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**IMCO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP
JOINT GROUP OF EXPERTS ON THE SCIENTIFIC ASPECTS
OF MARINE POLLUTION
- GESAMP -**

REPORTS AND STUDIES

No. 16

**Scientific Criteria for the Selection of
Waste Disposal Sites at Sea**

INTER-GOVERNMENTAL MARITIME CONSULTATIVE ORGANIZATION

Report and Studies No. 16

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

SCIENTIFIC CRITERIA FOR THE SELECTION OF WASTE DISPOSAL SITES AT SEA

IMCO, 1982

NOTES

1 GESAMP is an advisory body consisting of specialized experts nominated by the Sponsoring Agencies (IMCO, FAO, UNESCO, WMO, WHO, IAEA, UN, UNEP). Its principal task is to provide scientific advice on marine pollution problems to the Sponsoring Agencies and to the Intergovernmental Oceanographic Commission (IOC).

2 This report is available in English from any of the Sponsoring Agencies.

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Definition of Marine Pollution by GESAMP

"POLLUTION MEANS THE INTRODUCTION BY MAN, DIRECTLY OR INDIRECTLY, OF SUBSTANCES OR ENERGY INTO THE MARINE ENVIRONMENT (INCLUDING ESTUARIES) RESULTING IN SUCH DELETERIOUS EFFECTS AS HARM TO LIVING RESOURCES, HAZARDS TO HUMAN HEALTH, HINDRANCE TO MARINE ACTIVITIES INCLUDING FISHING, IMPAIRMENT OF QUALITY FOR USE OF SEA WATER AND REDUCTION OF AMENITIES."

* * *

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EXPLANATORY NOTE

This document, which appears in English only, is the edited and approved report of the GESAMP Working Group on Sea Disposal Studies. The Working Group met at the headquarters of the Inter-Governmental Maritime Consultative Organization (IMCO)* in London from 30 September to 29 October 1980 and from 27 to 30 April 1981 with the following members participating:

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* During the preparation of this report the name of the Organization has been changed to the International Maritime Organization (IMO). Throughout the text of this publication reference is made to the original name only.

SCIENTIFIC CRITERIA FOR THE SELECTION OF WASTE DISPOSAL SITES AT SEA

Contents

		Page
	ABSTRACT	1
1	INTRODUCTION	3
	1.1 General considerations	4
2	CHARACTERISTICS AND POSSIBLE EFFECTS OF WASTES	9
	2.1 Physical characteristics and effects	9
	2.2 Chemical characteristics and effects	12
	2.3 Biological characteristics and effects	17
3	METHOD OF DISPOSAL	22
	3.1 Confined wastes	22
	3.2 Bulk cargo wastes release techniques	23
	3.3 Capping and burial of contaminated solid wastes	26
	3.4 Incineration	28
4	SITE SELECTION	34
	4.1 Physical considerations	34
	4.2 Sedimentology	41
	4.3 Biological considerations	43
5	INVESTIGATIONS AT THE SITE AND ASSOCIATED EXPERIMENTAL WORK	45
	5.1 Physical observations	45
	5.2 Chemical observations	48
	5.3 Biological observations	49
	5.4 Remote sensing	51
6	CONCLUSIONS AND SUMMARY	51
	REFERENCES	56

ABSTRACT

The main concern with waste disposal at sea arises from possible adverse effects on living resources. Effects on human uses are chiefly associated with the accumulation of substances by marine organisms, tainting of sea food, interference with fishing and reduction of amenities by discoloration, turbidity and floating materials. The wastes of greatest concern are therefore those which are toxic (particularly at low concentrations), accumulate in organisms, reach the sea in large amounts, and persist there for long periods.

Disposal of those materials permitted under the Dumping Conventions should be done in such a way as to avoid adverse effects. Rapid and widespread dispersion is a principal objective particularly for liquid wastes. This can be done by ensuring maximum initial dilution through an appropriate means of disposal and by selecting areas where the dispersive processes of transport and mixing are active. On the other hand, in some circumstances it may be desirable to confine waste to a limited area of sea. This can be done by selecting more quiescent sites, by containerization, or by capping and burial.

Some wastes are amenable to incineration at sea. The problems associated with this method of disposal, including effects and site selection, are discussed.

The report takes a positive approach by identifying sites suitable for waste disposal, but this involves recognizing that some types of location are unsuitable. In all operations it is desirable to identify and avoid particularly sensitive areas.

Field observations are required at disposal sites at both the pre- and post- discharge stages. Physical observations should be directed mainly at evaluating dispersion characteristics and should include observations of wind, vertical density distribution, currents and bottom properties. Measurements of light penetration may also be relevant. Chemical measurements appropriate to the disposal material are required from wastes, sediments and benthos. Appropriate biological observations include data on primary production, zooplankton and benthic populations and on the commercial resources. For an adequate assessment, the field observations should be supplemented with experimental work designed to detect and evaluate effects.

At appropriate points in the report, attention is drawn to the need for greater research emphasis, or for new studies.

1 INTRODUCTION

A GESAMP Working Group met during 1974 to consider the scientific criteria for the selection of sites for dumping of wastes into the sea, and its conclusions were published in 1975 as GESAMP Reports and Studies No. 3. Since that publication, there have been international discussions on how to identify sea areas which might be particularly sensitive to marine disposal of waste, and partly arising from this concern a new Working Group was established by GESAMP in 1980. The terms of reference of the Working Group as set out in the Report of the Eleventh Session of GESAMP (Rep.Stud.GESAMP (10), paragraph 11.3) were as follows:

> "To review and update Rep.Stud.GESAMP(3) - Scientific Criteria for the Selection of Sites for Dumping of Wastes into the Sea - and compile a bibliography of relevant material."

The Working Group met on two occasions in 1980/81, and conducted an extensive examination of the existing report. In the five years since its publication there had clearly been advances in scientific research, significant changes in the pattern of dumping activities, and new thinking on the approach to waste disposal. However, the Working Group considered that much of the content of the report was still valid and that the general presentation could hardly be improved. It was therefore agreed to retain as much as possible of the original report, but to amend or expand those sections which required updating and to inject new material where necessary. In following this approach, the words of the original report have in many places been repeated unaltered, and the overall framework for the most part remains intact. During intersessional periods the members of the Working Group prepared a number of short case studies and working papers designed to assist its deliberations. The subjects covered were: acid iron wastes, sewage sludge, dredged material, capping and burial of contaminated solid wastes, processed ore wastes, biological effects, plankton blooms, bulky wastes, experimental techniques, fish migrations, and deep sea benthos. These papers can be made available by the IMCO Technical Secretary of GESAMP upon request.

Finally, the Working Group, in response to the terms of reference, considered the preparation of a comprehensive bibliography of relevant material. The Working Group recognized that a fully comprehensive compilation of all relevant material would, however, be a major task and one more appropriate to an abstracting or indexing service*. It was therefore considered more useful to produce a selective list containing mainly recent references which were judged to be of particular importance. A copy of that list is also available through the IMCO Technical Secretary of GESAMP on application.

1.1 General considerations

Dumping can be defined as any deliberate disposal at sea of wastes or other matter from vessels, aircraft, platforms or other man-made structures. The international and multilateral Conventions on the Prevention of Marine Pollution by Dumping (Dumping Conventions) which are currently in force** do, however, explicitly exclude in their definition the disposal of wastes or other matter derived from the normal operations of vessels, aircraft, platforms or other man-made structures at sea. The disposal of wastes or other matter arising from or related to the exploration and exploitation of sea-bed mineral resources is also excluded.

It should be recognized that dumping of wastes at sea is only one of several methods of disposal, and that all disposal operations merely move material from one part of the environment to another. Ideally, the only entirely safe way of dealing with a waste is to avoid disposal altogether by recovering and utilizing the various constituents. In practice this seems an

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* See also Champ, M.A. and P. Kilho Park: Global Marine Pollution Bibliography: for Ocean Dumping and Industrial Wastes, in press (Plenum Press, New York. 1982)

** Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (London Dumping Convention); Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft, 1972 (Oslo Convention); Convention on the Protection of the Marine Environment of the Baltic Sea Area 1974 (Helsinki Convention); Protocol for the Prevention of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft, 1976 (Barcelona Dumping Protocol).

unrealisable goal because costs and benefits are usually considered inequable. However, there is scope for the introduction of changes to industrial processes which, for example, either avoid the creation of wastes containing potentially harmful substances or which substantially reduce their concentration. Additionally, a number of processes are available by which wastes can be treated to render them less harmful, e.g. by degrading harmful constituents chemically or biologically, or by altering their physical or chemical state. Such processes may open up alternative disposal options.

For certain wastes, and under particular circumstances, the financial cost of operating disposal at sea may be less than that of the alternatives, such as disposal on land or recycling, but the cost must be assessed against the possible damage to marine resources, so that low operating costs should be viewed in the light of any environmental impact. It must also be recognized that the environment is not divisible into neat compartments. Consideration should be given to the costs and consequences of waste disposal in a variety of alternative ways. The Group did not examine cost-benefit analysis, and did not consider the alternatives to sea disposal, although it agreed these must be taken into account in determining the most appropriate procedure in each case. The purpose of this report is to consider what scientific principles are involved in the selection of dumping sites at sea, and how effects of ocean waste disposal can be assessed and reduced to a minimum. Matters related to pretreatment of wastes (dewatering, removal of trace metals, etc.) will obviously affect the development and application of criteria for site selection.

The Group agreed that the disposal of waste at sea can be scientifically discussed without attempting to justify the operation. The concept of a capacity of the oceans to receive waste has long been accepted and utilized by mankind, though the criteria of assimilative capacity have not been static. Early criteria tended to be based on visual or aesthetic factors, but the recognition of the eutrophic effects of nutrients resulted in a more quantitative approach tied to responses of organisms. More recently the potential effects of persistent and toxic wastes on the health and stability of the ecosystem and on its human uses have been highlighted. In accepting that the marine environment has a capacity to receive wastes, it must be recognized that this is often largely related to the great volume of the oceans; that the self-purification and buffering capacity of the water is limited, and that the sea-bed will not act as an effective sink for all materials or for infinite amounts. Given these facts, the particular conditions existing in any area proposed for dumping should be examined and suitable criteria relevant to the area's assimilative capacity should be developed. One basic decision is whether the dumped material should be quickly and widely dispersed, or whether it should be allowed to accumulate in a restricted area. There are different sorts of effects associated with either option, and these are discussed in the report.

The assessment of the probable effects of waste disposal at sea involves several disciplines, including physical oceanography, chemistry, sedimentology and marine biology, all of which are interdependent and none of which is adequate by itself in making an assessment. In a report of this scope it has been necessary to identify those matters of primary importance for predicting the behaviour and effects of materials dumped at sea. Having done this, an attempt has been made to specify subject areas where knowledge is reasonably precise and also those where it is lacking.

Detrimental effects of marine pollution include harm to living organisms, hazards to human health, hindrance to maritime activities and reduction of amenities. The Group noted the desirability of maintaining an overall balance and diversity in the marine ecosystem. The exploitation of living resources, one of the important uses of the sea, is closely related to this, and could be affected by the disposal of wastes. The young stages of many organisms are particularly vulnerable to changes in water quality, and certain areas of the marine environment, although not at present supporting commercial resources, may have potential value in this respect. In considering human health aspects possible contamination of food resources is important.

Activities which may require special attention include aquaculture, water abstraction for drinking or industrial purposes, recreation, preservation of endangered species and exploitation of mineral resources on or under the sea-bed.

The effects of marine waste disposal operations may be assessed by a calculation of waste dispersion, biological uptake, absorption and deposition on the sea floor or on suspended particles, and re-release or re-suspension. Most calculations of this kind are based on a mass balance approach; they attempt to account for the fate of the total waste released, since it is only by knowing where the waste or its component chemicals are distributed and in what quantities, that it is possible to predict environmental effects. The frequency of disposal, and the coupling between this frequency and the natural variability in ecosystems is of particular relevance to such studies.

A simplified variant of this approach is to focus on the most sensitive or vulnerable species. This "critical path" method is widely applied in the field of radioactive waste disposal, and although there have been problems in adapting it to other waste disposal problems, it may be useful under certain circumstances.

The principal physical processes involved in marine waste disposal are transport and mixing ("dispersion"), the analytical or numerical modelling of which may be done with reasonable success for short periods (around 100 hours) following release (Fischer et al. 1979). Dispersion calculations for time periods of several weeks to several months, or more complete mass balance calculations involving, for example, biological uptake, cannot at present be done with confidence, because several key parameters required in such calculations are not well known.

There is reason to hope that more complete assessment models will be developed in the near future for many coastal ocean applications. Within the last decade or so the knowledge of coastal ocean physics has increased dramatically (Csanady, 1981) and, if exploited, should materially improve chances of success in modelling. This requires, however, the development of an intellectual framework for pollution assessment in unsteady, non-uniform flow, a research problem of high priority. Equally important is the field verification of such models. Complex computer models, in particular, should not be relied upon without thorough observational checks.

The report considers the various properties of a waste which should be known in order to understand the way it will behave in the marine environment, and examines how its behaviour may be affected according to the disposal method used. The methods considered include release from hopper barges, discharges into the wake of a vessel, disposal of containerized or other bulky wastes, burial and capping, and incineration. It is important to ensure that conditions of licences are observed, especially in relation to site and method of disposal. It is also important, in the context of control, that adequate records are kept of all dumping operations (e.g. amounts, locations, methods of containment etc.).

The Group did not discuss the disposal of radioactive waste into the sea, as this has been covered elsewhere (IAEA, 1978 a and b). It is also relevant that GESAMP at its eleventh session (25-29 February 1980) established a Working Group to advise on the present knowledge of pathways by which substances might be transferred from a deep ocean dumping area to man.

The Group, noting that under the Dumping Conventions the disposal of wastes at sea directly arising from the exploration and exploitation of sea-bed minerals is not considered as "dumping", did not include in its consideration these sources of marine pollution. Reference is however made to GESAMP Reports and Studies No.7 (GESAMP 1977) describing scientific aspects of pollution arising from the exploration and exploitation of the sea-bed.

Attention is also drawn to the fact that many of the considerations made in preparing this report are not only relevant to the disposal at sea of wastes loaded on board ships for the purpose of dumping, but also include aspects which have to be taken into account when considering the discharges of wastes through pipes into coastal sea areas. These particular problems have also been addressed by GESAMP when discussing marine pollution implications of coastal area development (GESAMP 1980a).

It should be stressed that this report should not be thought of as replacing the criteria and conditions set out in the Dumping Conventions, of which note must always be taken. Rather, the report may serve to amplify and clarify the items listed in the Conventions. It deals in sequence with the following questions:

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

(2) How can the effects be minimized by appropriate selection of the method of disposal or by appropriate pre-dumping treatment of the waste?

(3) How can the effects be minimized by appropriate selection of the site for disposal and by alternative methods at sea?

Rather than structuring the report in terms of various zones of the oceans, the Group preferred to adopt a more general approach, citing specific examples as illustrations. Throughout the document, reference is made where appropriate to needs for new or additional research.

2 CHARACTERISTICS AND POSSIBLE EFFECTS OF WASTES

The characteristics of a waste may be discussed in terms of physical, chemical and biological properties. All three have a bearing on effects in the marine environment. Different wastes require different considerations, depending on the lifetime of the wastes or their components in the sea, and on factors such as the degree of toxicity of the substances and the turbidity resulting from their disposal. All these factors might influence the selection of dumping sites.

2.1 Physical characteristics and effects

The dispersal of liquid wastes miscible in sea water is influenced by their density, but this applies mostly in the initial period. After dilution with a thousandfold volume or more of sea water the density excess or deficiency usually becomes too small to matter. Thus liquid wastes discharged into the wake of a barge often disperse following rapid dilution as if they were coloured sea water (Ketchum et al, 1981), in contrast to domestic waste released from a submarine outfall which usually "boils" to the surface on account of its significantly lower density even after initial mixing. When the densities of overlying layers of water and diluted waste differ significantly (by one part in one thousand or so), mixing is suppressed at the interface.

Miscible or immiscible low density wastes which float on the sea surface often pose a particularly difficult disposal problem. They are confined to a two- instead of a three-dimensional medium and disperse much less effectively. Furthermore, surface convergences concentrate floating waste and may cause their reaccumulation rather than dispersal. Floatable wastes (including persistent plastics, ropes and netting) can interfere with fisheries, shipping and amenities, and if released near shore may be washed up on beaches. Such wastes, whether on beaches or at sea, are highly undesirable (Myers, 1981) and their dumping is prohibited by the Conventions.

Wastes of particulate form disperse according to their settling velocity. The median settling velocity of particulate material in sewage, for example, is very slow, some 10^{-3} cm s^{-1}. The reason is not so much that the particles are small, but that their density is close to that of sea water. On settling through progressively denser, deeper oceanic layers such particles may lose their negative buoyancy altogether and collect along isopycnal surfaces, at least until thermal and chemical equilibrium with surrounding sea water is re-established.

Deposition of particulate waste on the sea floor is affected by the density of the waste cloud and by the properties of the bottom surface. Under simple quiescent conditions the deposition rate is a function of settling velocity and concentration. Under the turbulent conditions prevailing in tidal waters, or over some continental shelves, the probability of permanent deposition for waste particles becomes very small (or, put another way, the probability of their resuspension becomes very high). Natural organic particles are normally not deposited permanently in locations where near-bottom velocities regularly exceed about 0.15 m s^{-1}. Over open continental shelves near-bottom velocities are usually greater than this.

Quantitatively, the vertical distribution of particulate waste depends mainly on the ratio of the vertical mixing coefficient (which is a measure of the vigorousness of mixing) to the settling velocity. The physical dimension of this ratio is length, and it indicates the layer depth over which vertical mixing tends to distribute the waste. Over continental shelves in well mixed conditions the mixing coefficient is of the order of 100 cm^2 s^{-1}, so that a waste with a settling velocity of 10^{-3} cm s^{-1} tends to be distributed evenly in the vertical over a layer up to a kilometre deep, i.e. over the entire available water depth. It should be noted, however, that in the varying physical situations of continental shelves such well-mixed conditions occur only periodically.

An important aspect of the behaviour of particulate waste is that individual particles are not necessarily permanent - they may aggregate, be enriched by flocculation or reduced by scavenging, and further complications may arise following their arrival on the sea-bed where they may be subject to chemical and biological processes different from those acting in the water column.

In view of these considerations it is necessary to know whether the waste is liquid, solid, or a solid in suspension, to know the density of the waste as a whole, and of any solids it may contain, since these properties will influence initial dilution as well as subsequent dispersion and settlement.

Particulate material can influence the marine environment in several ways. Adding particulate matter to the natural suspended particle load will increase turbidity and may cause discoloration of the water with possible adverse effects on fisheries and recreational interests. Light penetration may also be reduced, with consequent effects on photosynthesis. Certain forms of particulate waste may clog gill surfaces of marine fish and invertebrates. Also, particles settling in large amounts in a confined area will alter the composition of the sediment, and thus affect benthic organisms.

If the solids are organic, anoxic conditions may develop in the sediment and overlying water, which will lead to a reduction in the suitability of the habitat for spawning, shelter or feeding. The International Council for the Exploration of the Sea warned of the possible adverse ecological effects of altering marine sediment grain size and consistency through dumping of wastes (ICES, 1978). It was pointed out that gravel beds required by spawning fishes, such as herring, and the habitats of lobsters, could be adversely altered by particulate wastes, even at considerable distances from the dump site. Sediment changes following sewage sludge disposal have also been documented and shown to affect the structure of benthic animal communities (Topping & McIntyre, 1972). Coral habitats, which because of their complexity harbour a great diversity of specialized animals, are particularly sensitive and dumping of particulate matter in the vicinity of a coral reef could modify the structure of the habitat with subsequent reduction in productivity. When a reef community is damaged, it cannot be assumed that it will ever renew itself (Johannes, 1975).

Important fisheries may be adversely affected where sediment changes prevent burrowing or other activities. Thus, sewage sludge dumping on a Norway lobster (Nephrops norvegicus) fishing ground resulted in physical changes due to the accumulation of dumped material which made the sediment unsuitable for burrowing over an area of 10 km^2 (McIntyre and Johnston, 1975).

2.2 Chemical characteristics and effects

An appreciation of the chemical composition of a waste is necessary to assess its potential effects on water quality and on biota. This does not mean that every waste should be subjected to exhaustive chemical analysis to establish the concentration of a standard wide-ranging list of chemical elements or compounds. Knowledge of the raw materials and production processes used will often provide a key to the probable composition of the waste. A selective analysis may then be sufficient for a preliminary assessment.

Wastes can modify the chemistry of the marine environment in a number of ways. For example, they can lead to a change in the concentrations and distribution of chemicals already present in the water either directly through addition or by modifying the ionic balance leading to de-gassing or precipitation of otherwise soluble materials, or wastes may introduce new and alien compounds to the environment. There are often associated biological changes.

Under calm or quiescent conditions, as in lagoons or fjords, 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 of such wastes are the ferrous sulphate waste from titanium dioxide production, sewage and sewage sludge, pulpmill and food processing wastes. Where rapid dilution occurs, deoxygenation of the water column as a result of chemical oxygen demand alone is unlikely to affect marine life. Similarly deoxygenation of the water column as a direct consequence of disposal at sea of highly organic wastes is unlikely to occur where dumping takes place in well mixed waters. However, the decomposition of such wastes can release large amounts of plant nutrients, phosphate, nitrate and silicate, which can lead to massive blooms