Chapter 1

The Problem—Oil Spills

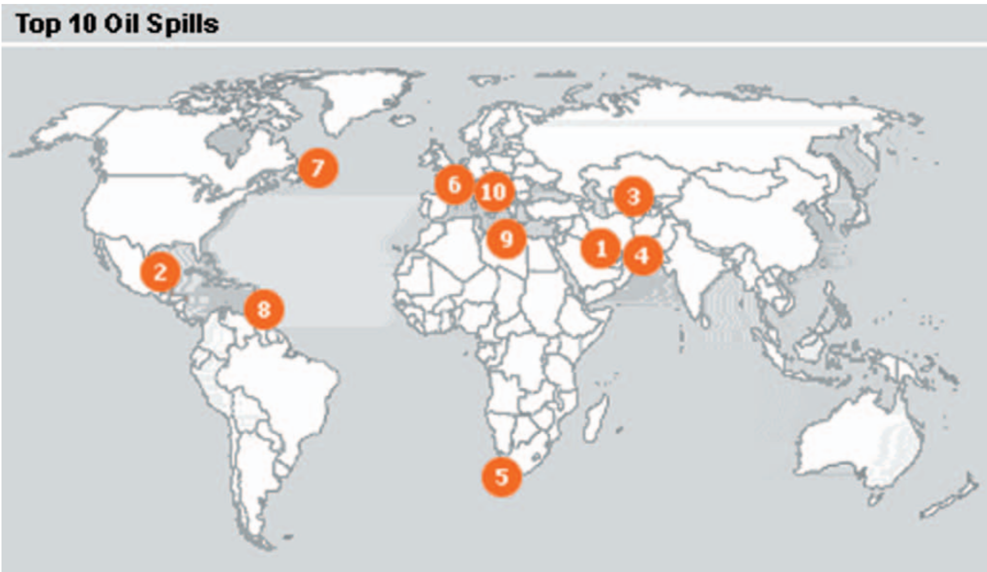
Oil spills present a unique public dilemma. Statistics indicate that human error causes 80% of the major oil spills. Society and economic development require the economic benefits from selling and transporting oil. While consumers experience these benefits from available oil, the negative impacts from spilled oil are far-reaching, economic, social and environmental. These are in addition to the money spent on the clean-up response, which may be passed on to the consumer subsequently. On a global basis, the size and number of oil spills are declining. As a source, these spills fortunately represent less than 5% of the oil contamination in the global oceans. But, even this limited percentage of pollution represents a concentrated point source that can significantly affect certain marine ecosystems.

By Wright, *Providence Journal Bulletin*, reprinted in *The Alameda Times-Star*, July 7, 1989.

Oil Spills First Principles: Prevention and Best Response. Edited by B.E. Ornitz and M.A. Champ

Data suggest that low energy coastal ecosystems, such as wetlands, marshes and beaches may need 50 years to fully recover from the impact of an oil spill. On a global basis, response to oil spills and clean-up can be quite different depending upon who pays for it and the extent of the clean-up. The concept of the "polluter pays" is the major difference between the International and US regimes. The complete concept as interpreted in the US under OPA 90 includes the costs for the clean-up and full restoration of the environment. The oil transporting industry is a global and Flag State based industry that is required to adhere to both national and international regulations and recent changes in public perception. The industry would prefer to have greater limitations of liability for clean-up and to use "natural" restoration processes over time for full restoration of the environment. However, with the world's population estimated to double by 2050, which subsequently should double the volume of oil transported and the number of tankers and spills, the international viewpoint may not be good for business in the future, because of the undergoing change in public acceptance of this damage to the marine ecosystems.

If, in the future, the number of choke points and high-risk spill zones stays the same, the probability of the number of spills and the annual volume of oil spilled in specific areas will increase as well. The effect of this increase is that certain ecosystems will be in some state of constant degradation, either being impacted or in recovery from oil spills. Unless we can delineate the root-causes and risk factors for oil spills to prevent these spills in the first instance and integrate better science and engineering into planning, training and response processes, the world's coastal marine resources will be seriously degraded over time.



Sites of top 10 oil spills.

The current legal, regulatory and convention framework affecting the transportation of oil by ship reflects a recent change in public attitude, which mirrors this dilemma, an insistence upon protection of the world's marine environments, and in particular, coastal ecosystems. This public concern places those linked to shipping in a position of making crucial decisions, which may well determine their future ability to conduct business.

There are significant legal and political motivators for a cultural shift by the industry, from an "evasion" to a "safety" culture. Those ship owners/operators who cut corners, shave costs, evade regulation and fudge on safety are facing a smaller and less rewarding arena in which to operate. Even those companies, which merely comply with minimum regulation and depend upon the responsible agencies to enforce the body of law governing the business of oil transportation, are finding themselves in positions of increasing risk. The new "safety" culture connotes continuous improvement in ship operations and a willingness to adopt the evolving safety culture concepts and a paradigm shift from the freedom of the seas. The high costs, (whether the consumer or the polluter experiences them) including environmental damages, from oil spills mean that the shipping industry must incorporate good science into each stage of decision making, in oil spill prevention and response.

1.1. Freedom of the Seas—Developing Law

For as long as ships have sailed the seas, man has done so with impunity. The "Right of Passage" through territorial waters has guaranteed the "freedom of the seas" (*mare liberum*) across the world's oceans. Until the recent past, the only judicially recognized constraint on maritime conduct was that established by international customary law, the principle that a nation (state) should *not* conduct its maritime business on the oceans in such a way as to *abuse the rights* of another nation. The growing recognition that ocean resources are not inexhaustible and that pollution poses a threat to marine ecosystems led to the development of national and international regulations for the transport of oil and the prevention of oil pollution. The first attempt to codify the Law of the Sea and create some limits upon this unfettered freedom occurred in a series of United Nations Conferences, which concluded in 1958 in Geneva. The conference resulted in the expression by treaty of two competing concepts:

(1) *Convention on the High Seas* (UN, 1958a) assured the supremacy of the Flag State, giving each nation freedom of navigation, the right to extend sovereignty to vessels registered under its flag, and absolute jurisdiction over their design, manning, and standards, as well as the right of enforcement of any legal or disciplinary process in the event of an incident of navigation on the high seas. To effectuate this treaty, states were to craft national regulations to prevent pollution of the seas.

(2) *Convention on the Territorial Sea and Contiguous Zone* (UN, 1958b) qualified this absolute regime by establishing the basic rule of limitation: "right of innocent passage". Passage through territorial waters of a state is guaranteed "so long as it is not prejudicial to the peace, good order or security of the coastal state". Even with the confirmation of "innocent passage" as an expressed principle, the two warring interests between Flag State supremacy and Flag State obligations continued. The primary concern affirmed by this Convention was that such passage not be "hampered" leaving enforcement of local regulation to a subsequent time and method other than direct interference with the vessel (Guruswamy et al., 1994).

Initially at the UN, the early focus on marine pollution was from ships, in which the concern was from the discharge of oil in bilge waters at sea. This led the UN to create the Intergovernmental Maritime Consultative Organization (IMCO) in Geneva in 1948. IMCO was subsequently renamed the International Maritime Organization (Convention effective as of March 1958). The Convention delegated to IMO the task of administering appropriate international treaties concerning pollution from oil and other substances from vessels. This administration includes among other tasks, facilitating intergovernmental cooperation, exchanging information on technical matters affecting shipping, and ensuring high standards of maritime safety. IMO generated conventions that form the framework for subsequent regimes governing international prevention, response, enforcement, and compensation for oil spills. These conventions are the subject of discussion in Sections 3.5, 4.2 and 4.3 of this book (IMO, 1998a).

The 1982 *United Nations Convention on the Law of the Sea* (UNCLOS) was the first comprehensive international agreement on the marine environment and the first real codification of then customary international law (UN, 1982). UNCLOS balanced the competing interests of coastal states and maritime nations. UNCLOS clarified the meaning of "innocence" in the phrase "right of innocent passage" to include among those activities considered prejudicial to a coastal nation, "willful and serious pollution" of its waters. Recognizing the "hybrid" nature of seas and oceans, that they are both global and national, UNCLOS mandates a regime that ensures that activities of states will not pollute the environment of other states beyond their sovereign jurisdiction. Nations must control all sources of pollution, including pollution from vessels caused by both intentional and unintentional discharges. The convention expanded the concept of global sovereignty and granted countries greater jurisdiction over their coastal waters to include the 200-mile Exclusive Economic Zone (EEZ) for research, exploration and preservation of natural resources (Champ, 1984, 1984/1985). UNCLOS designated global authority over seabeds, making nation states responsible for their environmental protection.

Of equal significance for future pollution control, UNCLOS created a clear concept of Port State control. Each coastal state has the right to adopt laws and regulations to preserve its environment, prevent, reduce, and control the pollution. Therefore, Port States can enforce rules against environmental damage to the oceans no matter where such damage occurs, once a ship voluntarily enters that country's port. This right is balanced by dispute settlement requirements involving control by the Flag State when a vessel flying its flag is alleged to have acted contrary to the treaty provisions for rights of navigation and preservation of the environment. UNCLOS entered into force on 16 November 1994.

UNCLOS was an important first step in international law, or the body of rules that governs relations between states. The Law of the Sea Conference started a process of consensus building whereby participating nations reached "final agreement by consensus," using the "power of international cooperative effort" (Clingan, 1992). IMO has continued this important precept to create the current regulatory body of law, which governs the oil shipping industry today. Subsequent treaties expanded control over marine pollution, which UNCLOS began, in three important areas:

- Standard setting;
- Enforcement of global provisions internationally and nationally; and
- Dispute settlement through international forums (Guruswamy et al., 1994).

The historical dispute between the competing principles of open seas and restricted travel, between Flag State and Port State jurisdiction, exists today. However, increasingly, since passage of UNCLOS, preservation of the environment has framed the debate and set the benchmark for regulation of foreign ships passing through coastal states' territorial waters. The legal framework of international conventions and US laws and regulations affecting the shipping industry reflects a change in public attitude about liability for oil spills.

1.2. Major Oil Spill Rates

Comparing data from several published sources (NRC, 1985; Anderson and LaBelle, 1994, 2001; DeCola, 1999) for the number of major oil spills (100,000 gallons or more/700 tonnes or more) and quantity of oil spilled with statistics from 10 to 25 years ago, lead to a positive conclusion that prevention strategies, regulations and treaties are working. The volume of oil spilled and the number of large spills are decreasing worldwide.

Globally, the data reported by national and international sources indicate a dramatic *decrease* in oil spills from ships, with a reported reduction of as much as 60% during the past 25 years, according to a study performed by the US National Academy of Sciences in the United States (NCR, 1985; Anderson and LaBelle, 1994, 2001; IMO, 1998a).

In addition, data from the International Tanker Owners Pollution Federation (ITOPF) databases also support this general assertion. ITOPF, has maintained a database of oil spills from tankers, carriers and barges since 1974. According to this database, the trend is toward decreasing spills:

- *Number of spills:* Per ITOPF figures, major spills of 700 tonnes or more have decreased. By the end of the 1980s the average number of major oil spills each year had dropped to one-third of that witnessed in the previous decade. From 1970 to 1979 there were 24.2 spills per year average, compared to 1980–1989, with an average per year of 8.9 major oil spills. From 1990 to 1997, this figure decreased further to 7.8 spills per year (Moore, 1999).
- *Quantity of oil spilled:* The vast majority of spills is less than 7 tonnes, and as such considered small spills. The data are incomplete for these types of spills. For spills greater than 7 tonnes, annual estimates are available for oil spilled. The comparison shows reduced quantity of oil spilled. For example, in 1970, 301,000 tonnes were spilled compared to the 1998 figure of 10,000 tonnes for spills greater than 7 tonnes. It is difficult to judge the comparative impact of regulation and prevention activities over a period of time, because any one incident can skew the data. For example, in the 10 years from 1989 to 1998, there were 366 spills of more than 7 tonnes per spill, which produced a total oil volume of 1,251,000 tonnes. However, 893,000 tonnes or 71% of the total came from 10 incidents, or less than 1% (ITOPF, 1999).

In the US, several distinct databases confirm the same trend of significant reduction of oil spilled for US waters. These sources include:

- US Coast Guard (1999) figures from 1982 through 1998, and 1999;
- American Petroleum Institute's (API) comparison of spills between 1987 and 1996;
- Cutter Information Corporation's Oil Spill Intelligence Report (1998) tracking of oil spills from 1962 through 1996; and
- INTERTANKO (1999), International Association of Independent Tanker Owners.

The findings can be summarized best as follows: All studies show a downward trend in oil spills in the US, specifically:

- Since the passage of OPA 90, the gallons spilled per million gallons of oil and chemicals shipped have decreased. The gallons spilled per million shipped have been reduced from an annual average of 14 gallons for the years 1983–1990 (pre-OPA) to 5 gallons spilled per million shipped from 1991 to 1998, a decrease of 64% according to US Coast Guard figures (Williams, personal interview, 1998, personal communication, 1999). Also, the average number of oil spills over 10,000 gallons has dropped by approximately 50% from pre-1991 levels. From 1994 to 1997, 1.5 gallons of oil were spilled per million gallons shipped. The annual oil spill volume from tanker ships, which contributes about 75% of the volume spilled, remained below 200,000 gallons for each year from 1991 through 1995 (USCG, 1997, 1999a).

- The most recent analysis, completed by the US Coast Guard in November 1999 indicates continued decreasing numbers of spills and amount of oil spilled in US waters. In spite of increased consumer demand, a review of statistics from the years 1973 through 1998 reveals a steady downward trend in oil spills in the US and in the volume of oil spilled. The significant findings are: (1) that 87% of all spills in this time period are between 1–100 gallons; (2) over 76% occurred on internal waters out to three nautical miles offshore; (3) of volume spilled, tank vessels generated almost 47%; and (4) the predominant oil spilled is crude or heavy oil, accounting for 62.5% of the total volume spilled (USCG, 1999b). These data are available on the Internet at the following URL: http://www.uscg.mil/hq/g%2dm/nmc/response/stats/aa.htm
- API (1998) reports a downward trend based on a 10-year comparison. From 1987 to 1991, the spillage from transport vessels decreased about 81%: an annual average of 5,943,000 gallons of oil spilled from freighters, barges and tankers in US waters, compared to an annual average of 1,142,000 gallons from 1992 to 1996. Tanker spills declined from an annual average of 4,010,000 gallons between 1987 and 1991 to 160,000 gallons from 1992 to 1996 (for a 96% decrease). Barges decreased oil spillage in the same comparative time frame by 51%. In 1996, the number of oil spills reported declined by about 10%, by more than 900.*
- Cutter Information Corporation's (Etkin, 1998) analysis of oil spills in US waters supports the same downward trend. Of a total of 195 tanker spills between 1960 and 1996, or almost 180 million gallons, 1996 accounted for 5 spills of 381,000 gallons (1296 tonnes). In the same 36-year period, 284 barge spills released almost 48 million gallons of petroleum into US waters. In 1996, seven barge spills released only a fraction of this total, 1,184 million gallons (4.027 tonnes). All other vessels, including non-oil cargo vessels, fishing boats, passenger ships and freighters, spilled 14,706 million gallons (50,020 tonnes) from 147 oil spills between 1960 and 1996, while there were only 5 spills in 1996 in the other vessel category, accounting for 112,000 gallons (381 tonnes).
- The preliminary estimates for 1999 spills indicate that the volume of oil spilled worldwide (of more than 10,000 gallons per spill) may be comparable to the 32 million gallons (109,000 tonnes) spilled in 1998. However, a closer review of the actual spills shows that a number of these occurred in ecologically sensitive areas at the unfortunate or "wrong times", such as during nesting season. For example, the Maltese freighter *Erika* broke up in France in the Bay of Biscay, causing extensive damage to shorebirds because of the time of the year when the spill occurred (OSIR, 2000a).

* This sum represents " …about one-thousandth of one percent of the 281 billion gallons of oil consumed by Americans during the year". The number of spills greater than 10,000 gallons, considered large spills, was the third lowest total per year over a 10-year period (API, 1998).

- USCG data indicate that the post-OPA 90 rate for incidents has decreased significantly to 0.5 major oil spills per year. No large spills of over 5000 barrels from tankers have occurred in the US since 1991 (Moore, 1999).
- INTERTANKO (1999a) data support the finding that spills from oil tankers have declined in US waters from 27% in the 70s, to 24% in the 80s, to 12% in the 90s.

The unanswered question is whether these trends will continue in the future, given some seemingly unchangeable realities. More oil will move to more people around the world, 75% of which will be carried by vessels. The following gives concern for the continued safe transport of oil by ship:

- Doubling of the world population from 6 billion in 1999 to 10.6 billion people in the next century, consistent with the UN projected growth factors (Brown et al., 1998).
- World fossil fuel energy consumption increasing annually with the US being the greatest energy consumer and with no sign of decreasing or alternative energy use in sight for the US and other developed countries (Olah, 1997). Oil consumption globally rose from a few thousand barrels of oil daily in 1900 to 72 million barrels a day by 1997 (Brown et al., 1998).
- Americans consume 281 billion gallons of oil annually (API, 1998). This equates to 294 million gallons of oil per day moved by tankers, or 107,310 million gallons of oil per year, 30% of the worldwide waterborne oil moved and imported to the US, with more than 4000 tanker port calls (INTERTANKO, 1999a).
- The current 67% consumption of oil for transport fuel is projected to increase to 80% in the forecasted future. By 1997, some 1600 foreign freight ships and 5800 foreign freight vessels moved through US waters, transporting petroleum products and accounting for 90% of all US port calls. Oil imports will experience continued growth, projected at 3.0% per year in the next decade (USCG, 1997).
- In 1998, the total crude oil and refined products transported by sea amounted to more than 2000 million tonnes, which in weight terms represented 40% of the total cargoes shipped by sea (Commission of the European Communities, 2000).

The fact that more oil moves to more people does not necessarily equate to more spills. Global transportation of oil has increased since the mid-1980s. Yet, the ratio of billion tonne-miles of seaborne oil trade to oil spills greater than 7 tonnes since 1974 has declined (White, personal communication, 1999). ITOPF concludes that even with an increase in seaborne oil trade, now approaching the high levels of the mid-1970s, the number of oil spills remains low (ITOPF, 1999a). Even though this analysis provides some comfort, the expected population growth and oil consumption levels and other statistical factors cited above do not allow for complacency in any sector of the oil transportation industry.

While statistics are meaningful, one oil spill like the *Exxon Valdez* spill of 1989 can bring about great annual variation in the total quantities of oil spilled. The figures

Anonymous, *AP*.

of a particular year may (therefore) be severely distorted by a single large incident (ITOPF, 1999). Captain Malcolm Williams, USCG, former Chief of the Office of Maritime and International Law, agrees with this statement.

> "The good news is that the total volume of oil spilled and the number of spills have declined. The fact the amount spilled annually has significantly declined strongly suggests that something is happening out there. Either the evasive shippers are getting weeded out or many have decided to initiate programs like the American Waterways Operators and others to be more responsible carriers. But, every now and again something happens as in the *Berman* spill in Puerto Rico. Big spills are still happening internationally. In the large spill category (>100,000 gallons) the numbers are down. But, the recent two large spills off Scotland and Wales, can greatly impact *statistics* about gallons spilled per million carried. The trends still show fewer spills and less oil in the marine environment. While a major spill could impact dramatically the statistics about gallons spilled per million gallons carried, the trend of fewer spills would not be affected. The *real* message is that the US Coast Guard and others have to continue to be vigilant, employ new technologies for prevention and response, and vigorously implement lessons learned from accidents and spills, notwithstanding the encouraging oil spill trends and statistics" (Williams, personal interview, 1998; Williams personal communication, 1999).

In the future, oil spill statistics may be heavily influenced by the following factors: (1) Increased population and corresponding worldwide consumption of oil; (2) increased vessel traffic through the same choke points; and (3) the fact that the global fleet is aging. Larger, safer and double-hulled (or equivalent alternative) vessels are a focus for the new millennium. Certainly, the unchangeable reality of these factors suggests a need for increased vigilance, continued action in preventing oil spills in the first instance, and then, when oil does spill, improved response capability through better integration of science and technologies.

1.3. Environmental Damage—The Debate

The amount of oil from natural seeps in the world's oceans and from land based sources (riverine transport and runoff) is significant in comparison to the amount spilled from ships. However, a point source of spilled oil creates potentially long-term environmental damage to natural resources and ecosystems, which is recognized as "pollution". During the development of the London Dumping Convention, many debates were held about the etymology of the term "pollution". Early debates argued that "pollution" included also the transport of sediment and contaminants during floods because of similarity of impacts from man made pollution events (discharges, spills, etc.). However, these natural catastrophic events were realized to be short-term natural events ($<$14 days) and not of longer-term as were man made events with more permanent environmental change or impact. This led to the development of a formal definition of pollution by GESAMP (Champ, 1983).

GESAMP, (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection) acts as an advisory body of specialized experts to the International Maritime Organization (IMO) and other international groups. GESAMP has defined "marine pollution" as follows:

> "Pollution means the introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities, including fishing, impairment of quality for use of seawater and reduction of amenities" (GESAMP, 1993).

Oil in appropriate concentrations is a toxic substance, which can affect marine organisms. Over the past 20 years, since the *Amoco Cadiz* 1978 oil spill, there have been numerous studies of the fate and impact of oil on marine biota. There is a strong difference of opinion among scientists conducting these studies about the ultimate impact, in terms of length and severity of disturbance on various marine organisms and ecosystems. That debate continues today and frames much of the disparity between the US and the international community in terms of:

By Jeff MacNelly, *The Daily Review*, May 22, 1989.

- Response techniques;
- Extent of restoration activities for damaged resources; and
- Compensation granted/awarded for natural resources following an oil spill incident.

In 1993, GESAMP issued a generalized statement, which contains the kernels of two prevailing theories of impact and distills the essence of the ecological debate on the effects of spilled oil. Spills in high-energy environments (open ocean, rocky shores, etc.) may not pose significant, long-term disturbance to ecosystems. Oil spills in low-energy environments (marshes, mangroves, beaches) may, on the other hand, lead to longer-term environmental impacts:

> "Marine birds and mammals are visible victims of oil spills, and concern for chronic sublethal effects caused by spills in low-energy, shallow coastal waters and shorelines is increasing. Some habitats, such as exposed rocky shorelines, recover quickly from oiling events. Other ecosystems, such as mangroves, salt marshes, seagrasses and coral reefs, and polar habitats, are particularly vulnerable and sensitive to oil spills, and may take years to recover" (GESAMP, 1993; Hayes, 1999).

In spite of disagreement as to particulars, review of numerous studies, both laboratory based and in the field, of differing spills over years yields some consistent observations about the potential of harmful effects of oil on marine biota. The harm can best be generalized for many species:

- Larvae and juveniles are particularly susceptible, and may often die on direct contact or when they ingest oil. The loss of juveniles or smaller prey leads to a reduction of food sources (Caldwell et al., 1977; Michael, 1977; Tatum, 1977; Teal, 1977; Thomas, 1977, Straughan, 1977; summary panel discussion in Wolfe, 1977);

- Adults can be affected by being coated with oil on skin, feathers and gills, and/or be asphyxiated from inhalation of oil. In addition, they can consume oil by ingestion of oil contamination in or on food chain organisms (Albers, 1992);
- Animals coated with oils can die of hypothermia (Kooyman et al., 1977);
- Marine organisms far removed from an oil spill may experience exposure from transported oil, and from sublethal ingestion of oil from coated or contaminated food sources. High exposure levels can alter immune resistance (Laughlin and Neff, 1977; Lee, 1977; Staniken, 1977; Teal, 1977);
- Marine plants and wildlife may experience changed habitat, with resulting significant disruption of feeding and reproduction (Ladner et al., 1982; Suchanek, 1993);
- Other direct impacts can range from neurological disruption to anemia (Ladner et al., 1982);
- Recruitment of certain biota may be dramatically reduced by oil, as for example, algae and intertidal grazers (limpets and snails) (Duncan and Hooten, 1996); and
- Oil may persist in the marine environment (Hays, 1999).

The impact of oil on marine ecosystems varies due to the degree of oil spilled and the length (time period) of exposure. In general, long-term acute and chronic exposure levels are both toxic and hazardous to marine organisms. There is an exception to this rule in the unique situation in coastal areas, or thermal vents where natural long-term oil seeps and methane seeps have existed for many years with resulting specialized ecosystems. These specialized benthic communities have evolved over eons to be chemosynthetic in that they are able to degrade these hydrocarbons as energy sources (MacDonald et al., 1990). These situations demonstrate the adaptability of marine organisms and the fact that acute and chronic toxicity is both dose and period of exposure related. Certain ecosystems can tolerate and possibly even benefit from low level inputs of material, which become toxic to the organism when a certain threshold level is reached (Shigenaka, personal communication, 1999).

Even with some agreement as to generalization of the impact of oil on marine ecosystems, there is a wide divergence of opinion as to length, severity, and permanence. What emerges from this difference of viewpoint is that a gap exists in our understanding of the biological effect of oil on the overall marine environment. This was first evidenced in the US National Academy of Sciences Report (Anon, 1975), which was a summary of the impact of Petroleum in the Environment (see Anon, 1978; Bourderu and Treshow, 1978; Connell and Miller, 1984; McIntyre and Whittle, 1975).

In 1989, the *Exxon Valdez* ran aground on Bligh Reef in Prince William Sound, Alaska, spilling about 37,000 metric tons of North Slope oil, which spread across 1750 km of pristine shoreline. *Exxon Valdez* is illustrative of the on-going argument. The question: has *Prince William Sound Recovered?* receives answers from scientists across the board: “yes and no”. The reason depends upon many factors, what type of

The *Amoco Cadiz* ran aground off the coast of Brittany, France, on 16 March 1978, spilling an estimated 68.7 million gallons (230,000 tonnes) of oil, of which a significant part became stranded in low energy environments: salt marshes and estuarine river mud flats and buried within sandy beaches. This spill is listed as number 6 on the list of the largest oil spills of all time. Photography courtesy of NOAA OR&R Photo Database.

marine organism is being studied, how long after the spill, and what the known pre-spill state of the environment was. The structure of these studies, their design features, the control sites taken for baseline data, the sites chosen for the studies, as well as the analytical approaches selected have impacted the emerging results.

While some argue that crude oil still remains on stream banks where tides can flush the hydrocarbons out to impact salmon embryos at low concentrations, others suggest that even such residual oil is relatively lacking in toxicity because it is so weathered (NOAA, 1999). The lack of pre-spill information makes post-spill analysis complex, as does the "high degree of variability in the Prince William Sound environment". "Things change" making it hard to separate the effects of oil from the natural fluctuations that such a dynamic environment faces in the natural course (NOAA, 1999).

An overall summary leads to both a positive and negative answer to the question about recovery. Rapid increases in *Fucus* (an intertidal algal species commonly called Rockweed), and other infaunal and epibiotic species (those living on the surface or substrate) occurred between 1989 and 1991 at oiled and washed sites, such that plant abundance basically indicated recovery in Prince William Sound, Alaska. However, Shigenaka, a marine biologist cautions that this analysis of recovery trends over time is based on a "gross measurement", abundance (Shigenaka, personal communica-

By Jim M. Borgman, *The Cincinnati Enquirer*, July 5, 1989.

tion, 1999). Although the measurement is a gross one, it is striking in its consistent occurrence in some taxa. However, this abundance may simply reflect the lack of competition or predation due to toxicity. Researchers may find indicators of impaired recovery as they analyze trends in the same groups of plants and animals using different parameters of biological health after further field collection and designing of manipulative field experiments (Shigenaka, personal communication, 1999).

For other infauna, (animals living in gravel beach sediments), such as littleneck clams, a different result occurred. Their distribution and abundance in oiled beaches is below unoiled sites, suggesting an impact on the population and subsequent non-recovery. The question remains whether this impact is due in part to alteration of the physical environment either: (1) by the presence of the oil in the sediments; or (2) by clean-up activities to wash the oil from the shoreline; or (3) by both, which may have indirectly delayed recovery of infaunal communities. These results are a mixed message: recovery and non-recovery. Then, too, the presence of oil remaining in the Sound and the extent of its continued adverse impact is open to debate, as are the questions about the decrease in the fisheries (NOAA, 1999; Shigenaka, personal communication, 1999). The scientific debate on "How clean is clean" may go on forever. In all this scientific complexity and scientific confusion, there is a further lesson of importance to the industry. In spite of the uncertainty of science, and interpretation of short- and long-term environmental impacts, a US jury entered a 5.3 billion dollar punitive damage award against Exxon (Holloway, 1996).

Regardless of eventual outcome in the *Exxon Valdez* spill, one well-renowned scientist states the obvious: human intervention was necessary to remove the oil. The question was how much intervention in an oil spill is required to reduce short- and long-term environmental impacts. In the clean-up, the question is "How clean is clean". Scientists will always be dealing with unknowns, never having perfect data to link actions and reactions. Uncertainty in oil spills as to the damage the substance will cause to marine biota is a given. Responsible, tailored action must happen in the face of this uncertainty (Michel, personal interview, 6 April 1999). One of Jacqueline Michel's favorite sayings is that she "has never been to the same spill twice"—meaning that no two spills are alike even if in the same place.

The uncertainty in data and understanding in environmental science have led to the development of the *precautionary principle* in assessing environmental effects and making environmental decisions (Weiss, 1989). The precautionary approach developed from situations in which data and understanding are not available to scientifically manage natural resources. In this approach, natural resource managers are interested in protecting living resources to "maintain their viability", but are without the data required for the "parameterization and verification of models that predict effects of various management actions with useful statistical confidence limits". The precautionary approach may be the only viable alternative, (less than rigorous scientific methods) for protecting vital natural resources after an oil spill. Data may not exist to make scientific decisions that meet the usual high standard of scientists. This boils down to a simplistic approach: "The choice is not between giving perfect or imperfect advice to managers. It is between giving imperfect advice or none at all". The dataless management doctrine may seem like heresy to some scientists, but to others working in the field, this system leads to making the best decisions possible when not all data are available (Johannes, 1998). In the precautionary approach, the error should be on the side of the environment.

It may be that studies of large oil spills such as the *Exxon Valdez* oil spill may be so unique due to the size of the spill, the nature of the oil spilled, the environment (with all of its unknowns) where the oil was spilled and the actual response actions taken to the spill, that it is very difficult to learn (or make comparable assessments) from that response and the scientific findings generated by that spill. Costello (1991, 1993) reported that at the time of the *Exxon Valdez* oil spill, the US preparation and available technology requirements to respond to an oil spill of that size were poorly underestimated and understaffed. Subsequently, the oil companies formed the Marine Spill Response Corporation (MSRC) when they realized that the state of oil spill response in the US for a spill the size of the *Exxon Valdez* was totally inadequate.

Therefore, assessments from smaller and more manageable oil spills in areas where on going studies with long-term biological data sets and research projects may be more useful for lessons learned from a spill (Champ et al., 1987; Wolfe et al., 1987).

An example of such studies would be those conducted at the Smithsonian Tropical Research Institute in Panama where research scientists were able to compare pre- and post-spill conditions of the ecosystems affected by the 1986 *Bahia Las Minas* oil spill. Of the 60,000 to 100,000 barrels of oil spilled in Panama, only 60,000 barrels of oil and water mix were recovered, with the balance spreading out over an 85-km stretch of coastline, including a significant stretch of coral reefs. Because of the Smithsonian historical studies, there were considerable baseline data about the ecosystem research conducted over a period of 5 years after the incident revealed negative ecosystem impacts.

Oil was found intact in bottom sediments years after the spill. Researchers concluded, " ... that toxic effects of hydrocarbons will probably persist for at least 20 years in deep mud tropical coastal habitats affected by catastrophic oil spills" (Burns, 1993). The entire ecosystem experienced loss, with interrelated species being depleted and with the predicted return of mangroves and seagrasses (by repopulation) to pre-spill levels requiring an estimated 50 years. Burns et al. (1993) and Pennissi (1994) have summarized the following impacts from the *Bahia Las Minas* oil spill:

- Most subtidal seagrass communities survived intact;
- Seagrass communities were damaged severely in the intertidal zone (area between high and low tide lines);
- Mangroves were affected down to their roots, with a loss of as much as 74% of vegetation in the fringe habitat;
- Marine creatures living in the mangrove root systems such as sponges, anemones, corals and hydroids were almost wiped out for up to 5 years when some, but not all, reappeared; and
- Serious shoreline erosion resulted as a side effect of the loss of natural barrier mangrove, seagrass and coral habitat.

The International Tanker Owner's Pollution Federation Limited (ITOPF) is an association that is a representative of the shipping industry for oil spills. ITOPF is very interested in the costs that industry pays for oil spill clean-up and for environmental damages. This would be expected due to the fact that industry as a whole, directly or indirectly through international funds is responsible for the costs for clean-up and, for "reinstatement" of the environment.

In contrast, under OPA 90, the polluter is held liable not only for the clean-up, but also for the full environmental restoration of the damaged area following a spill.

ITOPF has served as technical advisors to its tanker-owner members, associates and their Protection & Indemnity insurers in some 400 spills in about 75 countries (White, personal communication, 1999). The concerns of ITOPF's technical advisers influence opinions of the international community and the manner in which oil spill response is conducted in certain incidents.

The difference in the predominant international and US positions manifests itself in acceptance or rejection of:

- The level of physical removal and recovery of the spilled oil to a level of diminishing return (practical) from the environment (without a discussion of "How clean is clean"); and
- The use of "natural" and long-term recovery of the impacted ecosystem over time versus clean-up intervention to aid such recovery.

These differences are further delineated in the following. Generalized parameters for response in international communities begin with these underlying principles:

- Environmental impact of a spill depends upon a wide range of factors: type of oil, amount, resources affected, sensitivity of the resources, site physical features, weather, sea conditions, time of the year/season, and effectiveness of the response (ITOPF, 1986);
- Recovery potential of marine species varies greatly. Many species live in the environment of the intertidal zone and have adapted strategies to survive frequent natural devastation by producing large numbers of planktonic larvae that are ready to recolonize depleted areas. On the other hand, long-lived species or ones which produce few young are less able to withstand natural and man-made depletions (IPIECA, 1999/2000); and
- The end result is that clean-up and restoration alternatives are shaped by the event variables, the environment, nature and extent of the spill (ITOPF, 1986).

The differences in the enunciated oil spill response principles between ITOPF and for example certain US scientists are:

- Nature is highly resilient and natural recovery will often occur with minimum human intervention (Sell et al., 1995);
- Natural systems are variable, such that it is frequently hard to separate the impact of a spill from natural fluxes and determine if the spill caused the change in the environment (Dicks, unpublished manuscript, 1999);
- Again, a common theme emerges, the uncertainty of science in the face of unknown data and variables: "Whilst it is clear that oil spills can cause environmental damage and that some characteristics of a spill may appear to be relatively easy to measure or quantify (e.g. the type of oil and amount spilled), it is impossible to extrapolate to the nature and extent of damage that will be caused". (Dicks, unpublished manuscript, 1999); and
- Technology for spill clean-up is limited "Given the limits of existing cleanup techniques, the best that we can strive for is that everyone will cooperate in mounting the most effective response that technology and the circumstances of the incident will allow" (White, personal communication, 1999).

Under OPA 90, the natural resource damage assessment process is quite different from the international regime. Once there is a determination that damage has occurred and that restoration action is possible and appropriate, scientifically based models

By Tom Meyer, *The San Francisco Chronicle*, May 4, 1989.

and abstract methodology may be used to develop restoration plans to return injured resources to their pre-spill condition on an accelerated time frame. Natural recovery without human intervention is considered, but it is not always the preferred alternative. Compensatory restoration is recognized. Acquisition of equivalent resources is also provided under the regime. Technological resources include on-water recovery and onshore activity as well as bioremediation and use of dispersants (see discussion of NRDA, Section 4.3.2).

The debate about the length and severity of the impact of petroleum on marine ecosystems is influenced by another dimension, the compensation which the international or US regimes will pay for natural resource damages. This is seen from the language and requirements of OPA 90's liability system. In this system, the definition of "injury" to the natural resources is broad and includes " . . . not only direct mortality to fish and wildlife and destruction of plants, but also sublethal effects on biota, such as loss in the reproductive capacity of fish or wildlife and in the productivity of wetlands and other ecosystems" (Grigalunas et al., 1998).

The point being delineated is that damages under OPA 90 are measured in terms of the principle of making the public whole by restoring impaired resources to their pre-spill condition. Sublethal impacts, loss of biodiversity and biomass, and lack of a functioning ecosystem become elements crucial to determining the bottom line. The questions—"what resources has the public lost and for how long" and "can the ecosystem be restored to pre-spill conditions" translate into "how much will the polluter pay" and "has the public lost a valuable natural resource", which may not be restorable or for which there may be a need for replacement with an equivalent resource.

The International Regime defines damage and restoration of natural resources in a more limited fashion. Compensation for pollution damage from a discharge of oil is constrained by the relevant international conventions (1992 Civil Liability and Fund Conventions, see discussion in Section 4.3.3) and the clause for compensation: " ... provided that compensation for impairment of the environment other than loss of profit from such impairment shall be limited to costs of reasonable measures of reinstatement actually undertaken or to be undertaken" (IOPC Fund 1992, 1998). *Reinstatement* is viewed more as an extension of clean-up, not governed by abstract or theoretical damage models, determined by positive steps to encourage natural recovery, in which cost and benefits are closely linked, and where outcomes of intervention are supported by greater scientific certainty of outcome. For example, a restoration program such as an artificial breeding program at a nearby site may help overcome pollution losses if the technology exists and the "likelihood of a successful enhancement of the wild population is high". Experimental programs, those untried or using unproved technology would have little benefit and would be unacceptable projects (Dicks, unpublished manuscript, 1999).

This compensation point of view impacts oil spill response and clean-up. The international regime focuses on compensating proven financial loss, rather than upon environmental damages difficult or impossible to quantify. This approach is referred to as a "more direct and rational approach" of compensation founded on the principle of economic loss, resulting from restoration or reinstatement measures. Restoration programs should not be experimental nor publicity driven. There are significant limitations to the extent to which damage can be repaired by artificial means. Reinstatement of a damaged site may be "impossible and unreasonable", particularly if natural recovery is rapid. "Engineering" may be more destructive than natural recovery without human intervention (White, personal communication, 1999).

The resolution of the scientific argument and inconsistency in position as to the effect of oil on natural resources will be the focus of political and scientific debate for the new millennium. Harmonization of these philosophical attitudes toward the importance of marine ecosystems and the human ability to remedy the impact created by a spill is still far in the future. What is clear and not uncertain is that the oceans are at risk and careful, managed action needs to be taken. Scientists have concluded that: "Humans have fundamentally affected marine ecosystems worldwide. ... No part of the ocean remains unaffected by humans. ... Ocean ecology can no longer be understood adequately without recognizing these ecosystem-wide perturbations. ... Meeting these challenges will require better understanding and resolution of the causes and consequences of change on scales from hours to millennia" (Hay and Jumars, 1999).

GESAMP, in its 1998 annual session, underlines the above thinking as expressed in the following statement of the pollution problem and call for appropriate use of management and science: "Degradation of the oceans continues on a global scale, despite progress made during the last three decades in some places and on some issues. A fundamental solution to many of the sea's environmental problems lies in scientifically informed management that integrates the range of uses of the marine environment to ensure that their benefits are sustained. Such management regimes, when effectively implemented, have produced benefits for society and the environment, but they have not been widely applied. This is largely due to a lack of informed constituencies, appropriate institutional structures, and political will" (IMO, 1998).

Perhaps what the very uncertainty of science as to the fate and impact of oil on the marine environment means is that oil spill response requires a "good management regime" guided by a basic international principle, the "precautionary principle". The precautionary principle was first enunciated in 1987 at the International Conference on the North Sea and deals with the effects of our current actions on future generations. The most frequently cited definitions of the principle underline the fact that there will always be scientific uncertainty, but where actions taken may impact the environment irreparably, the activity taken should be guided by an overriding concern of preventing environmental harm.

This principle is often cited as follows: " ... in the face of threats of irreversible environmental damage, lack of full scientific certainty is no excuse to postpone actions which are justified in their own right. ... " "Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation". Preventive measures should be undertaken " ... even where there is no conclusive evidence to prove a causal link to certain effects ... " (Weiss, 1989).

The oil shipping industry is a risk business, where the possibilities of an oil spill are ever present, and where the impacts of that spill on humans and natural resources are certain, although difficult to measure. The very character of this industry argues for a systematic, scientifically based regime where all responsible players act with prudent care in the prevention and then response to oil spills. In fact, one can argue that the *precautionary principle* underlies the entirety of this heavily regulated industry and that the industry is a working example of how best to apply prudent care within an informed institutional structure. The Preambles to two major oil pollution treaties MARPOL 73/78 (the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978) and OPRC, (International Convention on Oil Pollution Preparedness, Response and Co-operation, 1990) (see discussions in Sections 4.2.1 and 2.4 respectively) reiterate the basic elements of this international doctrine:

For example, the wording of the Marpol 73, Preamble contains such language:

- "BEING CONSCIOUS of the need to preserve the human environment in general and the marine environment in particular;
- RECOGNIZING that deliberate, negligent or accidental release of oil and other harmful substances from ships constitutes a serious source of pollution;
- DESIRING to achieve the complete elimination of intentional pollution of the marine environment by oil and other harmful substances and the minimization of accidental discharge of such substances;
- CONSIDERING that this object may best be achieved by establishing rules not limited to oil pollution having a universal purport;
- HAVE AGREED as follows".

For example, the wording of OPRC, 1990 contains such language:

- "RECOGNIZING the serious threat posed to the marine environment by oil pollution incidents involving ships, offshore units, sea ports and oil handling facilities;
- MINDFUL of the importance of precautionary measures and prevention in avoiding oil pollution in the first instance, and the need for strict application of existing international instruments dealing with maritime safety and marine pollution prevention . . . ;
- MINDFUL ALSO that, in the event of an oil pollution incident, prompt and effective action is essential in order to minimize the damage which may result from such an incident;
- TAKING ACCOUNT of the 'polluter pays' principle as a general principle of international law,
- HAVE AGREED as follows" (OPRC, 1990, Preamble).

Oil spills are a continuing reality. "Oil spills in the US are a daily occurrence" (Etkin, 1998). The same statement applies to international waters. While the debate continues about how much and for how long oil affects the marine environment, the precautionary principle and good business sense argue for prudent care of the resources at risk. The benchmark criteria for this highly regulated industry should be adoption of the safety culture in management systems to prevent spills and of sound science to respond to them.

1.4. Reoccurrence of Spills: Root Causes/Risk Factors

Analysis of the most recent oil spills of 10,000 gallons or more internationally and in the US leads to the inevitable conclusion that oil spills have a high probability of occurrence. Their impact is not insignificant just because they are a localized point source. Oil spills from tankers account for 3–5% of all oil pollution into the oceans and seas of the world. Tanker operations account for another 7% (INTERTANKO, 1997, 1999b; GESAMP, 1993).

There are many root causes for reoccurrence of spills. These can be identified generally as:

- Aging world fleet;
- Decrease in maintenance;
- Seafarers less well trained;
- Multinational and smaller crews;
- Open registers/“Flags of Convenience”;
- Human error;
- Fatigue; and
- Limited trade routes/choke points.

Difficult economic conditions for the shipping industry over the past several decades have produced unintended consequences. Except for some of the large major companies, ship owners have not ordered new tonnage. The result is that the average age of the world fleet is over 15 years (INTERTANKO, 1997). Coupled with less money being put into maintenance, corrosion, mechanical breakdowns and other factors, the older ships are subject to accidents (IMO, 1995). A case in point was the oil spill of 1.3 million gallons (6200 tonnes) of medium fuel oil into the Sea of Japan on 2 January 1997, involving a Russian vessel, constructed in 1970, the *Nakhodka*. Experts engaged by the International Oil Pollution Compensation Fund concluded that a Japanese survey (JAMSTEC) of the structure revealed significant corrosion of the steel in the vessel and deficiencies in welding. The vessel broke up in 10-m seas in a storm in the Sea of Japan and oiled northern Japanese beaches. The spill occurred during the Japanese New Year and was first predicted not to come ashore since it occurred over 200 km offshore. However, the Japanese were unprepared for responding with technologies for open ocean response and clean-up and the oil came ashore oiling northern beaches. Over 8000 public volunteers were used to hand clean-up beaches and rocky shorelines (Champ et al., 1997b).

The report found that the *Nakhodka* had been improperly maintained and sent to sea in an unseaworthy condition, such that the stresses on her old hull as a result of heavy weather and rough seas caused the ship to break in two in 10-m seas in the Sea of Japan (Golob’s, 1997a; IOPC Fund, 1998). The Maltese tanker, *Erika*, broke in two during a storm on 12 December 1999, off the Southern coast of France. The French government concluded that long-neglected tank corrosion caused a chain of structural failures leading to the splitting up of the 24-year-old *Erika* (OSIR, 2000b). A major, recent study states that there is a positive correlation of risk factors in ships between 10 and 14 years of age, with the beginning of a trend in the incidence of major claims (for $100,000 or more), moving into a higher incidence of claims from ships in the 15- to 19-year bracket. This study cautions that other factors come into play than just age, including size, trading patterns, length of voyage, discharging and loading operations, and of course, human error (UK P&I Club, 1998).

In its Communication of March 2000, the Commission of the European Communities stressed the impact of the aging fleet pattern by calling for a regulation accelerating the phasing-in of double hulls or equivalent design requirements for single-hull oil tankers operating in European waters. The Communication called for conformity with age limits and end-dates regulated by OPA 90 (see Section 4.3.1), which provides essentially, that by the year 2015, single-hull tankers will no longer be able to operate in US waters. According to the Communication, as of 1999, the average age of the world tanker fleet transporting oil is 18 years, with 41% (2939) of these ships being over 20 years old. This figure translates into 36% of the total tanker tonnage at sea (Commission, 2000).

Ownership patterns and practices have changed from those traditionally in place in the industry, with shipping evolving from being controlled by the major oil companies who owned 25% of world tanker tonnage and controlled 50% of long-term charters, to many independents of different Flag States controlling vessel shipping, with the majors now owning less than 9% of the total tonnage (IMO, 1995). The world Independent owners fleet numbers 2551 tankers (as of February 1999) with tanker tonnage of an average drawing weight of 226.4 million. In contrast, the total oil company/state tanker owners' fleets are comprised of 877 tankers with tanker tonnage of 73.2 million drawing weight (INTERTANKO, 1999b).

This decentralization and internationalization of shipping in itself has had far-ranging consequences:

- Seafarers are less well trained and paid with crews being supplied in many cases from developing countries;
- Smaller and multinational crews are the norm with members speaking many languages and poor communication existing between officers and crew;
- There has been a shortage of trained officers and some predict this will problem will only increase; and
- Open registers often equate to "flags of convenience" with an established practice of substandard operators shopping for and finding such flags with less stringent regulations and qualifications for certification (IMO, 1994, 1995).

While these factors based in world economics play an important role in the reoccurrence of spills, the main cause of oil spills is "human error". After numerous studies, the shipping industry has come to realize that human error accounts for 80% of all marine casualties (US Coast Guard, 1995). ITOPF studies support this conclusion. Human error contributes most significantly to accidents and caused 83% of all oil spills over 700 tonnes during the period 1974 to 1998 (ITOPF, 1999).

The US Coast Guard defines *human error* as "acts or omissions of personnel which affect successful performance". *Human factors* involve the interaction between equipment and the human operator, and most importantly, the procedures the crew and management follow (Card, 1995).

Individuals are affected by errors in judgment, stress due to poor training, inadequate staffing, poor living conditions and fatigue. Several studies conducted by the IMO's Maritime Safety Committee, the USCG, and consortiums of stakeholders like that of the Prince William Sound Risk Assessment group have broken down the root causes for human error into discrete units in an attempt to predict and correct this endemic problem. Basic human and organizational errors defined as the primary causes of human error include: diminished ability due to physical or other condition, such as fatigue, hazardous shipboard environment, lack of knowledge, skills or experience, poor management practices, and faulty perceptions or understanding of the external environment. These causes in turn create vessel operational errors, which range from poor decision making, to poor judgment, to incomplete information, to poor communications (Harrald et al., 1997).

Fatigue plays a major role in marine accidents. Factors producing fatigue include among many, work and rest periods, manning levels, ship–shore communication and support, quality of working and living environment, crew composition, and environmental factors such as weather (Pattofatto, 1997).

The UK P&I Club, one of the largest protection and indemnity insurers of tankers in the world, concluded a comprehensive inspection of 555 ships insured by the Club over a 12-month period, which resulted in a report in 1996 entitled: *The Human Factor: A Report on Manning*. The conclusions drawn in this report support the above overview of factors which lead to the reoccurrence of oil spills. As a general statement, the report summarizes the state of manning of ships as of February 1996. While change is underway in many important areas due to implementation of new treaty requirements, the comments contained in the UK P&I Club (1996) report apply today:

- "The term *human element* is now commonly used but there are several constituent factors which are each worthy of separate consideration. Fatigue, for example, undoubtedly plays a significant part in accidents. Ships are required to operate twenty four hours a day and so are ships' crews .... The quality of a ship's crew has a direct bearing on the ship's overall performance. It is not necessarily true to say that sub-standard ships always have sub-standard crews but a sub-standard crew almost certainly means a sub-standard ship .... In the 1990s, ensuring that a ship is properly as well as economically manned, is not easy ...".
- "The relative decline in the numbers of ships sailing under traditional maritime flags, together with the associated or perhaps coincidental reduction in the numbers of experienced seafarers trained in those countries, has altered career patterns with changes in responsibilities, career development, depth of training, and in the levels of experience to be found among officers and ratings".
- "The need to reduce costs is evident in a climate of depression and overtonnage. Owners have always used cheap crews and there is nothing new about the employment of mixed crews. The inspectors found that, of the ships visited,

56% had mixed crews". While mixed crews do not necessarily mean substandard operations, the fact is that mixed languages result in potential communications problems (UK P&I Club, 1996).

- The 1998 major claims analysis report of the UK P&I Club affirms the finding that human error "dominates the underlying causes of major claims" and " . . . whether of the crew, deck officers, shore personnel, pilot, account(s) for a significant percentage of recorded incidents" (UK P&I, 1998). Recent examples of oil spills demonstrate several or all of these causes at play. Poor decision making, and ship handling error caused a Liberian tanker, the *Julie N*, to hit a bridge in Portland, Maine, spilling 170,000 gallons of fuel oil on 27 September 1996, when the docking pilot ordered the ship's helmsman to turn to port instead of starboard (Golob's, 1996, 1997b). Lack of knowledge of rocks and reefs near shore, caused a Panamanian tanker *San Jorge* to run aground on an uncharted rock near Punta Del Este, Uruguay, spilling 5000 metric tons of crude oil on 8 February 1997 (Golob's, 1998).

Cost cutting, improper emergency repair, poor training, poor judgment from illegal use of drugs, and poor decision making in ordering the ship to travel at full speed ahead on an emergency repair to a towing line, produced the *Morris J. Berman* spill, off the coast of San Juan, Puerto Rico on 4 January 1994, spilling 798,000 gallons of oil at a cost to the US taxpayer of $87 million dollars (Ornitz, 1996). Pilotage was the main cause of the *Sea Empress* spill off Milford Haven, South Wales in February, 1996. The pilot failed to take effective and appropriate action to keep the single-hull vessel in the deeper part of the channel. Due in part to poor training, the pilot and harbor masters did not discuss a pilotage plan before the vessel started its approach to port (INTERTANKO, 1997).

The continuing increased market for petroleum products is another risk factor that may undermine the best efforts of the shipping community. Ships are the most effective means for meeting worldwide, consumer demand, through limited trade routes. All ships transporting oil move through six major trade routes, commonly referred to as *choke points*, because they are subject to incredible shipping congestion. The shipping lanes include: Strait of Hormuz, Strait of Malacca, Suez Canal in Egypt, Bosporus, Rotterdam Harbor and the Panama Canal in Central American (Bordeaux, 1994). The highest risk of accident happens when a vessel enters port, traveling at slow speeds in "constrained waters". With more ships moving through the very narrow shipping lanes (for example, the Panama Canal is a narrow passage of about 50 miles), the potential for collisions, groundings and other mishaps rises correspondingly.

The US contributes significantly to this world problem. In 1998, Americans consumed an average of 18.7 million barrels of oil per day for transportation, heating, power for industrial facilities, and for about 3000 everyday products that facilitate a high standard of living. At least 56% of that was imported. In total, about 10 million barrels (420 million gallons) per day of oil are delivered to the US in ships owned and operated by members of API (the American Petroleum Institute, which represents over 400 companies) and INTERTANKO (the trade association which represents over 50% of the tanker tonnage afloat) (Moore, 1999).

These circumstances in world oil needs underline the overwhelming necessity for industry and governments to take preventive action and avoid the otherwise certain reoccurrence of oil spills. These facts support the most rigorous enforcement of the significant changes for shipping envisioned by the most recent amendments to international treaties. These same risk factors underscore the importance of the movement toward self-regulation and self-policing of the industry, including partnerships between industry and governmental agencies, and initiation within companies of numerous safety management systems implemented by responsible industry leaders. Without continual improvement and focus on safety and the human element, it is possible to project that the root causes and risk factors will, in the end, prove the demise of the improving safety record of the oil shipping business. Support for, rather than limitations placed upon, the working principles of the safety culture should be the order of the next decade.

1.5. Available Oil Spill Response Technologies: Limiting Factors

Oil spill response is a complex and challenging cross-disciplinary experience. In the operational decision-making process, spill response combines a wide range of issues and activities under emergency response conditions that include: the nature of the material spilled, which undergoes changes in physical and chemical properties (weathering) over time, local environmental conditions, sensitivity of impacted natural resources, and selection and effectiveness of response/clean-up technologies. Response encompasses, as well, emergency mobilization, marine operations and effectiveness of operations, air surveillance, remote sensing, on site and regional spill trajectory, human protection, safety assessments, oily waste minimization, handling and disposal; and education and training. Effective oil spill planning and response today requires a large amount of available data and information and the ability to rapidly process and manage this information.

Planning and decision making in oil spill response demands an understanding of oil weathering processes, the subsequent changes in an oil's characteristics, and the effect of these changes on response technologies over time. These changes have an important influence on the usefulness and effectiveness of response methods and technologies. Four major categories of response (clean-up) technologies are available:

- Chemical treatment (dispersants, emulsion breakers);
- In-situ burning;
- Mechanical recovery (booms, skimmers, oil-waster separators, adsorbents; and

- Bioremediation (including chemical).

The two dominant processes that cause changes in oil characteristics over time are evaporation and emulsification, which significantly increase the viscosity of spilled oil. Evaporation of the more volatile components and the formation of a water-in-oil emulsion during weathering occur simultaneously during and after a spill. The rate and extent to which they proceed depends on the chemical composition of the oil and prevailing environmental conditions (such as wind speed, seawater and air temperature, and sea state). The relationships between these factors and the changes in key properties during weathering have to be well understood as well as the effectiveness of specific response technologies under these conditions, in order to estimate and delineate windows-of-opportunity for specific clean-up methodologies and technologies. To reduce environmental risks and provide greater environmental protection and achieve maximum cost benefits in implementing response strategies, response tactics and technologies must incorporate better science in technology selection and use and spill response decision making (NRC, 1975, 1985, 1989; Fingas et al., 1978; ITOPF, 1986; Doerffer, 1992; Nordvik et al., 1995a, b; Champ et al., 1997a; Champ and Ornitz, 1999; Fingas and Punt, 2000).

Methods and technologies in each of these categories are limited by environmental conditions both operationally and as a result of the changes in oil characteristics over time. Effective use of dispersants, in-situ burning and some mechanical technologies is limited in time and governed by changes in oil properties. The most efficient, environmentally preferred, and cost effective spill response is dependent on the following factors:

- Chemistry of the spilled product;
- Quantity;
- Location;
- Response time;
- Environmental conditions; and
- Effectiveness of available or prepositioned response technologies.

1.6. Other Limiting Factors: Lack of Integration of Science and Engineering, Coordination in Planning and Training

There is strong motivation to incorporate good science into each stage of the business of shipping oil. The motivating factors include:

- High costs of environmental damages;
- Legal impacts of civil and criminal fines;
- Potential jail sentences for responsible parties from the highest company officials to crew;

- Public opinion and its resultant political outpourings;
- Recognition that safety is good for business; and
- Recognition that, in this era of competitive markets, zero accidents and zero casualties mean positive bottom line results for companies.

Companies who continue to be interested in their bottom line will need to heed the admonition of GESAMP, the joint group of experts advising IMO and other international organizations. The solution to marine pollution lies in great part in "sustainable management based on sound scientific information" (IMO, 1998).

This concept applies most particularly to shipping oil:

- First, good science is needed to inform and create appropriate oil spill contingency plans under the pre-planning requirements of OPA 90 (the Oil Pollution Act of 1990)—or pursuant to the respective international conventions (most specifically MARPOL 73/78, (shipboard oil pollution emergency plan requirement—International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978), (Regulation 26 of Annex I)—and the planning provisions of the OPRC Convention, (International Convention on Oil Pollution Preparedness, Response and Co-operation, 1990, Articles III and VI and Resolution 7).
- Second, decisions based on sound scientific principles are indispensable for effective and efficient response, either in training personnel who will conduct the response or during the actual clean-up of an oil spill. OPA 90 requires area drills for ship owners/operators, both internal and external and at times without prior notice, to test spill response preparedness. All stakeholders are to participate. The results are to be published on an annual basis (33 USC 1321 (j)(7)). In response to this requirement, the US Coast Guard and other responsible US agencies have developed the National Preparedness for Response Exercise Program (PREP). PREP exercises involve a range of drills, from internal exercises by companies, to tabletop exercises, to full Area Exercises, where all players are involved with deployment of equipment in a "worst case discharge" drill. For vessels, this phrase means that the entire cargo is discharged under adverse weather conditions. PREP Guidelines were published in August 1994. (See Section 2.6 of this book for further discussion of the US National Response System.)

The response plans required by OPA 90 must describe the training given to persons on a tank vessel so that they can respond to an oil spill. The US Coast Guard Regulations which relate to the training described in the company vessel response plans are found in 33 CFR parts 150, 154 and 155 (Sahatjian, 1996; USCG, 1994a, b).

Resolution 7 of the OPRC provides for an international commitment to training and preparedness. The International Maritime Organization, (IMO) with the cooperation and assistance of industry, interested governments, and other organizations has and is continuing to develop and implement training programs for oil pollution preparedness and response. Three levels of training have been targeted: Level 1—operational staff; Level 2—middle management or on-scene commanders; Senior management level—decision makers at the upper level. (See Section 2.4 of this book for further discussion of OPRC.)

Preparedness and training requirements have been incorporated into the national response system used in the US and into other response systems used worldwide. See Sections 2.3–2.6. Within each response regime is an underlying need for the use of appropriate technology as a basis of effective response. Decision making at each phase of an oil spill response must be:

- Scientifically based;
- Technically and environmentally correct;
- Able to integrate in real time a wide array of data & information;
- Reflective of extensive pre-planning and training at all levels; and
- Inclusive of all stakeholders in crucial stages (Ornitz, 1999).

Captain Harlan Henderson, former Commanding Officer of the US Coast Guard Marine Safety Office in San Francisco Bay, has been involved in the *Exxon Valdez*, the *Saudi Arabia* spills after the Gulf War, and the recent *M/V Kure* Oil Spill in November 1997 in Humboldt Bay, California. In speaking during an international meeting in Australia, Captain Henderson issued this telling admonishment against the blanket use of technology. He focused on the dangers of relying too strongly on technological wonders, without the use of careful science:

> "Use technology but be cautious. Significant technological progress has been made in the field of response management. Technology is an area within spill management with tremendous potential. New systems should be analyzed, carefully tested and aggressively implemented when determined to add value to the response. However, several systems have been too big and too complex to effectively use. Other systems have not been properly tested before being accepted. A great deal of time and money can be wasted without first completing up front analysis. Also, if the care and feeding of the system is too great, it will take away from the main objective of the response organization which is to minimize the impact of the spill" (Henderson, 1998).

Captain Henderson's points find international concurrence. Dr. Ian White, Managing Director of ITOPF (International Tanker Owners Pollution Federation Ltd.) echoes similar conclusions. ITOPF has experience with hundreds of oil spills. Dr. White, in his observations, identifies the strands of a successful, coordinated response: plans, well rehearsed in advance, training of a response organization before a spill occurs, and use of sound science applied to the particularized elements for each spill situation.

> "(However), an efficient and cost-effective response is only likely to be achieved if there are realistic and well-rehearsed local, area and national contingency

plans; effective organization and management of the response operations; and full attention given to the experience and technical knowledge accumulated worldwide over the past three decades so that past mistakes are not repeated" (White, personal communication, 1999).

Both these observers, from two different response regimes, point to the crucial need for a well-developed response system, based on real science, which is applied appropriately to training and then actual response. While Dr. White emphasizes that the keys to successful clean-up are good organization, management of response operations, and a large dose of "commonsense". Henderson and others underscore a current lack in today's response systems of an integration of science and technology into training, planning and response. The Technology "windows-of-opportunity", pioneered by Nordvik (1995), Nordvik et al., (1995a, b, c), Champ et al. (1997a, b, 1998) and Champ and Ornitz (1999), focuses on inserting the highest level of basic science and engineering into oil spill response decision making.

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