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MEMORANDUM

EXTERNAL AFFAIRS DEPARTMENT

H. G. R.
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Attached for your interest is a copy of the latest Exxon Background Series pamphlet, "Fate and Effects of Oil in the Sea;" we have a limited number of pamphlets on hand if you should want additional copies.

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Supervisor, Information Centre

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A background paper prepared by the Public Affairs Department of Exxon Corporation in cooperation with other Exxon departments and affiliates for Exxon and affiliate use.

INTRODUCTION

Oil enters the sea as a result of natural phenomena; it also enters the sea as the result of man's activities. Whether through natural seeps, accidental spills, or long-term, low-level discharges, the presence of oil in the marine environment is to some extent unavoidable.

Just as nature and man contribute to petroleum's appearance in the sea, so do they contribute to its removal. Natural processes, both chemical and biological, degrade the petroleum hydrocarbons. Man, in a more limited fashion, tries to contain and clean up oil spilled into the sea when his efforts at prevention have failed.

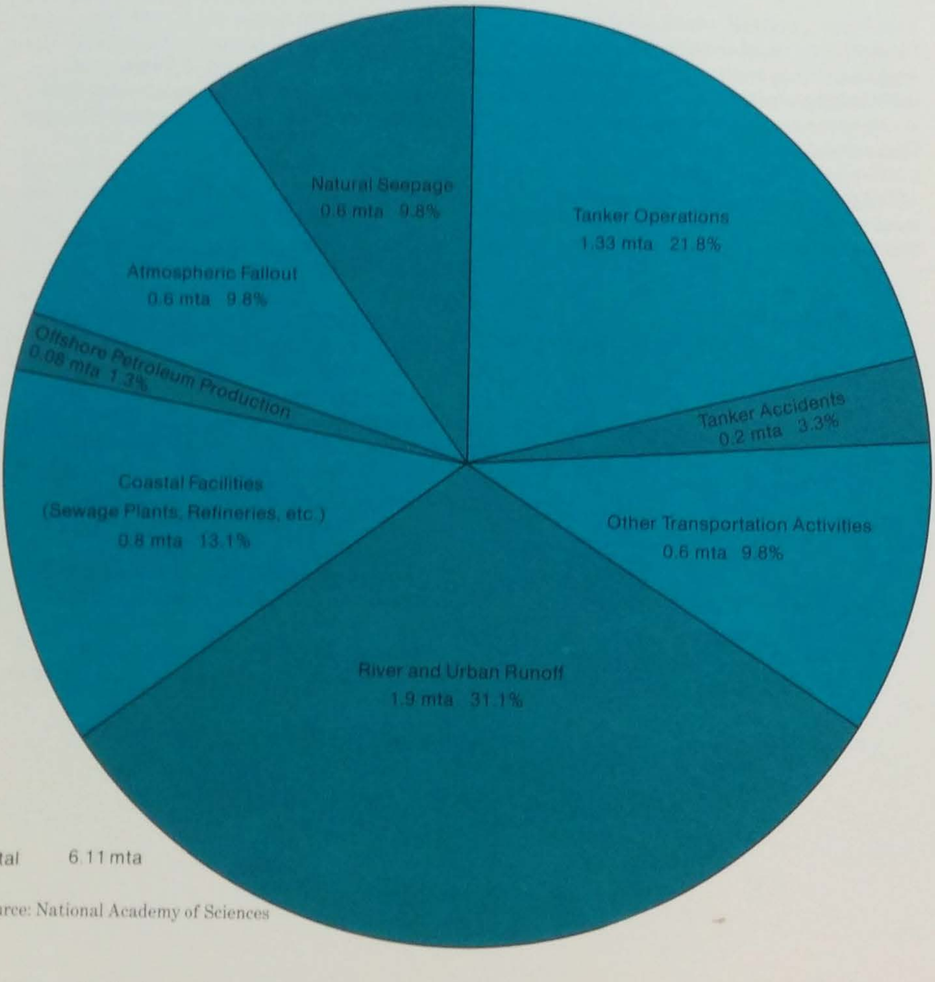
Too much petroleum at any one time or at any one place can be detrimental to marine life and aesthetically unpleasant. It is therefore important to know how much petroleum enters the world's ocean waters each year and what the consequences are. This paper attempts to provide some answers.

INPUTS OF OIL INTO THE SEA

The U.S. National Academy of Sciences, in a landmark study on petroleum pollution published in 1975,* estimated that annually 6.1 million metric tons (mta) enter the world's oceans. More recent estimates are still close to this amount. This petroleum comes from many sources and in differing amounts as shown in the following figure: Approximately one-third of the total petroleum entering the sea is introduced through transportation activities (tankers, dry docking, terminal operations, etc.). The share attributable to tanker accidents, the most newsworthy source, is only a small part of this. River and urban run-off account for another third. Coastal facilities, such as

FIGURE 1

SOURCES OF PETROLEUM GOING INTO THE OCEANS, MILLION METRIC TONS ANNUALLY (mta)



Total 6.11 mta

Source: National Academy of Sciences

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*[*Petroleum in the Marine Environment*, Washington, D.C., 1975.

municipal sewage plants, oil refineries, and industrial plants, contribute 13 percent. Some petroleum hydrocarbons initially go into the atmosphere and then are carried down by precipitation into the oceans. This source accounts for about 10 percent of the total.

Offshore production contributes less than 2 percent of the total petroleum going into the oceans. About three-fourths of this small amount comes from spills of more than 50 barrels and about one-fourth from lesser spills and normal drilling and production operation discharges.

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Hydrocarbons, the principal components of petroleum, are also generated by organisms living in the oceans. The quantity (6 million metric tons per year) of biological hydrocarbons produced by these organisms approximates the amount of hydrocarbons resulting from the sources portrayed in Figure 1. Some of the biologically produced hydrocarbons are identical in chemical composition to the petroleum hydrocarbons, others are chemically quite different.

Most surface and near-surface ocean waters contain hydrocarbons in the range of about 1 to 10 parts per billion (ppb), according to a study performed by Exxon Research and Engineering Company and Exxon Production Research Company with funding from the U.S. Department of Commerce's National Oceanic and Atmospheric Administration. In deeper waters the concentrations are smaller, often less than 1 ppb. One part per billion of oil equals one drop of oil in about 26,000 gallons of water.

Some coastal waters, particularly those in industrialized areas where there is greater probability for hydrocarbon inputs, show higher hydrocarbon levels (up to 100-200 ppb) than open ocean waters. Both petroleum-derived and biologically produced hydrocarbons are present in most samples of ocean water, but there is a relatively higher percentage of the latter type of hydrocarbons in the open ocean.

There is little or no toxic effect of hydrocarbons on marine life at these levels. Most of the laboratory experiments dealing with the toxicity of crude oil or petroleum products are conducted at concentrations which are from one hundred to one thousand times greater than the concentrations measured in the open ocean.

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FATE OF OIL IN THE SEA

What happens to oil once it enters the oceans? In order to develop reasonable contingency plans to control oil spills and long-term, low-level discharges, it is necessary to understand the processes acting on the oil at any given time following its release into the environment.

When a spill occurs, many physical, chemical, and biological processes going on naturally in the ocean act on the spilled oil. Some of the processes are most important immediately after the spill occurs; other processes become increasingly important as time goes on. Figure 2 relates the time following discharge of a crude oil into the sea to various processes of movement and degradation. Line length represents the probable time span of any process while the line width indicates the intensity of the process through time and in relation to other concurrent processes.

Spreading is a rapid and dominant process at the time of a spill, waning steadily until it more or less stops within a week to ten days. The spreading process is controlled by the physical and chemical properties of the oil and the environment into which it is released. In rough seas, wind and wave action play an important role in the distribution of the oil slick. Oil spilled into very cold water may spread at a slower rate, especially if it is a high viscosity oil, such as heavy fuel oil.

Other processes, such as evaporation, dissolution, dispersion, and emulsification, are enhanced by spreading.

The drifting process results from the action of currents, winds, and tides upon slicks. The drifting process is always active, from the moment of a spill until the slick disappears from the surface of the sea. The significance of the drift is dependent upon the proximity of the slick with respect to beaches and fishing grounds or other biological resources. Modeling of drift trajectories is relatively new and involves very complex technology. It can be useful in contingency planning for control of possible spills and, perhaps someday, in assisting oil spill cleanup operations. However, the state of the art is not yet very advanced.

Several techniques have been used to assist in monitoring the movement of oil spilled at sea. Drift buoys which travel with the slick and emit radio signals are now available. The combination of airborne infrared remote sensing techniques with surface samples permits determination of drift, as well as spreading, thickness, and volumes of the oil slick.

Evaporation is the primary initial process involved in the removal of oil from the sea. Evaporation is simply the process of transformation of oil components from the liquid phase to the vapor phase. Rates of evaporation of oil at sea are determined by wind velocity, water and air temperatures, intensity of the sun's rays, roughness of the sea, and the physical properties of the oil.

Through evaporation, an oil slick composed of light, low-boiling components will be rapidly depleted. Some of these low-boiling components, such as benzene and toluene, are among the most toxic hydrocarbons in oil. Thus, their removal decreases the toxicity to marine life of that fraction of the oil remaining on the sea's surface.

Dissolution is another initial process acting on any spilled oil. This process involves the dissolving in the sea water of certain components in the oil. Environmental factors, such as water turbulence, can significantly increase the rate of the dissolution process. The evidence, however, is that dissolution is less important than evaporation.

The process of dispersion results in a mixture of oil with water. Extremely small droplets of oil are incorporated into water in the form of a dilute oil-in-water suspension. The process reaches a maximum rate only a few hours (4 to 10) following a spill but continues for some time. The condition of the sea is probably the single most controlling factor but temperature, oil composition, viscosity, and specific gravity are also significant. Commercially available dispersants can help remove oil from the water surface by this means but, consequently, result in elevated concentrations of hydrocarbons in the water. In open seas these concentrations are rapidly reduced to very low levels. Most toxic components will have already evaporated prior to dispersion.

Water-in-oil (as distinct from oil-in-water) emulsions also may form. As with dispersion, sea conditions are probably the single most important factor in causing emulsions, but the chemical composition, viscosity, and specific gravity of the oil and the water temperature are also important. The rougher the seas, the more active the process. Water-in-oil emulsions form floating semisolid lumps, often described as "chocolate mousse." Most water-in-oil emulsification will occur from a few hours to several days after the spill. Depending on its stability, an emulsion may persist and age to form tar balls or lumps, or it may fragment and disperse as extremely small particles. Tar balls can persist for many years.

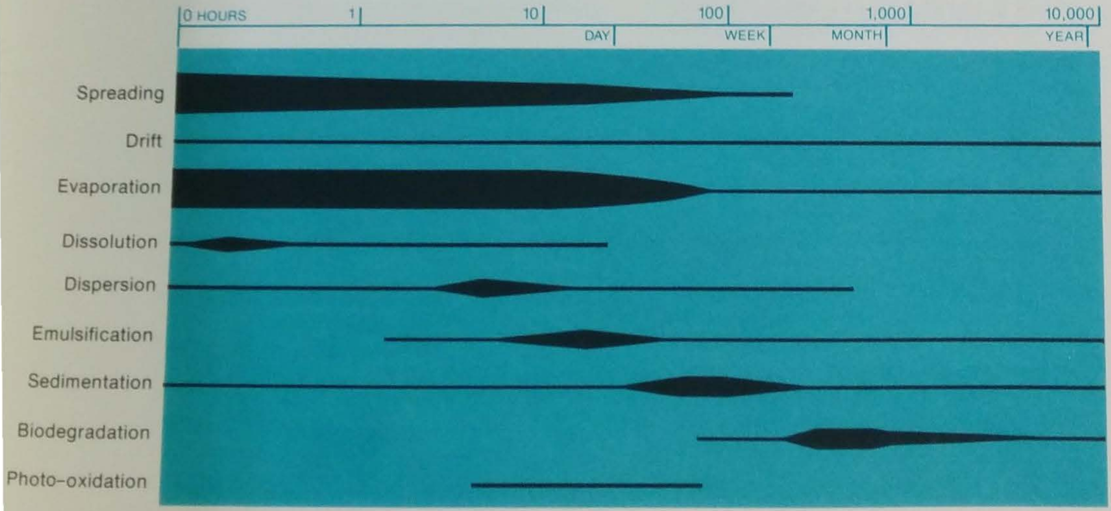
Sedimentation occurs if the specific gravity of the oil becomes greater than that of water or if the churning action of the waves drives the oil into the bottom. Evaporation and dissolution of lighter components may leave a residue of smaller, denser oil particles which can adhere to inorganic sediment. This process is most significant in areas near the shore, bays, and estuaries where the suspended inorganic sediment load is high. Sedimentation may occur throughout the lifetime of a spill.

Biodegradation is an important later process in degrading oil in the sea. Processes, such as evaporation and to a much lesser extent dissolution, remove the volatile components of the oil spill, leaving a residue. This residue may exist at the air-sea interface, in lower water, or in the underlying sediments. Were it not for planktonic (floating in water) and benthic (bottom-dwelling) marine microbes which use the oil as a food source, these oil residues might persist indefinitely. Petroleum-eating microbes (bacteria, yeasts, molds) are found in all the waters and sediments of the world.

Rates of biodegradation are controlled by the availability of petroleum-eating microbes, oil composition, temperature, and nutrient supplies, such as nitrogen, phosphorous, and iron. The lighter or lower molecular weight components are degraded faster than the heavier, high molecular weight ones. In general, higher temperatures increase degradation activities of microbes.

Photochemical oxidation is another process that degrades the oil on the sea's surface. This process is dependent on the intensity of sunlight, temperature, and the chemical composition and the physical state of the oil on the water surface. Studies have shown that as much as 40 barrels of oil spread over a square mile of ocean surface could be degraded in a few days by photochemical oxidation, given an effective eight-hour day of sunlight. The formation of tar lumps virtually precludes further photochemical oxidation because of their low surface area/volume ratios and because light cannot be transmitted beyond the highly degraded, tarry surface.

FIGURE 2



Line Length—Probable time span of any process.
Line Width—Relative magnitude of the process both through time and in relation to other contemporary processes.

Source: Exxon Production Research Company

Numerous research and academic institutions, throughout the world, have contributed to what is known about the effects of oil on the marine environment.

The National Academy of Sciences report, mentioned earlier, expressed the consensus of experts on the effects of oil in the sea. The principal conclusions of that report, generally accepted by the scientific community, were as follows:

- There is no evidence for food chain magnification of petroleum hydrocarbons in marine organisms.
- The most damaging effects of petroleum are the oiling and tarring of beaches, the endangering of seabird species, and the modification of benthic communities along polluted coastlines.
- Fish do not appear to suffer from oil spills as much as seabirds and benthic organisms.
- Different petroleum products have different effects. Toxicity is greatest for refined distillates high in aromatic contents, such as diesel or heating oils. However, physical smothering is most severe with heavy crudes or fuel oils.
- Although information is limited, the effect of oil contamination on human health does not appear to be cause for alarm.

Food Chain Magnification

Numerous studies with a variety of marine organisms have measured the uptake and release of hydrocarbons when the organisms are exposed to oil and when moved to clean water. Their findings show that the majority of marine animals, such as zooplankton, shellfish, and finfish, do accumulate hydrocarbons; but, when removed from the oil source, they purge themselves or break down the hydrocarbons through metabolism.

Because marine organisms do not tend to retain the hydrocarbons they accumulate when exposed to oil, it seems unlikely that magnification or increase in hydrocarbon levels will occur when larger organisms feed on smaller organisms in the natural food chain in the oceans. This biomagnification does occur with certain other pollutants, such as mercury, and possibly insecticides, such as DDT.

Oiling and Tarring of Beaches and Shorelines

Oil on beaches is the form of oil pollution most obvious to the public and affects it directly. Most of the oil can be removed by natural processes and modern cleaning techniques, but some oily residues, if buried, can persist for long periods of time.

On rocky coasts, oil may be deposited on rocks, usually in the upper part of the tidal zone, but most of it will be removed by surf action. In the splash zone, the oil will be gradually removed by weathering. The process of natural cleansing is slower with sandy beaches because the oil tends to become buried in the sediments. In bays, estuaries, and marshes, where fine sediments occur, natural cleansing by wave action is slower yet and any buried oil may remain for long periods of time.

In protecting coastlines from oil slicks, it would therefore appear that bays, estuaries, and marshes should be protected first. Since these environments are rich in organic life, there is an additional incentive to protect them.

Effects on Bird Population

Oil causes immediate and serious external harm to birds by destroying the waterproofing and insulation provided by their plumage. Harmful internal effects also emerge as the birds ingest oil in attempting to remove it from their feathers.

Not all seabirds are exposed to the same extent, nor are the long-term consequences the same for each species. The greatest risk is to species that congregate in flocks, in both breeding and wintering areas, and especially to those species that frequent offshore waters or whose migration paths take them near busy shipping lanes. The northern hemisphere species most susceptible to oil pollution are auks, followed by sea ducks.

Various strategies to protect seabirds have been proposed. Among these are reducing exposure to oil through scaring devices and dispersion of oil slicks, breeding in captivity, and research to discover ways of increasing reproductive success.

Effects on Benthic Communities

One of the more adverse effects of oil in the sea is believed to be the harm done to organisms living on bottom sediments along coastlines impacted by spilled oil. Those organisms living in the tidal zone and just below seem to be the most susceptible.

However, recent studies by a number of investigators show that these effects may not be as severe as was feared earlier. Studies in Louisiana bay waters near active oil drilling and production activities show that the distribution, density, and diversity of marine plants are a product of the natural environment and have not been significantly affected by 40 years of drilling and production activities. Offshore platforms in the area serve as artificial reefs and provide anchorage for more than 60 species of benthic plants. These plants are heavily grazed by fish living near the platforms.

In the North Sea biological surveys were conducted by Great Britain's Orielton Oil Pollution Research Unit in the vicinity of Ekofisk oil field in 1973, when it still was that new oil province's largest oil find. The surveys showed relatively uniform distribution of bottom-dwelling organisms throughout the area, near the center of the field and along transects up to 4 miles distant from the field. No evidence of significant ecological damage was detected.

In August 1974, the supertanker *Metula* went aground in the Strait of Magellan off the coast of Chile. Approximately 54,000 tons of oil was released into the sea and much of it came ashore. Benthic plants and animals living in the intertidal zone suffered appreciable immediate damage. When University of Southern California scientists studied the area in January 1975, they already noted signs of recovery. Subsequently, continuing gradual improvements have been observed by these and other scientists. Marsh plants had started growing through the oil residue. Mussels, however, were scarce in these oiled areas.

Effects on Fisheries

Fish are not affected by oil pollution as much as seabirds or bottom-dwelling organisms. They live and thrive in many offshore areas where oil is produced. Offshore Louisiana, where oil and gas wells have been producing since 1937, sport and commercial fisheries thrive. From 1950 to the early 1970s, when oil drilling and production activities increased significantly, the amount of fish and shellfish caught showed no decline. Similarly, in Lake Maracaibo (Venezuela), where oil production has been occurring for some 60 years, there is no evidence that fisheries resources are being depleted. Nor is there evidence of a detectable buildup of hydrocarbons in fish muscle tissue from the low, chronic concentrations of petroleum in Lake Maracaibo waters.

In offshore California waters near two oil producing platforms, a fish survey was conducted in 1976. A diverse (more than 40 species) and abundant (average of 20,000 fish under each platform) fish population abides there. Tissues from fish, mussels, and crabs showed no oil contamination. These platforms have been producing oil for more than 15 years.

During a five-month wartime period in 1942, some 500,000 tons of crude oil and refined oil spilled into the Atlantic Ocean within 50 miles of the U.S. eastern coast through the sinking of some 100 ships. Investigations revealed no evidence of oil-caused catastrophe to fish populations.

In December 1976, the tanker *Argo Merchant* ran aground and spilled approximately 26,000 tons of fuel oil into U.S. eastern coastal waters some 30 miles off Nantucket Island. Rough seas and high winds tended to drive the oil southeastward away from the U.S. coast, off the continental shelf, and into the Atlantic Ocean circulation patterns. Biological studies showed some evidence of oil contamination in fish, shellfish, and plankton. However, there was little adverse effect on fish trawling off the Rhode Island and Massachusetts coasts during the period December 1976 to March 1977. Of 900 fishermen interviewed, only 26 reported environmental damage, mostly to seabirds. Only two of the fishermen indicated problems associated with the fouling of fishing gear in the oil slick waters.

In April 1977, the North Sea's first large oil spill occurred from the Ekofisk Bravo platform blowout and released between 12,000 and 20,000 tons of crude oil over a nine-day period. Chemical analyses by different laboratories revealed that hydrocarbon levels in the water were not high enough to endanger marine life. No apparent serious damage to fish or seabirds has been reported to date.

In March 1978, the world's largest oil spill (226,000 tons of light crude oil) occurred near France when the supertanker *Amoco Cadiz* went aground and broke up one mile off the Brittany coast. The oil slick was extensive and affected more than 100 miles of coastline. Fish, as well as birds, were severely affected immediately after the spill. In a few months, the rocky coast and sandy beaches were mostly clean of oil where the coast was exposed to high energy wave action. The shallow bays and estuaries showed oil contamination. A three-year study of the biological effects of this spill is planned by a joint French-U.S. team of scientists. The results of this study will shed much light on this important subject.

Effects on Human Health

As to the effects of petroleum pollution on human health, the NAS report, *Petroleum in the Marine Environment,* concluded there was no cause for alarm, although the amount of information on this subject was limited. Most of the concern arose from the introduction into the marine environment of polycyclic aromatic hydrocarbons (PAH), some of which are known to be carcinogenic. However, these hydrocarbons, like the PAH introduced by nature, ultimately degrade, mostly by light-induced oxidation processes. The physical, chemical, biological, toxicological, and epidemiological studies on PAH in the marine environment, thus far carried out, support the belief that there is no cause for alarm for man's health.

SUMMARY

1. Best estimate of the annual input of hydrocarbons into the sea is about 12 million metric tons.
2. About half of the hydrocarbons found in the sea is generated by natural biological and chemical reactions. The remainder is introduced into the sea mostly by the action of man.
3. Most surface and near-surface waters in the open oceans have from 1 to 10 parts per billion total hydrocarbons. Waters near ports and industrialized areas contain higher levels, up to 200 parts per billion.
4. What happens to oil released into the marine environment involves many physical, chemical, and biological processes.
5. Evaporation is the most important initial process in removing oil from the ocean's surface. Its importance diminishes with time as the more volatile components in the oil are removed.
6. Drifting of oil slicks is another important factor; driving forces are the currents, winds, waves, and tides. A slick's geographic location relative to biological and recreational resources is of particular significance.
7. Biodegradation is an important decomposition process for removing petroleum from the ocean, particularly during the later stages of a spill.
8. There is no evidence that oil is magnified through the marine food chain, as occurs with certain metals such as mercury.
9. Estuaries and marshes appear most sensitive to the introduction of oil, whether in large or small doses. Rocky coastlines appear most resistant to oil contamination.
10. Among organisms, birds and bottom-dwelling creatures are most sensitive to petroleum.
11. Finfish, particularly adults, are more resistant to oil than most other marine organisms.
12. Information is still limited, but the effect on human health of oil at current levels in the sea appears not to be cause for alarm.

CONCLUSIONS

This paper has presented information which may be useful in assessing the nature and extent of the problem created by the presence of oil in the sea. The facts given suggest that to some extent the problem is both natural and self-correcting. But that does not mean that concern about identifiable adverse effects is illegitimate. Quite the contrary. All whose activities may contribute to the problem, including the petroleum industry, need to do everything they reasonably can do to minimize such effects.

As far as the petroleum industry is concerned, prevention of the release of oil into the sea, as well as perfection of containment and cleanup technology, continue to warrant a high priority. There is a special need to identify high-risk shorelines and to develop comprehensive marine casualty response plans to protect them.

Future research should be broadened beyond oil spills to include the effects of long-term, low-level hydrocarbon exposure on marine organisms. Such research will be expensive and probably will need to be funded cooperatively by government, industry and other private sector groups.

The following papers in the Exxon Background Series are available upon request from the Public Affairs Department, Exxon Corporation, 1251 Avenue of the Americas, New York, N.Y. 10020.

Reducing Tanker Accidents

Environmental Conservation—A Progress Report

Very Large Crude Carriers (VLCCs)

Middle East Oil

World Energy Outlook

The Offshore Search for Oil and Gas

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