices, or even parts of them, depends upon many factors, and only some of these may be associated with radiation protection. To this extent such calculations are therefore only an aid to the final process of decision-making, not an end in themselves, and have to be considered alongside any other political, social and economic factors which play a part in the final decision which is taken.

3. THE MANAGEMENT APPROACH

The approach, suggested by ICRP (1966,1979) recognized the fact that although there will be a large number of potential pathways from the environment to man, it will be found in practice that at any given site, one or perhaps two will prove to be so limiting that if exposure along these pathways is kept within the recommended dose limits, all other exposure pathways will be relatively minor. Additionally it will be found that only a few of the discharged or released radionuclides will predominate. In this way only a few critical radionuclides are transferred along a few critical pathways, and of these usually one combination predominates above all others. This method of limitation was therefore called the critical pathway approach. This approach for chronic discharges to the oceans requires a considerable amount of investigative effort, including physical, chemical and biological oceanography; radioecology; fisheries; habit surveys; model development; and expertise in the application of radiation protection principles. The general steps are outlined in Figure 2.

At the pre-operational stage it is usual for a provisional assessment to be made of the probable effluent composition and potential pathways of consumption. Predictions are then made of the average concentrations which are likely to arise in the immediate receiving water mass as a function of unit rate of discharge. This requires estimates of the turnover of water at the site of discharge and the rate of transport into other areas based upon hydrographic data. The concentration of the radionuclides in the

Fig. 2 Outline of the critical pathway approach to the assessment of release of radioactive wastes



and bottom sediments. The next step must be made of the degree of accumulation of the radionuclides in the receiving body of water by aquatic organisms which are likely to provide a pathway back to man.

This can be expressed as a concentration factor, defined as the ratio between the concentration of the radionuclide in the organism and the concentration of the radionuclide in the water. This factor does not necessarily imply that the biological process was one of direct accumulation from the water since it may have accumulated the radionuclide from other organisms in the local food web. Nevertheless, under chronic discharge or release rates, it is probable that the organism will attain a reasonably constant value relative to that of the water. Where field information is not available concentration factor data can be obtained, in some instances by stable element analyses, however there are difficulties in attaining accurate detection levels for many elements. While default values for these factors are available in the published literature it is necessary to confirm these in the early operational stages.

One of the most important aspects of the critical pathway approach is the determination of the working, eating and recreational habits of the local population - and in certain instances of populations at some distance from the site - in order to establish quantitative estimates of marine products consumed, hours spent on the beaches, mud flats, sand banks and handling fishing gear, etc. These site specific habit surveys allow the determination of the critical groups, that is those members of the public most likely to be exposed, and from the consumption data to make estimates of the daily rate of intake of each radionuclide - or external exposure to it - resulting from a unit rate of discharge. The calculated rate of discharge or release which would, in theory, result in the defined critical groups of the public being exposed at the recommended dose limit is referred to as the limiting environmental capacity. Before the site becomes operational it is usual for the regulating agency to apply an arbitrary safety factor and allow an initial discharge or release rate at a much lower rate in order for the calculated capacity to be validated.

Having set the maximum permissable discharge rates for that site it is then necessary to monitor the concentrations in the potential pathways in order to confirm the predictions. The most practical method has been found to be that of using the value from the calculations which relates to the concentration of the radionuclide in the critical material. In this way each component of the critical pathway used directly by man be it species of fish, shellfish or sediment can be sampled and analysed to demonstrate that it does not exceed the proscribed concentration.

This methodology has been applied and validated at a number of controlled coastal discharges, and is presently applied to dumping of solid wastes in the deep oceans.

The ICRP guidelines were developed to protect man and there are no comparable dose limits to protect marine organisms. However, comparison of experimental effects data, field dosimetry and productivity studies at contaminated sites would indicate that the stringent release rates developed by the methodology to protect man appear to be adequate to protect the marine resources (IAEA, 1976).

4. DISCUSSION

How can we apply this approach to non-radioactive releases? The fundamental scientific requirement for the determination of a permissable discharge or release rate is the determination of the relationship between rate of input and effect. In the case of the ICRP critical pathway approach the effect is defined in terms of radiation dose to man. However, should man not be involved in any pathway the concept could equally well be applied to the marine biota, where some populations would become the critical groups.

There is no reason why this approach has to be limited to radionuclides, since the effects of metals, organochlorine pesticides and PCB residues, for example, can be expressed in the same terms of 'dose' either to man or to the marine biota. I see little difference between 'dose' and 'endpoint,' the latter term used by the proponents of the assimilative capacity approach (NOAA 1979) (Goldberg 1981). While the latter approach precludes protection of public health by definition I would suggest that if we are to have a rational and scientific approach to this problem we need to apply these concepts in concert.

The application of the critical pathway approach to non-nuclear material for the protection of man can be directly applied today. However, it is indeed rare to see reported in any assessment of coastal water contamination whether the consumption of marine resources is detrimental to those who consume them or not. It would be instructive to determine, for instance, to what degree fish and shellfish from the Southern California Bight, if consumed by a critical group in that area, poses any public health problem. Such a determination would also allow a preliminary assessment of whether public health or ecosystem effects constitute the limiting effect.

The establishment of 'doses' or 'endpoints' for marine biota are more difficult. We need to pose the question 'What to protect?' and particularly to agree on what constitutes 'harm' to the ecosystem. If damage is to be established it must be shown to occur on a scale which can be related to the changes produced by other natural environmental variations. Initially we need to develop simplified ecosystem models to establish some agreed upon critical pathways and concentrate our research to validate them. Although most of our research is often experimental and laboratory-oriented, the significance of that research lies in its capacity to provide meaningful information on the ability of an individual organism to survive and successfully inhabit its natural, but possibly perturbed, environment. The importance of such information on the understanding of the viability of more complex systems of biological organization, i.e., populations and communities, is evident. Such an approach to research demands that studies are not restricted to the examination of processes or conditions which are relevant only to the laboratory context and which only test the responses of organisms in the extremes of environmental conditions as is often done with studies on the effects of pollutants.

In this context, one area of research that I find particularly exciting is the recent research on the occurrence, structure and function of metal binding proteins, and their possible relationships with the cellular vesicular systems. If it can be established that there are definable upper limits to saturation of metallothioneins, before 'spill over' and toxicity occurs, and that these processes can be related to environmental concentrations, we will have gone a long way to establishing quantifiable 'endpoints' and to determining environmental or assimilative capacities for some if not all species.

Of equal importance is the need to apply the ICRP recommendations on justification and optimization. The alternatives to using the oceans, in Goldberg's parlance, as 'waste space' is to utilize the terrestrial environment. However, before we can make that decision we need to compare the costs of ocean disposal with that on land; to compare the costs of the public health and ecological detriments in each medium; and to balance those costs and detriments if we are to achieve the optimum level of protection for the environment.

ACKNOWLEDGEMENTS

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Figure 1. Differential cost-benefit analysis in which cost is related to a variable reflecting exposure - for example collective or committed dose A is direct monetary cost (Set 1), B is the cost of radiological detriment (Set 2). The dotted arrow indicates the minimum value of A and B. (After Pentreath, 1980).

Figure 2. Outline of the critical pathway approach to the assessment of release of radioactive wastes to the oceans.