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SCIENTIFIC ASPECTS OF THE OIL SPILL PROBLEM

*By Max Blumer**

THE EXTENT OF MARINE OIL POLLUTION

Oil pollution is the almost inevitable consequence of our dependence on an oil-based technology. The use of a natural resource without losses is nearly impossible and environmental pollution occurs through intentional disposal or through inadvertent losses in production, transportation, refining and use. How large is the oil influx to the ocean? The washing of cargo tanks at sea, according to the director of Shell International, Marine Ltd.[1] had the potential in 1967 of introducing 2.8 million tons into the ocean, assuming that no use was made of the Load on Top (LOT) technique. With the increase in ocean oil transport from 1967 to 1970 this potential has grown to 6 million tons. The LOT technique is not being applied to one quarter of the oil tonnage moved by tankers; consequently, these vessels introduce about 1.5 million tons of oil into the sea. The limitations of the LOT technique have been described by E. S. Dillon[2]: the technique is not always used even if the equipment exists, the equipment may be inadequate, shore receiving facilities may be lacking and principal limitations lie in the formation of emulsions in heavy seas or with heavy crude oils. Insufficient time may be available for the separation of the emulsion or the oil water interface may not be readily recognized. In addition the most toxic components of oil are also readily soluble in water and their disposal into the ocean could be avoided only if clean ballasting were substituted for the LOT technique. For these reasons it is estimated that the present practices in tanker ballasting introduce about 3 million tons of petroleum into the ocean. The pumping of bilges by vessels other than tankers contributes another 500,000 tons.[3] In addition, in-port losses from collisions and during loading and unloading contribute an estimated 1 million tons.[4]

Oil enters the ocean from many other sources whose magnitude is much less readily assessed. Among these are accidents on the high seas (Torrey Canyon) or near shore, outside of harbors (West Falmouth, Mass.), losses during exploration (oil based drilling mud) and production (Santa Barbara, Gulf of Mexico), in storage (submarine storage tanks) and in pipeline breaks, and spent marine lubricants and incompletely burned fuels. A major contribution may come from untreated domestic and industrial wastes; it is estimated that nearly 2 million tons of used lubricating oil is unaccounted for each year in the United States alone, and, a significant portion of this reaches our coastal waters.[5,6]

Thus, the total annual oil influx to the ocean lies probably between 5 and 10 million tons. A more accurate assessment of the oil pollution of the oceans and of the relative contribution of different oils to the different marine environments is urgently needed. Such an assessment might well lie within the role of the NATO Committee on Challenges of the Modern Society.

With the anticipated increase in foreign and domestic oil production, with increased oil transport and with the shift of production to more hazardous regions (Alaska, continental shelf, deep ocean), we can expect a rapid increase of the spillage rate and of the oil influx to the ocean. Floating masses of crude oil ("tar") are now commonly encountered on the oceans and crude oil is present on most beaches. Oil occurs in the stomach of surface feeding fishes[7] and finely dispersed hydrocarbons occur in marine plants (e.g. sargassum[8]) and in the fat of fish and shellfish.[6,9a] Hydrocarbons from a relatively small and restricted oil spill in the coastal waters of Massachusetts, U.S.A., have spread, nine months after the accident to an area occupying 5000 acres (20 km^2) offshore and 500 acres (2 km^2) in tidal rivers and marshes. The effect on the natural populations in this area has been catastrophic. The full extent of the coverage of the ocean bottom by petroleum hydrocarbons is unknown; chemical analyses are scarce or non-existent.

Evaluation of the Threat

Oil: Immediate Toxicity

All crude oils and all oil fractions except highly purified and pure materials are poisonous to all marine organisms. This is not a new finding. The wreck of the "Tampico" in Baja, California, Mexico (1957) "created a situation where a completely natural area was almost totally destroyed suddenly on a large scale. . . . Among the dead species were lobsters, abalone, sea urchins, starfish, mussels, clams and hosts of smaller forms."[10] Similarly, the spill of fuel oil in West Falmouth, Massachusetts, U.S.A., has virtually extinguished life in a productive coastal and intertidal area, with a complete kill extending over all phyla represented in that habitat (Hampson and Sanders[11] and unpublished data). Toxicity is immediate and leads to death within minutes or hours.[12]

Principally responsible for this immediate toxicity are three complex fractions. The *low boiling saturated hydrocarbons* have, until quite recently, been considered harmless to the marine environment. It has now been found that this fraction, which is rather readily soluble in sea water, produces at low concentration anaesthesia and narcosis and at greater concentration cell damage and death in a wide variety of lower animals; it may be especially damaging to the young forms of marine life.[13] The *low boiling aromatic hydrocarbons* are the most immediately toxic fraction. Benzene, toluene and xylene are acute poisons for man as well as for other organisms; naphthalene and phenanthrene are even more toxic to fishes than benzene, toluene and xylene.[14] These hydrocarbons and substituted one-, two-, and three-ring hydrocarbons of similar toxicity are abundant in all oils and most, especially the lower boiling, oil products. Low boiling aromatics are even more water soluble than the saturates and can kill marine organisms either by direct contact or through contact with dilute solutions. *Olefinic hydrocarbons*, intermediate in structure and properties, and probably in toxicity, between saturated and aromatic hydrocarbons are absent in crude oil but occur in refining products (*e.g.*, gasoline and cracked products) and are in part responsible for their immediate toxicity.

Numerous other components of crude oils are toxic. Among those named by Speers and Whitehead,[15] cresols, xylenols, naphthols, quinoline and substituted quinolines and pyridines and hydroxybenzoquinolines are of special concern here because of their great toxicity and their solubility in water. It is unfortunate that statements which disclaim this established toxicity are still being circulated. Simpson[16] claimed that "there is no evidence that oil spilt round the British Isles has ever killed any of these (mussels, cockles, winkles, oysters, shrimps, lobsters, crabs) shellfish." It was obvious when this statement was made that such animals were indeed killed by the accident of the Torrey Canyon as well as by earlier accidents; work since then has confirmed the earlier investigation. In addition, this statement, by its emphasis only on the adult life forms, implies wrongly that juvenile forms were also unaffected.

Oil and Cancer

The higher boiling crude oil fractions are rich in multiring aromatic compounds. It was at one time thought that only a few of these compounds, mainly 3,4-benzopyrene, were capable of inducing cancer. As R. A. Dean[17] of British Petroleum Company stated, "no 3,4-benzopyrene has been detected in any crude oil . . . [I]t therefore seems that the risk to the health of a member of the public by spillage of oil at sea is probably far less than that which he normally encounters by eating the foods he enjoys." However, at the time this statement was made, carcinogenic fractions containing 1,2-benzanthracene and alkylbenzanthracenes had already been isolated by Carruthers, Stewart and Watkins[18] and it was known that "biological tests have shown that the extracts obtained from high-boiling fractions of the Kuwait oil . . . (method) . . . are carcinogenic." Further, "Benzanthracene derivatives, however, are evidently not the only type of carcinogen in the oil. . . ." In 1968, the year when Dean claimed the absence of the powerful carcinogen 3,4 benzopyrene in crude oil, this hydrocarbon was isolated in crude oil from Libya, Venezuela and the Persian Gulf.[19] The amounts measured were between 450 and 1800 milligrams per ton of the crude oil.

Thus, we know that chemicals responsible for cancer in animals and man occur in petroleum. The causation of cancer in man by crude oil and oil products was observed some years ago, when a high incidence of skin cancer in some refinery personnel was observed. The cause was traced to prolonged skin contact by these persons with petroleum and with refinery products. Better plant design and education, aimed at preventing the contact, have since reduced or eliminated this hazard.[20] However, these incidents have demonstrated that oil and oil products can cause cancer in man, and have supported the conclusions based on the finding of known carcinogens in oil. These references and a general knowledge of the composition of crude oils suggest that all crude oils and all oil products containing high boiling aromatic hydrocarbons should be viewed as potential cancer inducers.

Safeguards in plant operations protect the public from this hazard. However, when oil is spilled into the environment we loose control over it and should again be concerned about the possible public health hazard from cancer-causing chemicals in the oil. We have shown that marine organisms ingest and retain hydrocarbons to which they are exposed. These are transferred to and retained by predators. In this way even animals that were not directly exposed to a spill can become polluted by eating contaminated chemicals. This has severe implications for commercial fisheries and for human health. It suggests that marketing and eating of oil contaminated fish and shellfish at the very least increases the body burden of carcinogenic chemicals and may constitute a public health hazard.

Other questions suggest themselves: Floating masses of crude oil now cover all oceans and are being washed up on shores. It has been thought that such stranded lumps are of little consequence ecologically. It has been shown that such lumps, even after considerable weathering, still contain nearly the full range of hydrocarbons of the original crude oil, extending in boiling point as low as 100°C. Thus such lumps still contain some of the immediately toxic lower boiling hydrocarbons. In addition, the oil lumps contain all of the potentially carcinogenic material in the 300–500° boiling fraction. The presence of oil lumps ("tar") or finely dispersed oil on recreational beaches may well constitute a severe public health hazard, through continued skin contact.

Low Level Effects of Oil Pollution

The short-term toxicity of crude oil and of oil products and their carcinogenic properties are fairly well understood. In contrast to this we are rather ignorant about the long term and low level effects of oil pollution. These may well be far more serious and long lasting than the more obvious short term effects. Let us look at low level interference of oil pollution with the marine ecology.

Many biological processes which are important for the survival of marine organisms and which occupy key positions in their life processes are mediated by extremely low concentration of chemical messengers in the sea water. We have demonstrated that marine predators are attracted to their prey by organic compounds at concentrations below the part per billion level.[21] Such chemical attraction—and in a similar way repulsion—plays a role in the finding of food, the escape from predators, in homing of many commercially important species of fishes, in the selection of habitats and in sex attraction. There is good reason to believe that pollution interferes with these processes in two ways, by blocking the taste receptors and by mimicking for natural stimuli. The latter leads to false response. Those crude oil fractions likely to interfere with such processes are the high boiling saturated and aromatic hydrocarbons and the full range of the olefinic hydrocarbons. It is obvious that a very simple—and seemingly innocuous—interference at extremely low concentration levels may have a disastrous effect on the survival of any marine species and on many other species to which it is tied by the marine food chain.

Research in this critical area is urgently needed. The experience with DDT has shown that low level effects are unpredictable and may suddenly become an ecological threat of unanticipated magnitude.

The Persistence of Oil in the Environment

Hydrocarbons are among the most persistent organic chemicals in the marine environment. It has been demonstrated that hydrocarbons are transferred from prey to predator and that they may be retained in organisms for long time periods, if not for life. Thus, a coastal spill near Cape Cod, Massachusetts, U.S.A., has led to the pollution of shellfish by fuel oil. Transplanting of the shellfish to clean water does not remove the hydrocarbons from the tissues. Oil may contaminate organisms not only at the time of the spill; hydrocarbon-loaded sediments continue to be a source of pollution for many months after the accident.

Oil, though lighter than water, does not remain at the sea surface alone; storms, or the uptake of organisms or minerals, sink the oil. Oil at the sea bottom has been found after the accidents of the Torrey Canyon at Santa Barbara and near Cape Cod. Clay minerals with adsorbed organic matter are an excellent adsorbent for hydrocarbons; they retain oil and may transport it to areas distant from the primary spill. Thus, ten months after the accident at Cape Cod, the pollution of the bottom sediments covers an area that is much larger than that immediately after the spill.

In sediments, especially if they are anaerobic, oil is stable for long time periods. Indeed, it is a key fact of organic geochemistry that hydrocarbons in anaerobic recent sediments survive for millions of years until they eventually contribute to the formation of petroleum.

Countermeasures

Compared to the number and size of accidents and disasters the present countermeasures are inadequate. Thus, in spite of considerable improvement in skimming efficiency since the Santa Barbara accident, only 10% of the oil spilled from the Chevron well in the Gulf of Mexico was recovered.[22] From an ecological point of view this gain is nearly meaningless. While we may remain hopeful that the gross esthetic damage from oil spills may be avoided in the future, there is no reason to be hopeful that existing or planned countermeasures will eliminate the biological impact of oil pollution.

The most immediately toxic fractions of oil and oil products are soluble in sea water; therefore, biological damage will occur at the very moment of the accident. Water currents will immediately spread the toxic plume of dissolved oil components and, if the accident occurs in inshore waters, the whole water column will be poisoned even if the bulk of the oil floats on the surface. The speed with which the oil dissolves is increased by agitation, and in storms the oil will partly emulsify and will then present a much larger surface area to the water; consequently, the toxic fractions dissolve more rapidly and reach higher concentrations. From the point of view of avoiding the immediate biological effect of oil spills, countermeasures are completely effective only if *all of the oil is recovered immediately* after the spill. *The technology to achieve this goal does not exist.*

Oil spills damage many coastal and marine values: water fowl, fisheries, and recreational resources; they lead to increased erosion; they diminish the water quality and may threaten human life or property through fire hazard. A judicious choice has to be made in each case: which—if any—of the existing but imperfect countermeasures to apply to minimize the overall damage or the damage to the most valuable resources. Guidelines for the use of countermeasures, especially of chemical countermeasures, exist[23] and are being improved.[24] Some comments on the ecological effects and desirability of the existing countermeasures appear appropriate.

Detergents and Dispersants

The toxic, solvent-based detergents which did so much damage in the clean-up after the Torrey Canyon accident are presently only in limited use. However, so-called "nontoxic dispersants" have been developed. The term "nontoxic" is misleading; these chemicals may be nontoxic to a limited number of often quite resistant test organisms but they are rarely tested in their effects upon a very wide spectrum of marine organisms including their juvenile forms, preferably in their normal habitat. Further, in actual use all dispersant-oil mixtures are severely toxic, because of the inherent toxicity of the oil, and bacterial degradation of "nontoxic" detergents may lead to toxic breakdown products.

The effect of a dispersant is to lower the surface tension of the oil to a point where it will disperse in the form of small droplets. It is recommended that the breakup of the oil slick be aided by agitation, natural or mechanical. Thus, the purpose of the detergent is essentially a cosmetic one. However, the recommendation to apply dispersants is often made in disregard of their ecological effects. Instead of removing the oil, dispersants push the oil actively into the marine environment; because of the finer degree of dispersion, the immediately toxic fraction dissolves rapidly and reaches a higher concentration in the sea water than it would if natural dispersal were allowed. The long term poisons (e.g. the carcinogens) are made available to and are ingested by marine filter feeders, and they can eventually return to man incorporated into the food he recovers from the ocean.

For these reasons I feel that the use of dispersants is unacceptable, inshore or offshore, except under special circumstances, *e.g.*, extreme fire hazard from spillage of gasoline, as outlined in the Contingency Plan for Oil Spills, Federal Water Quality Administration, 1969.[23,24]

Physical Sinking

Sinking has been recommended. "The long term effects on marine life will not be as disastrous as previously envisaged. Sinking of oil may result in the mobile bottom dwellers moving to new locations for several years; however, conditions may return to normal as the oil decays."[25] Again, these conclusions disregard our present knowledge of the effect of oil spills.

Sunken oil will kill the bottom faunas rapidly, before most mobile dwellers have time to move away. The sessile forms of commercial importance (oysters, scallops, etc.) will be killed and other mobile organisms (lobsters) may be attracted into the direction of the spill where the exposure will contaminate or kill them. The persistent fraction of the oil which is not readily attacked by bacteria contains the long term poisons, *e.g.*, the carcinogens, and they will remain on the sea bottom for very long periods of time. Exposure to these compounds may damage organisms or render them unfit for human nutrition even after the area has been repopulated.

The bacterial degradation of sunken oil requires much oxygen. As a result, sediments loaded with oil become anaerobic and bacterial degradation and reworking of the sediments by aerobic benthic organisms is arrested. It is one of the key principles of organic geochemistry that hydrocarbons in anaerobic sediments persist for million of years. Similarly, sunken oil will remain; it will slow down the resettlement of the polluted area; and it may constitute a source for the pollution of the water column and of fisheries resources for a long time after the original accident.

For these reasons I believe that sinking of oil is unacceptable in the productive coastal and offshore regions. Before we apply this technique to the deep ocean with its limited oxygen supply and its fragile faunas we should gather more information about the interplay of the deep marine life with the commercial species of shallower waters.

Combustion

Burning the oil through the addition of wicks or oxidants appears more attractive from the point of view of avoiding biological damage than dispersion and sinking. However, it will be effective only if burning can start immediately after a spill. For complete combustion, the entire spill must be covered by the combustion promoters, since burning will not extend to the untreated areas; in practice, in stormy conditions, this may be impossible to achieve.

Mechanical Containment and Removal

Containment and removal appear ideal from the point of avoiding biological damage. However, they can be effective only if applied immediately after the accident. Under severe weather conditions floating booms and barriers are ineffective. Booms were applied during the West Falmouth oil spill; however, the biological damage in the sealed-off harbors was severe and was caused probably by the oil which bypassed the booms in solution in sea water and in the form of wind-dispersed droplets.

Bacterial Degradation

Hydrocarbons in the sea are naturally degraded by marine microorganisms. Many hope to make this the basis of an oil removal technology through bacterial seeding and fertilization of oil slicks. However, great obstacles and many unknowns stand in the way of the application of this attractive idea.

No single microbial species will degrade any whole crude oil; bacteria are highly selective and complete degradation requires many different bacterial species. Bacterial oxidation of hydrocarbons produces many intermediates which may be more toxic than the hydrocarbons; therefore, organisms are also required that will further attack the hydrocarbon decomposition products.

Hydrocarbons and other compounds in crude oil may be bacteriostatic or bacteriocidal; this may reduce the rate of degradation, where it is most urgently needed. The fraction of crude oil that is most readily attacked by bacteria is the least toxic one, the normal paraffins; the toxic aromatic hydrocarbons, especially the carcinogenic polynuclear aromatics, are not rapidly attacked.

The oxygen requirement in bacterial oil degradation is severe; the complete oxidation of 1 gallon of crude oil requires all the dissolved oxygen in 320,000 gallons of air saturated sea water. Therefore, oxidation may be slow in areas where the oxygen content has been lowered by previous pollution and the bacterial degradation may cause additional ecological damage through oxygen depletion.

Cost Effectiveness

The high value of fisheries resources, which exceeds that of the oil recovery from the sea, and the importance of marine proteins for human nutrition demand that cost effectiveness analysis of oil spill countermeasures consider the cost of direct and indirect ecological damage. It is disappointing that existing studies completely neglect to consider these real values.[17] A similarly one-sided approach would be, for instance, a demand by fisheries concerns that all marine oil production and shipping be terminated, since it clearly interferes with fisheries interests.

We must start to realize that we are paying for the damage to the environment, especially if the damage is as tangible as that of oil pollution to fisheries resources and to recreation. Experience has shown that cleaning up a polluted aquatic environment is much more expensive than it would have been to keep the environment clean from the beginning.[26] In terms of minimizing the environmental damage, spill prevention will produce far greater returns than cleanup—and we believe that this relationship will hold in a *realistic* analysis of the overall cost effectiveness of prevention or cleanup costs.

The Risk of Marine Oil Pollution

The Risk to Marine Life

Our knowledge of crude oil composition and of the effects of petroleum on marine organisms in the laboratory and in the marine environment force the conclusion that petroleum and petroleum products are toxic to most or all marine organisms. Petroleum hydrocarbons are persistent poisons. They enter the marine food chain, they are stabilized in the lipids of marine organisms and they are transferred from prey to predator. The persistence is especially severe for the most poisonous compounds of oil; most of these do not normally occur in organisms and natural pathways for their biodegradation are missing.

Pollution with crude oil and oil fractions *damages the marine ecology* through different effects:

1. Direct kill of organisms through coating and asphyxiation.[27]
2. Direct kill through contact poisoning of organisms.
3. Direct kill through exposure to the water soluble toxic components of oil at some distance in space and time from the accident.
4. Destruction of the generally more sensitive juvenile forms of organisms.
5. Destruction of the food sources of higher species.
6. Incorporation of sublethal amounts of oil and oil products into organisms resulting in reduced resistance to infection and other stresses (the principal cause of death in birds surviving the immediate exposure to oil[28]).
7. Incorporation of carcinogenic and potentially mutagenic chemicals into marine organisms.
8. Low level effects that may interrupt any of the numerous events necessary for the propagation of marine species and for

the survival of those species which stand higher in the marine food web.

The degree of toxicity of oil to marine organisms and the mode of action are fairly well understood. On the other hand, we are still far from understanding the effect of the existing and increasing oil pollution on the marine ecology on a large, especially world wide, scale.

Few, if any, comprehensive studies of the effects of oil spills on the marine ecology have been undertaken. Petroleum and petroleum products are toxic *chemicals*; the long term biological effect of oil and its persistence cannot be studied without chemical analyses. Unfortunately, chemical analysis has not been used to support such studies in the past and conclusions on the persistence of oil in the environment have been arrived at solely by visual inspection. This is not sufficient; a sediment can be uninhabitable to marine bottom organisms because of the presence of finely divided oil, but the oil may not be visually evident. Marine foods may be polluted by petroleum and may be hazardous to man but neither taste nor visual observation may disclose the presence of the toxic hydrocarbons.

A coordinated biological and chemical study of the long-term effect and fate of a coastal oil spill in West Falmouth, Massachusetts, U.S.A. has shown that even a relatively low boiling, soluble and volatile oil persists and damages the ecology for many months after the spill. In this instance about 650 tons of #2 fuel oil were accidentally discharged into the coastal waters off the Massachusetts coast. I wish to summarize our present findings of the effect of this accident.

Persistence and Spread of the Pollution[9a,b]

Oil from the accident has been incorporated into the sediments of the tidal rivers and marshes and into the offshore sediments, down to 42 feet, the greatest water depth in the sea. The fuel oil is still present in inshore and offshore sediments, eight months after the accident. The pollution has been spreading on the sea bottom and now covers at least 5000 acres offshore and 500 acres of marshes and tidal rivers. This is a much larger area than that affected immediately after the accident. Bacterial degradation of the oil is slow; degradation is still negligible in the most heavily polluted areas and the more rapid degradation in outlying, less affected, areas has been reversed by the influx of less degraded oil from the more polluted regions. The kill of bottom plants and animals has reduced the stability of marshland and sea bottom; increased erosion results and may be responsible for the spread of the pollution along the sea bottom.

Bacterial degradation first attacks the least toxic hydrocarbons. The hydrocarbons remaining in the sediments are now more toxic on an equal weight basis than immediately after the spill. Oil has penetrated the marshes to a depth of at least 1–2 feet; bacterial degradation within the marsh sediment is still negligible eight months after the accident.

Biological Effects of the Pollution[11,12]

Where oil can be detected in the sediments there has been a kill of animals; in the most polluted areas the kill has been almost total. Control stations outside the area contain normal, healthy bottom faunas. The kill associated with the presence of oil is detected down to the maximum water depth in the area. A massive, immediate kill occurred offshore during the first few days after the accident. Affected were a wide range of fish, shellfish, worms, crabs and other crustaceans and invertebrates. Bottom living fishes and lobsters were killed and washed up on the beaches. Trawls in 10 feet of water showed 95% of the animals dead and many still dying. The bottom sediments contained many dead clams, crustaceans and snails. Fish, crabs, shellfish and invertebrates were killed in the tidal Wild Harbor River; and in the most heavily polluted locations of the river almost no animals have survived.

The affected areas have not been repopulated, nine months after the accident. Mussels that survived last year's spill as juveniles have developed almost no eggs and sperm.

Effect on Commercial Shellfish Values[9a,b]

Oil from the spill was incorporated into oysters, scallops, softshell clams and quahaugs. As a result, the area had to be closed to the taking of shellfish.

The 1970 crop of shellfish is as heavily contaminated as was last year's crop. Closure will have to be maintained at least through this second year and will have to be extended to areas more distant from the spill than last year. Oysters that were removed from the polluted area and that were maintained in clean water for as long as 6 months retained the oil without change in composition or quantity. Thus, once contaminated, shellfish cannot cleanse themselves of oil pollution.

The tidal Wild Harbor River, a productive shellfish area of about 22 acres, contains an estimated 4 tons of the fuel oil. This amount has destroyed the shellfish harvest for two years. The severe biological damage to the area and the slow rate of biodegradation of the oil suggest that the productivity will be ruined for a longer time.

Some have commented to us that the effects measured in the West Falmouth oil spill are not representative of those from a crude oil spill and that #2 fuel oil is more toxic than petroleum. However, the fuel oil is a typical refinery product that is involved in marine shipping and in many marine spillages; also, the fuel oil is a part of petroleum and as such it is contained within petroleum. Therefore, its effect is typical, both for unrefined oil and for refinery products. In terms of chemical composition crude oils span a wide range; many lighter crude oils have a composition very similar to those of the fuel oils and their toxicity and environmental danger corresponds respectively. However, many crude oils contain more of the persistent, long term poisons, including the carcinogens, than the fuel oils. Therefore, crude oils can be expected to have even more serious long term effects than the lower boiling fuel oils.

The pollution of fisheries resources in the West Falmouth oil spill is independent of the molecular size of the hydrocarbons; the oil taken up reflects exactly the boiling point distribution of the spilled oil. Thus, spills by other oils of different boiling point distributions can be expected to destroy fisheries resources in the same manner.

We believe that the environmental hazard of oil and oil products has been widely underestimated, because of the lack of thorough and extended investigations. The toxicity and persistence of the oil and the destruction of the fisheries resources observed in West Falmouth are typical for the effects of marine oil pollution.

The Risk to Human Use of Marine Resources

The destruction of marine organisms, of their habitats and food sources directly affects man and his intent to utilize marine proteins for the nutrition of an expanding population. However, the presence in oil of toxic and carcinogenic compounds combined with the persistence of hydrocarbons in the marine food chain poses an even more direct threat to human health. The magnitude of this problem is difficult to assess at this time. Our knowledge of the occurrence of carcinogens in oil is recent and their relative concentrations have been measured in very few oils. Also, our understanding of the fate of hydrocarbons, especially of carcinogens, in the marine food chain needs to be expanded.

Methods for the analysis of fisheries products for the presence of hazardous hydrocarbons exist and are relatively simple and the analyses are inexpensive. In spite of this no public laboratory in the United States—and probably in the world—can routinely perform such analysis for public health authorities. There is increasing evidence that fish and shellfish have been and are now being marketed which are hazardous from a public health point of view. Taste tests, which are commonly used to test for the presence of oil pollutants in fish or shellfish, are inconclusive. Only a small fraction of petroleum has a pronounced odor; this may be lost while the more harmful long term poisons are retained. Boiling or frying may remove the odor but will not eliminate the toxicity.

The Risk to the Recreational Use of Marine Resources

The presence of petroleum, petroleum products and petroleum residue ("tar," "beach tar") is now common on most recreational beaches. Toxic hydrocarbons contained in crude oil can pass through the barrier of the human skin and the prolonged skin contact with carcinogenic hydrocarbons constitutes a public health hazard. Intense solar radiation is known to be one of the contributing factors for skin cancer. The presence of carcinogens in beach tar may increase the risk to the public in a situation where a severe stress from solar radiation already exists.

The Risk to Water Utilization

Many of the toxic petroleum hydrocarbons are also water soluble. Water treatment plants, especially those using distillation, may transfer or concentrate the steam-volatile toxic hydrocarbons into the refined water streams, especially if dissolved hydrocarbons are present in the feed streams or if particulate oil finds its way into the plant intake.

Conclusions

1. Oil and oil products must be recognized as poisons that damage the marine ecology and that are dangerous to man. Fisheries resources are destroyed through direct kill of commercially valuable species, through sublethal damage and through the destruction of food sources. Fisheries products that are contaminated by oil must be considered as a public health hazard.

2. Only crude estimates exist of the extent of marine oil pollution. We need surveys that can assess the influx of petroleum and petroleum products into the ocean. They should be worldwide and special attention should be paid to the productive regions of the ocean; data are needed on the oil influx from tankers and non-tanker vessels, on losses in ports, on offshore and inshore accidents from shipping, exploration and production and on the influx of oil from domestic and industrial wastes.

3. The marine ecology is changing rapidly in many areas as a result of man's activities. We need to establish baseline information on composition and densities of marine faunas and floras and on the hydrocarbon levels and concentrations encountered in marine organisms, sediments and in the water masses.

4. All precautions must be taken to prevent oil spills. Prevention measures must be aimed at eliminating human error, at the present time the principal cause of oil spills.

5. Spill prevention must be backed by effective surveillance and law enforcement. *In terms of cost effectiveness spill prevention is far superior to cleanup.*

6. Perfection and further extension of the use of the Load on Top methods is promising as a first step in reduction of the oil pollution from tankers. The effectiveness of the technique should be more closely assessed and improvements are necessary in interface detection, separation and measurement of hydrocarbon content in the effluent, both in the dispersed and dissolved state. On a longer time scale, clean ballast techniques should supersede the Load on Top technique.

7. The impact of oil pollution on marine organisms and on sources of human food from the ocean has been underestimated because of the lack of coordinated chemical and biological investigations. Studies of the effect of oil spills on organisms in different geographic and climatic regions are needed. The persistence of hydrocarbon pollution in sea water, sediments and organisms should be studied.

8. Research is urgently needed on the low-level and long term effects of oil pollution. Does oil pollution interfere with feeding and life processes at concentrations below those where effects are immediately measured? Are hydrocarbons concentrated in the marine food chain?

9. Carcinogens have been isolated from crude oil but additional efforts are needed to define further the concentrations and types of carcinogens in different crude oils and oil products.

10. The public health hazard from oil derived carcinogens must be studied. What are the levels of oil derived carcinogens ingested by man and how wide is the exposure of the population? How much does this increase the present body burden with carcinogens? Is there direct evidence for the causation of cancer in man by petroleum and petroleum products outside of oil refinery operations?

11. Public laboratories must be established for the analysis of fisheries products for toxic and carcinogenic chemicals derived from oil and oil products, and tolerance levels will have to be set.

12. The ocean has a limited tolerance for hydrocarbon pollution. The tolerance varies with the composition of the hydrocarbons and is different in different regions and in different ecological sub-systems. The tolerance of the water column may be greater than that of the sediments and of organisms. An assessment of this inherent tolerance is necessary to determine the maximum pollution load that can be imposed on the environment.

13. Countermeasures which remove the oil from the environment reduce the ecological impact and danger to fisheries resources. All efforts should be aimed at the most rapid and complete removal since the extent of the biological damage increases with extended exposure of the oil to sea water.

14. Countermeasures that introduce the entire, undegraded oil into the environment should be used only as a last resort in situations such as those outlined in the Contingency Plan of the Federal Water Quality Administration, involving extreme hazard to a major segment of a vulnerable species of waterfowl or to prevent hazard to life and limb or substantial hazard of fire to property. Even in those cases assessment of the long term ecological hazard must enter into the decision whether to use these countermeasures (detergents, dispersants, sinking agents).

15. As other countermeasures become more effective, the use

of detergents, dispersants and sinking agents should be further curtailed or abolished.

16. Efforts to intensify the natural bacterial degradation of oil in the environment appear promising and should be supported by basic research and development.

17. Ecological damage and damage to fisheries resources are direct consequences of oil spills. In the future, the cost of oil leases should include a fee for environmental protection.

18. Environmental protection funds derived from oil leases should be used to accomplish the necessary research and education in the oil pollution field.

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