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No. 3 1975

SCIENTIFIC CRITERIA FOR THE SELECTION OF SITES FOR DUMPING OF WASTES INTO THE SEA

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

REPORTS AND STUDIES No. 3

IMCO/FAO/UNESCO/WMO/WHO/IAEA/UN Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP)

SCIENTIFIC CRITERIA FOR THE SELECTION OF SITES FOR DUMPING OF WASTES INTO THE SEA

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ROME, September 1975

PREPARATION OF THIS STUDY

This document is the edited and approved original English version of the report of the GESAMP Working Group on the Scientific Basis for Disposal of Waste into the Sea which met from 4-8 February 1974 in Rome and from 5-11 October 1974 in Copenhagen with the following members participating: Dr. E.K. Duursma, Dr. B.H. Ketchum, Dr. G. Kullenberg (Chairman), Dr. S.-A. Malmberg, Dr. J.E. Portmann, Dr. G.H. Tomczak, FAO (Technical Secretary), Dr. M. Waldichuk and Dr. G.F. Weichart.

The Working Group was charged with identifying gaps in our present knowledge, focussing attention on urgent research needs and suggesting research priorities, particularly as regards the fate of the waste into the sea, and its activities were financially supported by the United Nations Environment Programme.

The study is also being issued in French, Spanish and Russian.

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SCIENTIFIC CRITERIA FOR THE SELECTION OF SITES FOR DUMPING OF WASTES INTO THE SEA

CONTENTS

ABSTRACT

The main concerns with dumping of wastes at sea are their possible adverse effects on living resources. Effects on human uses are mainly associated with bioaccumulation of substances by marine organisms, tainting of sea food and reduction of amenities arising from discolouration, turbidity and floating materials. The wastes of greatest concern are those which are toxic to marine organisms or accumulate within organisms to a concentration substantially greater than that in the environment, and which reach the sea in large amounts or persist there for long periods of time. For liquid waste disposal, a principal objective is rapid and widespread dispersion.

Dumping of those materials permitted under the London Convention should be done in such a way as to avoid, or minimize, undesirable effects by: (1) ensuring maximum initial dilution, through an appropriate means of disposal; (2) selecting areas where dispersive processes (transport and mixing) are active and (3) avoiding particularly sensitive areas.

Sewage sludge and dredge spoils constitute about 90% of the total materials presently being dumped. Both can contain heavy metals, petroleum hydrocarbons, animal and vegetable fats and oils and chlorinated hydrocarbons. They may also introduce into the sea micro-organisms which require special attention, particularly the pathogenic bacteria and viruses.

Wastes are sometimes containerized. An overall density of at least 1.2 g/cm^3 is recommended to ensure that containers of wastes sink to the bottom and remain there. Since containerized materials and bulky solids interfere with bottom trawling, they should be dumped only in selected areas in the deep ocean.

Biological observations might be expected to include: fisheries resources, primary productivity, zooplankton and benthic populations, as well as turbidity, dissolved oxygen and the nature of the sediments. Chemical measurements in water, benthos and sediments might include organochlorine substances, petroleum hydrocarbons, nutrients and such metals as mercury and cadmium. Physical observations should be mainly directed to evaluating dispersion processes. Wind and wave features, vertical density distribution, including mixed-layer depth, and data on currents and bottom conditions would be desirable.

A number of research priorities have been identified which, if met, would greatly improve our predictive ability.

1. INTRODUCTION

The dumping* of wastes into the sea is only one method of disposal of a material and should be carried out only after other alternative methods of dealing with the waste have been fully considered. Ideally, the only ultimate method of eliminating waste disposal of conservative substances is recovery and reutilization of the materials presently considered to be wastes; other disposal operations merely move material from one part of our environment to another. The decision to consider a substance a "waste" rather than a potential "natural resource" is based on economic rather than on scientific principles, because the technology to recover the material in useful form is either not available, or is more costly than the value of the recovered product.

For certain wastes, and under particular circumstances, the cost of disposal at sea may be less than that of recycling or of disposal on land, but the cost must be assessed against the risk and cost of damage to marine resources. Thus low operating costs may have to be set against costs of damage to the environment which may be quite high. It must be recognized, however, that the environment is not divisible into neat compartments and that the cost and risk of effect of waste disposal in a variety of alternative ways, must be examined. In the event it may be necessary to select one method, even though some damage does occur, simply because it provides the safest long-term solution; financial considerations may or may not help justify such a course of action.

However, the GESAMP Working Group on the Scientific Basis for Disposal of Waste into the Sea has not considered cost benefit analysis, which is involved in waste disposal as currently practised, nor did the Working Group discuss alternative disposal methods, but agreed that these will always have to be taken into account when choosing the best procedure. The purpose of this report is to consider how the effects of waste disposal can be assessed and reduced to a minimum, and in particular, what scientific principles are involved in the selection of sites for dumping.

The Working Group agreed that the disposal of waste at sea can be scientifically discussed without taking into account consideration of the justification of waste disposal. The sea has a capacity for receiving a finite amount of waste. This is often largely related to its great volume. The self-purification and buffering capacity of the water is limited, while the seabed as a sink will not be effective for all materials.

The Working Group did not discuss the disposal of radioactive waste into the sea, as this is being covered by a specialized Working Group (IAEA, 1974, 1975). Dumping in relation to specific marine geological features was considered at the fourth session of GESAMP by an ad hoc Working Group on the Consequences of the Human Perturbation of the Deep-Sea Floor (GESAMP IV/19, Annex VII).

In preparing this report, the Working Group was aware that considerable experience could be drawn upon in relation to the effects of marine dumping. Some examples have been cited from the members' own experience; such examples should not be assumed to mean that disposal of those particular wastes is safe under all conditions. The reader should therefore pay due attention to the particular conditions existing in any proposed area of dumping, before making a decision for any new situation.

*The definition of dumping used by the Working Group is that given by the London Convention on the Dumping of Wastes at Sea (UN, 1972).

The assessment of the probable effects of waste disposal at sea involves several disciplines, namely, physical oceanography, chemistry, sedimentology and marine biology, all of which are interdependent and none of which can be considered in isolation. In a report of this scope it has been necessary to concentrate on an identification of those matters of primary importance in order to predict the behaviour and effect of materials when dumped at sea. Having done this, an attempt has been made to identify those subject areas where knowledge is reasonably precise and also those in which knowledge is lacking.

Detrimental effects of pollution of the sea include harm to marine organisms, hazards to human health, hindrance to maritime activities and reduction of amenities. Of the various uses of the sea likely to be affected by the disposal of wastes by dumping, the Working Group considered that attention should be focussed particularly on the living resources of the sea and their exploitation. This was interpreted as including those species which are, or may be exploited commercially, and the food organisms on which they directly or indirectly depend, plus the need to avoid interference with fishing activity. It should be noted that, in many cases, the young stages are particularly vulnerable. Certain areas of the marine environment, although not at present supporting commercial resources, have potential value in this respect and should be protected. The Working Group also realized that human health aspects must be considered, especially in respect of possible contamination of food resources.

Possible concerns which may be important in special circumstances include aquaculture, recreation, preservation of endangered species and exploitation of mineral resources on or under the sea bed.

In making an assessment of the most sensitive species or use to be protected, it is worth noting the merit of the critical pathway approach which has been used with success in the field of radioactive waste disposal. The problems involved in adapting this approach to non-radioactive waste disposal are complex owing to the greater variability of the sensitive species or use to be considered, plus the different types of waste and different modes of action. Nevertheless the system should be applicable and has considerable merit since, once the decision has been made as to what has to be protected, all other interests are subjugated (Preston, 1974).

The report deals with the various properties of the waste which should be known in order to understand the way it will behave in the marine environment, and considers how these may be affected according to the method of disposal used. The methods of disposal considered include the discharge from hopper barges, discharges into the wake of a vessel and disposal of containerized or other bulky wastes. Attention should be drawn to the need to ensure that conditions of licences are observed, especially in relation to site and method of disposal.

The Working Group wishes to stress that this report is not intended to replace Annex III of either Dumping Convention (Norway, 1972; UN 1972), of which note must always be taken. Rather, it is hoped that the report will serve to amplify and clarify the items listed in the Annex III of the two Conventions. In attempting to satisfy its terms of reference the Working Group has prepared its report in the following sequence:

(i) What are the biological, physical and chemical characteristics of the waste and possible effects of the waste in the marine environment?

(ii) How can the effects be minimized by appropriate selection of the method of disposal?

(iii) How can the effects be minimised by appropriate selection of the site for disposal?

Rather than considering various zones of the oceans, such as shallow coastal waters, fjords and the deep sea, the Working Group preferred to work on a more general basis, giving specific examples as illustrations. Finally, in accordance with its terms of reference, the Working Group prepared a section on research needs, whereby an attempt has been made to identify those requiring the most urgent attention.

2. CHARACTERISTICS AND POSSIBLE EFFECTS OF WASTES

The characteristics of a waste fall into three categories of properties: physical, chemical and biological. All three have a bearing on their effects on the marine environment. Different criteria might be applicable, e.g. for degradable and non-degradable substances, and also the degree of toxicity of the substances and turbidity might influence the selection of dumping sites.

2.1 Biological characteristics and effects

The wastes of greatest concern relative to marine life include those materials which are toxic to marine organisms and/or are accumulated within organisms to a concentration substantially greater than that in the environment, or which reach the environment in large amounts, and/or which persist in the environment for long periods of time. Some substances are generally recognized as being of a particularly hazardous nature to the marine environment or its resources; these are listed in Annex I of the Dumping Conventions, and their deliberate disposal by dumping is not permitted.

Less hazardous wastes, e.g. sewage sludges and polluted dredge spoils, may also introduce into the sea micro-organisms and as such may still require special attention. Of principal concern are the pathogenic bacteria and viruses. Amoebae, parasites, yeasts and fungi, which can cause human diseases, may also be present. The principal concern when dumping such contaminated waste is to avoid the possibility of their encroachment on beaches or the return to man via his food, especially shellfish which may be eaten raw, or without sterlization by adequate cooking. Harvesting of shellfish in the vicinity of sludge or spoil dumps, and their marketing, may need to be prohibited or at least be subjected to systematic, hygienic control, in order to protect human health. However, shellfish growth or reproduction may not necessarily be adversely affected.

In order to cause human disease, pathogenic agents must be taken in at certain minimal infecting dose levels. For micro-chemical hazards, certain harmful levels are also needed. Some enteropathogenic micro-organisms are quite resistant to the various effects of sea water. It is clear that micro-biological research should be conducted on the problems associated with sewage sludge.

The acute toxicity of waste materials to marine organisms must be evaluated in order to specify the degree of dilution and dispersion needed to render the waste harmless. The customary method is to conduct a bioassay test, generally for 96 hours, to determine the concentration which will kill half of the population of test organisms in that period of time. Ideally, the test organism should be either the most sensitive locally important in the proposed dumping area, or an organism critical to the maintenance of the ecosystem of the area. This is not always possible, since the first type may be difficult to keep alive even under the best of laboratory conditions; equally, it is often not possible to maintain the most sensitive life stages; finally, the critical organisms may not be known. Thus the results of bioassays are applied with application factors, of one to three orders of magnitude.

Another complexity of applying bioassay test results to dumping of wastes, where dispersion and dilution is the objective, rests in the fact that the organisms in the sea are not exposed to a fixed concentration, but rather, to a constantly decreasing concentration as natural mixing and dilution with uncontaminated sea water follows the disposal. Bioassays which simulate this natural dilution in the laboratory would be useful, but at present probably unrealistically difficult to achieve and control. Therefore it is suggested that as a general rule the concentration found to be toxic in a 96-hour bioassay might be stipulated as the maximum allowable concentration at the disposal site one hour after discharge. The further natural mixing and dilution would be expected to give additional factors of safety during the next four days. Further safety factors might be necessary for wastes which accumulate either biologically or physically, or if the discharge is made under quiescent conditions.

The possibility of sub-lethal, chronic, toxic effects must also be evaluated. These longer term effects may interfere with behavioural activities of marine organism such as feeding, breeding and migrations. There is also the possibility that exposure to sub-lethal concentrations of some pollutants may render the organism more susceptible to disease or to other environmental stress. However, if the waste is dispersed in an area of rapid circulation these sub-lethal effects may not be of great importance. Some waste disposal operations may produce local concentrations of the pollutants on the bottom, such as the disposal of sewage sludge or dredging spoils. In such cases the chronic effects need to be evaluated.

Living organisms can accumulate some pollutants within their tissues to a concentration greater than that found in the environment. For example, heavy metals can combine with proteins, and petroleum and chlorinated hydrocarbons are concentrated in the lipid components. This bio-accumulation results from an imbalance between the rate of assimilation and the rate of excretion. The concentration factor (the ratio of the concentration within the organism to that in the water) may reach several orders of magnitude. When these organisms are eaten, the predator is, in turn, ingesting larger quantitites of the pollutant than it would be exposed to otherwise. Although substances such as mercury and DDT and its breakdown products are recognized as being potentially harmful to marine organisms or to man, it should not be assumed that bio-accumulation *per se* is harmful, since bio-accumulation may also represent a mechanism by which the organism counteracts the toxic effect.

Another indirect effect of dumping might be the change of habitat characteristics. This would be most critical with wastes which accumulate on the bottom. Sessile benthic organisms can be smothered if the waste accumulates to depths of a few centimetres, and the characteristics of the bottom might be changed so that it is no longer suitable for the life style of the natural benthic biota and organisms feeding thereon. Characteristically such modified bottoms will be invaded by opportunistic species (such as the worm *Capitella*) which breed rapidly and are tolerant of polluted conditions. Although in some circumstances they may be replaced by other exploitable species, previously present species of value to man, such as molluscan shellfish, lobsters and crabs, may be excluded from these modified bottoms. As mentioned above, if microbial contamination is also present, harvesting may have to be prohibited even in adjacent areas where the organisms survive, in order to prevent the danger of return of pathogens to man.

2.2 Chemical characteristics and effects

It is possible to obtain some clues, but not a full chemical characterization of a waste, from a knowledge of the raw materials and the production process used. A standard, full-scale analysis for an extensive list of chemical elements or compounds is not necessary; rather, analysis should be tailored to the needs for each waste. However, certain general guidelines can be given. For example, analysis for total solids, total particulates, organic matter and specific gravity will generally be applicable. Analysis for several trace metals, pesticide compounds and PCBs will provide useful information on persistent substances; these are likely to be present in many wastes.

Sea water has a considerable buffering capacity for acids and alkalies. For example, the acid-iron waste from the production of titanium dioxide using the sulphuric acid process is rapidly neutralized on release into the sea. Following neutralization, the original ferrous sulphate is oxidized to the ferric state, thus exerting a chemical oxygen demand, and is precipitated as ferric hydroxide.

Under stagnant conditions, wastes with a high chemical oxygen demand (COD) and/or biochemical oxygen demand (BOD) can lead to deoxygenation of the water or the sediment (examples are sewage sludge, pulp-mill wastes and food processing wastes). This decomposition of organic matter can lead to release of large amounts of nutrients such as phosphate and available nitrogen which, if not adequately dispersed, can cause local enrichment of the water and changes in species composition. In such circumstances, blooms of algae, including those associated with red-tides, may occur and ultimately, on death and decay, cause deoxygenation and odour problems.

Certain chemicals, of which the chlorophenols are probably the best-known example, can, even at very low concentrations, cause tainting of fish and shellfish, rendering them unacceptable for human consumption. It is important, therefore, to avoid disposal of such wastes to the sea.

Other chemicals (e.g. cyanide, free chlorine, organophosphorus compounds) are acutely toxic to marine life. In many cases, they are rather rapidly rendered harmless by chemical or biological processes. Cyanides, which are present in some heat treatment salts used in the case-hardening of steels, are hydrolysed to formic acid and ammonia. Barium, which may also be present in some heat treatment salt mixtures, is precipitated by the sulphate of the sea water as insoluble barium sulphate. Chlorine is reduced to chloride, which is a major constituent of sea water. The highly toxic organophosphorus compounds are hydrolysed in sea water, with a half-life ranging from a few days to several months. However, colloidal elemental phosphorus is only very slowly oxidised in sea water and has been known to cause damage to marine resources (Jangaard, 1972).

Many heavy metals are accumulated by marine organisms. The special risks posed to human health by mercury and cadmium are recognized by total prohibition of disposal (except as trace contaminants) under both Dumping Conventions. Investigations have shown that, in the aquatic environment, mercury is transformed into organic mercury compounds, e.g. methyl mercury, which are far more toxic than inorganic or metallic mercury (Jernelöv, 1969).

Wastes containing other metals or elements such as lead, zinc, copper and arsenic, can be dumped but require special attention. A local build-up of any of these compounds or elements is likely to be undesirable. Again, the chemical state is important; in insoluble form, and in some cases also in complexed form, the acute toxicity of lead, zinc and copper is much reduced. In anoxic areas of the sea, where hydrogen sulphide occurs, many heavy metals can be eliminated from the sea water by formation of very insoluble metal sulphides. One exception is iron, which as ferrous sulphide is more soluble in sea water than in the form of ferric hydroxide which is the normal form under oxygenated conditions. In some cases, the precipitation of heavy metals as sulphides can be prevented by complexing agents present in sea water which form soluble metal complexes. It should be noted that it has been found that under anoxic conditions, mercury sulphide is more soluble in sea water than would be expected from its solubility product (IAEA, 1971).

It should be pointed out that certain metals and organic substances are readily and strongly adsorbed on to and/or absorbed into, particulate matter, such as clay or metal hydroxides. There is some evidence that in this form they are much less readily available to marine organisms, i.e. the risk of bio-accumulation or toxic effects is reduced. Similar effects may also be created by the formation of organic complexes, but this would be largely dependent upon the stability of that complex. It should be noted that the valency state of an element is of importance when its effects on marine organisms are to be predicted, e.g. arsenic is less toxic in the pentavalent form than the trivalent form, but hexavalent chromium is more toxic than trivalent chromium.

The incineration at sea of chlorinated hydrocarbons results in the formation of large amounts of gaseous hydrochloric acid and water vapour. These combine and condense to form droplets, which precipitate usually within a relatively short distance of the incineration vessel. The acid is readily neutralized by the sea water.

2.3 Physical characteristics and effects

It is necessary to know whether the waste is a liquid or solid, or a solid in suspension, and the density of the waste as a whole and of any solids it may contain, since these properties will influence both initial dilution, and subsequent dispersion and settlement. Settling velocity will be influenced by the shape, size and density of the particles, and aggregated matter will settle more rapidly than individual particles of the same density. Under stratified conditions, particulate matter may be retained or have its vertical dispersion suppressed in a pycnocline layer.

Particulate material can influence the marine environment in several ways. If it settles in large amounts in a confined area, the benthic flora and fauna will probably be adversely affected. If the solids are organic, anoxic conditions could become established. Although in some sea areas the natural suspended particle load is high, addition of suspended matter will increase turbidity and may cause discolouration of the water with possible adverse effects on fisheries and recreational interests. Certain forms of particulate waste may clog gill surfaces of marine fish, crustacea and bivalve shellfish. If a waste is practically insoluble and positively buoyant, it will float and shipping or amenity interests may be adversely affected.

2.4 Organic matter

In spite of the fact that natural dissolved organic substances decompose under favourable conditions (Duursma, 1965) they have a residence time of some thousands of years in the deep water of the open ocean (Williams, 1969). This means that an introduction of more stable artificial organic compounds into the deep sea could lead to an even longer residence time. The conditions close to land are more favourable for decomposition since, owing to the presence of solid matter, lower pressure and generally higher temperatures, the bacterial activities are much higher; as a result a rapid turnover of dissolved organic materials is commonly observed (Jannasch, 1969; Jannasch et al, 1971). It should be noted, that the rates of such processes are substantially reduced at low temperatures, e.g. in high latitudes.

This does not imply that dissolved organic materials should preferably be dumped in coastal areas. It is clear that aspects other than degradation are important. In particular, some toxic compounds are resistant to degradation. For certain materials, disposal in areas far from land may be preferable to dilution and degradation in near-coastal waters. For artificial organic wastes it is usually safest to neglect degradation (which may be very slow), and to base the evaluation of limits on the concentration achieved by physical dispersion.

2.5 Sewage sludge and dredge spoils

On the basis of U.S. and European figures, the largest bulk of materials dumped into the sea is dredge spoils (about 80 per cent) and sewage sludge (about 10 per cent). For this reason, special attention is given to these wastes. Both can be contaminated with metals, bacteria and viruses, polynuclear aromatic hydrocarbons, petroleum hydrocarbons and organohalogens.

Dredge spoils consist of a heterogeneous aggregation of materials, very often anoxic, in a broad spectrum of sizes, ranging from submicron clay particles to stones of many centimetres in diameter, with often a large proportion of organic material. Sewage sludge is a more uniform mixture of finer organic and inorganic substances.

The principal ecological problems arising from the disposal of dredge spoils and sewage sludges are the large oxygen demand and deposition on the bottom to considerable thickness. Both may also have associated human health implications. Decomposition of the organic content of dredge spoils or of sewage sludge, particularly undigested sludge, can deoxygenate both the sediments and the overlying water and lead to the formation of highly toxic hydrogen sulphide.

The health hazard posed by pathogenic bacteria in sewage sludge can be diminished by digestion. For these reasons the dumping of sewage sludges must always be carefully operated according to the local oceanographic conditions. Only dilution will decrease residual hazards of the viruses. In order to cause human diseases, pathogenic agents must be ingested at certain minimum infecting doses.

2.6 Bulky and containerized wastes

The deliberate placing on the sea bed of bulky objects, such as old cars and car tyres, has been advocated by numerous interested parties and has been carried out on an experimental basis in a few countries. The artificial reefs so formed are usually reported to provide good settling surfaces for a variety of sessile organisms, and havens for creatures such as lobsters; they also appear to be attractive to a variety of species of interest to sport fishermen. Baled municipal wastes may provide similar havens, but buoyant materials, e.g. plastic, must either be packed so that they do not return to the surface, or be pretreated in an appropriate way. In many of the continental shelf areas trawl fishing is so intensive that great care would be necessary in order to avoid interference with fishing activities.

Particular care is required in relation to areas of fishing activity when dumping waste in containers. The recovery of such containers in the course of fishing operations could be hazardous to the crew of the fishing vessel, especially as the container is likely to be seriously weakened by corrosion. Under the terms of the Oslo Convention, disposal of bulky and containerized wastes is prohibited except in deep water.

It is considered necessary when dumping a containerized waste in the sea to ensure that disposal avoids known deep-sea cables, in case these might be damaged by the impact of a container on the cable. In several instances wastes are containerized to avoid release of the waste in the upper or middle layers of the ocean. Occasionally the waste may be in a container merely because this provides a convenient means of handling. However, most wastes disposed of in containers are toxic to man. Of the examples known to the members of the Working Group, most wastes dumped in containers are solids and also toxic to marine organisms. But since they are also solids in most cases, they will dissolve only slowly into the deep water layers and the area likely to be affected by toxic action can be shown to be relatively small (National Academy of Sciences - National Research Council, 1962). In some cases, wastes dumped in containers are either mixed with concrete or the container is encapsulated in concrete; in both cases the rate of release of the waste to the water is likely to be much reduced. Nevertheless any marine organisms in the immediate area of a container of waste on the deep sea floor may be at risk.

The areas of interest from a commercial fisheries point of view now extend to the continental slope regions down to at least 1000 m. Therefore if such wastes are to be disposed of in deep water, they should be dumped well away from the continental slopes. Similarly the higher regions of deep-sea ridges should be avoided. It should be noted that, although no definition is given in the London Convention, for the purpose of the Oslo Convention, deep-water dumping areas are defined as being at least: 2000 m deep and 150 nautical miles from land; additionally it has been agreed that dumping should not take place within 20 nautical miles of any known cables. However, these criteria alone are not sufficient, and care should be taken to avoid ecologically sensitive areas.

3. METHOD OF DISPOSAL

Dumping is defined by the terms of the London Convention on the Dumping of Wastes at Sea as an intermittent injection of waste materials into the sea, and it is pertinent to distinguish between the dumping of:

(i) waste confined in containers, or in the form of compacted bales, and/or bulky scrap materials; and

(ii) uncontained waste in a bulk cargo.

3.1 Confined wastes

Wastes of a heterogeneous type can be handled much more readily in contained form than in bulk, unincorporated state. Municipal solid wastes can, by high pressure compaction, be transformed into stable bales suitable for transportation.

The primary requirements for the containers and bales are that they meet the appropriate transport regulations and retain their contents during the descent to the sea bed, or some pre-determined intermediate depth. In a situation where prolonged confinement is required, the containers should not break owing to the increased pressure. Their overall density should exceed 1.2 g/cm^3.

Depending on the shape, size, integrity and weight of containers of waste, and the character of the sea bottom where the containers are dropped, there are a number of ways in which the containers may behave:

(i) sink intact into the bottom ooze without disintegration;

(ii) sink into the bottom ooze and disintegrate;

(iii) remain intact and sealed indefinitely on the bottom without significant penetration;

(iv) rupture on impact accidentally, or deliberately charged to do so, spewing their contents onto the ocean floor and into the overlying water;

(v) implode under the high pressure, or gradually disintegrate on the bottom, releasing their contents to the surroundings.

If the container and contents sink into the bottom ooze, without disintegration, they will, in effect, be permanently interred in bottom sediments. Provided the bottom is not disturbed later by mining or deep dredging activities, the effect on the bottom water and sediment will be minimal. Disintegration after penetrating the sediments would lead to local sediment contamination. If the container explodes or implodes, because of pressure, impact or explosive, the contents will be suddenly released to the water and sediments.

3.2 Bulk cargo wastes: Release techniques

In this case the wastes are discharged from barges in bulk. Usually two types of barges are used, self-propelled or towed, discharging either by pumping or by gravitation. In small dredging operations bottom release (bottom dump) may be used, whereas automated tank barges are used for sewage and industrial sludges and liquids.

The size of the barges varies from 300 to 8000 tons, and the discharge is usually about 5 metres below the surface through pipes which can have diameters in the range 10-60 cm. The release is usually carried out at speeds of 6-10 knots, at a discharge rate of 4-250 tons/minute. Sewage sludge is usually discharged from a hopper barge at a rate of 100-200 tons/minute, using gravity alone or in combination with low pressure air (EPA, 1971).

The incineration at sea of combustible waste materials can result in the formation of large amounts of gases. In most cases, these will be transferred back to the sea by the precipitation. The subsequent spreading of the remains, mainly in the surface layer, can be expected to be fairly rapid in most cases.

3.3 Bulk cargo wastes: Dispersion

The release technique has a considerable influence on the initial dilution and consequently the long-term physical dispersion in the marine environment.

Physical dispersion is defined as the combined action of (a) mixing on release followed by the turbulent mixing in the sea, and (b) the transport by currents. An effective dispersion requires good mixing conditions and a high rate of exchange between the dumping area and the surrounding sea, so that the waste becomes diluted by a large volume of water. It is primarily by means of the physical dispersion that the impact of the waste on the marine environment can be controlled. However, as noted earlier, there are a number of other processes acting in the same direction and these help to minimize the impact.

Two stages of the dispersion phase are considered, namely the initial phase covering the initial dilution, and the subsequent dispersion.

(i) The mixing on release will depend both upon the characteristics of the waste and the technique of release. The important physical characteristics of the waste in this connexion are the density distribution, the content of solids and their size distribution. The initial dilution is mainly controlled by the rate of release and the speed of the vessel during release.

In areas where there is some degree of density stratification, the waste material can be dispersed, so as to retain it temporarily in the surface layer, by releasing it into the wake of the steaming ship. An initial dilution of the order of 1:1000 of the waste shortly after release will reduce the density of the mixture to an acceptable level under most stratified marine conditions. This dilution is usually reached about 500 m astern of the ship, in its wake, at speeds of 6-8 knots (Abraham et al., 1972). When the water column is homogeneous, the contaminated water will sink or remain at the surface, depending upon whether the density of the waste is greater than, less than or the same as, that of sea water.

Wastes with an average density higher than sea water dumped from an almost stationary vessel, or in great amounts over a short period of time (order of one hour), will sink due to their initial excess density and momentum. Two phases of the initial dispersion can be defined (EPA, 1971).

(a) convective descent - due to initial excess density and momentum;

(b) collapse in a pycnocline layer where the falling waste cloud can be trapped.

The initial dilution appears in this case to be of the order 1:100-1:500, but this is based on relatively few observations (Crickmore, 1972; Kullenberg 1974). Models have been constructed for predicting the depth of penetration (i.e. maximum depth) of the waste and the vertical concentration distribution in the contaminated water column, but they suffer from many simplifying assumptions and approximations (EPA, 1971).

(ii) The subsequent environmental dispersion is due to the turbulent mixing and the transport by currents in the water. The rate of dispersion can be very slow, and will depend primarily on several physical environmental factors to be discussed in section 5 on site selection. However, the dispersion can be influenced considerably by the initial concentration distribution of the waste immediately after the dumping has been completed. This will depend upon the method of disposal, the characteristics of the waste, and the density stratification of the disposal area. Spreading over a large vertical distance will in practically all cases favour a rapid subsequent dispersion. Accumulation of waste at density interfaces will always suppress the rate of the subsequent dispersion. Such accumulation can occur by trapping of the falling cloud of waste in the pycnocline layer, or by trapping of buoyant waste material at the surface. Trapping of kraft-mill effluent from a submarine diffuser outfall has been demonstrated by Waldichuk (1964).

It can be concluded that in all cases when a rapid dilution is required, the method of disposal should be in the wake of a steaming ship. In general, an initial dilution as high as feasible should be secured; reasonable values which can be achieved under normal conditions are in the range 1:200-1:2000 (Weichart, 1972; Crickmore, 1972; Abraham et al., 1972; EPA, 1971).

Since both the disposal technique and the waste characteristics can be adjusted, at least to a certain extent, an initial dilution can usually be obtained which will meet requirements for minimum impact on the environment. Generally, trapping or collapse in pycnocline layers should be avoided.

The dumping frequency should be adjusted according to the capacity and dispersion characteristics in the dumping area: in areas of rapid mixing and transport, the frequency of disposal can be higher than in areas of less vigorous dispersion. A build-up of waste materials in the water column should be avoided. As a useful generalization, the dumping locations and frequency should be adjusted so that individual waste clouds do not overlap. This will be relatively easy in the open sea but may be impossible in an estuary. A preliminary assessment can be made on the basis of the current conditions in the area, such as tidal, wind-generated, and residual currents.

4. OTHER USES

Uses of the marine environment other than for ocean-dumping are manifold, they include fishing, transportation, recreation including sport fishing, mining including chemical extraction, aquaculture. In addition sea water is used as process water, and cables are laid on the ocean floor. Many of these uses can be adversely affected by marine pollution, but for the purposes of this report, only the relationships between the other uses and ocean dumping are considered.

Fishing: Fishing is one of man's major activities in the marine environment. The world fisheries (including all marine organisms) exceeded 65 x 10^6 metric tons in 1973 (FAO, 1974). It has been estimated that the maximum sustainable yield of world fisheries may be about twice this figure.

Transportation: Shipping and transportation is another of the major uses of the sea, and continually increases. Ocean dumping operations might interfere with the shipping directly by interference with navigation as well as by such effects as blockages of cooling systems and fouling of propellers.

Recreation: Outdoor recreation increases continually and sea shore recreation ranks as one of the most important, economically and socially; it is therefore important to avoid the stranding of aesthetically undesirable material such as grease, plastic and other slowly degradable organic matter.

Mining: Ocean mining on the bottom of the sea and extraction of chemicals from sea water may be affected by impurities or physical obstructions introduced by dumping.

Aquaculture: Aquaculture practices in marine and fresh water contribute, at present, 5-6 million metric tons to the world food supply of which about 85% is produced in Asia and the Far East region (Rabanal, 1974). The potential is great but economic factors currently confine the practice to high quality fish, invertebrates and seaweed.

Submarine cables and pipelines: Submarine cables and pipelines may be affected by ocean dumping, chemically as well as physically. Besides this possible direct effect of dumping on submarine cables and pipelines, submarine slides triggered by dumping could be a potential threat to them.

Scientific research: Geophysical exploration, meteorological-oceanographical measurements, for instance by means of moored buoys, or even studies on variations in fish stocks due to natural causes, may interfere with or be disturbed by dumping activities.

5. SITE SELECTION

The selection of dumping sites must be made in such a way as to minimize the influence on present and potential other uses of the sea.

5.1 Biological characteristics

An evaluation of the biological sensitivity of a potential dumping area should always be made. Disposal sites should, obviously, be selected to avoid areas of high biological productivity, intensive fishing, breeding or nursery grounds, and migrating routes of important fish resources. Some of these activities, such as breeding and migration, may be seasonal and dumping at other times of the year may be acceptable, provided no substantial mobilization of toxic material occurs after dumping. Dumping in active fishing areas may not only affect the living resources of the sea, but the operation may interfere with fishing vessels, and some kinds of wastes may damage or foul the nets or the fishing gear. The marine environment and its living resources are sensitive to natural changes and they have to be carefully guarded against artificial changes.

Food production is one of the major uses of the sea. Many areas are already over-exploited, whereas others are more or less untouched (FAO, 1972). The present world catch is largely restricted to the coastal zones and continental slopes where input of pollutants from all sources, is likely to be highest. In recent years fishing for new species has extended to much greater depths on the continental slopes than previously. It should be noted also that significant pelagic fisheries exist in some open ocean areas, e.g. the equatorial zones.

In relation to waste disposal at sea, it should be noted that the highly productive areas in the oceans are often related to such physical features as cyclonic gyres, upwelling, lateral boundary currents, ocean fronts, i.e. all areas of divergence. All these conditions are more or less conducive to high nutrient supplies and primary production and zooplankton concentrations, on which fish stocks and other marine life depend.

Conversely the ocean circulation gives rise to convergence such as the Sargasso Sea, equatorial convergences and coastal convergences. Although productivity is generally low in such areas, waste matter may accumulate there, especially if it is resistant to degradation.

The natural stress to which organisms are subjected varies in magnitude and frequency. For example, seasonal variations in temperature are extreme at high latitudes when compared with the tropics. A high degree of seasonal variability can also occur along ocean fronts. It is always cold and dark in the deep water of the open ocean, while salinity, light, and temperature can change rapidly in estuaries, on tidal, daily, and seasonal time scales. The organisms living in such highly stressed environments have evolved to withstand these changes, but may not be well adapted to artificial stress. Similarly, pollution might affect their capacity to adapt to natural changes.

Special attention must be paid to animal migration. Migrating species use their acute sense as a guide in homing on their native region. Interference with the natural characteristics of these waters by introduction of foreign materials can disrupt fish's detection processes. Dumped materials could conceivably mask natural characteristics of the sea water or of tributary streams. This might confuse migrating fish, possibly to the extent that they become lost and go unspawned or fail to find food.

Closely connected to these aspects are spawning, nursery and feeding processes of marine organisms. Critical species, vertical and horizontal biological transports, bio-accumulation, biotransformation, taint should also be considered.

Depending upon the characteristics of the waste material, certain general precautions should be observed in planning the disposal operations. If the waste contains toxic materials, the dilution achieved during disposal and the subsequent mixing of the waste with sea water should ensure that the concentrations are not sufficient to damage the marine biota. For substances that settle to the bottom, areas of little or no benthic productivity should be selected, or, if not possible, the sacrifice of a part of the benthic population should be assessed as part of the "cost" of the disposal.

5.2 Sediment characteristics

Sediments of the sea bed of the major ocean basins have a potential sorption capacity for all kinds of metals and organic substances. However, material originating from dumping of wastes may be dispersed in the water column rather than sorbed to the sea bed/sea water interface. In the presence of high turbidity, there is a scavenging effect by solid materials of substances from solution.

When the materials reach the sea bottom, a high affinity of the sediments for the waste material leads to a large total uptake by the sea bed. However, this uptake is primarily in a thin surface layer of the sediment, and penetration deeper into the sea bed is slow. Therefore, if resuspension or erosion occurs, the material might be recycled to the water and to the benthic epiflora and epifauna. Thus the sea bed will not always be the ultimate sink for dumped wastes.

Wastes submerged in the sea bed would in principle be removed from the water system. Migration to the supernatant sea water takes a long time when the wastes are buried under several centimetres of sediment. However, burying of wastes inside the sea bed is technically difficult to achieve.

For liquid or dissolved wastes, unless sediments are stirred up, little material will be bound by the sea bed. In a dumping site, most of the dissolved substances will become so dispersed within the water system that sorption by the sea bed will be extremely limited. However, with respect to repeated dumping, especially of materials which are not rapidly degradable, the area will accumulate more and more material in the sediments. This will apply particularly to certain heavy metals for which a phenomenon of immobilization exists via absorption inside crystal lattices of sedimentary particles (Ros-Vicent *et al.*, in press).

5.3 Dispersion characteristics

The turbulent mixing in an area, and the rate of exchange with the surrounding sea, should both be studied in order to assess the dispersion characteristics of a potential dumping site. In studying the physical dispersion characteristics of an area, the following generalizations should be borne in mind.

A. Mixing rate

The turbulent mixing in the sea is determined by such physical factors as wind, waves, mixed layer thickness, density stratification, currents including their temporal and spatial variations (Okubo, 1971; Weidemann and Sendner, 1972). In many shallow water areas, the tidal currents are the dominating mixing agents. In conditions of stable stratification, the mixing is suppressed, and very markedly so in pycnocline layers. There the rate of dilution is slow and varies very much with time, i.e. the mixing is intermittent. For contaminants which do not affect the flow, dilution rates of less than 1:10 in 24 hours have been observed in enclosed areas (Kullenberg, 1974a). Similarly suppressed mixing is likely to occur in strongly stratified open sea areas. Under those conditions, particulate matter settles due to gravity, although near-neutrally buoyant material may remain in suspension. The settling velocity of the waste particles will vary, although a rate of 1 m/hour appears to be representative for the flocculated state (Crickmore, 1972). Trapping of almost neutrally buoyant material can occur in pycnocline layers.

In the wind-mixed layer the dilution rate is considerably higher: a dilution in the range 1:10-1:50 over a period of 1-5 hours can be expected under light wind conditions. During strong winds, the rate of dilution increases approximately with the square of the wind speed (Bowden *et al.*, 1974; Kullenberg, 1971).

Close to the bottom, there will often be a turbulent boundary layer, the thickness of which will depend upon the bottom roughness and current velocity. An indication of the transport conditions along the bottom can often be obtained from the type of sediments at the interface. Fine-grained material normally suggests weak transport and a favourable settling environment, whereas coarse materials suggest resuspension and erosion. However, care should be taken in applying this concept, and it should be noted that conditions often vary seasonally.

In estuaries and river mouths, the compensation current transports material along the bottom towards the shore. This can also occur in shallow waters with horizontal density differences, eddies or wind-induced coastal upwelling. The oscillating (tidal) currents in many areas will cause resuspension and fractionation due to differential settling. This implies that the fine-grained fraction of a waste, which can serve as a carrier for pathogenic organisms and other pollutants, may be selectively transported inshore.

Available information on deep-sea, near-bottom currents suggests that resuspension will not take place except in certain areas. These are mainly located at the lateral boundaries and are related, in part, to topographic features such as slopes, canyons, and ridges.

B. Mixing mechanisms

In the wind-mixed layer, the vertical mixing down to the primary interface is quite rapid. Thus the thickness of the wind-mixed layer is significant in determining the mixing characteristics. An important dispersion mechanism for scales in the range 1-10 km is the vertical shear effect, i.e. the combined effect of vertical mixing and vertical current shear in generating horizontal dispersion. For an initially thick contaminated volume, the stretching due to the vertical shear is also important. In this connexion, the time-dependent and, in particular, the oscillatory components of the current are important in determining the spreading.

In the surface layer, the vertical mixing depends upon the wind, the shear and the stratification. In internal stratified layers the vertical mixing is suppressed, and is inversely proportional to the stratification. Dominant features of the internal motion in the sea are internal waves which only give rise to mixing when breaking.

At larger scales, above about 10 km or several days, the large-scale horizontal variations of the currents will dominate the mixing.

C. Exchange rate

When considering the dispersion characteristics of an area, it is necessary to take into account the rate of exchange with the connected open sea area. A useful indicator of the rate of exchange is the residence time for a particular element, which can be estimated by means of a natural tracer. This holds true in particular for enclosed or semi-enclosed areas like fjords, marginal seas and land-locked seas. The residence time will also give a measure of the build-up of a persistent material in the area.

From the point of view of dispersion, the following three categories of areas may be defined:

(i) Areas of great turbulence.

Areas of tidal activity are often characterized by a high degree of turbulence; and such areas offer great possibilities for natural dispersion. Care is necessary, however, to avoid conflict with local interests, especially aesthetic and recreational, and also in order to predict where particulate matter in the waste might ultimately be deposited.

(ii) Confined basins.

Confined basins (e.g. Baltic and Black Seas) will in many cases periodically approach anoxic conditions and be subject to periodic turnover. Such areas might sometimes be considered for the disposal of inert wastes, and perhaps also biodegradable ones. However, persistent and potentially bioaccumulatable substances should be avoided, since ultimately they might be returned to the productive surface waters. It should be pointed out that, as in all other cases, local considerations must be taken into account.

(iii) Other areas of minimal turbulence or "quiescent" conditions.

These areas are characterized by a distinctly limited capacity to receive wastes, since transport out of the area and renewal of oxygen supplies etc. are all limited. The all-important consideration in waste disposal in such areas is therefore how to achieve maximum possible initial dilution. The scale of the operation will also have to be controlled. The more inert a substance, in general, the greater the acceptable scale of dumping, but in this context the local existing or potential marine resources must be considered.

D. Methods of prediction

Predictive modelling of the dispersion of various wastes following a dumping operation is of great interest, but suffers as yet from several deficiencies. Nevertheless, simple models have been used with satisfactory results in predicting the dispersion of radioactive wastes. Attempts have been made to model both the initial and the subsequent dispersion (EPA, 1971; Koh and Chang, 1973). However, the results must be regarded with great caution since a number of very limiting assumptions are made, such as treating the contaminants as passive. The lack of relevant observational information is at present the most severe hindrance to further development of the predictive models.

6. OBSERVATIONS AT THE SITE

Once a preliminary selection of the site for disposal has been made on the basis of existing knowledge of conditions in the area, a series of observations of the physical, chemical and biological characteristics should be made. Ideally, these should extend over a period of at least one year in order to take account of variations which will occur with seasonal changes. It should be noted that long-term variations arise as a result of purely natural causes and at present it is often extremely difficult to distinguish these from artificially induced changes.

Observations of turbidity and chemical and biological characteristics should be continued after dumping commences to ensure that no detrimental changes occur. All observations should be made at and around the selected site, and it should be recognized that in the light of the pre-dumping, or even post-dumping observations, a new site may have to be selected.

6.1 Biological observations

Prior to approval of a disposal site, biological observations to characterize the site are usually essential. If repeated disposals at the same location are expected, these observations should be made at all seasons of the year and repeated more frequently at critical times of the year, both to monitor the biological effects and to account for year-to-year variations. For a single dump, which is not expected to be repeated, a single assessment prior to the dump should be acceptable, but observations following the dump would be desirable to evaluate the effect and to form the basis for future decisions concerning similar operations.

Desirable observations might be expected to include:

(i) Fisheries resources. Data on this subject are probably already available in the appropriate agencies or ministries for most coastal regions.

(ii) Primary (plant) productivity as related to light intensity and nutrients. This is especially important if decomposable organic matter is included in the waste, and if its decomposition would release nutrients stimulating plant growth, sometimes with undesirable effects such as modification of species composition.

(iii) Natural turbidity of the water, and the changes in turbidity which may be produced by the waste disposal. Turbidity influences the amount of light reaching various depths in the sea, and a persistent increase would be expected to reduce plant productivity. However, if rapid dispersion (or sinking) of the waste is achieved, and if the circulation in the area is such that the turbidity increase is transitory, little effect on productivity from a non-toxic waste would be expected. Phytoplankton reproduce at such a high rate that recovery from a decrease in photosynthesis is likely to be rapid.

(iv) Zooplankton populations and their vertical diurnal migrations. These organisms might transport elements from one level in the water column to another, through absorption, feeding and excretion.

(v) The oxygen content of the water and its natural variability. This will help to evaluate whether or not a waste with an oxygen demand may reduce the oxygen content to levels which will be detrimental to marine organisms.

(vi) Structures of normal benthic populations, whether or not they are of commercial importance. This is especially important whenever the waste may reach or accumulate on the bottom of the disposal site. Since benthic animals remain in a fixed location (in contrast to fishes and plankton), they reflect the integrated effect of chronic exposure to the pollutant and can provide early warning of potential damage.

(vii) Micro-biological indices in respect to water quality for protection of human health.

6.2 Chemical observations

The design of the chemical observations, unlike those of a biological or physical nature, can be tailored to the chemical characteristics of the waste. For example, if the waste to be dumped contains no nutrients, there is little point in carrying out an exhaustive survey of nutrient levels in the area selected for disposal.

It is difficult to provide a comprehensive list of substances which should be measured in the area, but depending upon the composition of the waste, the following substances might be worthy of attention: organochlorine pesticide residues, PCBs, petroleum hydrocarbons and metals such as mercury and cadmium, - these are all prohibited under the terms of Annex I of the Dumping Conventions, but they are known to be present in wastes such as sewage sludge and dredge spoils and may be found in a variety of industrial wastes. The Working Group noted that such substances are permitted to be present in trace amounts, regardless of the volume of the waste, and this raised the question in the minds of the members of the Working Group, that perhaps a prohibition as currently prescribed in the Dumping Conventions was debatable. The point highlights the need for the continuous reappraisal of the Annexes of the Dumping Conventions and their definitions.

A number of other elements, e.g. zinc, copper, lead and arsenic, may also be accumulated and should be measured. The highest concentrations of most of the substances listed above are likely to be found in sediments and benthic animals. It will in general be undesirable that the organic content of the sediments be unduly increased; as a measure of this, loss on ignition, or more preferably total organic carbon content, should be measured. If the waste contains substantial quantities of nutrients such as phosphate, nitrate, nitrite or ammonia, these should be measured in the water column.

It is perhaps worth pointing out that substances considered to be harmful in the freshwater environment may be less so in the marine environment, e.g. cyanide due to complexation with metal ions, and ammonia due to the buffering effect of sea water, or even virtually harmless, e.g. chloride, sulphate or barium (the former are present naturally in sea water at high concentrations, and the latter will precipitate as barium sulphate). Subject to such fairly obvious exceptions, in general, if a substance is known to be present in waste in high concentration, its presence should be expected in the dumping area and appropriate measurements should be made.

6.3 Physical observations

From the point of view of dispersion, the physical conditions at the dumping site should be observed, and a general assessment of the exchange rates between the waters in the dumping area, near-by-areas and the open ocean should be made.

Observations of the physical conditions might be expected to include:

(i) wind and wave features;

(ii) vertical density distributions during different weather conditions, including the mixed-layer depth on a seasonal basis; water temperature and its seasonal variations;

(iii) current conditions, including the vertical current distribution, velocity ranges and directions, time-dependence, oscillations and residual currents;

(iv) bottom conditions and geological characteristics, such as the nature of the sediment and topographic features (e.g. flat bottom, trenches, ridges);

Useful tools in such observations include dye diffusion experiments, the use of radioactive tracers, wave gauges, grab and core samples of the sediments.

7. SUBJECTS REQUIRING FURTHER RESEARCH

In the course of preparing its report, the Working Group has identified a number of areas where basic information is either imprecise or lacking. In particular, it considered that the predictive ability in a relatively unstudied area is inadequate. It is considered that research in the following subjects would be most productive in providing information relevant to the selection of dumping sites.

7.1 Biological and chemical aspects

Basic acute bioassay techniques are reasonably well established. Further attention is required in relation to the selection and culture of the most appropriate test organism for a particular set of site conditions. This should take into account possible food chain accumulation and the most appropriate life stage.

In order to be able to have a better appreciation of the appropriate factors and time effects, long-term (one or more generations) "flow-through" tests are required to evaluate potential sub-lethal or chronic effects.

It is recognized that combinations of two or more wastes may be more, or less, toxic than each waste separately. At present, there is little information on how the effects of such combinations can be predicted for conditions in the marine environment.

Much more detailed information is required on the mode of action of particular chemicals, especially in relation to uptake and availability from a toxic action standpoint. In this context information is also required on the various forms of a chemical substance which may be present in the sea, e.g. valency state of ionic species, metallo-organic complexes, adsorbed metal or organic compounds.

Similarly, and especially in relation to human health implications, studies are required of the form and toxicity of the compound once it has been accumulated by a marine organism, e.g. the forms of mercury, cadmium and arsenic in marine organisms and the way these may be altered. In this connexion, studies are required to provide more detailed information on the mechanisms of bioaccumulation within a single organism and transfers in a food chain.

Many inorganic and organic compounds find their way to the sediments. The rate of such transport, the residence times of substances in the sediments, and their subsequent mobilization, are generally not well understood. For deep-sea disposal, research is required to improve and modify the methodologies and measuring techniques.

The persistence of organic chemicals, especially petroleum and chlorinated hydrocarbons is a matter of concern. The rates of decomposition under various environmental conditions, such as tropical, temperate and arctic conditions, need to be established. Information is required on the dependence of marine bacteria on threshold concentrations of the organic substrate, and inorganic nutrients. The extent to which microbial activity takes place under deep-sea and mid-depth pressure and temperature conditions, requires detailed investigation.

In order to be able to assess the impact of a waste in the marine environment, some estimate of existing levels of waste constituents and their sources is required. River or pipeline inputs can be determined fairly readily, but the influence of aerial transport, including that on breakdown and production of pollutants, is unknown for most substances, although it is now genrally recognised as being of great importance.

It is known that a number of entero-pathogenic micro-organisms are quite resistant in sea water (Gameson, 1975). Further work is required in the study of the behaviour and fate of micro-organisms associated with wastes such as sewage sludge, especially the influence of such factors as temperature, light salinity and sedimentation.

7.2 Physical aspects

Carefully designed field experiments are required in order to obtain information for developing and testing models for predicting the depth of penetration and possible collapse of a falling cloud of waste. Measurements should provide information on the concentration distribution during descent, turbidity generation, settling velocity and subsequent dispersion in relation to physical conditions. Such experiments would need to be carried out under a variety of environmental conditions, ranging from quiescent to near-storm conditions and in both deep and shallow, stratified and unstratified waters. Particular attention should be paid to those conditions likely to give the least initial dilution and/or subsequent dispersion.

Due to the difficulty of covering all conditions occurring in nature, careful attention should be given to the selection of environmental conditions for field experiments, so that expensive field experiments can be backed by appropriate laboratory experiments. In many instances, large-scale dumping experiments can give required information more rapidly, on both physical and chemical behaviour of wastes in the sea.

There is a severe lack of information about the influence of the waste on the mixing processes, as well as about the possible physical interactions between various types of materials. At present, it is not possible to take into account properly the multiphase character of a waste when predicting its physical fate.

In relation to disposal in deep waters, there is an urgent need for studies of deep-water and near-bottom dispersion processes, including the development of new techniques, e.g. for measurements of currents and turbulent diffusion.

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