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SOME TECHNICAL AND ECONOMIC CONCERNS RELATING TO SHIPBOARD POLLUTION ABATEMENT

by

Charles F. Rowell

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

Rear Admiral Mason Freeman
Superintendent

M. U. Clauser
Provost

ABSTRACT:

Three questions related to abatement of pollution from Naval vessels are examined.

Current candidates for shipboard application are discussed with respect to limitations of development imposed by technical processes utilized. Limited flush with incineration and biological treatment are judged ready for application with the latter method less desirable for several secondary reasons. Wet air oxidation is considered a good candidate for an Integrated Waste Disposal System and merits R & D support.

Open ocean impact of oil and sewage discharge is examined. The technical literature is sparse but it is clear that oil is a significant contaminant, even now.

An examination of the economic factors related to contract sewage treatment shows that it is most probable that the Navy can work with municipal authorities to their mutual advantages. Reasonable amounts of salt water do not reduce efficiency of biological plants of the aerobic variety. Except where water reclamation or extensive municipal sewer replacements raises the cost of participation unreasonably, shared facilities are also the most economical.

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TABLE OF CONTENTS

CHAPTER I

Intoduction 1

CHAPTER II

Process Limitations of Current Candidates for On-board Sewage Treatment Systems 2

EPA Standards and Other Significant Criteria 2

Limited Flush and Recirculating Flush Systems 5

Incineration 5

Biological Techniques 7

Electro mechanical 10

Wet Air Oxidation 12

Summary 13

References in Chapter II 16

CHAPTER III

Open Ocean Impact of Oil and Normal Shipboard Sewage 17

Sewage Dumping 17

Discharged Organisms 18
The Non-living Components 20
Impact on Species Found in the Ocean 22

Oil Dumping 26

Biological Effects of Oil 27
Summary of the Literature 31

Suggestion for R & D 32

Bibliography 33

CHAPTER IV

Some Aspects of Cooperative Sewage Treatment Ashore	34
Salt Water and Sewage Treatment	34
Navy Impact on Municipal Systems	41
Estimate of Municipal Altitudes	43
Legal Liability	45
Model for Economic Comparison	46
Construction cost	46
Accelerated conversion	48
Land cost	48
Labor costs	49
Sewer installation	49
Sewer maintenance	50
Monitoring costs	50
Pretreatment	50
Bibliography	52

Chapter I

Introduction

When "Immediate Cost Effective Abatement of Water Pollution from Navy Ships" was written in March 1972, there were several questions that either were not addressed or which lay just beyond the scope of that effort.

These included an examination of the technical limitations that could be expected to provide the ultimate bounds to the application of each of the candidates for ship-board sewage treatment systems. With the current trend to "no effluent" systems for harbor applications, this question may be academic for a number of these. Under-way treatment may well become necessary and, if so, these candidates will again require examination.

On another point, the impact of sewage and oil on the open ocean was assumed to be outside of the purview of the study. Nevertheless, the estimation of the impact is important to long range plans. We have attempted to explore the current state of knowledge, to estimate probable regulatory directions and to assess the correctness of the conventional wisdom of the moment.

Further, the report suggested pumping waste ashore without examining the business alternatives for shore treatment. With each port situation different, our analysis can only provide information about the known impacts of saltwater on sewage treatment plants, probable liability relations and the components of the financial analysis. Nevertheless, the assemblage of these considerations should be useful when examining a specific case.

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Chapter II

Process Limitations of Current Candidates for On-board Sewage Treatment Systems

The purpose of this chapter is to examine the areas of technical limitation for the types of systems which have been proposed for shipboard sewage treatment. Our effort will be devoted primarily to areas of uncertainty and process characteristics and will not address problems which now exist in working models due to engineering choices which were inept or unfortunate. These latter problems may be solved by altered design or other "fix" but basic process parameters are reasonably outside the area where ingenuity can expect to be effective.

In attempting to designate these barriers we are limited by the dearth of information about the process at the molecular level and by the risk that some of these systems may change their molecular pathway as parameters change. This shortage of information is discussed in the final section as fruitful areas for some fundamental research.

We have made no systematic attempt to assess financial burdens of the competitive processes except to point out the most obvious factors where apparent.

EPA Standards and Other Significant Criteria

Many criteria can be cited as significant with respect to selection of any piece of hardware for application. Some of these, esthetic characteristics, for example, must be placed in a decidedly less significant category; others, such as cost, reliability, safety and physical size must be placed in a significant but intermediate status. The most significant question must be whether the process will work, or, as a more refined criterion, will it work well enough to meet the specifications imposed.

For on-board sewage treatment, the limits are determined by the ultimate usage of the effluent. A number of possibilities exist which range from dumping over the side to potable water recovery. The necessary sophistication required to achieve these goals is naturally responsive to the degree of difficulty with the cost going up very rapidly as the limits on acceptable contaminants decrease in value. In order to have a practical standard for analysis, we will use the EPA values for water exhausted back to the environment. This represents the minimum treatment that is acceptable in our harbors and gives us a starting point.

These values are:

Suspended solids	150 ppm
BOD	100 ppm
Coliform	240 mpn/100mℓ

where BOD means biological oxygen demand measured as depletion of dissolved oxygen from a controlled sample incubated for 5 days (a measure of the carbon nutrients available); coliform refers to a count of coliform bacteria stained to distinguish those that are alive, mpn means most probable number; and suspended solids are measured by filtration or light scattering and reported on a weight/weight basis.

Once these basic requirements are met one may move to important secondary consideration in making a choice between contenders.

Bulk and weight are important in a shipboard system, especially for backfitting. The replacement or substitution of a sewage-treatment plant for another function which was already in place leads to either loss of the supplanted function or movement of that function elsewhere in the ship. Since this often means moving it up in the structure it may mean raising the center of gravity of the ship and hence reducing its stability.

Economic effects and budgetary stability rank alongside the seaworthy arguments noted above. Cost of procurement is often less significant than cost of operation, maintenance and manpower. Reliability looms large in a budget-and-manpower-limited ship operation. Certainly, in this regard, sensitivity to environment, whether it is physical, as in the shock effects while underway, or sensitivity to contamination of the input, will have to be considered alongside of the probable wear lifetime of the component parts.

Also important in this intermediate range is safety and acceptability. A device that has shown dangerous characteristics in operation or whose operation is a nuisance to either the operator or his shipmates may well be not worth buying. The crews involved in some of the test and evaluation work have certainly been enthusiastic, as seen, for example, on the USS Fulton and the various groups working with the Destroyer Development Group. Whether this vigor would persist after the equipment became routine and more difficult to operate is uncertain. We can state that the idea of operating a sewage treatment plant aboard ship does not seem to be unacceptable to the sailor.

Limited Flush and Recirculating Flush Systems

If we treat the question of incineration separately, the rest of these systems really should not be called sewage treatment. The idea of reducing the volume of the flush water or eliminating it altogether by use of some other medium has merit as a strategem to reduce the loading on any of the other systems. All of the tested systems seem to work well toward that end although problems of general hygiene related to odors in the recycle systems and materials corrosion in the evaporator heaters have hardly made them trouble free. Final treatment is passed on to incinerators in the current models although this concept would aid our holding tank policy also.

Incineration

Several types of combustion systems have been proposed. These vary from a proposal to inject the entire waste stream into the ship's propulsion burners (Babcock and Wilcox) to the use of special incinerators to destroy a concentrate or reduced flush effluent. Only the latter approach would be acceptable to Navy needs as the former proposal presumed a merchant ship with few crewmen and no high performance requirements as far as the propulsion system is concerned.

The problems involved in the application of the technique seem to lie almost entirely in the materials and control areas. When either problem exists, the result seems to be air pollution traded for water pollution.

Most incineration systems have used a simple oil-fired approach. During the rapid drying phase prior to combustion the mass of sludge is pyrolized to some extent due to the poor heat transfer character of the wet sludge. This effluent passes out as air pollution giving both an odor (described as burning rags) and the basic ingredients for the more typical photochemical smog. Under fairly heavy loading this phase is constantly present and leads to incomplete burning as a result.

An attempt has been made to avoid this problem by use of a fluidized-bed reactor. The bed is made of flint shot and the operation is to be intermittent. The shot has been found to glaze and stick together under the influence of the sewage sludge as a flux. Temperature control becomes very critical if this is to be avoided. For such a small reactor, a study of the bed performance has suggested that the range of parameters in the sludge is too great and it is difficult to make process control certain.

Along these same lines, other materials problems arise in the incinerators. The sewage sludge, especially when sea water is the carriage, leads to extensive corrosion of "fingers" and shafts on agitation equipment. If the agitation is not provided the incinerator linings burn out very rapidly. The use of the stirring increases the rate of destruction of the sewage and hence the capacity of the unit as well. Loss of linings to corrosion is still a problem although reduced by this mechanism.

Use of preheating techniques by atomizing the waste input in one of the newer systems currently under study at Annapolis seems likely to reduce both of the incinerator problems by removing the drying stage from the reaction zones.

Since it is possible to operate in an essentially "no effluent" status when the incinerator is the total treatment system, and, since it is possible to use existing air pollution technology to control stack effluents, the incinerator-only systems can be made to meet EPA standards for both air and water pollution. Maintenance and operating costs are serious at the moment but solution to at least the materials problem seems to be within the state-of-the-art.

Biological Techniques

As a rule, municipal secondary treatment is at least partially biological. With no weight limitations and little spatial problem ashore, the simplicity of these systems has led to their extensive application. The material being treated brings with it the needed microorganisms and the operator needs to provide only a solid surface to support growth and sufficient air (aerobic cases) for success.

The rate of biological processing is limited in range. Environmental temperature affects it to some degree and control of this parameter can smooth out rate variations due to temperature fluctuation in the surroundings. Raising the temperature, within the tolerance of the biological species, can be used to improve throughput to some extent. For municipal application, the cost of utilities is more than the gain in processing speed warrants.

In bulk processing, the rate of the biological processes is often not the slow step. The rate of air absorption often takes on the role thereby making stirring and other dispersion techniques important to achieving the maximum rate.

One of the characteristics of this treatment system is the need to dispose of solids and generated biomass by other means. In time, the treatment beds develop too much bacterial growth and become restricted to flow unless back washed and the solids filtered. (One small system under study for space craft application is reported to have gelled!!) Incineration is the most common technique for sludge destruction but others such as wet-air oxidation and roasting are making tentative gains as part of the complex treatment.

A valuable aspect of these biological systems is that their process attacks soluble BOD directly. The dispersed and dilute molecular pollutents are converted to physically more tractable biomass. In addition, the particulate matter that eludes the filtration process in primary stages is now trapped in this matrix also. The need to chlorinate the effluent to remove bacterial contamination (as seen by the coliform count) remains but is probably avoidable by ultrafiltration if the data on environmental impact of chlorinated sewage (Arthur, 1972; Basch, 1972) leads to restrictions on this step.

In summary, the land based biological plants can provide abatement up to the standard of EPA for the effluent and incineration can be used to handle the solids.

In the sea-going context, there are problems that remain to be solved. The first problems relate to limitations on space and weight. Volume can be conserved if the rate of treatment can be increased and, of course, the proposed ship-board systems are moving to utilize this by raising the temperature in one case and "over-aerating" for another. The general proposal of Guss (1971) in terms of an immersion system with slug transfer of the sewage seems likely to increase the rate of all transfer processes as well as development of differential speciation along the axis of the rotating screw to provide the optimum biological community at all stages of the treatment. A combination of such an approach with raising the temperature seems likely to be the optimum physical condition.

A second set of problems relates to the salt water effects on the microorganisms. There is no problem with respect to finding species that will operate in sea water and at least two treatment systems using extended aeration are in operation in the Virgin Islands. Difficulties arise from the fact that any balanced steady-state system is at least temporarily slowed by sudden changes in salinity. With small volume plants such as expected for ship-board use, the inclusion of freshwater sources from the galley, etc., would represent a variable salinity input which might lead to reduced efficiency and larger design needs as a result. Use of holding tanks to assure more uniform mixing would, of course, tend to smooth this out but whether this would be enough to assure satisfactory performance remains to be seen.

Unfortunately, all biological systems are sensitive to toxic metals, etc., and the smaller the system the more serious a small addition of such things to the input becomes. Where a ship is as full of industrial processes as a warship, or worse, a tender, the probability of such accidental poisoning is quite high.

The failure of the Pall-Trinity and Aquanox units during the test in New London probably had either the poisoning or the salinity change as the explanation. The fact that the systems were functioning well on trucked-in sewage (fresh water flush?) and failed when connected to the USS Fulton seems most easily explained along these lines.

All of the comments so far have referred to aerobic systems although some such as the poisoning and salinity questions are applicable to both. The anaerobic systems do not seem desirable from at least two points of view. First, the parameters that might be used to increase the rate of the process is limited to temperature as stirring, etc., must be avoided to keep the oxygen out. Second, the gasses emitted are noxious and inflammable. This last can be solved by burning or scrubbers on the air stream but the process does not merit the additional cost since it does not offer greater efficiency than the aerobic systems.

The techniques of biological treatment are well worked out for shore systems but it seems unlikely that they will be able to handle waste rapidly enough for a warship, especially when they are exposed to such variable components in the input. A cargo vessel with a smaller crew per ton displacement may well find this the best route, especially since they may also be less space limited.

Electromechanical

Of the two systems which have used this technique, only one, the Fairbanks-Morse, can be said to have used this as the secondary treatment mode. The General Electric study on board the USS Gerig (Bryce, 1971) ended up with an assembly using electrochemistry to generate filter aid (and perhaps some treatment), biological activity in the sludge blanket and absorption columns, physical absorption on activated charcoal and final chlorination with hypochlorite to achieve a BOD average of 94 mg/l. Since this is within experimental error of the maximum allowable by EPA for a single measurement and, since each step of the final system was added as analysis of the effluent demanded it, it is clear that the electrochemistry of the G.E. unit was not able to perform the entire treatment of soluble BOD.

In the Fairbanks-Morse case, the data are equally discouraging since the use of exhaustive chlorination from the electromechanical sources could not meet specifications.

Part of this failure must be laid to the particularly high BOD of the influent noted in the Gerig study. In agreement with the authors of that report, I believe that it is proper to treat their ship-board sewage as the norm for the ocean-going situation.

What is the status of our knowledge with respect to the effect of chlorine on soluble BOD? This process is central to our use of such a device in which only this is provided as treatment.

It is part of the conventional wisdom of sanitary engineering that chlorine destroys soluble BOD. An examination of the literature of the involved chemistry is more confused. One discovers that the reactions of urea, the major constituent of soluble BOD from human wastes, are several and vary markedly as to importance depending on the pH and the concentration. On the whole, the reactions do lead to a reduction of BOD from this source.

Unfortunately, other materials besides urea are present as soluble BOD and, from the list in the Gerig report, their chemistry does not offer a rapid route of destruction by chlorine. Even in the absence of adventitious material, human waste provides some compounds whose availability for biological utilization in the environment is only slowly affected by chlorine. Some of these, especially the purines and pyrimidines, should give toxic materials as products of the chlorination and may be contributors to the observed effects of chlorinated municipal wastes (Arthur, 1971; Basch, 1971).

The generation of such biocidal products also raises questions about the validity of BOD_5 tests run on the effluent since inhibition of the growth of the organisms involved will give low BOD values thereby suggesting better treatment than actually provided. The use of COD as the measurement is a way to avoid this problem but one must be careful about the application of any proportionality arguments in relating this number to the environmental impact. The usual percentages assume that the waste is "normal waste" and all indications suggest that this is not so for ship-board systems.

With all of the factors that interact here, one must conclude that the conventional wisdom underlying the choice of this route to treatment was correct as far as it went but too many unknowns exist with respect to both the nature of the input and the complicated chemistry in the treatment chamber. Given the low values of BOD that are sought by EPA regulations, it does not seem fruitful to push to the limit exhaustive chlorination from any source.

Wet Air Oxidation

This approach seems to have broad promise for future application as part of an Integrated Waste Treatment System. It has been shown to handle sewage sludge, plastics, oil, propellants, wood and paper among the most obvious candidates from shipboard sources. Grinders and grinder pumps to reduce the feed stock to acceptable size are state-of-the-art. The effluent gases are either within EPA air quality standards or are fairly easily treated depending on the feed stock.

Nevertheless, there are drawbacks. The high pressure and temperature have been cited but they are no greater than the problems relating to the high-performance propulsion plants now in use. Corrosion remains a threat but progress is being made. A report in 1970 by Masabuchi noted that there was severe crevice and pit cracking in titanium alloys when they were exposed to oxygen and hot brine. On the other hand, contractors in the wet-oxidation field report that pure titanium, while less strong than the alloys, is very much more resistant to severe salt-water corrosion at high temperatures. Recent work by Dr. Edward Metzbower at NRL supports both observations and provides an explanation for the dependence on alloying composition.

A basic processing problem remains. The effluent from the reactor contains persistent organics, mostly acetic acid, and the concentration, while variable, is often above EPA standards for final BOD. The usual techniques applied in the municipal systems is the use of biological treatment to polish the effluent. The resultant biomass is periodically "harvested" and run through the reactor. At West Chicago, this has gradually increased the nitrogen content of the ultimate effluent and is judged not totally acceptable.

If some catalyst or process change could be found to eliminate this basic problem, the system would be a good candidate for broader application, especially in future ships.

Summary

There are currently available within range of the state-of-the-art several combinations of treatment processes which offer high promise with respect to meeting EPA standards. The combination of limited flush or recycled fluids with incineration, the use of biological treatment followed by incineration of solids and chlorination of the effluent, use of incineration and physical absorption followed by biological polishing and chlorination are all apparently viable options.

With the passage of time, environmental law has become more exacting and the design of a ship board system must consider probable increasing stringency. While it is likely that "grandfather clauses" will permit waivers on existing equipment it seems wise to design the best possible system independent of the current standards.

Not surprisingly, then, one is led to consider the "no effluent" solution more desirable from the point of view of meeting standards.

With these considerations in mind (as well as the relative simplicity involved) the current study of the Chrysler and the Jered systems at NSRDC (Annapolis) seems most proper. While not without some problems, these limited fluid-incinerator systems should receive first consideration for immediate application. They do represent some plumbing problems, etc., so economics may ultimately tip the balance to another system but, from the process point of view, they seem nearly ready for application. The creation of the G.E. atomizing incinerator as part of the Gerig study seems to have lowered the most significant remaining barrier.

The next highest priority seems to fall to the development of the wet-air oxidation-biological polishing system. Its promise in handling broader classes of material as part of an Integrated Waste Disposal System (even with its current need for biological polishing) seems great enough to warrant effort. Especially important is the probability that future standards for open ocean dumping will become applicable to sewage and more stringent on oil. Incineration could handle some of the components of the IWDS load.

The biological systems are as well developed as they are likely to be. Their limitations are apparent. Even presuming that bulk can be reduced, their sensitivity to toxic materials and their limitation to biological products as input makes them both less reliable and non-candidates for IWDS application.

The electromechanical processes (exhaustive chlorination) have simply been found wanting. The General Electric effort of the Gerig stands as a monument to persistence and balanced usage of several techniques together. It led to the development of one of the best incinerators available at this point. Nevertheless, it just barely made the EPA standards and is quite involved. For sharply space-limited and population-loaded application of a warship, these processes must join the biological ones in being less desirable from both an effectiveness and reliability standpoint.

With incineration processes in hand, research needs to be pursued toward solving the wet air oxidation dependence on biological polishing. Toxicity effects will remain a concern otherwise and reduce the general applicability of the technique. The search for new biological species to apply and new configurations to cut down bulk seems of a lower priority.

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Chapter III

Open Ocean Impact of Oil and Normal Shipboard Sewage

International concern for environmental matters is on the increase as evidenced by such events as the Stockholm meetings in June of 1972. While this concern for global problems in the atmosphere and oceans has only recently reached the top political levels, maritime nations have had agreements with respect to such matters as bilge and ballast dumping for some time. Current conventions for this case are based on a visible slick persisting as a violation. (Roughly 60 l. of oil per nautical mile will be the break point.)

For our inland waters, EPA has responsibility under the law to determine "toxic levels" of all effluents and regulate to avoid them. If international events were to move in a similar direction, i.e., from the current physical basis for enforcement to a more sophisticated ecological basis, what would they find available to use for developing standards? What do we know about the ecological effects of open ocean disposal of oil and sewage? Although we shall have occasion to comment on sewage sludge dumping, this is not considered normal and certainly represents an extreme impact relative to ordinary sewage discharge from vessels.

Sewage Dumping

Three separate aspects of sewage dumping need consideration. They are the effect of sea water on organisms in the sewage, the fate of the organic matter in the sewage and the impact of the sewage on species already present in the sea water.

Discharged Organisms - Coliform bacteria have been used as indicators of human waste contamination and as a measure of the success or failure of sewage treatment. It is not clear how the sensitivity to treatment of the coliforms relates to the pathogenic bacteria such as staphylococcus and streptococcus whose persistence in hospital situations is well known to be highly resistant to clean up efforts. Since the only work that has been reported for sea water effects is related to the coliform we must examine it for whatever guidance it can give us but we should be aware that the conclusions are suspect for hardier bacteria.

There is a wide variation in the observed survival times of coliform bacteria in sea water: 80% died within 1/2 hour of exposure (Carpenter, 1938), nothing survived beyond four days (Weston & Edwards, 1939), 90% died within 140 hours (Vaccaro et al, 1950), survival far in excess of 200 days (Buck et al, 1952), numbers increased for four days but died off at six days (Slanetz & Bartley, 1956), 90% died within 40 minutes (Thomas, 1964), die-off was noted in a few hours to 5 days (Mitchell, 1970). Besides the obvious disagreement as to the length of time the coliform survived, there is an almost complete lack of information about the conditions such as temperature, particulate matter available to offer growth surfaces needed by the bacteria, pH, nutrients and other species present that might act as predators. It does appear that we can conclude that dumping sewage into the ocean is not immediately effective as a bactericide.

A number of effects have been identified as leading to disappearance of the coliform.

Initially, upon discharge, the effluent containing the coliform is diluted by the sea water. This causes a drop in the concentration of bacteria. This is not deemed sufficient explanation for the rapid drop in bacteria count due to the magnitude of the change (Ketchum, et al, 1952). When the effluent is discharged, osmotic shock takes its toll of the bacteria; the change in salinity seems to have more effect than the actual salt concentration (Carlucci & Pramer, 1963). Upon discharge, there is a portion of bacteria, though not the major percentage, at the top of the water column due to surface tension, low specific gravity of the bacteria, and buoyancy of gasses associated with bacteria (Zobell, 1960), (Jensen, 1970). At this concentration point, it has been shown (Gaardner & Sparck, 1963), that the sun produces some bactericidal effect.

Predation upon bacteria released into the marine environment is another factor in the decline of numbers of bacteria following discharge (Harvey, 1937). The zooplankton are the chief predators, (Stryszak, 1950). Protozoa and nannoplankton are capable of consuming the coliforms or of lysing the bacterial walls and consuming the damaged victim. Some forms of amoebae will also consume the coliforms (Mitchell, 1970).

If the bacterium becomes protected by absorption on a particle or by entering the sediment its survival is enhanced. This effect was studied and found dependent on temperature, pH and salinity (Bernard, 1970). Since much of the bacteria is already embedded or absorbed at the time of discharge, this situation is common.

In along-shore studies it has been shown that most of the sewage bacteria are sedimented (Nussbaum & Garver, 1955), (Weiss, 1951), (Jensen, 1969) where their survival time is augmented through concentration in the nutrient rich bottom sediments (Buelow, 1968). In sediment, after 84 hours, the population had dropped to 51% of the initial number, but after 8 weeks, 10% still survived (Bernard, 1970). Bacterial count in sediment may be indicative of recent bacterial action in the waters above "Except where sampling closely followed a sludge discharge ... , the higher coliform determinations were found in the bottom samples" (Buelow, 1968). This sludge deposit may become permanent as found by Tulkki (1968) in the mouth of the Göta älv; "..., black sediment smelling strongly of H_2S with sewage fungi and bacteria threads (was found). No bottom animals found here."

All of the studies that we have noted relate to relatively shallow water along coasts where it is possible to study the impact conveniently. No data was found for populations of the abbysal plain. Any attempt to extrapolate to the open ocean must, at best, be tentative. What happens to the bacteria as the sewage settles below a few hundred meters is not known. Even this rate of sedimentation is open to conjecture.

The Non-Living Components - Besides the enteric organisms, the sewage contains a great deal of non-living material, most of which is of biological origin.

Because of this origin, it has not only biologically utilizable molecules but also offers a source of phosphorous and nitrogen which is generally in short supply in the surface waters of the open ocean. The nearly balanced nature of the sewage sludge, for example, is shown by its use as the sole (other than oxygen from the air) for aerobic digesters which can convert all of the input to living biomass. The soluble components are rich in nitrogen since urea is a major component. It is important to note that the waste will not proivde enough of these scarce elements to upset the balance of the ecosystem except where massive dumping is done as reported in work on the New York Bight (Gross, 1971). Even there the presence of toxic trace metals obscures the real impact of the biologically derived materials (Vaccaro, 1972).

The observations on the USS Gerig with respect to shipboard COD (Bryce, 1971) suggests that other components such as cleaning compounds are typically present and represent a non-biological component. Nevertheless, many of these are potentially biodegradable and one can control the potential impact by using only such compounds.

Biological activity in the open ocean is small due to limits on available plant nutrients (nitrate and phosphate) in surface waters. Hence, photosynthetic processes to start the chain of events that leads through the food web are inhibited.

Soluble BOD and the cleaning agents will tend to stay in the euphotic zone but they are probably not rich enough in nutrients to provide a balanced diet unless they achieve quite high concentrations of phosphates. The solids will tend to settle out of the euphotic zone if they have not undergone biological and physical breakdown before hand. The autotrophic breakdown by various bacteria, etc., can continue below this lighted region, limited only by the effects of temperature and pressure on the species involved.

While it is true that we can overload the ecological balance as has been done in the New York Bight, and that we can have sludge blankets develop (as has happened off from the old city outfall in San Diego) when the rate of input far exceeds natural rates that handle the breakdown, it does appear that we need not be concerned about the impact of normal shipboard sewage in the open ocean as the dilution brings it down to concentrations where normal natural processes can obtain.

In the cases cited above, the presence of trace metals which acted as poisons appears more important than the sewage itself in slowing the natural degradation. Care must be taken to avoid industrial contamination of sewage, but again, since there is limited biological activity in many parts of the open ocean, the accidental discharge of such water through sewage lines should have minimal effect. Prudence suggests that such discharge should be avoided.

In short, normal ship-board sewage should be within the capacity of the open ocean processes and the non-living components should not accumulate unless the usage becomes very much greater than it is currently or is likely to be in the near future.

Impact on Species Found in the Ocean - To this point we have traced the fate of the components of the added sewage. We need to consider briefly what is known and what we can guess about the effect on native species. As we have done before, we will have to use data from the continental shelf and extrapolate to the open ocean.

A general comment or two about ecological balance or homeostasis will be useful here.

A biological community is a steady-state system with some natural redundance built in to maintain stability. We find, for example, that the classic food chain or food web contains the so-called trophic levels of photosynthesizers, (green plants), grazers (animals), predators (animals) and autotrophs (bacteria, etc.) which decompose dead organic matter and complete the cycle by returning the needs chemical constituents to the medium in which all of these species live. The steady state is achieved when the limiting resource, either inorganic nutrients or light energy in the ocean, is cycled so that the net input equals the net output. The redundance arises because each of these defined levels has several species which carry on the role. Changes in conditions such as temperature may adversely affect the dominant species in such a level but usually one of the other occupants of the ecological niche may then compete more favorably due to greater tolerance for the change. Thus the dominant species changes but the work of the trophic level is still performed.

This concept of overlapping niches is the basis for using the count of numbers of species as an estimate of the degree of pollution. Typically, badly polluted areas have less than five species present when surveyed. This number is arbitrary and does not distinguish trophic levels in the count. It does seem to fit other indications of pollution, however.

Badly polluted areas such as sludge blankets often have many thousands of individuals of resistant species such as Polychaeta but only one or two species represented. The risk in such situations, termed unstable, is that changes in some other parameter may be adverse for the surviving species of the moment and nothing will be available to move into the niche. A life-less area would then arise and, in the case of further dumping of sewage sludge, the pollutant would accumulate.

In high concentrations, as in sludge dumping areas, or from continuous fixed point sources, as in municipal outfalls, the impact of sewage appears to be twofold. In the immediate area the conditions may be called toxic or at least very adverse for most species. The second effect is that of removing one of the limitations on growth in surrounding waters and the resultant "blooms," population crashes and "red tides" are seen.

As measures of the adversity effects we can cite the observations of Segerberg (1970) for the New York Bight where he found the area barren of benthic life. On the other hand, Vaccaro et al (1972) found that the plankton in the area were either not affected or only slightly affected by the dumping. This last suggests that little effect is noted in the water column.

Jones (1971) reported that in coastal areas with a population of less than ten people per acre with continuous dumping, off the northeast coast of Great Britain, 43% of the species natural to that area disappeared.

Along the California Coast, however, it was reported that except in the vicinity of an outfall, benthic fauna in areas along the coast did not differ significantly (Allan Hancock Foundation, 1970).

In San Francisco Bay, changes in diversity of benthic species have been correlated directly with waste concentrations discharged in the area. This is probably true in the open ocean (Kaiser Engineers Consortium, 1969).

Leppakoski (1968) found that Polychaeta and Mollusca appear to be organic-pollution-tolerant species and this is borne out by the work of Parrish, et al (1968) in his findings in San Diego Bay. He showed that less than 5 species or more than 200 Polychaetes per square foot were consistent indications of moderate to severe pollution. Parrish (1968) also found that since 1963, when an ocean outfall was built thus reducing the amount of dumping in the bay, conditions in the benthic community in the bay improved. He also adds, however, that a change in productivity has taken place at the site of the outfall.

Tulkki (1968) observed off the Swedish Coast that large populations of particular species, appearing to be organic pollution resistant, Capitella capitat, Polydora ciliata, Nereis diversicolor, Macome baltica, Mya arenia, Harpacticorda, and Nematoda coupled with a lack of diversity of species in the area are indicative of organic pollution.

A study of the effects on fish was done in Santa Monica Bay, California during the years 1958-1963 (J. G. Carlisle, 1969). In this study 705 bottom trawls were taken in 60-600 feet of water, netting 112,799 fish of 104 species. Although this is an area of heavy dumping, the fluctuations in abundance of different species did not seem to correlate with toxic contaminants. Carlisle did observe that certain fish seemed to avoid outfall areas.

The mode of adverse effect is not clear. Certainly the toxicity of some trace metal contaminants in the sewage is suspected and Vaccarro's work cited above does show some incorporation of these in the life system even though no marked effects were noted. The effect of the major components, i.e., the organic matter, may be of the bloom variety (cf. below). As for the coliform, their niche in the food chain has been the object of some study.

The coliforms serve as nutrients primarily at the first trophic level, that is for the zooplankton, amoebae, and as dietritic nutrients for larval stages of copepods and other crustacea (Steele, 1970). They are toxic to juvenile amphipods (Arthur & Eaton, 1971).

The second effect relates to removal of one of the boundary conditions that led to the homeostasis before the dumping. This type of effect occurs usually at a distance from the major site of effluence as the water mass carries away some of the material and dilution brings this fertilization into a formally favorable situation.

This over-fertilization, often due to increased phosphate, causes the photosynthesizers to grow luxuriantly, giving the water a green cast or even red, if there is an overabundance of the fagellate, Peridinae (Coker, 1962). There is some indication that the by-products of this overpopulation are toxic to some species which then die out of the system (Kaiser Engineers Consortium, 1969). A second effect rests on the increased oxygen and improved food supply which leads to an increasing population of grazers, etc., as the effect moves down the food chain.

As the limits are reached in the growth of the first trophic level, usually due to depletion of the nutrient, grazing pressure (and perhaps other overpopulation-caused pollutants) leads to a virtual disappearance of the photosynthesizers or a "population crash." Each level in turn starves to death or, since the source of oxygen is gone, dies for lack of oxygen. Fish kills which are often associated with such "blooms" may have this as a major cause or may suffer from ingestion of toxic dinoflagellates depending on the individual case. The result is ultimately a very sparsely populated water mass with, at best, only a few survivors. If the process has gone too far the ecosystem can not reestablish itself from within. If not, in time it will recover.

Upwelling in national oceanic events has this effect, and, if not as extreme as indicated above for massive injections of nutrient, can be conducive to good fish yields. In fact, most world wide fishing areas result from such phenomena.

Clearly all of the effects noted for coastal cases are for massive or prolonged impacts. With the small amounts dumped by ships in transit, it does not seem likely that a serious upset of homeostasis will occur. With the recent signing of the open ocean dumping agreement the open ocean problem for sewage may be under control. Scientifically it would appear likely but we must recognize that open ocean data is not available as such. Political questions remain to be answered.

Oil Dumping

The effects of massive oil spills, like sewage sludge dumping, are serious and easily recognizable by many observers. The death of sea birds from pneumonia and the smothering of tide-pool life has received extended discussion in the popular press.

A more subtle and yet potentially more disastrous question needs examination. What is the effect of low level chronic oil discharge and, from the Navy's point of view, how does open ocean underway discharge compare to serious levels? Basic to examination of these questions are three subsets of inquiry, what is the effect of oil on native species, how long does oil persist (or what are the current concentration trends) and what mechanism exists for its ultimate removal?

Biological Effects of Oil - The literature of studies in this area is somewhat confused. The chaotic nature of the observations can be sorted to some extent by recognition of two significant variants that affect the conclusions.

The generic name oil covers an extremely broad class of mixtures. Even the commercial categories, which depend on boiling point range for classification, do not define the molecular characteristics or composition of these materials. The biochemical processes which are described as intrinsic toxicity reactions are selective at the molecular level both as the molecular size and molecular structure.

A second problem of similar importance is related to the toxicity estimation method. It is usual that temporal and financial restraints limit the study to the crude LD50 measurement in which an adult population of some selected species is used to determine the concentration of pollutant which will just kill 50% of the population in some predetermined time. The problems with this approach are several.

Chronic levels of pollutants are often more important than acute levels. This is well demonstrated for air pollution where carbon monoxide requires nearly eight hours to achieve equilibrium with the human blood. Short time exposures to lethal concentrations, such as smoking, are not deadly although longer exposures at the same level would be.

Another problem of significance is the life stage involved. To really understand the impact of chronic pollution one should study several generations of the test species since it often occurs that the larvae, for example, are more sensitive than the adult. Barnacle larvae fail to attach to pilings in polluted circumstances and ultimately die. Attached adults can tolerate the same levels. Over a period of time the barnacle population disappears as the adults die of age.

The third problem is related to attempting to find and control all of the necessary parameters. Synergistic relations often arise where sensitivity and/or resistance to the pollutant are found to relate to some other constituent. As we will note below the persistence of oil gives us an example of several such needs; some of these have been ignored in many studies.

The fourth problem is really a subset of the third. Controls are often missing from consideration and, therefore, we must treat the numerical values as approximations and indicative only.

The fifth problem, also a subset of the third, involves reproducing the natural aging process for the oil. As evaporation and photochemistry due to sunlight occurs, as well as the dissolving of some components, the nature of the oil changes (Morris, 1971). Physical changes leading to tar-ball formation produce modified biological activity because some processes are sensitive to the state of dispersal and because the most soluble, and often the most toxic, components are also the most volatile and are lost during the early stages of aging in the environment.

With these considerations in mind, let us examine the biological impact as now understood.

Several authors have stated generally that their studies show all crude oils and oil fractions to be toxic (Blumer, 1969; Hampson and Sanders, 1969). Reports of environmental spills also noted fatalities of several species (Smith, 1968; Holems, 1969; Hampson and Sanders, 1969).

Mironov (1968) examined the general question of impact and noted that the hyponeuston (critical eggs, etc., of pelagic and benthic organisms) were in the critical surface layer affected by oil. Plaice were especially sensitive in this regard (40-100% prelarvae deformed by 10^{-4}-10^{-5}ml/l of oil in water). Toxic effects were reported for 20 species of plankton. He reports that Acartia and Calanus die at concentrations of 0.01 ml/l of oil in water over periods of from 72 to 96 hours. He makes reference to effects on dolphins but when questioned about it at the end of the paper he refused to say any more.

Ottway (1971) set about measuring relative toxicities of crude oils by selecting three species of varying sensitivity and determining percentages of recovery for populations exposed for one hour and then moved to fresh sea water. Temperature was also studied as a variable. The results confirm the toxicity of the crude oils, the variation in susceptibility and the importance of temperature, etc., on the results. Speculations on the significance of various components are offered.

Crapp (1971) compared a crude oil and its high boiling residuals on several species of molluscs. As noted before, the sensitivities of these adults varied widely. In general, the lower boiling components of the crude and several distillate oils were more toxic than the high boiling residuals. The individuals that survived the initial exposure were able to tolerate longer exposure to the same pollutant. Such immediate toxicity effects were also reported by Spooner (1969).

A good review that contains some other references in this area is by Hufford (1971).

In summing up the general situation of biological impact, it seems certain that even low concentrations of oil have a measurable effect on surface dwelling species known to be living in the open ocean. Because species vary in their sensitivity, total kills of plankton and copepods may not occur in low concentration ranges but reduction of diversity surely occurs.

Turning to the question of oil trends in the sea and the question of current oil concentrations, we find little quantitative data but several observations worthy of note.

Popular press reports of comments by Jacques Costeau and others have mentioned increased concentrations of visible "tar balls" in such areas as the Sargasso Sea. While such collections of material are unsightly and distressing, it appears that they represent only a small part of the oil globules in the sea. Morris (1971) and Horn (1970) have each taken samples by use of neuston nets. The work of Morris was done with a more quantitative device so his percentage recovery is probably higher but the part of the ocean is different. In the Mediterranean, Horn found 1.0 to 540.0 mg/m^2 on the surface, Morris found 0.1 to 9.7 mg/m^2 in the Northeast Atlantic.

Blumer (1972) returned to examine the shore life in Buzzard's Bay, Massachusetts after two years had elapsed since a spill of number 2 fuel oil. Sediments of the marsh and offshore were found to contain oil little changed from the material spilled.

Studies are not numerous but they indicate long life times for oil in the sea.

After evaporation, etc., have removed the volatiles, the removal of oil from the sea is commonly assumed to involve bacterial action. There is no doubt that such bacteria exist (Soli, 1972; O'Neill, 1972; Floodgate, 1972) and in tens of species. The explanation for their failure to "bloom" and remove the oil lies in the conditions that exist and the limitations they impose.

The open ocean fails to provide the needed inorganic nutrients and and the temperature of much of the ocean's surface is not conducive to rapid growth. Bacteria need a solid surface to grow on. The tar balls that form provide this but the most easily oxidized fraction is then gone. In areas where temperature is more favorable the biocidal character of the sunlight offers its own inhibition as the tar balls and the adherent bacteria can not move deeper into the water as the plankton does during the diurnal cycle. In short, the open ocean is a hostile environment for the oil consuming bacteria. Individual members of such species can be cultured out of open ocean water but they do not prosper in the open ocean.

Blumer's observation in Buzzard's Bay may find explanation by the observation of Gunkel (1967) that these species will use more easily degraded materials if present and, therefore, "spare" the oil.

With Floodgate (1972), we will have to conclude that "the Principle of Microbial Infallibility" will not serve as a reasonable basis for ecological policy making.

Summary of the Literature

We find that little open ocean study of our question has been done. An examination of what is known about the impact of sewage on biological systems suggests that there is little need for immediate alarm but the absence of immediately applicable data leaves the conclusion tentative. Similar impact data on the effect of oil supports the contention that oil dumping, even bilge and ballast water, can not be considered without negative effect. A system that will eliminate these pollutants should be developed as soon as practical. The priority must be considered less than that of along-shore abatement but international notice has been brought to the problem (Floodgate, 1972). Agitation to change the 60 l/mile regulations may well follow.

Suggestions for R&D

Besides development of a "no oil" effluent system as noted in the summary, there are several general problems that apply here as well as in much of the rest of the environmental problem.

We do not know enough about the biology and ecology of the sea. If we try to develop a quantitative model to ascertain what concentrations of various effluents can be dumped into the ocean without destroying homeostasis we need physical oceanographic data and meteorological data. This is available on a large scale but smaller scale concepts need expansion.

Nevertheless we are far better off in these areas than we are in the basic understanding of the present diversity of species (especially plankton), the rates of biological processes and the parameters that control those rates.

Such a model worked out in closed form represents a tremendous undertaking which probably can not be done totally but the effort to get closer to such understanding is critical if we are to rationally approach controlling the impact of man on the rest of the ecosystem.

The Navy should support efforts to get at some of the information needed here. Only through the efforts of many interested parties will the necessary information gradually develop.

Two suggestions then:

1) Develop a "no effluent" bilge and ballast water system as soon as possible. In the meantime reduce such discharges to an absolute minimum.

2) Provide sustaining support for studies related to marine ecology in order to permit rational limits to be placed on future effluents of any kind.

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CHAPTER IV

Some Aspects of Cooperative Sewage Treatment Ashore

INTRODUCTION

In the report, "Immediate Cost-Effective Water Pollution Abatement from Navy Ships," [Navy Pollution Study Group, Naval Postgraduate School Monterey, California, 1972], it was recommended that Navy ships pump sanitary wastes ashore when in port. The sewage was then to enter city systems to be treated municipally-owned treatment plants.

SALT WATER AND SEWAGE TREATMENT

In determining whether it is feasible for the Navy to hook into municipal sewage systems one needs an analysis of how the saline sewage will effect biological treatment systems. One must examine the impact of salt water as carrier for the sewage since the two are inseparable under economically acceptable conditions.

Consider the process itself. The typical concentration of chlorides in the salt water sewage may be taken as 35,000 ppm, that of average sea water. There is a wide range found in Navy effluent, anywhere from just slightly brackish to over the 3.5% level. At coastal bases the concentration is usually closest to the upper part of the range and, in admixture with fresh water, highly variable when arriving at the treatment plant unless care is taken to guarantee constant dilution.

Current municipal practice uses both anaerobic and aerobic biological systems, although the anaerobic system has become considerably less popular.

Anaerobic digesters are more sensitive to chlorides than those using aerobic biological processes. When chloride concentrations entering the digesters are below 8,000 ppm, there should be little problem with anaerobic processes; the cities of Miami and Hollywood, Florida, have anaerobic treatment systems working on effluent containing 5,000 ppm chlorides and no process problems attributable to high chloride concentration have been experienced [Reynolds, et al, 1969]. The aerobic process, within a "reasonable length of time" [Reynolds, et al, 1969], will adapt to concentrations up to 25,000 ppm.

Variations in chloride concentration are important in that changes of 500 ppm or more are detrimental to the efficiency of all biological treatment processes. In comparing the anaerobic and aerobic processes, the anaerobic process will adapt much more quickly to new chloride concentrations, but only up to its 8,000 ppm limit.

Control of organic and hydraulic loadings must also be used when there are variations in chloride concentration. When the plant receives low hydraulic loading and high organic and suspended solids (SS) loading, the tolerance of chloride concentration changes is lower than when a plant receives normal to high hydraulic loading and low organic and SS loading. In the latter situation "effluent quality will not be significantly impaired even with severe changes of salt water concentration" [Reynolds, et al, 1969].

Corrosion is an important problem with the treatment equipment. For example, in Hollywood, Florida, a town where the sewage treatment system has a high incidence of salt water, annual replacement of cutting edges, rebuilding of clarifiers every five years, and biannual sandblasting and repainting of all submerged equipment (clarifiers) has been deemed necessary to keep the system in optimum working condition. This additional maintenance should be compared with the twenty-year replacement cycle of such plant equipment in a freshwater plant [Newlin, 1969].

In the case of sewer pipe corrosion, the answer seems to be selection of the type of building material used. Ferrous metals and concretes are subject to a high incidence of corrosion. Vitrified clay pipe, on the other hand, is very resistant to corrosion by salt water.

It is clear that there is no technical reason that the treatment systems used currently will not perform satisfactorily on receiving the Navy's sea water-borne sewage providing the proper population relationships apply (cf. below, pg 51) and mixing in such areas as the primary settling ponts, etc., are used to smooth out variations in concentration.

NAVY IMPACT ON MUNICIPAL SYSTEMS

From the salinity dependence of the aerobic system above we can easily calculate that it required only two gallons of fresh water for every five gallons of sea water to achieve the value of the maximum allowable concentration. By the time one includes the hotel wastes borne in fresh water aboard the ship, the dilution would move fairly close to this value.

If we neglect all non-sewage water for the moment we can pick a more or less typical example and look at the worst case for the city - Navy combination, i.e., only sewage equivalent to population, no hotel wastes.

Using 800,000 as an approximation to San Diego's population and

26,000 as the average shipboard complement present at any time (half the home-ported number) and assuming that the sailors are living aboard 24 hours a day, we find the contribution from the Navy at 3.15% and the maximum salinity resulting at 1100 ppm if all sewage is treated in a central facility and a bay salinity of 35.0 o/oo is used. This bay salinity is too high for San Diego but again tends to maximize the effect. Nevertheless, the values are well within acceptable limits for the process.

Further, the exclusion of hotel wastes from both shore and Navy consideration is a sizable effect as these materials from showers, galleys, laundry, etc., are major portions of the actual material treated in the plant. The assumption of 24 hour residency has a similar effect as the berthing of any sizable number of men ashore will lead to the reduction of the salt water input. This effect will be especially large as the usage of the heads is greatest on arising and before going to bed. By the time these effects are included the value of the salinity should be approaching that of undiluted fresh water sewage (300-500 ppm). In short, for the types of cities where major Navy ports are found, the salinity will be raised over that found without such input but not into a range that represents any abnormality. We have assumed a single central sewage treatment plant for the city, a condition that may not obtain in some cases.

ESTIMATE OF MUNICIPAL ATTITUDES

The Naval Facilities Engineering Command polled cities with large naval bases adjacent to them trying to assess willingness of sewage treatment authorities to consider accepting salt-water-carried sewage from ships for treatment. Most of the cities' authorities stated that they would need more time for further study and consultation with engineers before they could give written approval. In unofficial oral response, however, 9 of the 19 questioned had expressed a willingness to accept the affluent [NFEC letter, FAC PC-4B/JEW:rb 21 September 1971].

Since this survey was carried out the port authorities have been carrying on such a study and are still doing so as shown in correspondence with this author.

Response during the summer of 1972 from several cities (Seattle, Long Beach, San Francisco) have indicated that further evaluation is required. Most notably, Seattle originally gave oral acceptance; more recently they have indicated a 3 to 6 year study period is necessary to reach a decision.

Other cities (San Francisco, Honolulu) have set up conditions that the Navy must meet before written approval will be given. The city of Honolulu says they will accept the sewage if: 1) flow and waste characteristics will not deviate from what they are stated to be; 2) the Navy will install necessary traps and separators to minimize the discharge of grease and other objectionable material into the municipal system; 3) wastes which are considered to be industrial waste under the catagory "Division D-Manufacturing" of the Standard Industrial Classification Manual, Bureau of the Budget, 1967, will require city approval before being discharged into the municipal system; 4) the Navy will agree to take whatever action deemed necessary by the city, at Navy expense, to reduce to acceptable limits the salinity of its saline wastes; 5) where installed, all interceptors shall be maintained by the owner at his expense, in continuously efficient operation at all time, and in case of construction charges; 6) whenever the Engineer requires installation of permanent treatment plants and similar sewage modifications the Navy would pay a minimum of half of the cost of this construction. Clearly the Navy will have to establish monitoring capability as well.

These requiements from Honolulu are really rather excessive since the city does not now have secondary treatment and such conditions will require the Navy to pay an unusually large part of such construction. Further, the demand for desalinization of the sewage is based on the assumption that Honolulu will start recovering her water within a few years. From a practical point of view the only efficient way to carry out desalinization processes is to perform them before the water is used in the sewer system at all. Making fresh water by any of the desalinization modes is not inexpensive and may tip the cost comparison in favor of Navy-operated treatment where the plant is permitted to run at higher salinity.

LEGAL LIABILITY

One argument that might be marshalled for using contract services is the transfer of responsibility to the municipal authorities. Examination of current trends [Baldwin, et al, 1970] in legal action in the area is worthwhile because this assumption appears fallacious.

Presuming that careful legal contracts are drawn up to provide clear cut understanding of each party's normal relation to the other, we must ask the tort status (liability) thus established.

Although a contract to treat might be written to assign the responsibility to the city, the city may sue for "unusual and negligent" acts which affect its operation. This action, which requires monitoring records and involved chemical and biological analyses for defense, is likely to go against the Navy. It is likely that any malfunction of the treatment system will be attributed to Naval error. Manufacturers have had this experience with industrial waste and the legal precedents are clearly unfavorable [Newlin, 1971].

Quite aside from the more classical liability relation, the environmental legal movement has established a concept of absolute liability which may mean that "ultimate source" responsibility will become an established legal status. Like auto companies, the source or manufacturer may be held responsible regardless of the dealers or treatment contractors involved. Such policy is currently applied to oil removal contracts in the San Francisco Bay area.

With the smaller volumes of liquid that are available to a Navy owned plant the impact of an error is likely to be greater. With no difference in the legal liability (except internal relations with one's treatment partner), considerations of responsibility seem to favor neither alternative.

ECONOMIC COMPARISON

Because the current treatment systems in various port cities are quite variable (Honolulu - primary only; San Diego - relatively modern secondary, for example) one can hardly develop the proper policy for all municipal relationships. Nevertheless, the examination of relative magnitudes of the various terms in the decision is instructive.

There are three situations that we might examine: the new construction of a joint project vs. Navy owned, the relationship to an existing system, and the relative populations needed for small ports to justify Navy efforts.

For the first case, we have the major components of the analysis indicated in Table 1. The explanation of the terms is as follows:

Construction cost: The figure of \$2.5M was selected as the Navy owned cost based on a paper by Burns (1971). The figure was found to apply to plants with a range of capacities from 0.5 million gallons per day to 2.5 million gallons per day. The dates of building the plants are variable but corrected to the same dollar base. Current costs would be higher but so would the costs in the comparison column.

In the strictest sense the Navy should only be responsible for a proportionate share of the cost of the plant. This proportion which we have called N_p is simply the fraction of the total input to the plant from the Navy. This is based on our earlier discussion which showed that the salinity should not influence the operations significantly for this option. The reason that the basic cost figure is \$2.5M+ is that the city might build a plant of greater capacity than the 2.5 MGD value noted above. Since this would make N_p smaller, the product is still likely to be about the same.

Using the population data we had above for San Diego we obtain an N_p of 0.031. This ignores industrial contributions so it may be too high. Applied to a \$2.5M figure it works out to be \$77.5K. Amortized over 20 years it works out to \$3875/yr. Most municipal systems would expect more

ECONOMIC ANALYSIS OF TREATMENT ALTERNATIVES

Expense	Navy Owned	Cooperative Ownership
Construction Cost	$2.5 M	N_p ($2.5M+)
Accelerated Corrosion	X	Y (Smaller than X)
Land Cost	High due to downtown location	N_p (Cost)
Labor Cost	S($100K)	$N_p S$
Sewer Installation	Varies but higher than simple connection in most cases	Smaller than separate unless city must replace existing lines
Sewer Maintenance	Cost of all gathering system	Connection lines plus $N_s \cdot A$
Monitoring Costs	Zero (Part of S above)	For monitors at interfaces
Pretreatment	Zero	Zero to $? depending on reclamation plans

Terms are discussed in the text

participation than this but it is the size of the strict share.

Accelerated corrosion: The salinity that we worked out earlier for a typical city gave us about 1000 ppm. The corrosion data in the literature is for Hollywood, Florida which has 1200 ppm as a typical value. The replacement of some parts of this plant are about four times as often with replacement of other parts varying from three to 1.5 times as often. In any event, the data is not adequate to give a good numerical value for Y but we can examine its relative size as to X, the cost in the Navy's own plant. With the salinity much higher similar equipment will corrode much faster so X must be larger than Y. Of course, changes in the materials, etc., might avoid this difference but would increase the construction costs.

Land Cost: An additional cost that the Navy would have to bear is the land cost. Even if the Navy currently owns the property its use for a sewage disposal plant removes it from other use. Since the property is usually in a part of the city where property values are high, the Navy's use of the land will be more expensive than N_p times the cost of the property used by the city. Additionally, the downtown zoning of the plant will require extra care in design and operation if the public relations aspects are not to get out of hand.

Labor costs: The Navy's cost and those of the commonly owned plant will be similar and, based on Michel (1970), will be about $100K/yr. (These are 1965 figures that were quoted and, therefore, are too low but permit order of magnitude comparisons.)

For the cooperative plant, the Navy's cost will be N_p($100K.)

For the plant itself we see that the option to cooperate with a city is less expensive. We must, however, examine the entire system to properly evaluate the options.

Sewer installation: This item refers to the Navy base only at this point. If the City's sewers have to be rebuilt to handle the sea water (only likely if the sewers are cast iron,) the cost could be prohibitive and even the Navy's share would have to be larger as the need for the change is largely Navy caused, although commercial shipping is also a contributer.

Since our concern is with treating sea-water-borne waste we are dealing with harbor facilities and the general geometry to be expected is the extension of the Navy's property along the waterfront with the civilian community built up behind it. Where this is true, or worse, where the Navy's property is not contiguous, the cost of running several short runs to connect with the municipal system surely must be cheaper than running a parallel system within the base.

Sewer maintenance: If the city sewers can take the salt water without additional corrosion, the Navy's portion of the sewer maintenance should be calculated on the basis of a factor N_s similar to the N_p figure but varying with approach to the plant according to the relative volume of Navy sewage in each segment and approach N_p as the lower limit as it approaches the plant. A represents the actual cost of maintenance of the municipal sewers involved in carrying Navy waste.

For the Navy option the total cost would be Navy but the differences in the distances involved makes it hard to assign a sure value for the relative sizes of the costs.

Monitoring costs: There are some costs which would be absent in a Navy owned system but present in the cooperative venture. They are small items such as monitoring equipment and personnel which are needed at the interfaces between the city and the Navy. The cost of such work in the other option is buried in the routine operation of the plant. The cost of these will depend on the city's demands but volume and salinity can be monitored automatically at the input to the city's system and should suffice in most cases.

Pretreatment: One possible major cost might arise if future plans call for the city to reclaim its water for some use. The presence of an additional 1000 ppm or so of salt will generally cause the cost of such reclamation to go up quite sharply. In this event the Navy's choice may be paying for a sizable part of desalinization which could well approach the cost of inhouse treatment.

An analysis of this first option shows that the most probable cost factors support the current practice of contracting with the city for most cases. The costs that the Navy is strictly responsible for are quite minimal although it seems likely that the municipal system will seek to receive more aid than the strict use figures that we have calculated. For the favorable cases, the Navy could still pay quite a bit less in this option and still aid the city.

Using the same sort of data one can examine the mode of assigning Navy costs for a system that is already built and functioning.

A first possibility is to charge normal users fees and a proportionate part of the bonded indebtedness as assessed against private users. This places the Navy on pretty much the same footing as any other user except that the others pay taxes and the Navy pays the bond fee directly. With our demonstration that the impact of the salt water should be negligible, any further surcharges seem improper.

The alternative is to calculate the parameters listed above and pay annual fees as a stock holder in the consortium. This has the advantage of more policy control.

Let us estimate the minimum size of Naval detachment required to make consideration of these alternatives meaningful. If we use 0.5 million gallons per day as the minimum plant size and we use 39 gallons per day per man which includes the 9 gallons/day of fresh water needed to bring the salt content to an acceptable 25,000 ppm, we find that about 13,000 people using sea water flush can be handled. A better number for approximation is about 10,000 as fresh water from the military establishment ashore must certainly be added on in the event of a decision to build a Navy-owned plant.

Certainly anytime the Navy has an installation of this size with respect to shipboard personnel, the community associated with it will be enough larger to justify cooperative efforts. Except in foreign ports where the city involved might not wish to participate, it does not seem profitable for the Navy to proceed alone on a classical shore-side sewage treatment plant. For such areas, other types of plants must be considered as well.

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13. ABSTRACT

Three questions related to abatement of pollution from Naval vessels are examined

Current candidates for shipboard application are discussed with respect to limitations of development imposed by technical processes utilized. Limited flush with incineration and biological treatment are judged ready for application with the latter method less desirable for several secondary reasons. Wet air oxidation is considered a good candidate for an Integrated Waste Disposal System and merits R & D support.

Open ocean impact of oil and sewage discharge is examined. The technical literature is sparse but it is clear that oil is a significant contaminant, even now.

An examination of the economic factors related to contract sewage treatment shows that it is most probable that the Navy can work with municipal authorities to their mutual advantages. Reasonable amounts of salt water do not reduce efficiency of biological plants of the aerobic variety. Except where water reclamation or extensive municipal sewer replacements raises the cost of participation unreasonably, shared facilities are also the most economical.

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