

Oceanus



Marine Pollution

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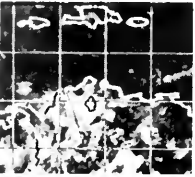
Marine Pollution

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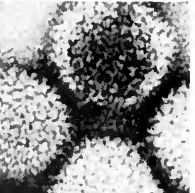
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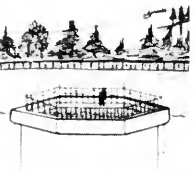
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COVER: *Aerial view of pollution plume on the Hudson River, north of Albany. (Robert Perron, from A River for the Living)*

Commentary

The Petroleum Problem

In May 1973, I participated in a workshop on the inputs, fates, and effects of petroleum in the marine environment, sponsored by the Ocean Affairs Board of the National Academy of Sciences.* Our objective was to evaluate existing information, indicate gaps in our knowledge, and suggest directions for future research. I intend to discuss only a few results of the workshop and give some personal comments on the problems we encountered.

If I were to ask for a material balance of the oil entering and leaving the world's oceans in a year, I doubt if anyone could come within a factor of two in determining the true input or output. Oil spillage from dry docking, terminal operations, tanker accidents, offshore drilling rigs, and coastal refineries can be reasonably well documented. But estimates of spillage from tanker operations and bilges and bunkering of all ships on the high seas are based on many assumptions and could be off by an order of magnitude. Even more difficult is the estimate of oil entering the ocean from natural seeps and atmospheric fallout. There are a few well-defined oil seeps such as Pitch Lake in Trinidad and the area off Coal Oil Point

in California. However, most reported marine seeps have not been quantified or even verified. As to input from the air, it may be anywhere from near 0 to 10 million metric tons a year. Despite our considerable ignorance in this field, most authoritative scientific reports of the last few years have settled on a range of from 5 to 10 million tons as a probable annual oil input into the ocean.

Where does it all go? We know that part evaporates into the atmosphere, part dissolves in the water, part is incorporated with sediment particles and either carried down to the sea floor or moved on the surface until it contacts a coastline. Another part is oxidized by chemical and biological means to more soluble organic materials and CO₂.

Unfortunately, we have no idea of how much oil follows each pathway, nor do we understand the relative rates of degradation. Even if pathways were quantified in one experiment, the data would not apply to an oil of different composition spilled in a different environment.

Of real concern to all of us, of course, are the current and long-range effects of petroleum on man and the biosphere. The media have reported extensively on the global contamination of beaches. Documentation

* The workshop report is scheduled for release in a few weeks.

of biological effects has been more difficult. Major spills have killed large numbers of intertidal and subtidal benthic organisms and pelagic diving birds, particularly in inshore areas with abundant biota. Generally, recovery occurs within a few months or years, depending on the severity of the spill. Organisms that survive seem to be able to cleanse themselves of much of the oil. There is no evidence of food-web magnification of petroleum comparable to that observed with DDT.

Much more controversial is the long-range effect of repeated spills or chronic inputs of oil. There are many natural causes of population variability in both marine organisms and sea birds that could mask the possible effects of oil. Also, man's impact on the coastal environment over the last century has resulted in long-term effects from a variety of pollutants.

One debate that has generated more emotional statements than scientific data is in the area of human health. Since oil contains a few parts per million of carcinogens, it is argued that eating oil-contaminated fish represents a health hazard. It is true that both finfish and shellfish can incorporate a few hundred parts per million of oil, which could be transmitted to man. However,

based on the analysis of one well-known carcinogen, benzopyrene, the quantities of carcinogens ingested with such fish differ little from those in many of our foods. The larger question, then, involves the relative quantities of carcinogens in what we eat—a question that cannot be answered until the incidence of all possible carcinogens in our food supply has been evaluated.

Two indisputable facts have emerged from the workshop that can be of use to decision makers. First, if this country continues to consume oil at its present rate, it would be far better for the environment if we were to obtain this oil by offshore production rather than by marine transportation. Spillage by drilling is less than 5 percent of that by transport, on a world-wide basis. Second, urban and industrial waste oils and greases entering rivers, bays, and estuaries constitute the major, low-level, chronic pollution by petroleum in the coastal environment. Tighter control of coastal inputs, plus better regulation of tanker operations, will go a long way toward minimizing the petroleum problem in the oceans.—JOHN M. HUNT, *senior scientist, Department of Chemistry, Woods Hole Oceanographic Institution.*

Marine Pollution:

Edward D. Goldberg



Action and Reaction Times

Thousands of substances used or produced by human society now move through the oceans. Some of these substances, such as the pesticides DDT and dieldrin and the artificial radioactive materials produced in nuclear reactors, are alien to the marine system. Others, such as lead, occur naturally; but their concentrations are altered by man's activities. For example, the concentrations of lead in coastal waters have been increased by the entry of antiknock agents and the products of their combustion in automobiles.

Only a few of these many compounds

Fishing in the polluted waters of the Edo River estuary, near Tokyo, Japan, at the site of a landfill operation.
(Robert Perron)



are likely to have negative effects, such as the contamination of seafood, the alteration of communities of marine organisms (see page 29), and the loss or restricted use of nonliving resources, such as recreational areas (see page 55). Nevertheless, we must be prepared to counteract the destructive impact of pollutants on the marine environment and to develop strategies for managing toxic materials. Toward this end, it is necessary to understand the time scales involved in both natural processes and societal responses.

Oceanic Time Scales

The times that chemicals spend in seawater may be estimated by means of simple mathematical models in which the oceans are depicted as a vast reservoir for continental materials mobilized by winds, rivers, and glaciers. Substances involved in these estimates are usually considered to have time-invariant concentrations in the oceans. The amount of a material entering the oceans in a given period of time is compensated by the same amount of the material falling to the sediments or undergoing radioactive decay or microbial degradation. Thus, the time a chemical spends in the oceans is given by the total amount in the oceans divided by the total flux into or out of the oceans. This period is known as the residence time. (The assumption is made that there is complete mixing of the substance within the reservoir in a time span that is short with respect to its residence time there.)

Several characteristics of these models are important to pollution studies. First, a pollutant will reach a steady-state level in a period equal to approximately four residence times. If the release of the pollutant stops after the steady-state concentration is reached, original conditions will prevail after the same period—four residence times. Second, the residence time of a chemical is inversely related to its level of reactivity in

the reservoir. Persistent (low-reactivity) chemicals will have longer residence times, whereas more reactive chemicals will be removed more quickly by either breakdown or precipitation to the sediments. Use of these two concepts may allow the prediction of pollutant levels in the ocean environment where the residence time of a naturally occurring substance or of a previously studied pollutant with similar chemical properties is known.

Coastal Ocean

The world ocean can be conveniently divided into two zones for the purposes of both scientific and societal inquiries: the coastal ocean and the open ocean. The coastal ocean constitutes about 10 percent of the total oceanic area and includes estuaries, lagoons, inshore waters, and many marginal seas and waters over the continental shelves and slopes. The North Sea, Chesapeake Bay, Persian Gulf, and Sea of Japan are examples of coastal waters. Their properties are strongly influenced by boundaries with the continents and the sea floor. The coastal ocean receives direct injections of continental materials via rivers, direct terrestrial runoff and drainage, and the atmosphere, and through such mobilizing agents of man as domestic and industrial outfalls and ships.

Coastal waters are the sites of high rates of biological activity. The marine primary production of organic material—photosynthesis, which is the base of the food chain that ends in fish, birds, and marine mammals—takes place predominantly in these waters. The open ocean areas, with a few exceptions, such as some productive equatorial waters, are the marine deserts. Within the coastal zone there are some especially productive waters—upwelling areas—where a coupling of strong offshore winds with prevailing boundary currents brings nutrient-rich deep waters to the surface. Here, with even higher levels of primary productivity, fish stocks are large. These most important upwelling areas are off



Pollutants can enter coastal waters via the atmosphere. Discarded automobile batteries are burned in a plant near Houston, Texas. (EPA-Documerica, Marc St. Gil)

Peru, California, and the western coast of Africa. Although they are estimated to constitute only 0.1 percent of oceanic areas, they are responsible for about 50 percent of fish production (the other 50 percent occurs in the remainder of the coastal zone).

High rates of biological activity in coastal seas affect materials introduced from the continents. Some organisms have a remarkable ability to accumulate substances from seawater, even where the materials are in extremely low concentrations (parts per billion or parts per trillion). For example, vanadium, at levels of about one part per

billion in seawater, is enriched in the blood of tunicates to levels of parts per thousand. DDT and its residues are found in surface seawaters in concentrations of parts per trillion; yet in the fish, levels of parts or tens of parts per million are not uncommon. Organisms living in coastal waters may therefore act as conveyors of man's wastes. They can move substances from surface waters to the sea floor through their death or the discharge of metabolic waste products. Or they may return such materials to man in the form of food.

The persistence of chemicals in coastal



The presence of DDT and its residues in the diet of the Anacapa Island brown pelican resulted in thin-shelled eggs and breakage during incubation. (Franklin Gress)

waters—before removal by sedimentation, degradation, mixing with the open ocean, or harvesting of living organisms—may extend from months to decades. Estuaries exchange their waters with the open ocean in such periods of time. Recent work at the Scripps Institution of Oceanography showed that the residence times of radium and lead isotopes in the highly productive Gulf of California were a few months and almost one month, respectively. Calculations such as these may not be applicable to many pollution problems, because they assume a steady-state situation in which the concentration of the substance in the water is invariant with time. For most pollution problems, however, there is a gradual accumulation of the material. The time from initial entry of a pollutant to awareness of a problem may be measured in decades. In the case of the brown pelican colony on Anacapa Island, off the California coast, failures to reproduce during the period 1969–72 were attributed to extensive DDT pollution that had first appeared in sediments in 1952.

Open Ocean

The open ocean, which constitutes approximately 90 percent of the world ocean, differs from coastal waters in its time scales and its relationships with the continents and sediments. Whereas time spans describing natural processes in coastal waters extend from months to decades, periods associated with the open ocean are between hundreds and hundreds of millions of years. For example, aluminum species, which enter the ocean as a result of weathering processes on the continents, spend almost one hundred years in the open-ocean waters before precipitating to the sediments. Sodium, one of the principal elements in seawater, remains in the open ocean for perhaps a hundred million years before accommodation in the sediments.

Deeper waters of the open ocean, those below 100 meters or so, are out of contact with coastal or surface waters for periods that average between a few hundred and a thousand years, depending upon the ocean basin. Herein lie not only the present value of these waters as accepters of man's wastes, but also the future perils that can arise from the small, but continuous, introductions of highly toxic substances. For example, open-ocean waters contain about 100 million tons of mercury, an amount far greater than the hundredth of a million tons mined annually by man. Thus, the deep ocean can today safely accept low-level mercury wastes, especially in the inorganic forms, and similar arguments can be made for the disposal of such toxic metals as arsenic and antimony.

On the other hand, the long residence times of chemicals in the open ocean may lead to the formation of a toxic broth through the slow accumulation of man's wastes. There is taking place today in the deep waters of the open ocean a gradual, but continuous, build-up of halogenated hydrocarbons—synthetic organic chemicals, some of which contain chlorine atoms (see page 19).

They enter the coastal ocean through sewer outfalls, and the surface waters of the open ocean as gases via the atmosphere; they are transferred by physical and biological processes to the deep ocean in less than a decade. Some of these chemicals are known to interfere with metabolic processes of living organisms. The heavier compounds, such as DDT and its degradation products, and polychlorinated biphenyl (PCB), affect the calcium metabolism of marine birds, with the result that their eggs have thin shells. The lower-molecular-weight species, such as the chlorofluorocarbons, which are used as aerosol propellants, may inhibit the fermentation activities of microorganisms.

Of major concern is the possibility that a toxic material can reach such levels that the exposure of organisms in the open ocean, as well as the coastal ocean, to these levels will result in widespread mortalities or morbidities. The great volume of the open ocean makes removal of a toxic substance, identified by a catastrophic event, impossible with the technologies of today or the foreseeable future.

Open-ocean sediments accumulate natural debris a thousand or so times more slowly than do coastal deposits. The fluxes of solids that are mobilized during weathering processes and carried to the open ocean primarily through the atmosphere are much smaller than those that enter coastal waters from rivers and direct terrestrial runoff. Also, since biological activity is less intense in the surface waters of the open ocean than in those of the coastal ocean, there is a lesser potential for the downward transport of pollutants through biological activities. Most of the materials dispersed to the open-ocean environment through man's activities are still in the water column. Only a very few have been taken up by the sediments.

Today the open-ocean water column contains many signatures of our technological society. Radioactive isotopes of strontium and cesium, produced primarily in nuclear

bomb detonations, have been found to depths of 1000 meters or so, approximately one-fourth of the way down to the sea floor (see page 43). Other radioactive isotopes, such as those of cerium and promethium, which are chemically more reactive, have been found at even greater depths, although in smaller concentrations than those in surface waters. DDT and its degradation products have been found in all open-ocean species sampled over the past five years.

The surface of the open ocean is soiled with petroleum products in the forms of tar balls and coatings (oil slicks) whose thicknesses have molecular dimensions. In addition, ocean currents carry litter, plastics (see page 61), glass, wood products, and metals, many of which are used to contain products of commerce. These visible alterations of the surface signal the need for continual measurement and assessment of the invisible pollutants below.



Goose barnacles on a tar lump collected in the western North Atlantic Ocean. (BIO photo by Belanger)



In February 1970, the Liberian tanker Arrow went aground in Chedabucto Bay, off Nova Scotia, and spilled 108,000 barrels of bunker C crude oil. Scientists at the Bedford Institute of Oceanography studied the effects of the spill and tested various methods of dealing with the oil. (Top and center) Scientists set up a time-lapse motion picture camera to film the natural dispersion of the crude oil during a tidal cycle. (Bottom) Testing of high-pressure water as a method of cleaning oil off a stony beach. (BIO photos by Belanger)

Societal Time Scales

The scientific community or a catastrophic event alerts governing bodies to regulate the release to the environment of substances that can jeopardize marine resources. The possibility that the discharge of high levels of radioactivity from nuclear power reactors or from nuclear detonations could harm public health and the vitality of marine organisms prompted scientists to action during the years following World War II. The primary concern was the return of ionizing radiation to man through food or through direct exposure by swimming or recreational activities on beaches. There was the sense that it would be convenient, and perhaps necessary, to deliberately dispose of some amounts of radioactive nuclides in the seas. The complexities of chemical processes in the oceans did not allow prediction of the fate of a specific chemical introduced to a particular place. Thus, the initial recommendations for sea disposal of radioactive wastes contained an explicit sense of caution, control, and limitation. They were intended to be experimental. Since that time, the amounts of radioactivity introduced to the oceans have been strictly limited under national regulations based on internationally promulgated standards (primarily by the International Atomic Energy Agency and the International Commission on Radiological Protection).

The policies of the United Kingdom are an example of the national management of radioactive materials. Minimum risk to its citizenry is sought in the area of both somatic and genetic effects. Of primary importance is the identification of potentially significant pathways along which radioactive substances released by man can return to man. Once identified, they provide the basis for the "critical pathway approach" (see page 50), a management strategy that provides an adequate and economic surveillance of the return routes. (These pathways

usually involve the ingestion of foods or the inhalation of atmospheric constituents. For any specific isotope, the routes are few; in many cases only one has been found to exist.)

How quickly can governments respond to an unexpected catastrophe resulting from the unregulated discharge of an unknown toxic substance into the marine environment? The Minimata Bay incident in Japan and subsequent events provide a time scale that may reflect a unique social-economic framework rather than a general set of reaction times that may be expected in the future. Still, it is worthy of review because it may provide a guide for better and faster responses.

The Minimata Bay incident started in the late 1930s when the Chisso Corporation, one of the leading chemical industries in Japan, began to produce vinyl chlorides and formaldehyde at its factory on the shores of Minimata Bay. Spent catalysts containing mercury were discharged into the bay, and fish and shellfish accumulated the mercury

in the form of methyl-mercury chloride. Their consumption by the inhabitants of the area, primarily the fishermen and their families, resulted in an epidemic of neurological disease. The first occurrence of the disease was reported in 1953, about 15 years after the wastes first entered the bay. It was not until 1959, after some 80 cases of neurological disorders had been diagnosed, that mercury was associated with these afflictions.

In 1960, articles describing both the disease and the circumstances under which it developed began to appear in environmental and medical journals throughout the world. At this time the prevailing opinion was that a still-unidentified organic compound of mercury was the cause. During this early period, the Chisso factory was making every effort to avoid an association with or a responsibility for the disease. The company had gathered together a group of scientists who refuted the evidence of the workers at the Kumamoto Prefecture University, who

The Chisso factory on the shores of Minimata Bay. (W. Eugene Smith, Magnum)





(Above) A mother holds her 16-year-old mercury-poisoned son. (Below) Members of the Patients Congress of Minimata Disease seek compensation from company representatives for victims of the disease. (W. Eugene Smith, Magnum)



had established the relationship between mercury and the disease. The company then found new waste-discharge sites in a northern area, where, soon thereafter, several new cases of the disease were reported. By this time, the citizens of Minimata Bay had become aware that local seafood was the source of the epidemic. Strong animosities developed between the fishermen and the Chisso Company as the demand for fish by the local inhabitants fell to zero. The fishermen became violent and stormed and destroyed the factory offices. Through such actions the Minimata Bay disease became known throughout Japan. Eventually, the company paid very small compensations to the fishermen for the loss of their livelihood and to the victims of the disease. For a few years the problem was forgotten. However, in 1965, a second outbreak occurred, this time in a new location along the Agano River in Niigata. Here the source of the pollution was attributed to an acetaldehyde factory of the Show Denko Company that discharged its spent mercury catalysts into the river. The victims of the second outbreak initiated a civil action in the court in June 1967; this is presumed to be the first large civil suit brought against a polluter in the history of modern Japan.

In 1963, ten years after the first cases were diagnosed, the active agent causing the disease was identified as methyl-mercury chloride. This discovery introduced a new dimension into the marine chemistry of mercury. Before this time it was thought that only inorganic forms of mercury were involved in natural processes. But further surprises were in the offing. In Sweden, as a consequence of some disastrous impacts of mercurial pesticides on wildlife, a group of scientists was working on the environmental chemistry of mercury. Their analyses of mercury in uncontaminated fish indicated that nearly all the mercury was in the form of an organic compound, methyl-mercury. The toxic form causing the Minimata Bay

disease was similar to the naturally occurring form. These unexpected results were eventually confirmed by Japanese scientists.

The first group to systematically evaluate the risks involved in the consumption of fish containing mercury—at naturally occurring levels or at higher levels caused by man's activities—was appointed in 1968 by the Swedish National Institute of Public Health in conjunction with the Swedish National Board of Health and the Swedish National Veterinary Board. The group assessed the toxicological evidence from the Japanese epidemic and the fish-eating habits of both the Japanese and the Scandinavian populations. It was found that in Sweden there was a small number of persons who had no symptoms of Minimata Bay disease but who had consumed fish to such an extent that mercury concentrations in their hair and blood were the same as those of Japanese who had shown neurological symptoms of poisoning. These results emphasized the varying sensitivity of peoples to methyl-mercury poisoning and the differences in their eating habits.

Although the group was not charged with the formulation of allowable methyl-mercury levels in fish, they did consider the problem in their report, published in 1971.

Subsequently, Sweden adopted the level of 0.5 parts per million. Several other countries followed, including the United States, where the average daily consumption of fish is 17 grams, less than one-third that of Sweden. These levels apply not only to coastal fish, whose mercury levels may have been raised by man's activities, but also to deep-sea fish, such as tuna, whose mercury levels appear to have remained unchanged during the past century.

It took more than two decades for the Japanese government to halt the discharge of mercury into the marine coastal zone and for other countries to determine what are acceptable mercury levels in seafood. Recently, mercury has been blacklisted by the ocean-

dumping convention. What the mercury episodes have shown is that the time periods required by scientists to get to the root of a problem and by environmental managers to formulate measures to protect coastal resources are similar to those involving reactive chemicals in near-shore systems.

Societal Restraints

There are several impediments, each with an economic root, to the development of a scientific basis for the description and forecasting of ocean pollution problems. The first involves the difficulties in acquiring a knowledge of past, present, and predicted production and use data for chemicals that may insult the marine system. A continual assessment by scientists of the production and uses of chemicals and energy can provide a means to predict which substances, if released to the environment, might jeopardize the continued uses of marine resources (see page 17). Such evaluations usually involve estimates of toxicity and the construction of mass balance models—schematization to understand the flow patterns of materials from the site of release to the environmental reservoirs. However, there are obstacles to such undertakings: the production and use data are often maintained as privileged information by manufacturers or sovereign nations. For example, in the United States, where a chemical is produced by no more than two companies, the production and use figures are proprietary information. The rationale that prohibits the release of such data is economic. Governments have an obligation to protect their manufacturers from being placed at an economic disadvantage through the publication of production and use data. Yet it is in the interest of their citizenry that there be a continual assessment of the state of marine resources, for which such data are essential.

New concerns are evolving for which production and use figures are urgently needed. For example, there is a geographical shift in the applications of DDT in agriculture

and public health. Most DDT was initially used at mid-latitudes of the northern hemisphere. It now appears that the center of usage is shifting southward as more industrial countries ban DDT. However, the details of this change are not available to the scientists to assess the possible impact on marine life. As another example, a group of marine scientists wants specific information about the discharges of transuranics from nuclear reactors and reprocessing plants. For military and economic reasons, much of this data is classified.

As a result of a general lack of production and use data, in early 1974 the Intergovernmental Oceanographic Commission formed an ad hoc group of experts (POOL—Pollution of the Ocean Originating on Land) who have been directed to “suggest practicable and effective means for obtaining information on the quantities of important pollutants, present and potential, introduced into the ocean from land-based sources by whatever route.” The charge is well defined, the task formidable.

Of greater concern than either the chemical manufacturer or the sovereign nation are the multinational corporations (MNCs), whose activities compete with those of major nations in the utilization of materials and energy. Effective controls on their actions still have not been formulated by international organizations (debate has now begun in the United Nations), yet concern for the environment in the prosecution of their activities seems to be minimal.

The global influences of MNCs can be seen in terms of their annual products. For example, General Motors in 1970 had an annual product of \$24 billion (the gross national product of Switzerland was \$20 billion, of Denmark \$15.5 billion). Of the first fifty institutions or nations ranked in order of annual product value, nine are MNCs. But what is more foreboding is that their annual rate of growth exceeds that of national states. Most probably there will be more transnational mergers of firms, with an

increase in the number of MNCs. Clearly, one of the problems facing the international community of nations is to find ways of dealing with the MNCs, especially as they impinge on common environmental resources. The weak link in plans to protect the world ocean may be the country willing to negotiate the quality of its coastal environment for short-term economic gains.

Future Strategies

Strategies for the management of highly toxic marine pollutants must be formulated by the major producers. One cannot expect a large group of nations, such as the United Nations and its family, to address itself to the pollution problems that plague the technologically advanced societies when there are basic problems of survival for the populations of developing member countries. Bilateral and multilateral agreements to deal with these problems seem to be the best approach. Recent agreements between the United States and Canada to protect the Great Lakes; among the North Sea countries, through the International Council for the Exploration of the Sea, to understand their pollution problems; and between the United States and Russia to exchange scientists and jointly publish a periodical dedicated to marine quality problems are some of the steps necessary to recognize potentially dangerous leakages to the environment and to propose remedial actions. Efforts to solve the first-order problems of marine pollution by large international organizations have, in general, been both noble and futile. Information needed for the statement and solution of problems has usually been unavailable, because economic and social concerns have overridden environmental ones. The starting point is acknowledgment of a problem by political leaders and scientists alike.

Edward D. Goldberg is professor of chemistry at Scripps Institution of Oceanography, University of California at San Diego.

Predicting Ocean Pollutants

Man's effects on the environment have increased rapidly as his technology and its use of materials and energy has expanded. As a result, environmental scientists have been confronted with an unprecedented demand for solutions to problems for which little or no information exists that can be used to formulate answers. Because our decision-making processes are driven mainly by political and economic forces, several recent crash programs have responded to real or apparent marine environmental crises. Mercury, polychlorinated biphenyl, and petroleum in the marine environment are specific examples where major public concern has forced the adoption of regulations and monitoring programs *after* a "crisis" was identified.

In July 1972, a group of scientists met, under the auspices of the Ocean Affairs Board of the National Academy of Sciences, to discuss the possibilities for assessing the potential of various materials and technological endeavors for affecting the oceans. The organizing committee decided that the most promising approach involved determining the characteristics of the substance that might make it dangerous to the marine system; calculating the production, release to the environment, and levels of man-induced and natural fluxes; and estimating transport routes to and through the environment, and concentrations and residence times in various reservoirs within the environment.

At a second meeting, the applicability of the approach was discussed and modifications were developed. At a third meeting, early in 1973, it was decided to proceed with a full-scale investigation of a few substances to serve as an experiment in developing and evaluating the mass-flow-estimate method.

The quantity and variety of information required was sobering, and the steering committee decided to assemble a special group of young scientists to make a

concentrated effort to find, compile, and conduct a preliminary evaluation of the needed information about the selected materials. This information was obtained from open literature, obscure literature, and government and industrial files; some of it was deduced from related information.

The study focused on a variety of substances within five general classes of man-made materials: transuranic elements, such as plutonium; synthetic organic chemicals, such as low-molecular-weight hydrocarbons—tetrachloroethylene; 1,1,1-trichloroethane; 1,2-dichloroethane; and 1,2-dichloropropane—benzene and toluene, hexachlorobenzene, and acrylonitrile; ocean discharge of metallic wastes, such as iron and copper; medicinal wastes, such as tetracyclines and technetium-99m; and marine litter. Ten predoctoral and postdoctoral students worked more than full time for three months to accumulate the existing relevant information. Their effort required perseverance and a great deal of ingenuity.

The mass of information assembled was evaluated at a workshop in the fall of 1973. The overall conclusion of the workshop and the organizing committee was that this approach is workable and should be applied generally to the materials of our technology.

This study has demonstrated that a relatively modest but intensive effort can result in the identification of some potential future ocean pollutants and some materials that are unlikely to become pollutants, as well as the kind of data that are needed to reduce the uncertainty regarding other substances. The report of this study, *Assessing Potential Ocean Pollutants*, will soon be available from the National Academy of Sciences.—RICHARD C. VETTER and WILLIAM ROBERTSON IV.

Richard C. Vetter is executive secretary of the Ocean Affairs Board of the National Academy of Sciences. William Robertson IV is senior staff officer responsible for this study to the Ocean Affairs Board of the National Academy of Sciences.



DDT and PCB in the Atlantic

George R. Harvey

The insecticide DDT was introduced to world agriculture and public health after World War II. It was valued for both its toxicity to insects and its persistence in the field. It is estimated that over ten million tons have been used during the last thirty years. Polychlorinated biphenyls (PCB) were first introduced to the electrical industry in 1935 as dielectric and insulating fluids. Because of their low conductivity, heat stability, resistance to bacterial degradation, and solvent properties they soon found their way into hundreds of commercial products. About one million tons have been manufactured to date. It was inevitable that the same properties that make these chemicals so valuable in commerce, agriculture, and health would lead to their accumulation and persistence in the environment. Also, since the oceans cover most of the surface of the globe, it would have been reasonable to predict that large fractions of these chemicals would find their way to the sea. These predictions would have been of little concern if both DDT and PCB were not members of a class of organic compounds known as chlorinated hydrocarbons, substances that are physiologically active in a deleterious way. They are not lethal, as are the nerve gases, but they insidiously interfere with important

biochemical processes, leading to a variety of unnatural symptoms.

Public awareness of the possible effects of chlorinated hydrocarbons on the environment was first roused by Rachel Carson in her now famous book *Silent Spring*, published in 1962. Although the book contained many errors, it struck a sensitive international nerve and catalyzed the formation of federal pollution agencies and new areas of research funding, and heightened public awareness of the classical science of ecology. Still, by 1970 there was no information available on the presence, if any, of DDT or PCB in the open sea.

Being uniquely situated at an oceanographic laboratory with open-sea capabilities, we began to study the distribution of chlorinated hydrocarbons in the sea by making a diverse collection of fish and crustacea on a cruise that transected the North Atlantic between the Cape Verde Islands and Woods Hole during November and December of 1970. Since that time we have made a dozen cruises into the open Atlantic to collect and analyze organisms, water, air, and sediments as a part of the Environmental Quality Program of the International Decade of Ocean Exploration (IDOE), an office of the National Science Foundation.

When our work began in 1970, we proceeded on the following assumptions: We would find mainly DDT and its derivatives

The accumulation of chlorinated hydrocarbons in the marine environment has led to reproductive failures in populations of sea birds, such as the Anacapa Island brown pelican. (Franklin Gress)



PCB released during the burning of municipal dumps may reach coastal waters via atmospheric transport and fallout. (Massachusetts Audubon Society)

and little, if any, PCB; we would note decreasing concentrations of DDT in fish and water as we moved seaward; we would observe food chain magnification of chlorinated hydrocarbons in marine animals; and we would detect toxic effects of DDT and PCB. Fortunately, our approaches were flexible because all four assumptions were wrong.

More than ten times as much DDT as PCB had been used during previous decades. All the DDT had been sprayed directly into the environment, while the PCB had to have leaked or been accidentally introduced. Yet, our first few analyses of Atlantic organisms collected in 1970 revealed ten to one hundred times more PCB than DDT. These initial observations did not change during our subsequent work and eventually led to the conclusion that DDT is not as persistent as once believed and is confined fairly closely to the point of its introduction. Recent work at the Gulf Breeze (Florida) Laboratory of the U.S. Environmental Protection Agency (EPA) has shown that the half-life of DDT in naturally illuminated seawater is about ten days. Consequently, DDT is now undetectable in Atlantic deep-sea water or sediments, while PCB has been measured in

sediments lying under 5500 meters (18,000 feet) of water. Along the coast of the United States, DDT is more abundant and can be detected in sediments, shellfish, and finfish.

After examining a large body of data on the PCB and DDT content of seawater, plankton, and fish, we faced a second unexpected conclusion: there was no trend toward a decrease in the chlorinated hydrocarbon content of the water or the plankton as one went seaward. This is illustrated in Figure 1. Looking for an explanation, we measured the PCB and DDT content of the air over the Atlantic and the

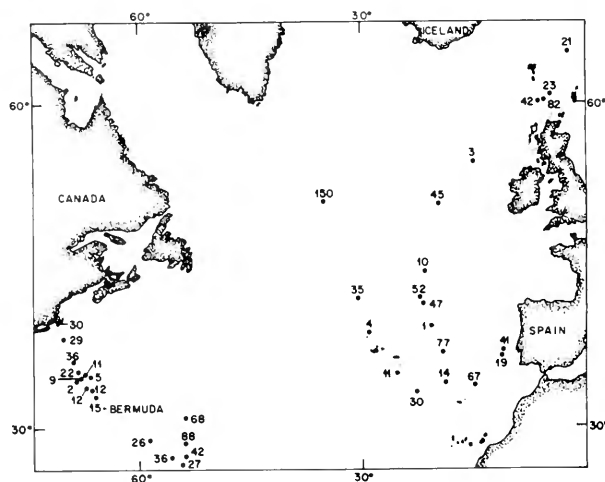


FIGURE 1. PCB concentrations (in parts per trillion) in the surface waters of the North Atlantic in 1972.

sediments beneath the water at several sites from inshore to the open sea. There we did find a very rapid decrease in concentrations away from the coast. This is illustrated for the atmospheric concentrations in Figure 2. The question we encountered was, if more PCB and DDT are getting into the coastal ocean than into the open sea, why aren't concentrations higher in coastal waters, plankton, and fish? We now believe that the greater amounts of solid particles in the coastal waters can adsorb PCB and DDT from the water while falling to the sediments. In fact, we have demonstrated in the laboratory that ocean particles—a mixture of clay, dead

plankton, algae skeletons, and so on—can adsorb one million times more PCB than an equal quantity of water can dissolve. In the open ocean, where there is very little particulate matter, the adsorption process is slower. Thus, the near-shore ocean, which is the source of most of our fish, has been protected from having higher and probably toxic concentrations of chlorinated hydrocarbons in the water by virtue of having a higher load of solid particles. The blue water of the open ocean, because of its low particle population, would be ineffective in protecting the coastal zone. Fortunately,

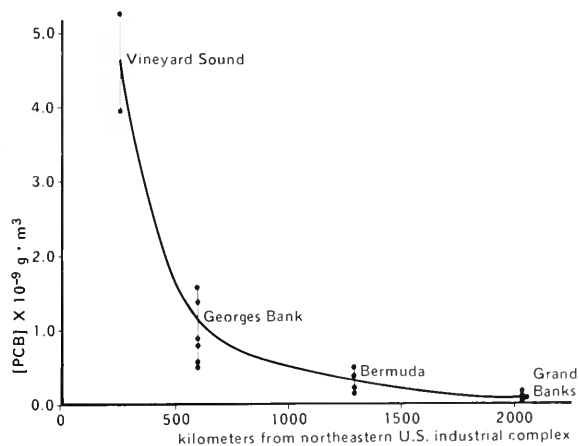


FIGURE 2. PCB concentrations in atmosphere directly over the western North Atlantic in spring 1973.

much less PCB or DDT ever reaches the open ocean.

Another unexpected result of our data and that of others was a lack of support for the concept of food chain magnification, as first popularized by Rachel Carson. Although, like others, we found some carnivorous fish with more chlorinated hydrocarbons than herbivorous fish, or large fish with a higher body burden of DDT than small fish, we also found the reverse in many cases. For example, plankton, although they are at the base of the food chain, contain the highest PCB concentrations of any organisms in the sea analyzed to date (about 200 micrograms per

kilogram). In contrast, barracuda contain about 10 micrograms per kilogram, and flying fish, which feed on plankton, contain one hundred times less PCB or DDT than plankton. Conversely, sharks, which, like barracuda, feed on anything that moves, contain PCB and DDT levels almost as high as those in plankton. In fact, there are now sufficient data from many sources in the scientific literature to conclude that food chain magnification of pollutants is not a useful concept with water-breathing animals. However, air-breathing animals such as seals, sea lions, and sea birds do seem to concentrate DDT and PCB from their diets and to build up enormous quantities in their fat stores. For example, open-ocean-feeding sea birds, such as the great skua and the British storm petrel, can accumulate as much as 20 parts per million PCB from their diets. The reasons for the lack of food chain magnification among gilled organisms are unknown but probably relate to differences in body chemistry rather than trophic level. Differences in PCB concentrations in various water- and air-breathing animals are illustrated in Table 1.

During our cruises we have not observed any effects attributable to DDT or PCB. Planktonic distribution and the size of most

Table 1

PCB Concentrations in Various Reservoirs of the Atlantic Ocean	
Reservoir	Concentrations (parts per billion)
Sea mammals	3000
Sea birds	1200
Mixed plankton	200
Finfish of upper ocean	50
Fish of mid-water depths	10
Bottom-living invertebrates	1
Deep-sea sediments	1
Seawater	0.001

NOTE: Data were taken from several sources and averaged.

fish catches in the open ocean have not changed for as long as Institution scientists can remember. There are fewer sharks now than fifteen years ago, but this can be blamed on the tuna long-lining industry. Also, few haddock are left on Georges Bank, but as a result of reckless overfishing. Marine mammals and sea birds do appear to have been adversely affected by DDT and PCB. California sea lion cows have shown an increased incidence of delivering premature pups while concentrating very high body levels of DDT and PCB from their environment. When a massive wreck of guillemots occurred in the Irish Sea in 1969, investigators initially concluded that PCB toxicity probably could not be blamed. More recently, however, after having collected additional data, they determined that the dead guillemots had about twice the PCB concentration of healthy birds collected in the same area, and that PCB was the cause of the wreck.

Data collected during observations of a colony of terns near Long Island have shown a correlation between deformed chicks and PCB levels. DDT and mercury concentrations in the terns did not correlate with the incidence of deformed young as well as did PCB levels. Recent work at the Marine Biological Laboratory in Woods Hole demonstrated that sewage applied to a marsh in various amounts caused aberrant behavior and death among the fiddler crab population. The DDT fraction of an extract of the sewage produced the same effects. Also, the various species in a population of marine algae treated with environmental levels of PCB in a laboratory culture system gradually shifted to a few dominant species, although the total biomass remained constant.

In each case cited above, there is an apparent causal relationship between the observed effect and the presence of DDT and/or PCB. However, there is no absolute proof because many other chemicals were also present. Unfortunately, by the time such proof could be demonstrated, irreversible



DDT residues are transported to the ocean via rivers (surface runoff) and atmosphere. Routes of atmospheric transport include aerial drift during application, and vaporization from soil and plants. (EPA-Documerica, Charles O'Rear)

damage could be done to a whole population. We therefore cannot delay installation of control programs until the harmful effects of chemicals in the sea are demonstrated beyond doubt.

The situation may be improving, thanks mostly to pressure from scientific and citizen groups that arose during the late 1960s. DDT has been essentially banned in the United States, except for a few special applications. The use of PCB has been restricted in the United States, Europe, and Japan to products that minimize the possibility of leakage to the environment. Since those restrictions were made, the DDT content of coastal marine shellfish has decreased to a level where monitoring by the EPA has been discontinued. PCB concentrations in North Atlantic seawater have decreased fortyfold since 1972, and there now appears to be a constant, but lower, leakage from the cities to the sea. The response of the marine environment to these restrictions has been more rapid than we anticipated, and most welcome. However, we cannot assume that persistence of any concentration of a foreign substance is harmless to the environment.

Although DDT and PCB levels have decreased to the point where we should be concerned rather than alarmed, research should continue for the following reasons.

In the years ahead, as the world food shortage intensifies, there will probably be massive use of persistent agricultural chemicals because of the favorable economics of spraying only once a year. If we know how these chemicals move in the environment, where they go, and how long they last, we can use them more wisely, with minimal damage to the environment, especially the seas. Furthermore, although PCB and DDT may be phased out of use, other chemicals will have to replace them. New chemicals will find new uses. Rather than being armed with perfect hindsight, we should be prepared with intelligent predictions of possible use patterns and thereby avoid unnecessary pollution of the seas. Finally, it has been very difficult to trace and understand the movement and cycling of organic carbon compounds in the oceans. They can come from land or be synthesized by algae in surface waters. Bacteria can make organic matter or degrade

it in surface waters or bottom sediments. Studies of the movements and whereabouts of the chlorinated hydrocarbons DDT and PCB, which originate on land and are not made within the sea, can contribute greatly to our knowledge of the cycling of natural organic matter.

The seas are like a giant, complicated organism composed mostly of water, with some solid materials (dust, fish, whales), all interacting in ways that determine the movements of foreign chemicals through the ocean. We believe the effects of foreign chemicals on ocean life are controlled by regular chemical, physical, and biological processes that we are trying to understand. Only when we understand these processes can we effectively protect the ocean from a premature senility.

George R. Harvey is an associate scientist in the Department of Chemistry, Woods Hole Oceanographic Institution.

HUMAN VIRUSES AS MARINE POLLUTANTS

J. M. Vaughn

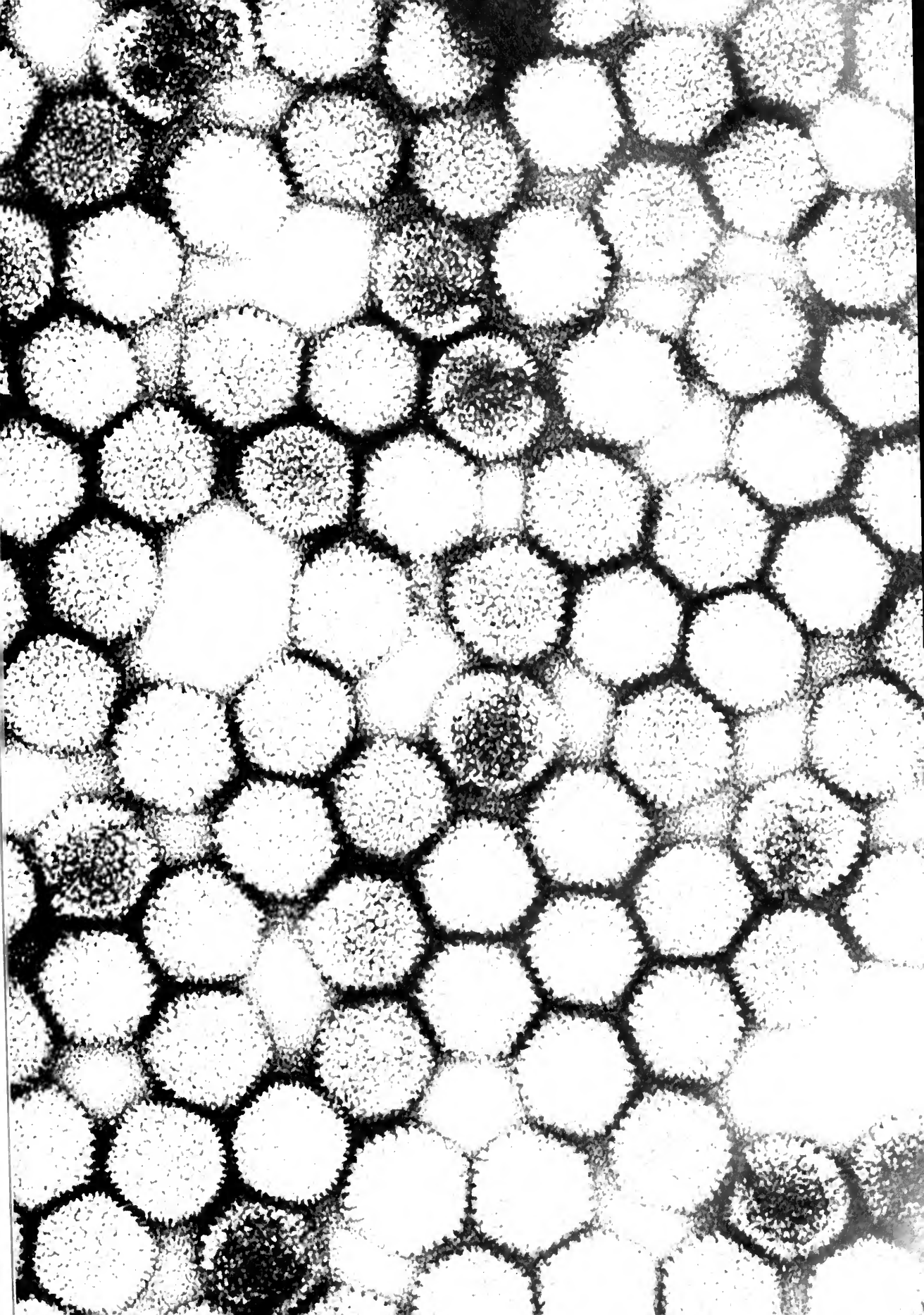
Rapid urbanization along American coastlines during the past century and a half, together with a comparatively slow development of adequate waste disposal methods, have done much to belie the myth that the oceans can serve indefinitely as sinks for industrial and domestic wastes. Already, many coastal areas have been declared unsafe due to potentially toxic levels of chemical and biological pollutants. At the same time, recent shortages of food and minerals have served to underscore the need for the economic development and utilization of marine resources. The problem of preventing water pollution, once the province of diehard environmentalists only, has now become a national priority among an increasingly informed public. Successful abatement of water pollution depends on a certain amount of insight into the nature of the various pollutants and their interactions within their environments.

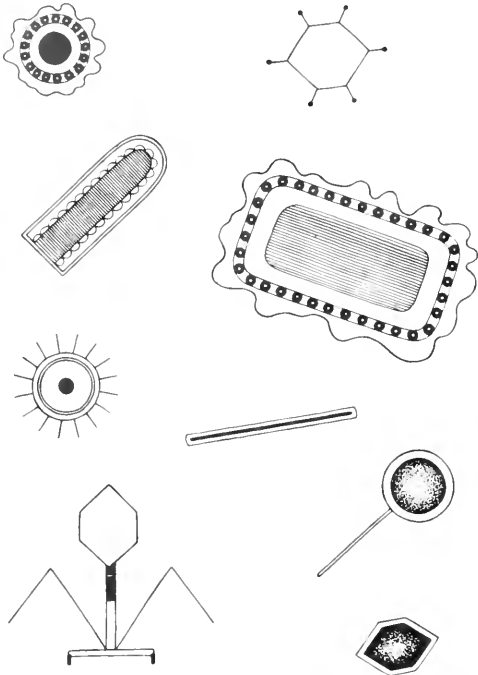
Of the numerous types of pollutants affecting coastal areas, the human pathogenic bacteria and viruses from domestic sewage have elicited the most emotional public response. Within this group, the human viruses are considered to pose the greater threat because of their varied disease potential, their lack of response to antibiotics, and their incompletely understood properties. Viruses, the smallest known pathogenic entities, lie somewhere between living organisms and nonliving organic matter. They have been described as being "one-third alive," because their only true life-function is their ability to cause their own replication, using the

metabolic processes of their specific host cells. Studies have shown that, like many chemical compounds, viruses can be crystallized and maintained intact for years without losing their infectivity. When examined in the electron microscope, viruses are seen to possess regular geometric shapes in sizes ranging from 12 to 500 nanometers (1 nanometer is 1/25,000,000 of an inch). Each virus particle consists of an outer protein coat (which in some cases may be covered by a layer of lipid material derived from the the host cell) surrounding a single or double strand of either DNA or RNA. It is this nucleic acid moiety that initiates the process of "genetic parasitism," resulting in the production of new virus particles and damage to or destruction of the host cell.

Viruses are capable of causing a great variety of severe, sometimes fatal, diseases. A list of potentially waterborne viruses that are commonly found in sewage, and the known diseases associated with them, are listed in Table 1. Of the several varieties occurring in domestic sewage, the group most often encountered are the enteroviruses, which enter the intestines through the mouth. From there they may initiate many kinds of infection.

Electron micrograph of isolated adenovirus type 5. Hollow elongated capsomeres are clearly visible at the surface of the virus. Magnification is approximately 230,000 times. (R. W. Home, J. M. Hobart, and I. Pasquali Ronchetti, J. Ultrastruct. Res., 1975, in press)





Schematic viral structures (not drawn to scale).

The waterborne viruses that are receiving the greatest amount of attention at the present time are those of the hepatitis group. Evidence for the transmission of hepatitis by the water route is well documented, even though the nature of the specific viral particles remains undefined. In 1972 alone, approximately 54,074 cases of infectious hepatitis and 9402 cases of serum hepatitis were reported in the United States. (The largest single waterborne outbreak of infectious hepatitis occurred in 1955 in Delhi, India, where over 30,000 cases were reported.)

One of the most unpredictable aspects of sewageborne viruses is their survival capabilities on leaving sewage treatment plants, especially when they enter marine waters. Although seawater has various antiviral properties, features such as organic matter, particulates, and heavy-metal ions are antagonistic to these properties and ultimately extend the survival of viral

particles. Thus, despite the massive dilution and adverse environmental conditions posed by coastal marine waters, there is growing concern that viruses will be capable of surviving for a period of days to weeks following discharge.

Direct contact with contaminated waters (recreation, repair work, mineral exploration, aquacultural ventures) is not the only way in which humans may be infected by waterborne viruses. The ability of filter-feeding shellfish (oysters, scallops, clams, mussels) to accumulate and concentrate viruses within their tissues offers a means for widespread dissemination of infectious particles. Consumption of raw, contaminated shellfish has often been linked to outbreaks of various enteric diseases; many of the cases of infectious hepatitis in the United States in 1972, cited above, were traced to the eating of raw shellfish taken from sewage-polluted coastal regions.

Despite the hazards posed by viruses, no water quality standards with respect to viruses have been established. However, this situation is not surprising in light of a few facts about routine viral examinations. Although there have been significant advances in virus-detection techniques during the past decade, none of the methods can yet be applied quickly and generally. Furthermore, the cost of setting up and maintaining a facility where even moderate sample loads of viruses can be competently handled remains prohibitive for most public health laboratories. It would, therefore, serve no useful purpose to establish water quality standards in this area when only a few specialized laboratories could do the work. Attempts to assess virus presence by means of standard bacterial sewage indices, such as the fecal coliform and fecal streptococci determinations, have been unsuccessful. Viruses have been shown to be more resistant than bacteria not only to disinfection processes at treatment plants, but also to the natural inactivating components of seawater. Attempts to use a

Table 1

Human Viruses Commonly Found in Sewage, and Diseases Associated with Them

Group	Subgroup	No. of Serotypes	Type of Nucleic Acid	Diseases
Enterovirus	Poliovirus	3	RNA	Mild-severe gastroenteritis Abortive poliomyelitis Aseptic meningitis Paralytic poliomyelitis
	Coxsackie virus	24	RNA	Summer minor illness Herpangina Aseptic meningitis Common cold Hand, foot, and mouth disease Infant diarrhea
				B
	Echovirus	34	RNA	Aseptic meningitis Mild paralysis Febrile illness Conjunctivitis Boston exanthem disease Infant diarrhea Cervicitis, vaginitis Myocarditis, pericarditis
Hepatitis	A		RNA?	Infectious (viral) hepatitis
	B		DNA?	Serum hepatitis
Adenovirus		31	DNA	Acute respiratory disease Pharyngoconjunctival fever Primary atypical pneumonia Epidemic keratoconjunctivitis (shipyard eye) Intussusception Febrile catarrh
Reovirus		6	RNA	?

bacterial virus index for human virus pollution have similarly been abandoned due to lack of adequate correlation between the two virus types in environmental samples. Clearly, research efforts to streamline and economize current virus-detection methods must be accelerated.

Although improvements in virus-monitoring techniques will aid greatly in defining the extent to which viral pollution occurs, they will not provide a solution to the problem. The elimination of raw sewage outfalls or the recycling of waste water would reduce but not eliminate the number of virus particles entering coastal waters. The obvious answer to the problem is the elimination of viruses from sewage effluent before it leaves the treatment plant. Many theories have been advanced toward this end, several of which may be applied to large-volume, flow-through treatment systems. The most promising techniques include removal of viruses by high-gradient magnetic separation, sterilization of sewage effluent

by high-energy electron bombardment, and treatment of effluent with high-frequency sound waves and ozone (O_3). All three methods are currently under investigation. Unfortunately, it will be some time before their effectiveness and economic feasibility can be determined.

With increased awareness of the nature of viruses and their role in the pollution of marine and freshwater systems, the attitudes of both expert and layman toward their potential danger range from complacency to predictions of rampant plague. Neither extreme is correct, but each has an impact on waste-water treatment policy. It is hoped that technological developments directed from the slightly pessimistic side of center will result in virus-free effluents well before the need arises to study epidemics associated with some future pathogen-laden coastal region.

J. M. Vaughn was a postdoctoral scholar in the Department of Biology, Woods Hole Oceanographic Institution. He is now an assistant biologist at Brookhaven National Laboratory.



Untreated sewage effluent is a major source of viral pollution in rivers and coastal waters. (USDI)

Controlled Ecosystem Pollution Experiment

George D. Grice

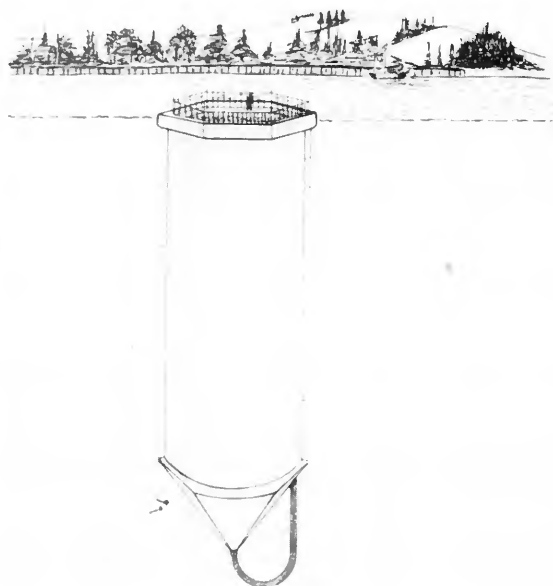
Probably the greatest challenge in marine pollution research is presented by the sub-lethal effects of chronic exposure of the open-ocean ecosystem to low levels of pollutants. Of major concern are changes in the reproduction, behavior, and feeding patterns of marine populations as a result of chemical perturbations, and the long-term effects of these changes on the stability of marine populations.

It is a relatively easy matter to bring coastal organisms into the laboratory and, through short-term exposure to selected pollutants, ascertain the specific concentrations that kill a certain percentage of the experimental organisms. The results of such tests are frequently reported as the "L · D₅₀" for a given set of organisms, that is, the pollutant level that kills one-half of the test organisms under uniform conditions. The results of these and similar laboratory tests, although often used by regulatory agencies, have limited ecological value, because the test organisms represent only one trophic level, the experimental period is too short, and the test receptacles are unrealistically small.

The immensity of the ocean, its apparent lack of boundaries, and the interactions of populations place restraints on the design of pollution

experiments that simulate conditions in nature. If experiments were to be performed in the ocean, it would be necessary to understand the hydrography, to assess plankton production rates, and to determine the seasonal occurrence, distribution, and movement of species into and out of the study area. Moreover, the residual levels and distribution of the introduced pollutant would need to be measured over time periods at least equivalent to the life histories of the larger zooplankton. Finally, the constant movement of water with its entrained biota, the patchy distribution of plankton population, and the lack of understanding for the causes of natural variation in populations make such an open-ocean experiment scientifically and logistically unsound at this time.

Aware of the problems discussed above and concerned about the importance of possible alterations of marine ecosystems by chronic exposure to pollutants, the United States office for the International Decade of Ocean Exploration (IDOE) sponsored a meeting of scientists in fall 1972. The purpose of the meeting was to develop a scientific strategy to experimentally assess the effects of low levels of pollutants on open-ocean populations and to develop the capability of predicting such effects on the ecosystem. This group



Representation of one of the large CEEs scheduled for use this fall in the CEPEX program. The cylinder is transparent plastic. At the top is a six-sided acrylic float; there is a circular walkway and a Y-shaped crosswalk. At the bottom is a tube through which sediments can be pumped to the surface for analysis.

recommended the use of transparent plastic cylinders, termed Controlled Experimental Ecosystems (CEEs), containing seawater and natural populations as the most feasible method of performing large-scale pollution experiments (see drawing). It was further recommended that the experiment be conducted in an area where there are large populations of relatively few species, preferably in close proximity to the ocean.

Subsequently, scientists from Canada, the United Kingdom, and the United States organized the Controlled Ecosystem Pollution Experiment (CEPEX) program and selected Patricia Bay, British Columbia, as the operational site. The IDOE officially accepted the CEPEX project in 1973 as part of its Environmental Quality Program, and research at Patricia Bay

began that summer.

During the first year, studies were conducted in small plastic cylinders, each containing 64 cubic meters of water, that were suspended from acrylic floats moored in Patricia Bay. They had funnel-shaped bottoms and removable sediment traps. These cylinders were to be used until larger ones could be designed, fabricated, tested, and deployed, which would require at least two years. The CEEs were filled simultaneously as divers raised them from a folded position on the bottom to the surface—an operation requiring less than three minutes.

The first of the preliminary studies were devoted to determining how populations in several CEEs compared with one another and with those in adjacent waters of the bay. For the first several weeks, periodic measurements were made of the density, types, and physiological activities of the biota within the CEEs and in surrounding waters. Specifically, the work involved quantitative assessment and species identification of phytoplankton/zooplankton, and measurement of bacterial activity and the rates of phytoplankton production. The results of the replication experiments were highly satisfactory: the populations in the CEEs were found to be comparable to one another and representative of those in the neighboring waters. It was therefore decided that the first pollution experiment could be initiated in the small CEEs in June 1974.

This first experiment consisted of introducing high and low levels of a toxic pollutant, in this case copper, into two CEEs. The other CEEs were designated as controls, and all four were sampled every second day for a month. Throughout the experimental period, the following parameters, among others,

were measured either within the CEEs or on samples of water or biota collected from the CEEs: temperature, salinity, light, nutrients, dissolved oxygen, total carbon dioxide, particulate organic carbon, dissolved organic carbon, chlorophyll concentration, carbon fixation, particle size, nutrient uptake, amino acid uptake, bacterial numbers, phytoplankton species counts, microzooplankton species counts, zooplankton species counts, zooplankton feeding rates, sedimentation rates, and copper concentrations in biota, water, and sediment. Some of these measurements produced real-time data, others required longer periods to obtain results; but all are being considered and analyzed in relation to the interdependency of trophic levels in marine food chains. These analyses are ongoing.

A petroleum experiment is currently under way, in which four CEEs are being used in much the same manner as they were in the copper experiment. In September 1974, the large (10 meters \times 30 meters) CEEs, each containing approximately 2300 cubic meters of water, are scheduled to be deployed. This event will mark the moment of truth for the CEPEX program.

In the long run the results of the CEPEX program may have practical application. The technique could be used to predict the effects of a pollutant on local biota at a potential discharge site prior to the release of the substance to the marine environment.

George D. Grice is a senior scientist in and chairman of the Department of Biology, Woods Hole Oceanographic Institution.

Heavy Metals in Estuarine Systems

There is an increasing mobilization of metals to the environment as the result of man's growing demands. The production of metal-bearing compounds for use in a wide range of industries, including the manufacture of pharmaceuticals and plastics, and the direct fabrication of metal artifacts have been increasing rapidly throughout the world. This has resulted in an increasing flux of metals such as lead, zinc, copper, cadmium, and chromium to the oceans via the atmosphere, streams, and artificial discharges. The atmospheric pathway may enable extensive dispersals of the man-made metallic contaminants; but most of these substances, like most of the effluents from cities and factories, are deposited in coastal waters.

Because of the proximity of the major oceanic repositories for these metals to the area of intensive human exploitation of the sea, such as fishing and recreation, interest in the importance of human perturbation of the coastal system relative to the normal processes operating there has been great. Indeed, only the careful study of both natural and artificially perturbed systems can provide useful answers about the impact of man's impingement on the sea. A major problem has been the fate of materials dumped into coastal waters from sewer outfalls and sewage treatment plants.

As far as metals are concerned, sludge from a sewage treatment plant and top soil from a forest have much in common. Both are rich in the organic products of bacterial degradation that have the capacity to sequester metals. Sewage sludge from Cranston, Rhode Island, for example, has virtually the same, generally high, concentration of zinc, copper,

lead, and uranium as top soil from a forest in New Hampshire.

Erosion of the land results in the burdening of rivers with soil particles. A survey of the suspended matter in United States streams has shown that the heavy-metal content increases with increasing organic carbon concentration. The metal-sequestering property of organic soil particles apparently remains active in the river and diminishes its dissolved heavy-metal concentration.

When released to a stream, organic products from sewage sludge or from industrial processes replicate the behavior of top soil with respect to heavy metals. Thus, the organic particles of a stream, whether derived from natural or from man-made sources, are rich in heavy metals and can effectively extract much of the dissolved metal delivered to a stream. For example, the Rhine River, which flows through the most industrialized real estate in the world, has suspended particles with one of the highest heavy-metal concentrations of any so far examined.

There are indications that some of this metal-rich organic material is somehow destroyed when the river meets the sea, with the consequent release of the metals to the marine system. The remainder becomes part of the sediment deposited on the estuarine floor. Indeed, some people believe that this land-derived organic matter is a major component in the estuarine food chain. By tracing the behavior of a natural radioactive isotope of lead, Pb 210, we conclude that most of the metals found in sediments of an estuary like Long Island Sound have their sources in the particles delivered from the

land and are not primarily due to marine organisms.

Man's activities clearly have increased the flux of metals delivered to coastal waters by streams, sewer outfalls, and atmosphere. It is therefore not surprising to find that the sediments of an urban estuary like Long Island Sound have become progressively more metal-rich over the past one hundred years.

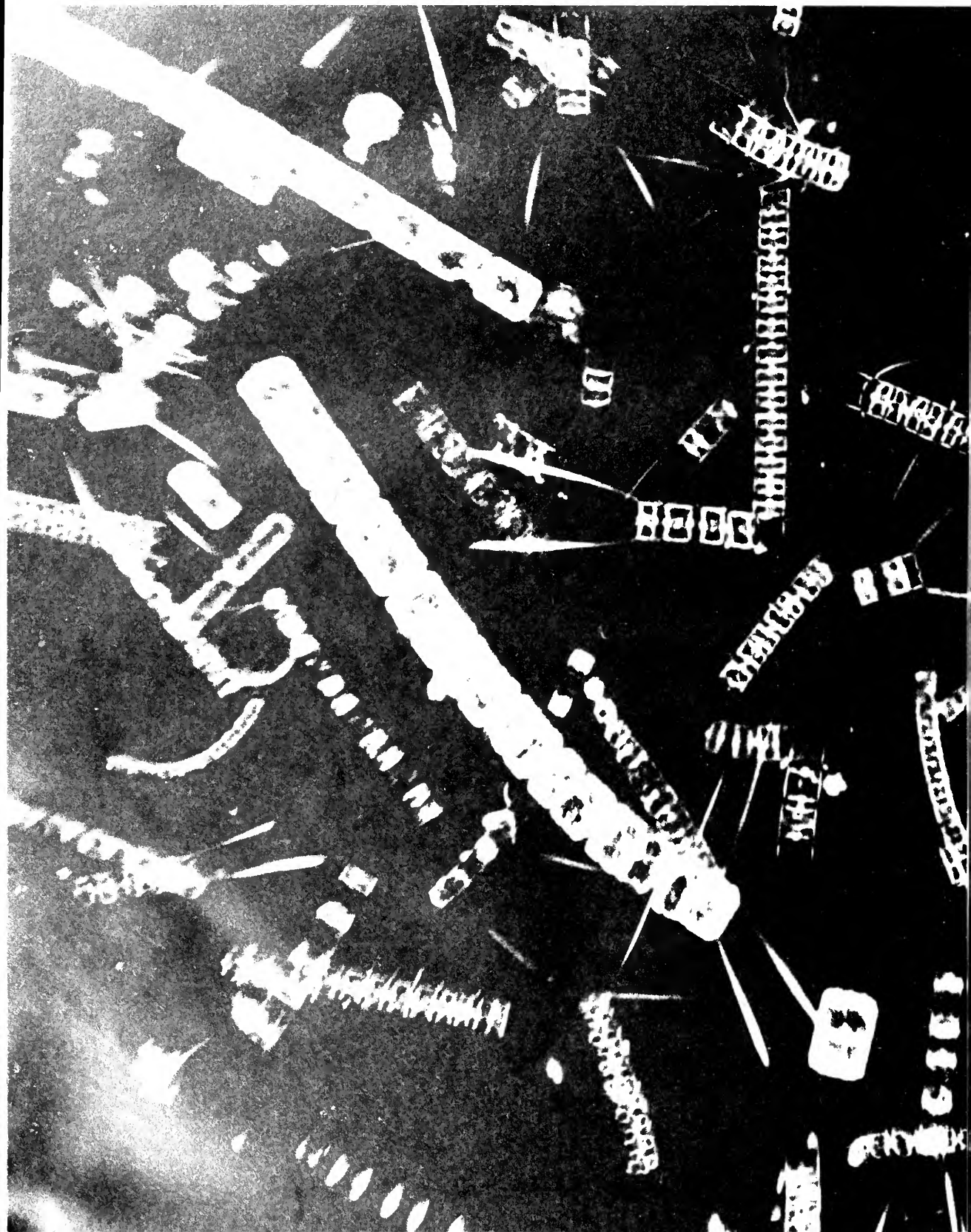
Some of this increase is due to the higher metal concentration of the particles delivered by streams, but some of it is due to the dumping of metal-rich dredge spoils from the harbors of the major cities on the sound. The highest metal concentrations of harbor sediments are found near sewer outfalls and outfalls from sewage treatment plants. In New Haven (Connecticut) harbor, for example, the major sources of mercury are municipal sewage plant outfalls. The other heavy metals such as lead, zinc, and copper have exactly the same distribution pattern as mercury in New Haven harbor, and the concentrations of all these metals are correlated with the concentration of organic matter. This indicates loss of organic solids from these plants to the harbor—probably during times of high storm runoff, since sanitary and storm sewers are not separate. When harbors are dredged, this metal-contaminated material is frequently transported farther out to sea.

What is the fate of the metals reaching the estuarine floor from natural sources and from dredge spoil dumping by barges? Bottom currents move the fine particles around, thus generalizing the areal distribution of the metal-bearing particles within a relatively short time. The large mounds made by dredge spoil dumping persist for long periods of time. The oxygenated waters of most estuaries result in the oxidation of sediments at the water-sediment interface and in active bioturbation to depths from 10 centimeters

to 50 centimeters below the interface. Nevertheless, the sediment at more than about 2 centimeters below the interface becomes anoxic because of the high organic content. Sulfate-reducing bacteria in the anoxic sediment utilize the organic matter as food and produce hydrogen sulfide (the gas with the rotten egg smell).

The presence of sulfide in the estuarine system greatly reduces the solubility, and thus the mobility, of most heavy metals. For example, lead sulfide, silver sulfide, and zinc sulfide have extremely low solubilities. Only manganese and iron sulfides are easily solubilized under these conditions. The only way of increasing the solubilization of the refractory sulfides appears to be to make methylated complexes of the metals, as in the case of methyl mercury. The present indication is that bacteria responsible for methylation are most effective in freshwater sediments and least effective in marine sediments. Metals that do have the opportunity to escape from the sediment pile are sequestered by the precipitation of iron and manganese oxide formation at the sediment-water interface. Thus, once heavy metals are deposited on the estuarine floor, by whatever means, they have virtually no chance of escaping the estuary, except as particles when strong physical transport at the bottom markedly perturbs the system.

What are the implications of these results for the problem of polluted dredge spoil dumping? The best-informed conclusion must be that, as far as metals are concerned, what has been deposited with the dredge spoil has little chance of leaching out of the sediment. The problems of polluted dredge spoil dumping are thus more concerned with mobilized toxic organic compounds and changes in the physical character of the substrate than with the potentially toxic heavy metals.—KARL K. TUREKIAN, *Henry Barnard Davis Professor of Geology and Geophysics, Yale University.*



Power Plant Entrainment of Aquatic Organisms

Edward J. Carpenter

America's total energy demand is now doubling approximately every twenty years, and the electric power generating requirement is doubling even faster, every ten years. In the production of this electricity, a sizeable portion of energy is lost due to in-plant consumption, transmission, and so on, but the greatest loss by far is the heat rejected in condenser cooling. About 1.75 times the energy that reaches a home metering box is lost via heat rejection at the condenser. Cooling is generally accomplished by siting a power plant near a body of water and passing that water through the power plant (Figure 1). The volume of water required for the cooling and the amount of heat rejected can be tremendous. For example, a typical nuclear power plant, such as the two-unit (1480-megawatt) Millstone Point station on northeastern Long Island Sound, entrains about 1.4 million gallons of seawater per minute and heats the water 25°F (13°C) over ambient water temperature. Addition of a third unit will provide 1150 megawatts of generating capacity and will entrain another 1.3 million gallons of seawater per minute.

Living diatoms (single-celled plants) from marine phytoplankton, including several species of chain-forming diatoms of the genera Chaetoceros (with spines), Thalassiosira, and Lauderia. Magnification is approximately 140 times. (Photo © Douglas P. Wilson)



Millstone Point nuclear power station, units 1 and 2. At lower right are two intake structures; at right center is effluent pond; at upper right center is discharge from effluent pond. (Courtesy of Millstone Point nuclear power station, Northeast Utilities)

Planktonic organisms such as phytoplankton, zooplankton, fish eggs and larvae, the larvae of benthic organisms, and others are all passed through the condenser cooling system. Because of the huge volume of water needed for condenser cooling, the rapid increase in its usage, and the fact that plankton may be harmed by passage through the cooling system, there is at present considerable environmental concern over power plants. There is also some concern about the ecological consequences of, among other things, the increase in temperature of natural waters. However, I will discuss only the effects of passing plankton through cooling systems.

When a typical organism undergoes power plant entrainment, it first experiences a current at an intake structure (Figure 2). The speed of the current is usually about 1 foot per second, or less; and most mature fish can easily escape. Next, it encounters vertical bar racks with about 2-inch-wide openings, which are designed to remove large debris. Some relatively broad organisms, such as flounder or blue crabs, can become immobilized against these racks due to the pressure of water current. Behind the bar racks are traveling

screens of about 3/8-inch mesh, designed to remove smaller debris, large fish, crabs, and other animals. At some power plants the animals captured on these screens (impinged) are returned alive to the water at a site several hundred yards away, while at others they are deposited ashore.

After passing the traveling screens, the organism is pumped through circulating pumps where some mechanical damage from turbulence and abrasion may result. Next, chlorine is applied to the entrained seawater to prevent the growth of foulers on the conduit walls. Unfortunately, chlorine is toxic to plankton as well as fouling organisms, and this is an added hazard to entrained plants and animals. An alternative to chlorination is the removal of fouling organisms by small spheres passed through the cooling system. The spheres remove foulers by abrasion and do not harm the plankton.

The entrained water next passes from the concrete conduits to condenser tubes of about 3/4-inch inside diameter and about 50 feet in length. A typical condenser has tens of thousands of these metal tubes. In passage through the tubes, the organisms travel at about 7 feet per second and receive an almost immediate temperature increase of 25° F above ambient temperature. After moving through the condenser, the water enters larger concrete pipes, then a canal or cooling pond. Passage through the power plant takes a matter of minutes. However, at many plants the water remains in the canal or pond for as long as several hours, where exposure to raised temperatures is prolonged. Finally, the water is released to the body of water from which it originated.

Some organisms may be affected primarily by chlorination, others by mechanical and pressure damage, others by temperature increase. These stresses may also act synergistically and provide sufficient stress to destroy an entrained plankton. At Millstone Point it is apparent that mechanical damage alone is responsible for the loss of an

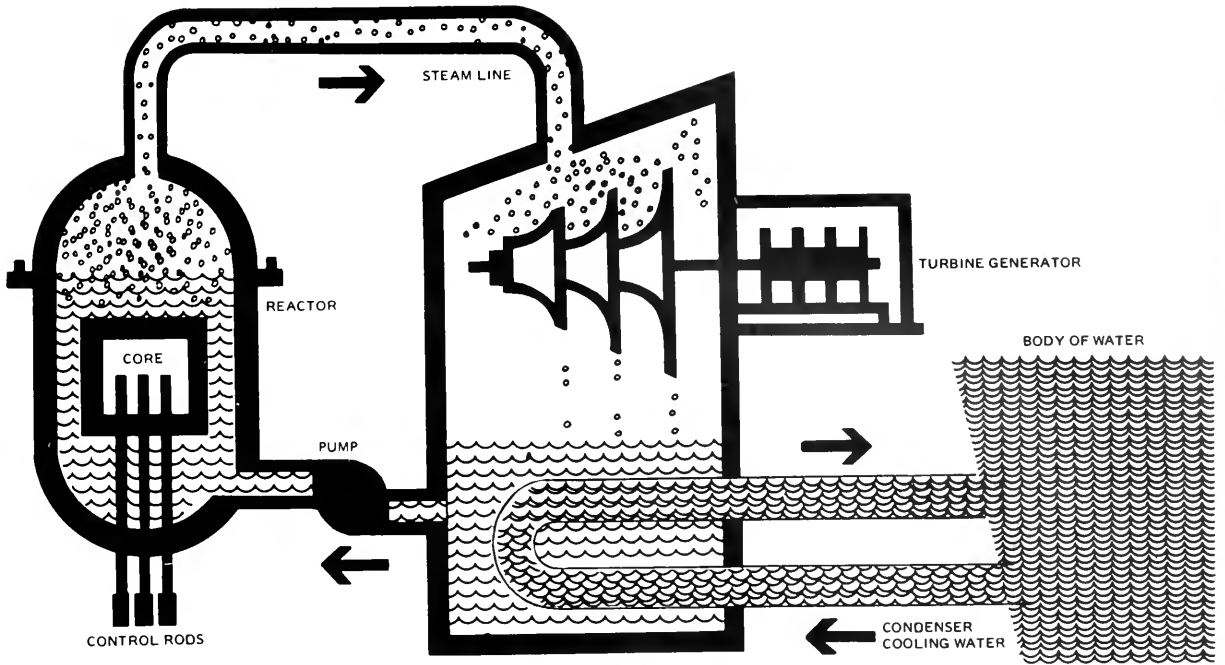


FIGURE 1. Nuclear-fired, boiling water reactor system for electric power generation. (John Clark, American Littoral Society)

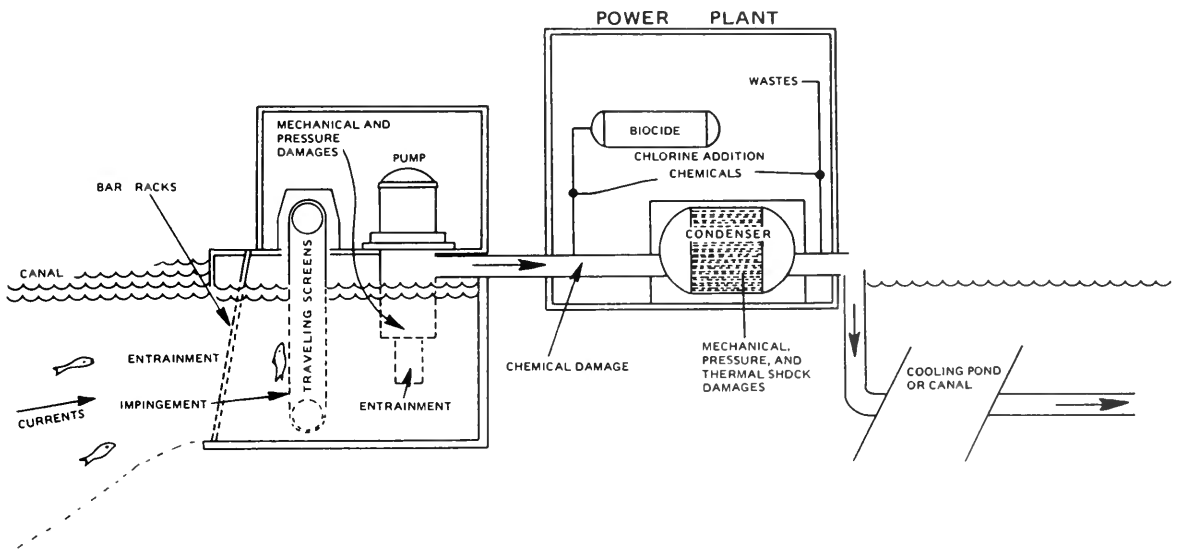


FIGURE 2. Schematic representation of a condenser cooling system and sources of potential biological damage. (John Clark, American Littoral Society)



Living zooplankton. Most of the organisms are copepods: the large one near the center is Calanus; the smaller ones are Pseudocalanus (two females are carrying egg clusters). To the right of the fish egg is a young arrow-worm, Sagitta; near bottom center is a tunicate, Oikopleura. There are two different anthomedusan jellyfish, and a few chain diatoms also are visible. Magnification is approximately 25 times. (Photo © Douglas P. Wilson)

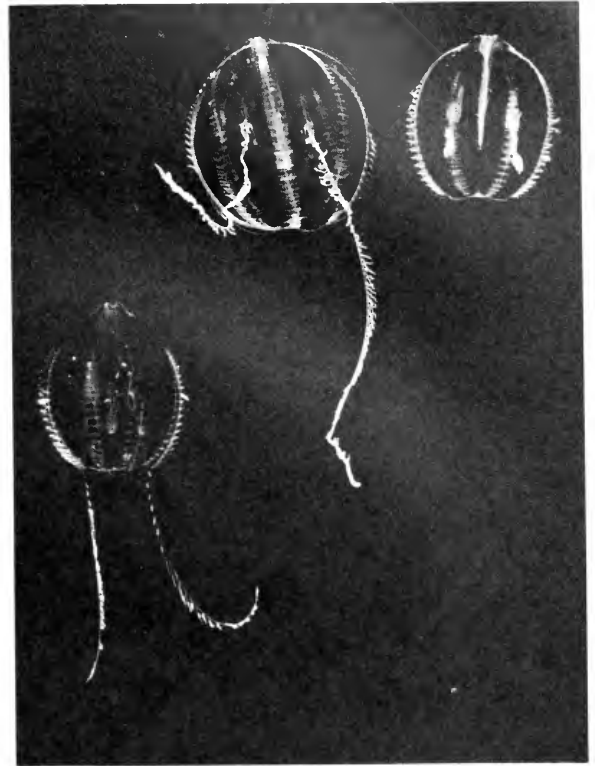
average of 70 percent of all copepods entrained. In contrast, the phytoplankton at this power station are affected primarily by chlorination and temperature increase. Generally, in winter, phytoplankton photosynthesis is stimulated by the entrainment temperature increase. However, when ambient water temperature reaches 60°F (15°C), photosynthesis is inhibited somewhat by the temperature increase. By August, when ambient intake water temperature is highest, photosynthesis is

almost completely inhibited. When chlorine is applied to entrained water at any time during the year, photosynthesis decreases by 60 to 80 percent.

For several reasons the actual net effects of a power plant on a body of water are exceedingly complex and difficult to measure. First, each power plant site is unique and has its own particular characteristics of water currents, tide, bottom type, benthic organisms, nutrient concentrations, and so on. Second, an entrained species may be affected

differently in one area or time as opposed to another, depending upon its life stage, previous thermal history, and physiological state. For example, at Millstone Point, winter flounder larvae that are less than 5 millimeters long are unable to survive a 25°F temperature increase of a 1-to-9-hour duration. In contrast, the older post-metamorphosis larvae, which are between 5 and 7 millimeters, can withstand that temperature increase for up to 9 hours with no mortality. Third, the primary producers (phytoplankton), herbivores, and predators may be selectively affected from one week to the next, thus causing almost unpredictable disruptions in the adjacent ecosystem. As an example, one power plant in Massachusetts destroys a small percentage of the copepods that are passed through it. Normally this would result in a slight reduction in the copepod concentration in the estuary where the heated water is released. However, the power plant also destroys virtually all of the ctenophores (comb jellies) that it entrains when they are abundant in late summer. The ctenophore is a voracious predator on copepods, and with few ctenophores in the bay receiving the power plant effluent, the resultant copepod population is actually greater than it would be without the power plant present. In this respect, this power station probably aids in the production of young fish since there are more copepods for them to feed on. Thus, to predict the effect of a power plant on an aquatic ecosystem it is imperative that we know what organisms are removed by entrainment and how the ecosystem functions. Unfortunately, much more data must be collected for both of these concerns.

Increasingly, as freshwater sites are utilized, power plants are being located on estuaries. For example, there are 26 proposed or existing power plants on the Chesapeake Bay drainage system in Maryland. Together these plants will entrain about 8.5 billion gallons of water per day. In contrast, the total freshwater flow rate into the Chesapeake averages 49.1 billion gallons per day (30-year average). Until



Ctenophores (top) typically compete with young fish for the smaller crustaceans in marine zooplankton (bottom). If ctenophores in the area of a power plant are destroyed by entrainment, there may be an increase in the population of copepods, for example, and a resultant increase in the production of young fish. Magnifications are approximately (top) 2 times and (bottom) 23 times. (Photos © Douglas P. Wilson)

recently most power plants on this estuary were relatively small (about 100 to 500 megawatts) and near cities. In the past few years the trend has been toward larger plants (500 to 1000-plus megawatts), and these are located farther downstream on the estuary. Such an example is the Calvert Cliffs plant. This 1690-megawatt nuclear facility alone entrains 2.5 million gallons of water per minute (3.5 billion gallons per day).

It is estimated that by 1980 about one-third of all power plants in the country will be located on estuaries. Unfortunately, estuaries are nursery grounds for many coastal and oceanic species and are among the most productive ecosystems in the world. Figure 3 illustrates how a power plant could affect shrimp, crabs, and one common sport fish, the striped bass, and indicates the complexity of an estuarine ecosystem. The organisms susceptible to entrainment may all be entrained, and any damage done to them may affect the growth of young-of-the-year and adult bass. On some estuaries the probability that a plankton will be entrained through a power plant is relatively high. For example, on the lower Potomac River the probability of a given particle of water's being entrained after it moves downstream past three power stations is about 25 to 30 percent. This assumes neutral buoyancy and a homogenous distribution of the organism. In nature, however, plankton and larvae are not typically homogeneously distributed, and the percentage entrained for any given species could be more or less than the 25-percent estimate. For example, in 1969 and 1970, plankton tows for striped bass larvae were made at the Morgantown plant on the Potomac, and in neither year were any bass larvae observed to be entrained, even though the adult bass were known to have spawned upriver and the larvae were drifting down-estuary with the water current. Obviously their distribution was such that they had avoided the plant intake. However,

if the intake had not been properly sited, a disproportionately high percentage of larvae could have been entrained.

The Hudson River is another area where there is great environmental concern over power plants. This estuary is thought to be the spawning and nursery ground for 20 to 80 percent of the striped bass found from New Jersey northward, and it is the only estuary north of the Chesapeake where the stripers spawn. An Atomic Energy Commission (AEC) staff analysis of the proposed Indian Point power plant on the Hudson showed that "during June and July of most years from 30 to 50 percent of the striped bass larvae which migrate past Indian Point from upstream spawning areas are likely to be killed by entrainment. . . . In addition, large numbers of older striped bass will be killed by impingement (on intake screens). The combined effect of these two sources of mortality will decrease recruitment to the adult population of striped bass which depend on the Hudson River for spawning. As a result there is a high probability that there will be an initial 30 to 50 percent reduction in the striped bass fishery which depends upon the Hudson for recruitment" (AEC Final Environmental Statement, Indian Point No. 2, United States Atomic Energy Commission). Later, the staff refined the estimates using simulated rates of flow for various years and including the effects of other plants on the Hudson estuary and found that as much as 64 percent (average = 55 percent) of a year's production of young bass will be killed.

An additional threat to the striped bass on the Hudson is the Cornwall or "Storm King" project, which involves a pump-storage electrical generating facility. This will utilize river water at an extremely high rate—about 8 million gallons per minute. The Environmental Science Division of the AEC has issued a preliminary report that estimates that the cumulative effect of the Cornwall plant's withdrawal alone will destroy 25 to

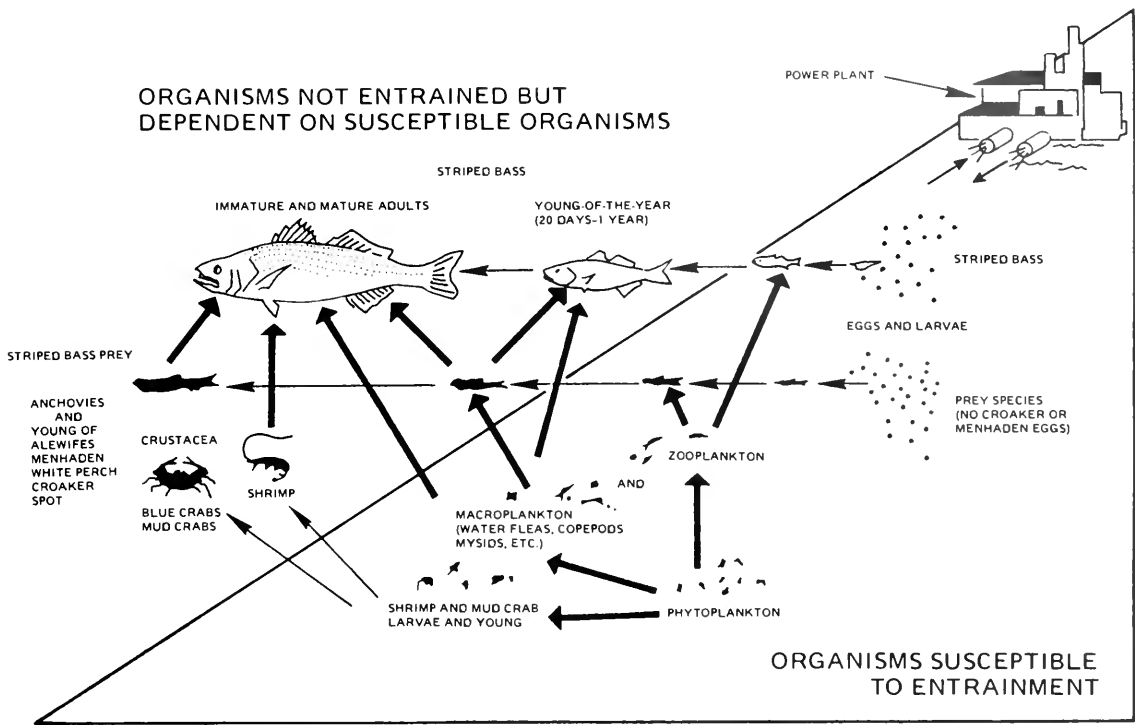


FIGURE 3. The complexity of an estuarine ecosystem is such that damage done to organisms susceptible to entrainment may affect young-of-the-year and adult striped bass. (John Clark, American Littoral Society)

75 percent of the striped bass hatch.

It should be pointed out that many, if not most, power plants do relatively little damage to coastal ecosystems. If a plant is not sited on nursery or spawning areas and if there is an adequate dilution capacity for the entrained water, there can be negligible harm to the adjacent ecosystem. Also, as the technology for building cooling towers improves, some stations may have closed-cycle cooling and need not entrain seawater.

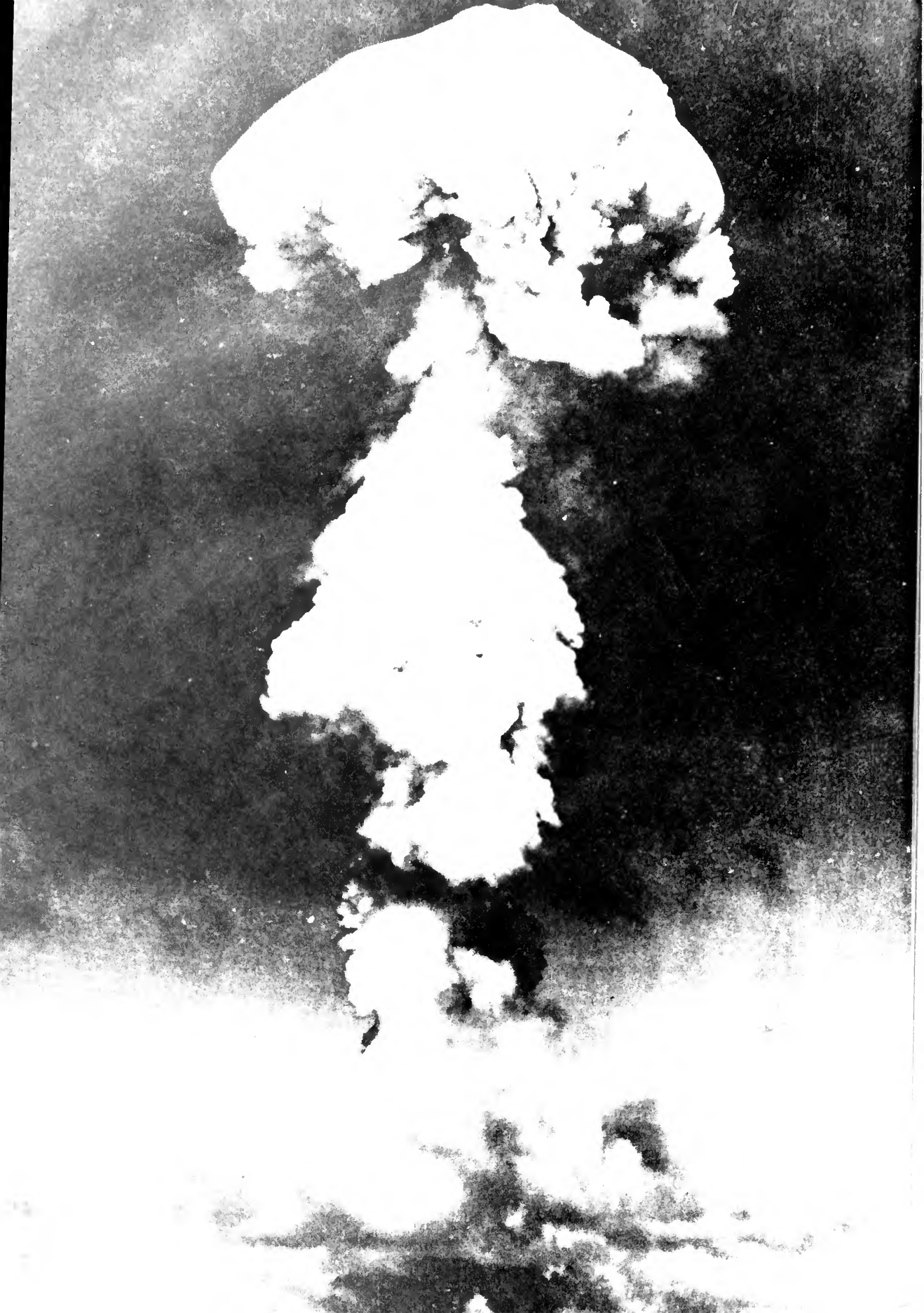
Plans now call for some nuclear plants to be sited offshore, on small man-made islands. It is quite probable that these will have a lesser effect on the aquatic biota since they will be located in areas of greater dilution capacity and away from nursery areas. However, much more marine research must be carried out to insure that these plants will be safe. This involves studies of the water currents, geology, weather patterns, and biology of various sites.

The heated effluent from power stations

can be used to advantage, especially for marine aquaculture work. A 25°F temperature increase will more than double the metabolic rate of an aquatic organism, and fish and shellfish could reach marketable size more rapidly in the heated effluent. The tremendous volume of heated water passed by a power plant could allow large crops of commercially valuable species to be grown.

The number of power plants and the volume of water they entrain are increasing rapidly. Properly sited, away from major spawning and nursery areas, and with a suitable condenser design, these plants can have minimal impact on local ecosystems. Furthermore, there is the potential advantage of using the heat rejected by power plant condensers for projects such as marine aquaculture.

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Transuranic Elements and Nuclear Wastes

Vaughan T. Bowen

Waste, in the form of unusable heat, chemical by-products, unburned residues, or nonexploitable by-products of mining fields, is an unavoidable problem in most sorts of power production. Even such "clean" power industries as hydroelectric or geothermal plants produce waste in the form of land inundated to make reservoirs or preempted by long-distance transmission lines. The wastes from nuclear power have often been attacked as so noxious as to indicate abandonment of this source of civilian power; it is certainly true that the management of these wastes puts a great financial burden on the production of nuclear power. Recently, the thinking about wastes from nuclear power has turned, at least partly, from an initial emphasis on "biological" radionuclides, such as strontium 90 or cesium 137, to a concern about the transuranic nuclides.

Semantically, the term transuranics refers to all elements heavier than uranium—or of atomic number greater than 92. Although minute traces of two isotopes of plutonium, the best known transuranic, have been found in nature, for practical purposes we may regard all the transuranics as wholly man-made—and in amounts that will reach the thousands of tons by the year 2000. The transuranic elements are inescapable products of the production of power by the fission of uranium nuclei; this is because they result from the interaction of neutrons (present as inducers of fission and also as products of fission) with either the fissionable or the

nonfissionable isotopes of uranium. In other words, they result from side reactions of the reactor fuel itself.

From a typical light-water cooled reactor (LWR), long-lived isotopes of four transuranic elements are produced in quantity, as shown in Table 1. Major differences occur in proportions of the various transuranics and in the total amount produced per unit of electrical power; these relate to the fuel composition, but most especially to the amount of "burn-up"—that is, the fraction of fissionable fuel that is allowed to undergo fission before being cleared of reaction products. In general, both the amount of transuranics produced and the proportion among them of the longer-lived and heavier species may be expected to increase in the future, since greater burn-up is, in general, one path to greater economy of operation. Breeder reactors may be expected to produce up to ten times as much Pu 239, in proportion to units of electricity, as LWR reactors, with only Np 239 increasing in greater proportion than Pu 239.

It is, of course, possible to run a fission reactor specifically for transuranic production, and indeed this was done for many years at the United States Atomic Energy Commission's Hanford Works, near Richland, Washington, to produce plutonium for military purposes. By-product plutonium, from electric power production, is, however, now being produced in most "nuclear" countries—the United States, Great Britain, France, and (one believes) the Soviet Union—in amounts that exceed military demands, and at lower cost. Consequently, the Hanford reactors have been closed down. One result of the increased use of by-product plutonium,

Five-mile-high mushroom cloud from "Able" nuclear test explosion at Bikini Atoll, June 30, 1946. Information on transuranic distributions from world-wide fallout is the only data generally relevant to environmental, long-term situations. (Argonne National Laboratory)

Table 1

Actinides Expected in Wastes from Spent LWR Fuel*				
Nuclide	Half-Life (years)	Grams per 10 years	Metric Ton of Fuel, after 100 years	Metric Ton of Fuel, after 1000 years
Np 237	2.1×10^6	760	770†	810
Pu 238	89	6	3	0.007
Pu 239	2.4×10^4	27	28†	34†
Pu 240	6.8×10^3	20	40†	37
Pu 241	13	3	0.025	0††
Pu 242	3.8×10^5	1.8	1.8	1.8
Am 241	458	54	50	13
Am 243	7.6×10^3	90	90	83
Cm 244	18.1	21	0.7	0††
Total grams/metric ton fuel (activity, including daughter products)		983 ($\sim 10,000$ curies)	983 (~ 2200 curies)	979 (~ 600 curies)

Source: *The Safety of Nuclear Power Reactors (Light-Water Cooled) and Related Facilities*, Wash 1250 (draft), USAEC, December 1972.

* Assumes fuel burn-up of about 33,000 megawatts per day/metric ton. Only actinides present in significant quantities listed.

† Increases because nuclide is daughter product of other radionuclide present; for example, Am 241 \rightarrow Np 237 + alpha.

†† 0 indicates less than 10^{-16} gram.

as emphasized above, is that the proportion of other transuranic nuclides to plutonium increases as one attempts to optimize electrical costs, and further increases as one goes to breeder technology in an effort to achieve greater fuel economy.

Nature and Amounts of Wastes Produced

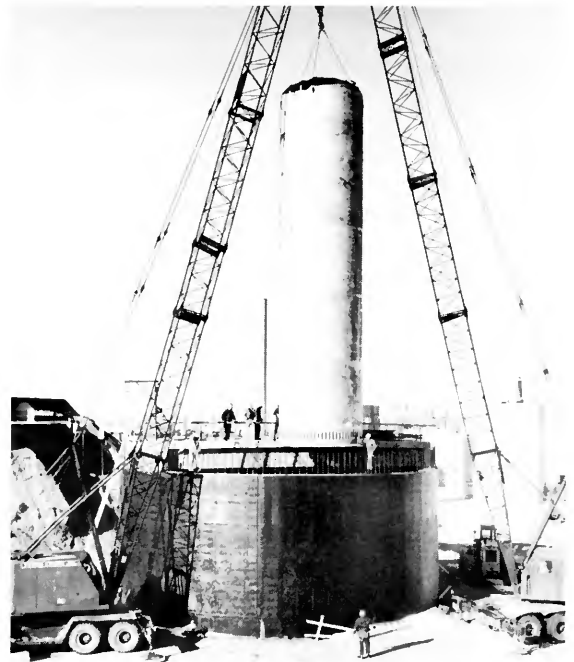
The mining of nuclear fuels and their industrial technology produce wastes much like those from other mining and manufacturing operations; cleanliness may be claimed here to result—on a relative basis—from the fact that much smaller volumes of fuel are required, with proportionate saving all along the line. If, of course, one equates breeder reactor technology with the mining of nuclear or other fuels, then the situation appears less favorable since by-product radionuclide

wastes are produced both in the “mining” and in the power production steps.

The radioactive wastes can be subdivided into three classes, whose treatments are rather different:

1. Low-level wastes, from cooling waters, plant operations, and some parts of the fuel reprocessing cycle. These are usually diluted to below hazardous limits and disposed to the environment.

2. Intermediate-level wastes, from laboratory operations and fuel reprocessing. In the United States, these are converted to a large volume of low-level wastes, to be disposed of as above, and a small volume of high-level wastes; in other nuclear countries like the United Kingdom and France, these are—with supervision, to be discussed



The first of seven 53-foot-high stainless steel tanks used to store solid nuclear wastes is being lowered into a reinforced-concrete underground vault at the AEC's Waste Calcining Facility in Idaho. Liquid high-level wastes are converted into solid granules, which take up only 10 percent of the space required by liquid. Storage is designed to prevent release of radioactivity for about 500 years. (USAEC)



Nuclear power reactors in the United States: ■, licensed by AEC to operate; ★, being built; ●, planned—reactors ordered. (USAEC, 6/30/74)

below—disposed to the environment, generally by coastal marine outfalls.

3. High-level wastes, almost entirely from fuel reprocessing. Because of the large amounts of radioactivity and the associated chemical and physical problems, these present the real “waste disposal problem.” At present the only way that all nuclear countries deal with these wastes is to store them—a solution that is rapidly coming to seem intolerable.

Projecting into the future the amounts of high-level wastes to be expected is a difficult exercise that requires juggling three imponderables: projections of electrical power demand; projections of the proportion to be found from nuclear fission; and projections of the speed at which new nuclear technologies may be adopted, and what these new technologies may be. We can confidently adopt the working hypothesis that any projection is sure to be wrong and likely to be misleading. A reasonably conservative one, useful as any for discussion, is presented

in Table 2. In conventional waste disposal terms, the annual *volume*, reduced to solid, even by the year 2000 would be trivial: a cube about the size of a small house. This can be thought of as comparable to the sanitary landfill volume required by a United States town in the 10,000 population range. In terms of radioactivity, however, the problem is severe; this is usually illustrated either by the total radioactivity produced or by the possible effects of specific components of known high hazard to man.

The first illustration may be put in these terms: if the waste were subdivided into 2-cubic-foot parcels, after 10 years' storage, a man spending 5 minutes within 10 feet of such a parcel would receive a lethal radiation dose; and even after 100 years' storage, a man could not survive an hour within 10 feet of the parcel—and the United States alone could be producing tens of thousands of such parcels each year. The second illustration—in terms of strontium 90 or cesium 137, the

Table 2

Estimated Future Levels of High-Level Reactor Wastes			
	1970	1980	2000
Installed capacity, 10 ³ MWe	6	150	1100
Fuel processed, 10 ³ tons/year	0.055	3	21
Increment of HLW, 10 ⁶ gal/year	0.017	1	6.9
(as liquid) 10 ³ ft ³ /year	2.3	135	920
(as solid) 10 ³ ft ³ /year	0.17	9.7	69
Accumulated HLW			
(as liquid) 10 ⁶ gal	0.4	4.4	90
10 ³ ft ³	53	590	12,000
(as solid) 10 ³ ft ³	4	44	900
Accumulated fission products			
Weight, tons	2	550	16,000
Beta activity, megacuries	200	19,000	312,000
Power output, megawatts	0.7	55	850
Sr 90, megacuries	4	960	14,000
Cs 137, megacuries	5	1280	23,400

Source: *A Workshop on the Ocean Basin Floors and Radioactive Materials*, SLA-73-0596, Sandia Laboratories, September 1973, page 23.

two radioactive waste products that, until recently, have been the focus of most attention—is that the accumulations expected by the year 2000 could be reduced by sharing them among mankind. To yield an “acceptable” radiation dose per person, the Sr 90 would have to be divided among 7 million billion people, and the Cs 137 among 1 million billion people. Evidently the suggestion of personal responsibility for nuclear waste is untenable: none of us could tolerate receiving with the monthly electric bill his fraction of the wastes incurred in producing the electricity. It will clearly be worth some effort to ensure that these wastes never become biologically available to man or to other populations of organisms.

Recently many concerned scientists have turned their attention to the fact that the transuranic elements represent a fraction of all of the wastes produced from nuclear power production. It has even been stated by the Fisheries Radiobiology Laboratory at Lowestoft, the responsible British agency, that each of their power reactors leaks detectable, although believed insignificant, amounts of transuranics. We are concerned,

basically, by three aspects of the problem posed by these wastes: in general, the nuclides are known to be very toxic to living things; many decay only very slowly and so require attention for tens or even hundreds of thousands of years; and we have very little basis for prediction of their behavior in the environment. It is generally believed that the nuclides of the transuranic elements are toxic only because of their radioactivity. This belief is readily reconciled with a recent Russian report of high chemical toxicity of neptunium 237, a very long-lived isotope, by arguing that the higher rates of emission of alpha radiation, by the shorter-lived isotopes, lead to radiotoxic effects before their chemotoxic effects can be observed. Many critical experiments with less-common beta-emitting transuranic nuclides remain to be done.

It has, however, been repeatedly shown that alpha-particle radiation is especially effective in producing long-term biological effects. Because most of the commonly produced transuranic nuclides are alpha emitters, and because most of the nuclides studied tend to be retained for long periods after absorption by mammals, these materials are frequently described as among the most toxic agents known. Since “occupational permissible” body burdens of the transuranics range in the tenths of micrograms (or thousandths of millionths of an ounce), this is not strictly true; more agents are known. We believe, however, that none of these more toxic agents are retained so long by the body, and none accumulate slowly over long periods. These considerations, coupled with the certainty that large quantities of transuranics, especially of plutonium, will continue to be produced, processed, and used by man in the next few decades, force the conclusion that these nuclides are among the most hazardous of man’s environmental problems.

The primary radiotoxic effect of the transuranics in mammals, including man, is

the induction of cancer. Plutonium, in fact, is surprisingly effective in producing cancers, of kinds that depend on details of the path of plutonium uptake. Some of the other transuranics equal plutonium in this respect, but it is very rare for any to exceed it. Compared on the basis of their rates of disintegration per unit of tissue, most are a good deal less effective. This is remarkable because many of the transuranics heavier than plutonium (transplutonics) are more effective in irradiating the body's soft tissues. In such cases as that of americium 241, for instance, organisms seem to be killed by other effects on the soft tissues (liver or kidney failure especially) before cancer induction can be observed. In all of these considerations there is possible synergism between chemotoxic and radiotoxic effects, but no relevant data are available. It is also, of course, quite impossible to tell how "lower organisms"—of all kinds—may respond to transuranic concentrations at either likely environmental, or accidental release, levels.

In discussing hazards from plutonium or other transuranics, it is usual to draw encouragement from the statements that these elements are of uniformly low solubility, and poorly absorbed across biological membranes. Hundredths to ten-thousandths of a percent are absorbed from plutonium doses usually administered, depending on details of the dose composition and of the physiology of the organism. The transplutonics have proved to be somewhat more active than plutonium, and to be absorbed more effectively—even some hundreds of times more. But even here gut absorption rarely reaches one percent of dose.

Such data have obvious relevance to the hazard from accidental releases of transuranics and have, in fact, been used to argue that uptake of particulate material by the lung is the major—or even the only—pathway that need be considered. Unfortunately, however, the relevance of

these studies to environmental contamination is marginal at best. My own belief is that only the data available describing the distributions of the transuranics from world-wide fallout (resulting from atmospheric nuclear explosions) can be taken as generally relevant to environmental, long-term situations. In fact, I believe that the fallout situation represents, in a geochemical sense, the end-member of the series that includes all the other sorts of environmental introduction of transuranics, and that they will each approach, whether slowly or rapidly. This conclusion is based on the certainty of the steady elimination, with time, of those complicating factors that characterize and make unique each of the other paths of environmental introduction: the large proportion of chemically resistant oxides that characterize close-in fallout (that portion which falls to the ground in the immediate vicinity of the explosion), the results of "safety-test shots," or accidents like that at Thule, Greenland, gradually will equilibrate with the relevant chemicals and minerals of the environments in which they lie; the accompanying organic complexers and inorganic anions, whose presence appears to affect, characteristically, each of the existing liquid-waste outfalls, gradually disappear by degradation or dilution. In each case the final situation must be the one that seems to characterize world-wide fallout from the beginning: direct interaction, on an atom by atom basis, with the materials of the environment.

Marine Biogeochemistry of Fallout Plutonium

Viewed from this position, the fallout plutonium data do not offer a secure basis for optimism about the ability of marine environments to tolerate transuranics, nor even about their ability to retain transuranics with minimal transfer back to man. Perhaps the most worrying aspect of the body of data we now possess is its complexity. Although some tendencies are discernible, there is not the sort of clear pattern that should result from a general absorption inefficiency for plutonium,

such as was inferred from feeding and injection experiments on mammals in laboratories. Faced with so complex a body of information, the marine biogeochemist is reluctant to make any predictions until he obtains enough additional data so that regularities begin to appear.

A usual way to treat values for uptake of chemicals, or radionuclides, from the environment, and especially from aquatic environments, is by calculating "concentration factors." These are most useful when they express the ratio of the concentration of the element in the fresh tissue of the organism, to the concentration in the solution from which the element was drawn. In the oceans, then, we divide concentration in fresh organism (or tissue) by concentration in seawater. Such concentration factors range from less than one, in the case of sodium, magnesium, or other elements present in seawater in excess of biological needs, to tens or even hundreds of thousands, in the cases either of elements that organisms use in large amounts—like phosphorus, zinc, iron, or iodine—or of elements that organisms are unable to avoid becoming involved with—like zirconium, niobium, lead, or chromium.

On a scale like this, fallout plutonium occupies a middle position. The highest concentration factors we have so far seen have been in the floating alga *Sargassum*, in which the mean factor is about 20,000 and the highest as much as 100,000; attached marine plants exhibit lower concentration factors, but still in the hundreds to thousands range. Among marine animals, whether invertebrates or fish, high concentration factors are consistently seen in creatures that feed on or in the bottom sediments, and in plankton—creatures that float neutrally in the water, and that represent a large fraction of the food base of the whole system—factors are about as high. In general, the filter-feeding bivalves, like oysters, clams, or mussels, show concentration factors about one-fourth or one-fifth those in plankton. From this we tend to

argue that the plutonium in plankton or plankton detritus is not efficiently assimilated by these bivalves; the data so far available seem, however, to indicate that the absorption efficiencies are much closer to several percent than to the tenth-to-hundredths of one percent quoted above for mammals. A small amount of data, perhaps the most worrisome of all, pertain to the concentration factors in organisms that eat filter-feeding bivalves. Starfish rather consistently show four times the concentration factor of the mussels on which they feed, and moon snails half-again to three times the factors of their prey.

These data may indicate that once absorbed and metabolized by a grazing or filter-feeding organism, the transuranics are absorbed with significantly greater efficiency than they are directly from water, sediment, or even plant tissues. In view of the increasingly wide use of fish meal or other marine protein sources as supplements for feeding chickens or cattle, it seems strange that we have been unable to find a record of any experimental study of plutonium uptake from metabolically contaminated foods. Our analyses of fish, it should quickly be stated, offer no support for alarm: concentration factors in fish muscle have been mostly less than 5, and only once have exceeded 10. The use of these data for *prediction*, however, is contraindicated by the extent of differences between species: flounder and tautog, for instance, both feed on or near the bottom, have considerable plutonium in their intestines, and have a concentration factor about 60 in the liver—rather high for bony fish; but tautog has 10 times as much plutonium in its bones. Such differences occur often enough to make one reluctant to say that in no fish, in no circumstance, will plutonium be stored in muscle.

Another kind of uncertainty, also, besets data such as these. We do not *know* in any of these cases what fraction of the plutonium concentrated really derives from the organism's food and what fraction is taken directly from

the water; we do know from other work that even so similar creatures as lobsters and crabs differ, in that one takes essentially all of its manganese from food, and the other virtually all from the water. It will be a long, difficult job to obtain this sort of information about all the marine creatures that enter the human food chain, but it must eventually be done to give the basis needed for prediction. Also relevant to these arguments is the possibility of age effects. We know that plutonium absorption is more efficient in some juvenile mammals than in adults, and we know that this is similarly true for other elements in some marine invertebrates. We also know that some organisms show, as they age, a steadily increasing concentration factor for some elements—zinc in tuna is a classic case—simply because little, if any, of the element accumulated is ever lost. Should either of these effects be usual in plutonium metabolism, we would have to be very careful to compare only creatures of the same physiological age.

The analysis of plutonium at fallout-derived levels is unfortunately a very slow and expensive job—that of americium or curium much more so—which means the answers to these questions will be long in coming. Again, the transplutonics appear generally to be more mobile, more easily absorbed, and more effectively transferred along food chains than is plutonium. Even different nuclides of plutonium have been shown to move differently in one land area of interest, the ratio of Pu 238 was found to change from 20 in the soil, to 10 in the plants, to 1 in the rodents eating the plants. Observations such as this do not encourage one to extrapolate data concerning one nuclide to predict the behavior of another.

Marine Geochemistry of Fallout Transuranics

We must consider, as well, how the transuranics move through the oceans, and how these movements may affect their availability to organisms on the long term. The fallout radionuclides seem now to be clearly divisible into two groups: one that moves principally

as dissolved material with the water, and one that associates largely with particles and sinks with them. In shallow water the latter group quickly comes to be found mostly in the sediment; and in the deep ocean, vertical distributions of this group are characterized by ratios to the soluble group, that increase with depth, showing one or more subsurface maxima.

By any of these criteria—and, indeed, as one would have predicted from its laboratory chemistry—plutonium has been shown to be associated with particles, as has americium. Details of the distributions of plutonium in water and sediments, as well as evidence that americium separates partly from plutonium during settling, have led me to suggest that plutonium settles largely by association with biological detritus, and americium with inorganic detritus; this remains a hypothesis, however. It is interesting, and relevant, that americium seems to leave the water column faster than does plutonium—just opposite from the prediction that would be made from the observation that “transplutonics are more soluble than plutonium.” Both transuranics are removed, by settling toward the bottom, rather rapidly from the illuminated layer of the ocean where most life processes take place; they are even more rapidly removed from the water to the sediments in shallow coastal areas, where biological activity is even more intense. In the North Atlantic, for instance, at a given rate of plutonium delivery in fallout, concentrations in near-shore surface water averaged about one-quarter those in the open ocean. One piece of evidence that biogenous material is involved in plutonium removal is that, in 1969, the western Mediterranean Sea showed significantly more of its plutonium still in the water column, compared to stations in the eastern North Atlantic (it is well established that the Mediterranean is characterized by much lower biological activity).

Once incorporated in the sediments,

however, plutonium does not seem to be effectively removed from biological cycles. Discussed above was the observation that bottom-feeding marine organisms contain more plutonium than do those feeding higher in the water column; it should be emphasized here that this refers to metabolized, tissue plutonium, not just to the presence of a standing concentration of the element attached to sediment passing through the intestines—although that, also, is readily observed. In the local shallow-water sediments of Buzzards Bay (probably the most thoroughly studied place in the world in respect to fallout radioactivity), evidence seems to us overwhelming that plutonium moves freely within the sediments. At high delivery rates, downward movement, to 10 or 15 centimeters, was observed; but since the delivery rates became low because of the ban on atmospheric testing, we have been able to observe a slow upward movement. Although the data are not quite conclusive, my own belief is that little plutonium actually returns to the water column, most, if not all, of it being immobilized at the sediment-water interface. This process does, however, have the effect of maintaining the sediment plutonium, even in an area of very rapid sedimentation rate, in the upper parts of the mud, where biological activity is greatest, and where its availability for mechanical resuspension is maximized. Some of our cores from the deep ocean appear to show the same processes in operation, although the upward flux must be much slower than in Buzzards Bay. We do not yet have enough data showing americium distributions to support any arguments about how it moves. The only conservative hypothesis at present is that once introduced to marine water columns, whether in the open ocean or near shore, the transuranics will be available to and involved with marine organisms for long periods of time—tens, if not hundreds, of years, at least. This convinces me that such releases should be made only as last resorts, and should be very carefully controlled.

Waste Disposal Practices

As discussed earlier, although in the United States the planned release of radioactive wastes to the oceans has been banned for some years, in some other nuclear countries intermediate-level wastes are released to the coastal ocean. Often this is done only after some additional processing to remove nuclides thought especially dangerous (strontium 90, for instance), and often after a considerable aging period, to allow the decay of such short-lived but dangerous nuclides as iodine 131.

The oldest, best controlled, and best documented of these releases is that from the Windscale Plant in Great Britain. Since about 1957, processed and aged wastes from this plant have been discharged by pipeline into the Irish Sea. Before the operation was begun, careful studies of the circulation and biology were made, and on these was based a discharge-rate limit that was thought to be conservative. Furthermore, monitoring regulations were set up, and the responsibility for carrying out this function—as well as the authority to apply further limits on the operation if indicated—was placed in a separate laboratory under the Ministry of Agriculture, Fisheries, and Food. Rather quickly this laboratory, the Fisheries Radiobiology Laboratory at Lowestoft, was given responsibility for all environmental monitoring of radioactive wastes in aquatic systems; their practices and the openness of their reporting have offered an example to the world.

It is not surprising that the primary emphasis of this monitoring effort has been on the control of direct exposure of the human population to radioactivity. To do this they have adopted and evolved what is known as the “critical pathway approach,” based on the view that, in any situation of disposal of toxic materials, one (or a very few) pathways will be so dominant in leading to the exposure of small subsets of the population (or, in some cases, of specific individuals) that, in controlling these pathways

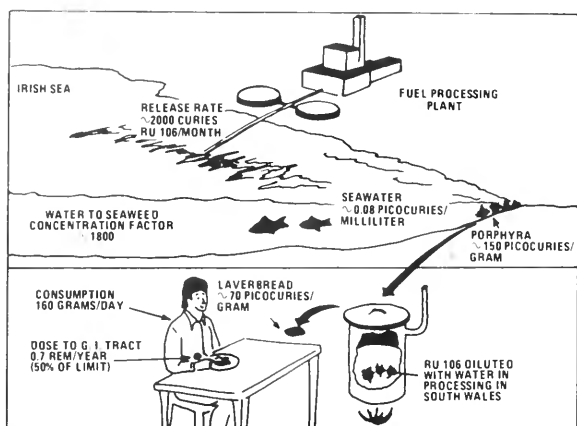


Aerial view of British Nuclear Fuels Limited's Windscale Plant on the Cumberland coast, England. (Courtesy of BNFL Windscale)

to ensure only “acceptable” exposures resulting from them, the general safety is assured (see page 12). The pathways that have been found cover a wide range and are not always involved with food. In some cases exposure of the skin of sunbathers, or of the hands of fishermen whose tackle becomes contaminated, has proved to be critical. But more often it has been food.

In the case of Windscale the critical path has been the use for food of an alga, *Porphyra*, that avidly takes up radioactive ruthenium from the waste stream; in this case the pattern is complicated by the fact that the alga is not eaten locally but is transported to a small area in southern Wales. In other instances

either lobsters or oysters contaminated by particular waste radionuclides have proved critical. In many such cases, careful study of the “critical populations” has shown that the range of rates of consumption of the critical food was so wide as to make the mean rate almost useless, and the decision has had to be reached that protection must be provided to a critical—and wildly aberrant—individual. Individuals were found, for instance, who consumed daily over two pounds of *Porphyra* (against a mean, for the critical population, of only about six ounces and of only about a half-ounce for the whole *Porphyra*-eating population) or who consumed daily four large lobsters (of his



The critical exposure pathway at Windscale. Ru 106 is released to the Irish Sea, where it is accumulated by Porphyra. The seaweed is processed in South Wales and consumed by man. (Redrawn from Radioactivity in the Marine Environment, pub. 0-309-01865-X, Panel on Radioactivity in the Marine Environment of the Committee on Oceanography, National Academy of Sciences-National Research Council, Washington, D.C., 1971)

own catching, needless to say). Both the complexity of the pathways identified and the variability of the human behavior involved indicate that each disposal situation must be continually—or at least frequently—reexamined for changes that would suggest further modification of the controls imposed. Needless to say, detailed reexamination is also required by any substantial change in the operation of the plants involved or in the details of disposal.

There are two salient weaknesses even in this approach, which is still by far the best activity both in theory and in practice: first, it is assumed that by protecting man one can be sure of protecting nature; second, almost all effort goes to study of the pathways currently found critical, with little energy (or money) left for research on the long-term developments in each area.

The argument with respect to man is very clear-cut: that only in the case of man are we concerned to avoid damage to individual organisms, and that any dose-levels that are established as safe by this criterion are bound to be conservatively safe for all those populations of "lower organisms" where we are concerned only with the continuance of

populations or of ecosystems. To the extent that our present data are significant, this argument is supported by the fact that several careful reviews have been utterly unable to find any conclusive case of population or ecosystem change as a result of environmental radioactivity, even in the various nuclear test sites. Acceptance of this argument by many ecologists is limited by two main concerns: first, that relatively few populations have, in fact, been examined, and even then the conclusions have been somewhat blurred both by the lack of detailed pre-exposure population data and by the general accompaniment of radioactivity exposures with other physical or chemical disturbances of the same environments; second, that the periods of observation have been too short to reveal the sort of slow changes that many expect as result of genetic effects of the radiation exposures.

The argument with respect to limitation of the breadth of study of radioactive waste-disposal sites may appear to the layman too subtle. My own concern here is twofold: first, that by concentrating *only* on the critical pathway, monitoring will miss seeing slow changes in the levels in other pathways that are certain to become critical, and that could, if observed, be controlled before this; second, that each disposal situation is, in fact, an environmental experiment, and that it is only by squeezing every bit of information from all of these that man will finally put himself in the position of really understanding what may happen to his wastes and what they may do to individual environments.

The situation of monitoring the transuranics from the Windscale disposal seems to me to offer examples of all these various deficiencies. In 1970 the authorized limit on discharge of alpha-emitting wastes from Windscale was raised from 1800 curies per year to 6000 curies per year; the decision was based explicitly on the assumptions, first, that plutonium 239 and americium 241 accumulated by *Porphyra* represented the critical pathway

for transuranics, as had long been the case for ruthenium, and second, that these transuranics were absorbed by *Porphyr*a-eaters with the same inefficiency that had been observed in the case of Pu 239 added to the diets of rats or mice. As discussed earlier, however, the latter assumption rests on no data that have been published. The first assumption I believe to be untenable—in face of some of our data, for instance—without careful study of several, obvious, alternative pathways ranging from shellfish eating (with possible more efficient uptake from their bodies) to the contamination of potatoes by transuranic-loaded bladder-wrack used as mulch or fertilizer. Consideration of these, and other, alternatives

should especially be undertaken because of the evidence that the transuranics are immobilized rather close to the pipeline outfall by association with the sediments, and that consequently some steady rate of increase of their local concentration must be anticipated.

It is especially in this latter context that one feels the lack of a broader examination of the transuranics in this area. Earlier I referred to Buzzards Bay and deep-ocean data indicating that fallout transuranics stay near the sediment surface, available for biological uptake as well as for transport with resuspended sediment particles. There are no published data from the Windscale operation that we can compare to ours,

Aerial view of the Nevada test site. Detonation point was several hundred feet below convergence of signal cables, at lower left; instruments to record test results were housed in trailers, at right. Surface subsidence from an earlier detonation is visible at left of center. (Lawrence Radiation Laboratory, Livermore)



however; this lack is made even more worrisome by our recent acquisition of a little evidence that Windscale transuranics do not behave as we have found for those from fallout: whereas red algae and brown algae from the Cape Cod area, fallout contaminated, show about the same ratios of americium to plutonium that characterize the water or sediments, in the Irish Sea one recent collection of brown algae contained 5 times as much plutonium as americium, while the mean ratio of these two transuranics in *Porphyra*, in the same year, was just about 1. We believe that this contrast is caused not by biological behavior differences, but by alteration of the chemistry of plutonium or americium—or of both—by complexing agents that accompany them in the Windscale effluent. Without careful examination of the sediment concentration profiles, and of many other biological systems, it would appear unwise in the extreme to predict the future of so complicated a situation from observations made under very different environmental conditions.

It seems to me likely that each coastal outfall will prove to present a unique problem in respect to the transuranic elements, at least in the immediate vicinity of waste material entry to the ocean. Strong priority should be given to study of the factors that control these unique behaviors, with a view to selecting, and generally adopting, any that appear to work, in at least the short term, to our advantage: that is by immobilizing, and making biologically unavailable, the transuranic elements in the waste. Obviously such studies must address also the question of how lasting

these factors are, both in respect to time and in respect to distance or dilution. Here the difficulties become great, for in the case of plutonium 239, we must extrapolate over a hundred thousand years or so, and, in cases of multiple outfalls, over distances of perhaps thousands of miles. Consideration obviously must also be given to the results of interaction between radioactive waste effluents and chemical wastes disposed to coastal areas, wastes that may be nontoxic in themselves but that may act in an undesirable way to modify the transuranic behaviors.

At this time—and this is the consensus of several recent examinations of the transuranic problem—monitoring is really not enough. Rather, each situation of their release to the environment should be treated as an experiment and milked for all the information that it can reveal. This applies quite as much to releases of no conceivable health hazard to man—like fallout or the tiny leaks from some power reactors—as to situations that must also be monitored to ensure human safety—like intermediate-level wastes from fuel reprocessing, or the various test sites, or such accidents as that at Thule. The information needed is very expensive, and its interpretation promises to demand a good deal of ingenuity. The magnitude of the problem, considering either the amount of transuranic waste *now on hand* or that to be produced by our increasing dependence on fission-energy for the next few decades, requires that these studies be made.

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Economics of Marine Pollution

Leah J. Smith



The ocean has long been considered a reservoir for man's wastes, but it is clear that in many areas of the world the capacity of the coastal ocean for such materials is at or past its limit. As the capacity of near-shore marine areas to absorb wastes is approached, it becomes apparent that such disposal is not "free," as it has always been treated. Instead, other uses of coastal areas are impaired, and the social costs of waste disposal begin to be recognized. The multiple uses of coastal areas include, besides industrial and domestic waste disposal, recreation (swimming, boating, picnicking), shellfishing, fishing (commercial and sport), waterfowl hunting, supplying of industrial and municipal water, and navigation. Each of these uses has considerable economic value. If one of them is precluded or limited because of pollution, there is an economic loss to society. As the amount of wastes in the marine environment increases, it becomes more important to determine the economic

impact of pollution in terms of foregone alternate activities.

Perhaps the most disturbing aspect of the coastal pollution problem is its rapid rate of growth. More than 60 percent of the United States population lives within 250 miles of a coast, and it has been estimated that yearly municipal wastes generated by the estuarine population of the United States will increase by more than 30 percent between 1960 and 1980. Currently 29 billion gallons of untreated sewage, including industrial wastes, are dumped into coastal waters every day. The volume of industrial production is increasing at about 4.5 percent per year—three times the population growth rate—and many of the heaviest water-pollution-generating industries are concentrated in the coastal states, especially in the Northeast and Northwest, and along the Gulf of Mexico.

(Photo courtesy New England Aquarium)



Municipal wastes contribute greatly to coastal pollution. Garbage from New York City is moved along the East River to be dumped in the ocean. (EPA-Documerica, Gary E. Miller)

Eighty-five percent of the water used by manufacturers is accounted for by four major industries: primary metals, chemical, paper, and petroleum products. The paper, chemical, and petroleum industries are all expected to continue to grow quickly. Two-thirds of the pulp mills and of the factories producing pesticides and organic chemical products are in coastal areas. In addition, 60 percent of plants producing inorganic chemicals and 50 percent of petroleum refineries are in the coastal states. Thermal wastes from power plants are also expected to increase rapidly. In other parts of the world, population and industry, in general, are also concentrated near oceans; and pollution levels are becoming more harmful.

It is difficult to evaluate the economic impact of pollution for several reasons. One

is the fact that most pollution damages involve externalities—the person or institution causing the pollution is not the person or institution who suffers from it. For example, a pulp mill takes in clean water and dumps its wastes downstream of the mill, where they affect downstream water users. In most cases, there is no price or cost imposed on the polluter by society; the use of a limited resource for waste disposal is free for the polluter. However, because the resource is limited, and his use of it prevents or makes more expensive other competing uses of that resource, there is in fact a *social* cost of the waste disposal process.

Another difficulty in evaluating the economic impact of pollution is the attachment of dollar values to the social costs, which are outside the usual market pricing system. Since alternate uses of coastal areas have often been precluded by pollution, it is difficult to measure accurately the value of such uses. One possible method is to find a similar area without pollution and then to determine the value of the alternate activity—swimming, shellfishing, tourism, and so forth. But data, economic and physical, for this kind of study are scarce. Furthermore, many of the costs of pollution are aesthetic or social, rather than economic. Therefore, the value of such activities as tourism and picnicking must depend on more than simply what people spend in similar, unpolluted areas. Finally, it is sometimes difficult to separate the effects of man-made pollution from the adverse effects of natural phenomena, such as periodic siltation or secular changes in water temperature.

Economic Value of Coastal Resources

Calculating the monetary value of ocean-related activities that may be affected by pollution in near-shore areas is difficult, but some comprehensive estimates are available. Three major areas of activity for which estimates have been made are commercial

fishing, recreation, and navigation.

The landed value of world commercial fisheries was almost \$8.2 billion in 1970; slightly more than 50 percent of this total was caught in coastal areas. In the United States alone, commercial fish landings were valued at \$613 million in 1970. The 1964 expenditure on all recreational uses of the oceans in the United States totaled \$3.9 billion. This included \$1.5 billion for swimming, \$0.8 billion for sports fishing, and \$0.7 billion for pleasure boating. Salt water sports fishermen in the United States spent \$1.2 billion in 1970 (\$129 per person), concentrated particularly along the Atlantic seaboard. Demand for outdoor recreation has risen at an average rate of 10 percent per year as incomes and population have grown; with increasing price levels, the total annual expenditure on ocean-related leisure activities will probably be more than \$10 billion in 1974.

Dollar estimates of value are not available for some of the other uses of coastal waters, such as industrial and municipal water supplies, but transportation in coastal areas was valued at more than \$12 billion in 1964. The major type of pollution that affects transportation is floating debris; some damage in harbors results from oil pollution, turbidity, and silting. Coastal pollution, especially in resort areas, also decreases the values of residential housing.

Cost Estimates of U.S. Pollution Damages

Various estimates have been made of the dollar value of pollution damage to coastal areas in terms of their uses. The major types of activities for which dollar estimates are available are commercial fishing and shellfishing, recreation (including sports fishing), and navigation. In each case, the value lost should ultimately be assessed in terms of cost-benefit analysis. That is, the benefits derived from reducing the pollution levels of coastal waters must be compared to the costs of reducing the pollution levels.

One specific example of cost-benefit comparisons is the cleanup of San Diego Bay. During the late 1950s and early 1960s, the bay was so polluted that all water contact, including swimming and sports fishing, was prohibited. In 1963 a sewage system was initiated, and it has improved water quality in the bay sufficiently to permit extensive recreational use. In 1970 the annual cost of abatement was about \$2 million; the recreational benefits were \$6 million for swimming, boating, and fishing. In this case the benefit-cost ratio is 3:1; by the year 2000 the benefit-cost ratio is expected to be 4:1, because the recreational demand for San Diego Bay will rise faster than the cost of pollution abatement. In any individual polluted area, the costs as well as the

Many costs of pollution cannot be expressed in economic terms. Mustang Island, on the Gulf Coast. (EPA-Documerica, Marc St. Gil)



benefits of pollution abatement should be evaluated over time. However, the following discussion will be limited to the economic value of pollution damages, or the benefit side of the problem.

Losses from polluted shellfish areas in the United States were estimated by the National Marine Fisheries Service at \$12 million in 1970, assuming only clams and oysters are affected. The Council on Environmental Quality (CEQ), however, includes lobsters, shrimp, and crabs among the shellfish contaminated by pollution. Based on potential revenue lost because one-fifth of the United States shellfish beds are closed because of pollution, the annual loss in 1970 was estimated by the CEQ to have been \$63 million.

In addition to these overall assessments, many revenue losses due to pollution have been documented in local areas. Most pollution damage estimates of this kind are based on landed value to fishermen, not retail value; and no multipliers for secondary repercussions of the lost revenues are included. The following are some specific losses from pollution-generated fish kills, sedimentation or dredging of shellfish beds, and contamination of fishing or shellfishing waters:

- In Connecticut, a combination of pollution and marsh destruction has reduced the annual harvest of clams from \$20 million during the 1920s (equivalent to \$48 million at today's prices) to only \$1.5 million during the 1970s.
- In Galveston Bay, the catch of shrimp declined, even with increased efforts at harvesting, from 14.2 million pounds in 1962 to 1.9 million pounds in 1966, as industrial, domestic, and oil pollution increased.
- In Raritan Bay, between New Jersey and New York, the current harvest of hard clams is worth \$40,000 a year. With clean water, the annual harvest could be \$3.85 million. The present annual finfish harvest, worth \$200,000, could be doubled if the water were clean.



Commercial fishing and shellfishing, sports fishing, and pleasure boating are among the ocean-related activities affected economically by pollution of coastal waters. (Top to bottom: Robert K. Brigham, NMFS; J. W. Ropes, NMFS; Hatteras)

- In the Chesapeake Bay, over 50 percent of the upper estuarine areas for fish-spawning and shellfishing were destroyed between 1800 and 1950 by dredging, filling, and pollution.

- In Falmouth, Massachusetts, an oil spill in 1969 ruined the shellfish harvest, including an estimated \$150,000 worth of scallops in one harbor alone.

The overall impact of such localized problems is substantial, as indicated by the national annual loss figures given above.

Recreational damages may be assessed according to people's willingness to pay for certain recreational activities that may have been limited or eliminated by pollution damages. Assuming that the consumers' demands for recreation follow the usual pattern, at a high unit price the quantity of recreation demanded will be smaller than at a low unit price. Thus, the number of recreation-units (for example, hours of swimming or days of boating) will be higher if a low price is attached to these activities. There is, in fact, an extra value, known as consumers' surplus, that accrues to consumers who would have been willing to pay more than the set price for some recreation-units. Thus, the *total* value of recreation to the consumers will be greater than the revenues represented by price/unit X number of recreation-units.

Data required to estimate the value of recreation foregone because of pollution are scarce, but one study has examined recreational activities along California's coast and in Chesapeake Bay. Of 3000 beaches inventoried in 1972, 200 beaches were closed temporarily or year-round (about 50 percent year-round) because of pollution, 120 of these because of sewage. When questioned about closures of state beaches because of pollution, officials from all coastal states reported beach closures of approximately 2.9 percent on the Pacific Coast, 0.5 percent on the Gulf Coast, and 1.2 percent on the Atlantic Coast.

The overall recreational value of pollution-closed beaches can be estimated from beach attendance figures and demand patterns for clean beaches, and per capita benefits or expenditures at typical beaches. Increased utilization of formerly closed beaches would stem from two sources, both resulting from an increased overall supply of beaches: current participants would increase the number of days at the beach, and some nonparticipants would start to use the beaches. A study of the Delaware Estuary in 1970 showed that for the best water quality levels, people had the following dollar benefits for a day's activity: fishermen, \$1.10-\$2.20; boaters, \$1.20-\$1.90; picnickers, \$1.00-\$1.50; and swimmers, \$0.75-\$1.50. Based on these per capita figures, net benefits from increased recreational demand resulting from the opening of pollution-closed beaches would be roughly \$12.7-\$22.1 million per year, according to a study by the Environmental Protection Agency. Since the closed beaches are typically near large population centers, additional savings of \$0.05-\$0.10 per day for each current participant could be assumed because of reduced travel time. Net benefits would rise by an additional \$8.2-\$16.4 million per year. Thus, a total estimate of the net value of recreational benefits in 1970 if closed beaches in the United States had been opened would have been \$20.9-\$38.5 million.

Adverse health effects of marine pollution also involve an economic cost. There are several documented cases of the outbreaks of diseases (particularly typhoid) caused by swimming in polluted waters, and many cases of hepatitis and other diseases caused by eating shellfish from contaminated waters (see page 26). Clearly there is an economic cost to such health damages in terms of cost of treatment and foregone productivity of the victims.

Navigational damages from floating debris in major ports, especially New York and

Boston, amount to a sizeable dollar value. The U.S. Army Corps of Engineers estimated that in 1969 annual benefits of eliminating pollution for the large ports handling a total of one-third the annual cargo tonnage in all United States coastal ports would have been \$17.4 million. Benefits derived by major ports on the Atlantic Coast would have been worth \$14.2 million, on the Gulf Coast \$0.8 million, and along the Pacific Coast \$2.4 million. These benefits include reduced direct damages from collisions, reduced towing and recovery costs, fewer law suits from accident victims, and increased value of shore-front property.

Estimates of the economic costs of pollution damages in the coastal waters of the United States, which yield a total annual value of at least \$101.3 million, are incomplete. In addition to economic benefits of cleaning up pollution, there are also aesthetic and social benefits that cannot be readily translated into dollar values.

International Marine Pollution

Marine pollution damages are world-wide, and the tendency for populations and industrial production to be concentrated along coastlines is universal. A study by the United Nations in 1966 showed that the greatest coastal pollution damages probably occur in the United States, Italy, England, Germany, South Africa, and Australia. Japan, the Soviet

Union, Venezuela, Singapore, Sweden, and Mexico also face increasing marine pollution damages. While industrialized nations have attempted to establish international standards for water pollution control, developing countries have resisted such requirements, arguing that the extra costs of pollution control would put them at an unfair disadvantage during the process of industrialization. However, the pollution damages are increasing at such a rapid pace in some developing countries that the economic costs are becoming apparent. The unfavorable impact of near-shore pollution on promising tourist industries often provides one of the most compelling reasons for cleanup and control.

In view of the world-wide economic impact of pollution and the growing dimensions of the problem, prompt action to halt further pollution seems imperative. The economic value of damages from marine pollution can only rise, unless strong action is taken to slow the rate of waste disposal in coastal waters. As the demands made on these waters for fishing, recreation, navigation, and other activities increase, the high costs that polluters impose on others can only become more obvious.

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At-sea dumping of plastics and other solid wastes accounts for their high concentration in the open ocean. (Kevin Ulmer)



Plastics in the Ocean

John B. Colton, Jr.

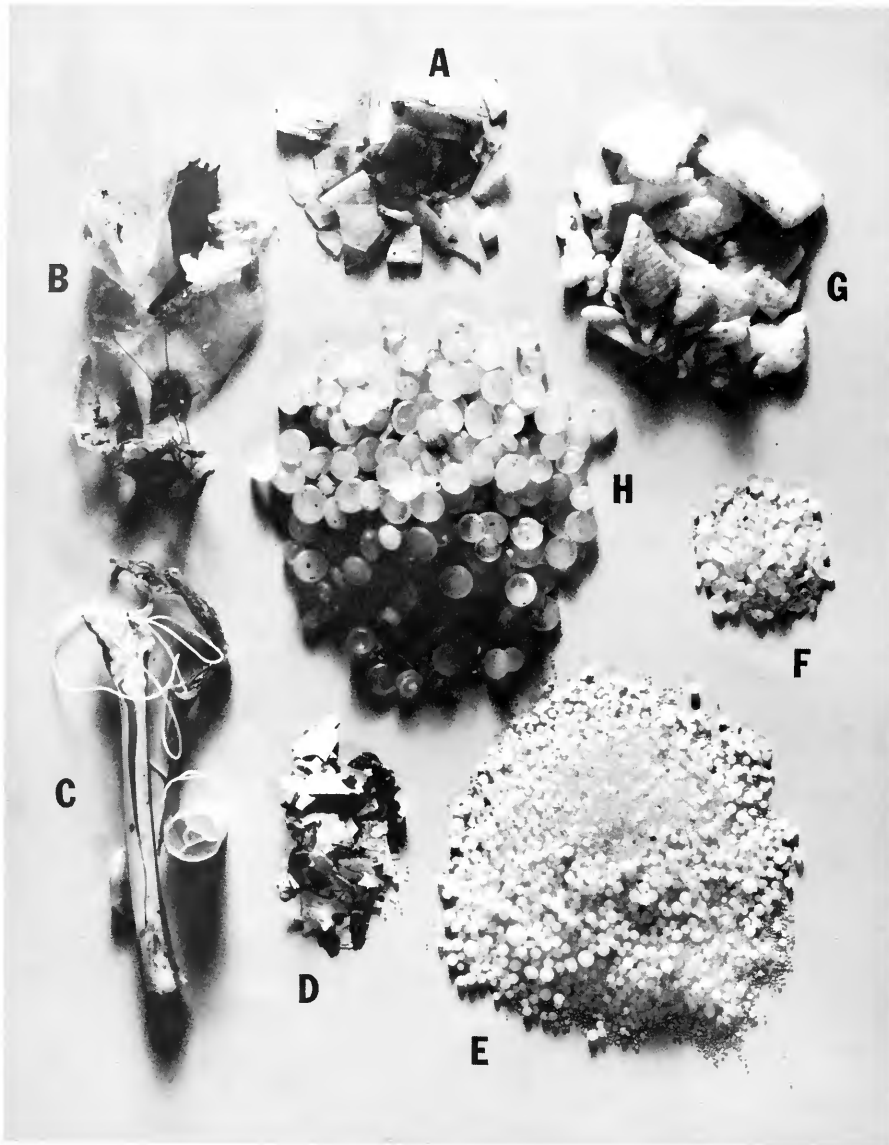
The ocean gives increasing evidence of the plastics age. A walk along most any stretch of beach will reveal the presence of fabricated plastics ranging from food containers and other packaging and wrapping material to synthetic ropes and nets. This situation is not unique to highly populated areas. The National Marine Fisheries Service estimated that about 24,000 plastic items (including, in addition to tiny scraps, 12 tons of trawl web and 7000 gillnet floats) had washed up along 60 miles of Alaska's remote Amchitka Island beaches during a six-month period in 1972.

In most ocean areas the highest concentrations of formulated and compounded plastics are found well offshore, which indicates that municipal solid-waste disposal and coastal landfill operations are not major sources of plastics. The main

source is routine, at-sea solid-waste disposal by individual vessels, as shown by the fact that where plastics are most abundant, vessels are most active.

In 1971, for the first time, plastic particles were found that most likely entered the ocean via river or estuary. Clear and opaque polystyrene spherules, 0.1-2.0 millimeters in diameter, were collected in plankton tows made in southern New England coastal waters. These spherules were identical to what is known in the chemical trade as "suspension beads," a bulk material produced by plastics manufacturers and shipped to plastics fabricators.

More polystyrene spherules were found in neuston (surface) net samples collected July through August 1972 and January through March 1973 on the initial multiship



Typical plastic particles collected in neuston net: (A) plastic pieces, (B) plastic sheets, (C) miscellaneous plastics including straw and cigarette filter, (D) paint chips, (E) opaque polystyrene spherules, (F) clear polystyrene spherules, (G) Styrofoam, (H) polyethylene cylinders. (Wes Pratt, NMFS, Narragansett Laboratory)

MARMAP* ichthyoplankton surveys of coastal and oceanic waters in a 700,000 square-mile area extending from Cape Cod to the Caribbean. Included were white opaque spherules, 0.2–1.7 millimeters in diameter, and translucent to clear spherules, 0.9–2.5 millimeters in diameter. Also found in the neuston net samples were polyethylene cylinders, or disks, 1.7–4.9 millimeters in diameter and 1.1–3.4 millimeters thick. Like suspension beads, they are a bulk material used in making plastic products. The most abundant and widely dispersed plastics found during the MARMAP surveys were sheets and pieces of wrapping and packing material. In general, approximately 50 percent of the samples collected in the Caribbean Sea, 60 percent of the samples collected in the Antilles Current area, and 70 percent of the samples collected in continental shelf, continental slope, and Gulf Stream waters between Florida and Cape Cod contained plastics.

The distribution of opaque polystyrene spherules was restricted to coastal and slope water areas north of latitude 37°N. With the exception of one spherule found well east of the main axis of the Gulf Stream at latitude 34°N, the clear polystyrene spherules were restricted to the coastal and slope water areas north of latitude 36°N. The greatest concentrations of both types of polystyrene particles occurred in coastal waters south of Rhode Island and eastern Long Island. Only off southern New England and Long Island were these plastics found at stations immediately adjacent to the coast.

The most extensive concentrations of polyethylene cylinders occurred in coastal waters off southern New England and eastern Long Island, and off southern New Jersey and Delaware. Limited concentrations were found in and east of the Gulf Stream as far south as latitude 33°N, and in the Yucatan Channel. These particles were also found

at stations scattered throughout the Antilles Current area and at two stations in the Caribbean Sea. The polyethylene cylinders occurred at stations immediately adjacent to the coast of southern New England and eastern Long Island; at one station off Ocean City, Maryland; at one station off the south coast of Puerto Rico; and at one station off the north coast of Cuba. These particles have also been found on beaches at Lisbon, Portugal; Barranquilla, Colombia; Corpus Christi, Texas; and Kalaloch, Washington.

It is now obvious that the polystyrene spherules and polyethylene disks enter the ocean via the waste-water discharge from plastics-producing or plastics-processing plants. Polystyrene spherules have been found in sand and leaf litter near the sewage outlet of a plastics-manufacturing plant on the Chicopee River, Massachusetts, and in the waters and bottom sediments of the Connecticut River. Polyethylene cylinders have been found at sewage outlets of plastics-manufacturing plants in Massachusetts, Connecticut, and New Jersey, and in streams just below plants in New York and New Jersey. The occurrence of spherules and disks in plankton samples collected in eastern Long Island Sound and Block Island Sound is now commonplace.

The distribution of the polystyrene spherules and polyethylene cylinders collected on the MARMAP surveys indicates that the majority of these particles entered open coastal waters in the area between Block Island and the eastern tip of Long Island. A significant number of polyethylene cylinders entered open coastal waters via Delaware Bay. However, the widespread occurrence of the cylinders indicates that there are additional sources of these particles. Supporting evidence for this statement is that the cylinders collected in the Caribbean Sea and on the beach at Barranquilla were less weathered and brittle than those found in other areas of the North Atlantic.

As far as we know, the plastics being

* Marine Resources Monitoring, Assessment, and Prediction, a nationally coordinated program of the National Marine Fisheries Service.

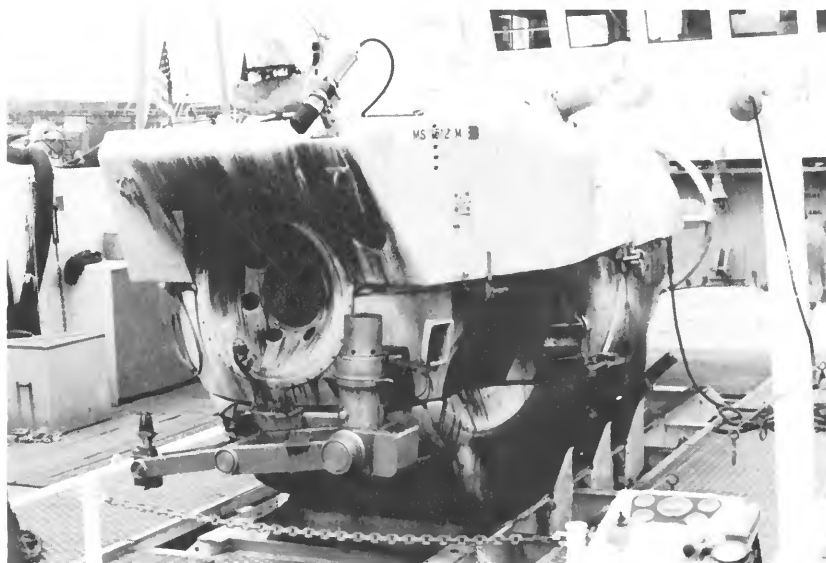
discussed here are not toxic, and adverse biological consequences of their presence in coastal waters appear to be minor compared to the damaging effects of other such contaminants as petroleum residues and other chemical wastes. The larger pieces of formulated plastics have obvious physical effects. Vessels have been disabled because their propellers were entangled in synthetic ropes and nets. Fish, diving sea birds, and marine mammals have been caught, injured, or drowned in the nets. The white opaque polystyrene spherules have been found in the stomachs of ten species of larval, juvenile, and adult fishes; in tern and gull pellets; and in the gizzards and stomachs of Leach's petrels and parakeet auklets. It has been suggested that the ingestion of plastic particles leads to intestinal blockage and possible mortality, but to date there is no evidence to support this theory.

The most disturbing thing about plastics is that they do not decompose. Once they are introduced into the marine environment, they remain indefinitely, even though they gradually break up into smaller particles. Increasing production of plastics, combined with present waste disposal practices, will undoubtedly increase the concentrations of these particles in rivers, estuaries, and open ocean. Whether or not

plastics pose a threat to marine life, it is inexcusable to allow them to accumulate in the marine environment.

To reduce the accumulation of plastics in the ocean will require the technological development of water-soluble or photodegradable polymers for disposable plastic products, an increased effort in the development of plastics reclamation systems, and the implementation of strong federal, state, and municipal pollution control and monitoring programs. Most important, it will require a change in attitude toward the ocean. Noël Mostert, in an article on supertankers in *The New Yorker* (May 13, 1974), summarized this attitude: "The salt seas have always seemed to offer assurance of an accessible freshness and cleanness, and I suppose there is in this the remnants of an atavistic instinct defensive of our remote origins, a much needed conviction that whatever other havoc we wreak, however deeply we pile the ashes, the seas will still rise and fall and safely breathe in their depths."

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The research submersible Alvin is covered with oil from Ponta Delgada Bay, Azores. No oil spill, just the usual amount of pollution in the bay. At Ponta Delgada, Alvin was transferred from R/V Knorr to catamaran Lulu for work on Project FAMOUS and, later, the New England seamounts. (Kenneth Wagner)

