

# THE ECONOMICS OF DOUBLE-HULLED TANKERS

by

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## ABSTRACT

A cost-benefit analysis is conducted on the double-hull requirements for oil tankers in United States' waters contained in the Oil Pollution Act of 1990. The benefits of reduced spillage are compared with the increased construction and operations costs of double-hulled vessels. In the most probable scenario, the expected benefits are only 20% of the expected costs. Double-hulls do not even show a positive net present value in the most favorable assumptions. Even if double-hulls prevent all of the spillage that occurs due to collisions and groundings, and that the damage per gallon spilled is as extensive as in the "Exxon Valdez" incident, the benefits are under half of the costs.

### 1. BACKGROUND

On March 24, 1989 the tanker "Exxon Valdez" ran aground in the pristine waters of Alaska's Prince William Sound. The disaster resulted in the spilling of ten million gallons, or about 20%, of the cargo of crude oil. The ensuing public outcry led to the establishment of a special National Research Council committee to investigate the preparedness for, and response to, the incident. Their report (1) presented several alternatives to tanker design that might be used to prevent oil spills of the magnitude of the "Exxon Valdez" in the future. Large spills comprise only 3% of incidents yet cause more than 95% of accidental spillage (2). The primary cause of these serious incidents is groundings. In light of these facts, the National Research Council committee concluded that the most cost-effective design for the prevention of major oil spills was a double-skinned hull.

Based on the recommendations of the National Research Council, Congress included in the Oil Pollution Act of 1990 a requirement that by the year 2015 vessels operating in United States (U.S.) waters would have to have a double hull. The Act contained other requirements concerning vessel manning and safety requirements, and increased penalties for the discharge of oil within 200 nautical miles of the U.S. coast.

A double hull is essentially two skins of steel separated by a small space known as a cofferdam. This space is typically about two meters wide, and is used as a ballast tank when the vessel is operating without cargo. The idea behind a double hull is that in the event of a collision or grounding, the first skin will absorb the impact while the second skin remains intact. There are limitations to this design. If the momentum is sufficient, then both skins will be breached. Thus the double hull concept is only valid for low velocity impacts. Indeed, Professor Henry Marcus of MIT argues that "double hulls would not have completely protected the "Exxon Valdez" from spilling" (2).

This paper is a cost-benefit analysis of the double-hull requirements of the Oil Pollution Act of 1990. It draws on a variety of data sources. For some parameters in our calculations, data are not available or are in considerable dispute. We have chosen to use government data where possible so as to avoid the biases of the maritime industry. We also present a range of scenarios

where data are irreconcilable. In particular we will present "favorable," "most probable," and "unfavorable" scenarios. By "favorable" we mean the scenario that is most favorable to double-hull designs, where the costs are the smallest and the benefits are the largest. Data are presented at 1990 prices. Distances are measured in nautical miles. It is a comparative static analysis, in that a comparison is made of carrying current oil shipments by double- versus single-hulled tankers. It is generally thought that shipments of oil will increase substantially over the next decade.

## 2. PREVIOUS LITERATURE

Economists have discussed the costs of oil pollution (3), and government efforts to enforce safety standards and internalize the costs of oil spills (4,5). However, the authors have found only one economic analysis of tanker design, and that dates from the 1970s. Pedrick (6) calculates that requiring double-hulls would increase the cost of shipping oil from the Middle East to the U.S. by 14¢ a barrel at 1978 prices. However, he does not make a comparison of costs and benefits. The National Research Council report (1), while containing a wealth of information, was widely criticized as inconclusive (2). In particular, while both design solutions were discussed, no conclusions were drawn about the relative desirability of double hulls versus an alternative hydrostatic design. This latter design concept pioneered by Mitsubishi Corporation would use natural hydrostatic forces to displace oil from ruptured cargo tanks into specifically designed cofferdams. This principle displaces water into the cargo tanks rather than allowing oil to spill out. It is telling that a consortium of ship owners is heavily in favor of the hydrostatic approach (7).

## 3. COSTS OF DOUBLE-HULLED TANKERS

### 3.1 Capital Costs

It is unlikely that there will be a large number of existing tankers that will undergo retrofitting of double hulls. The retrofitting costs of a 30-year old U.S. built tanker would be approximately \$1.5 million. In addition, a conversion of this magnitude would constitute a "major conversion" and additional safety requirements would be required. The combined costs of the double-hull retrofit and the additional safety requirements would constitute 50 to 80 percent of the replacement cost of the vessel (8). Thus, the retrofitting of double hulls on existing vessels is generally economically unfeasible, although undoubtedly there will be some conversions (9).

It is therefore most likely that vessels that comply with the Oil Pollution Act of 1990 will be newly constructed. Given the twenty-five year period over which the requirements of the Act are phased in, we are going to assume that these new vessels are introduced in the normal cycle of vessel replacement, and that no vessels are retired early to comply with the Act.

We will assume that tankers come in three basic sizes: small, medium and large. Small vessels are of 40,000 deadweight tonnage (dwt) and are used for the carriage of refined

petroleum products such as gasoline and jet fuel along coastal routes. Medium sized vessels of 80,000 dwt are used for imported crude and refined products. Large vessels of 240,000 dwt are used for the primary carriage of crude oil. The primary routes for these latter vessels are the Alaska route, and also imports into the Louisiana Off-Shore Oil Port.

Table 1 presents a comparison for the construction costs for double- versus single-hulled tankers of these three sizes. Data are from the National Research Council (1). A double-hulled vessel costs about 16-18% more than a comparable single-hulled design primarily because of the increased steel requirements for the additional hull. The costs presented in table 1 are mid-range estimates and will vary depending on the country and shipyard that constructs the vessel. A range of construction costs will be considered with the favorable estimate 5% below that presented in table 1 and the unfavorable estimate 5% above those in table 1.

**Table 1: Comparison of Construction and Operating Costs**

Vessel Size	Construction Cost		Annual Operating Costs	
	Single Hull	Double Hull	Single Hull	Double Hull
Small	\$ 34.00m	\$ 39.40m	\$3.07m	\$3.28m
Medium	\$ 49.70m	\$ 58.20m	\$4.08m	\$4.33m
Large	\$ 89.60m	\$105.70m	\$6.29m	\$6.65m

### 3.2 Annual Operating Expenses

Table 1 also shows annual operating expenses for double- versus single-hulled tankers of the various sizes. Again the data are from the National Research Council (1). Operating costs include manning, supplies, routine maintenance and repairs, administrative costs, fuel and port costs. We have excluded the cost of vessel and cargo insurance premiums, as this expense is inappropriate in a cost-benefit analysis. The increased operating cost of double-hulled tankers come exclusive in the maintenance and repair category. A double-hull design increases the inspection area on a vessel by approximately 100% over a single-hull design. In addition, the amount of steel surface subject to corrosion and fatigue is increased by a factor of three which leads to a significant increase in the amount of steel replacement (10).

### 3.3 The Number of Vessels Required

Drewry (8) estimates that 52.7 million dwt of vessels will be subject to the requirements of the Oil Pollution Act of 1990 requirements for double hulls. Based on data from the National Research Council (1), and shown in table 2, we are estimating that 739 vessels will be subject to the Act. This number should be compared with an estimate that 1,500 tankers visited U.S. ports in 1989. Of these tankers, 80% were foreign flagged but about 50% were under U.S. ownership or control. Drewry (8) comments that the requirements of the Act will effectively segregate the

world's tanker fleet into two: those who visit U.S. waters, and those employed elsewhere in the world.

The National Research Council (1) reports that 0.6 billion tons of oil are moved through U.S. waters each year. Data on cruising speeds, voyage length and port time in the National Research Council report suggests that the ratio of the number of voyages of small, medium and large vessels is 3.4:1:1.6 respectively. Knowing the number of vessels and the cargo displacement tonnage permits us to calculate the number of voyages a year.

Therefore these 739 vessels in U.S. trade carry a total of 0.6 billion tons of oil a year. To do this they operate 29 million vessel nautical miles. Nearly all oil movements are one-way flows therefore half of the time the vessel will be run in a ballast condition (i.e., not carrying cargo). This is an important consideration as accidents that occur while the vessel is in ballast will have negligible oil-spill implications.

**Table 2: Statistics on Current U.S. Tanker Fleet**

Vessel Size	Small	Medium	Large
Number of Vessels	471	178	90
Average Voyage Length (nautical miles)	2,000	8,000	4,000
Voyages per year	18.9	5.5	8.8
Cargo Deadweight Tonnage	38,000	76,800	234,000
Annual Miles per Vessel	37,900	44,300	35,100
Annual Loaded Miles per Vessel	18,900	22,100	17,600
Annual Cargo Ton Miles per Vessel	719.2m	1700.3m	4,111.9m
Fleet Annual Loaded Vessel Miles	14.5 million		
Fleet Annual Cargo Ton Miles	1,013 billion		

The existence of a cofferdam on a double-hulled vessel means that the vessel will have a lower cargo capacity. The National Research Council (1) estimates that the cargo carrying capacity of a double-hulled vessel is 2.6% less than a comparable single-hulled vessel. The implication is that there will need to be 2.7% more vessels, voyages and vessel-miles to carry the same amount of cargo. There will need to be approximately twenty additional vessels and 0.8 million more vessel miles operated a year. Therefore, while requiring a double-hull may reduce the probability of a spillage when an incident occurs, the reduced cargo capacity is implicitly increasing the exposure to incidents by requiring more vessel miles to carry the same total amount of oil.

The calculations in the preceding paragraph assume that the total amount of oil transported remains constant. The increased construction costs of double- versus single-hulled vessels, the increased fleet requirements and the increased number of vessel miles will be reflected in the price of water transportation. A higher transportation price will increase the price of oil and reduce total demand.

A simple calculation was made on the basis of tables 1 and 2. An assumption was made that the construction cost of vessels was spread evenly over their twenty year life. Combining construction and operating costs the current annual shipping cost for single-hulled vessels is \$4.4 billion to transport 0.6 billion tons of oil. If a similar calculation is made for double-hulled vessels, allowing for the fact that 2.7% more vessels will be needed, then the total annual cost rises to \$5.0 billion, a 15% increase.

Of course, shipping costs represent only a small part of the price of oil. When expressed in terms of dollars per barrel, the shipping component increases from \$1.00 to \$1.14 (conversion factors for this analysis are based on Arabian light crude oil, i.e. 1 ton equals 7.33 barrels, and 42 gallons equals 1 barrel). Our estimate of a 14¢ increase a barrel lies between the increase of 8¢ a barrel estimated by Lloyd's of London, and the 17¢ a barrel estimated by the U.S. Coast Guard (1). It is considerably less than the 28¢ a barrel, in 1990 prices, estimated by Pedrick (6). However, Pedrick's calculation was made for the long distance middle-east traffic to the U.S. The estimated increase can be compared with the prevailing 1990 price of crude oil of \$21.08 a barrel (11). If the cost increase is exactly matched in prices, then oil prices would increase by 0.7 of one percent.

One could then ask what effect this small price increase will have on the amount of oil shipped. A very basic calculation can be made by using evidence on the elasticity of demand for crude oil. Hawdon (12) estimates a price elasticity of demand of -0.36. Using this elasticity the demand for shipping oil will fall by about a quarter of one percent. One might argue that the elasticity used should be higher given that the elasticity we are concerned about is the cross-elasticity between waterborne oil and oil transported by other modes of transportation. However, half of the tonnage is carried by the medium and large vessels that operate on international and Alaska routes where pipeline is not a competitor. It is also quite unlikely that the increase cost of shipping will lead to a significant substitution of land-based drilling for imported or Alaska oil.

Incorporating both the cofferdam effect and the small reduction in total oil shipped, we calculate that the requirement for double-hulled vessels will require an increase in fleet size of 2.43% based on the most probable costs of new vessel construction.

### 3.4 Deadweight Loss

The reduced demand for oil will result in a deadweight loss to consumers that can be calculated in the usual way assuming that the demand curve is linear over the relevant range. Based on the most probable costs of new vessel construction, the price per barrel increases by about 14¢ per barrel, and the number of barrels declines by 11 million. The deadweight loss is therefore approximately \$800,000 a year.

#### 4. BENEFITS OF DOUBLE-HULLED TANKERS

The primary benefit of double-hulled tankers is the reduced spillage rate. There is no evidence that the existence of a double hull changes fatalities or injuries, most of which occur in incidents involving fire and explosion. Calculation of the benefits is a four step process: (i) calculation of the current spillage rate, (ii) estimating the effect that double-hulls would have on the spillage rate, (iii) calculating the change in the number of vessel miles, and (iv) placing a value on the reduced spillage.

##### 4.1 Current Spillage Rate

Clearly the amount of spillage will vary from year to year, because large disasters which comprise 3% of incidents but 95% of oil spilled, occur in a random Poisson manner. Therefore the average amount of spillage was calculated for an eight year period 1986-1993. This period included the "Exxon Valdez" incident. Data on gallons of oil spilled per year in U.S. waters were obtained from the casualty maintenance database of the U.S. Coast Guard. (We would like to thank Ensign Richard Shultz of the U.S. Coast Guard for his valuable assistance in extracting appropriate data.) Over the eight year period 19 million gallons of oil were spilled, at an average of 8135 tons or 2.5 million gallons a year.

The number of ton-nautical miles of oil shipped in 1990 was obtained from the U.S. Army, Corp of Engineers (13). In 1990 there were 449 million ton-miles of oil moved domestically. This is equivalent to 391 ton-nautical miles. In addition 418 million tons of oil was imported from foreign countries and 47 million tons were exported to foreign countries. Assuming that each of these loads passed through 200 nautical miles of U.S. territorial waters, total shipments of oil were 483.83 ton-nautical miles.

Based on the average tanker size, calculated from table 1, this spillage rate converts to 0.363 gallons spilled per loaded vessel mile.

##### 4.2 Effect of Double Hulls on Spillage

The National Research Council (14) calculates that only 36% of oil spillage is due to accidents. The rest is due to what they term "operational losses." This includes bilge water, loss of fuel oil, and spills at ports associated with the rupture of hoses during loading and unloading. Lloyd's Register of Shipping (15) conducted a study of the causes of accident spills and calculated the proportion of accidental spillage attributable to each cause. This information is presented in table 3, where correction has been made for the estimate that accidental spills account for only 36% of total oil spillage. Double hulls are only effective against accidents due to collisions or groundings which comprise 21% of spills worldwide and 30% of spills in U.S. waters. The shallow waters of the Gulf of Mexico make groundings a more prevalent hazard in U.S. waters.

**Table 3: Percentage of Total Oil Spillage by Cause**

	Worldwide	U.S. Waters
"Operational Loses"	64.0%	64.0%
Groundings	10.1%	23.4%
Collisions	10.8%	6.1%
Fire/Explosion	12.2%	2.9%
Structural Defects	2.9%	3.6%

There is clearly some uncertainty in the marine engineering community as to the proportion of the spills due to collisions or groundings that could be prevented or mitigated by a double hull. Double hulls will only protect against low velocity impacts. As reported in the introduction, a double hull would not have entirely prevented the spill from the "Exxon Valdez." Det norske Veritas (16), a world leader in the simulation of oil loss from tankers, concluded in a study commissioned by the National Research Council, that 85% of spillage due groundings and 50% of spillage due to collisions would be prevented by a double hull.

Incorporating these figures and the accident causality data in table 3 suggests that spillage could be reduced by 14% on a worldwide basis and 23% in U.S. waters if double hulls were adopted. Given the controversial nature of this figure we have used the 14% reduction in the unfavorable case, the 23% reduction in the most probable case, and a 30% reduction in the favorable case. The latter assumes that double hulls prevent all spillage that occurs in collisions and groundings.

In addition we have reduced the spillage rate by 2.6% to reflect the reduced cargo capacity of double-hulled tankers. In the event of an accident there will be proportionately less oil to spill. Therefore, we estimate that the number of gallons spilled per vessel mile will decline from the current 0.363 to 0.247 in the favorable case, 0.272 in the most probable case, and 0.304 in the unfavorable case.

#### 4.3 Increased Vessel Mileage

A countervailing factor to the reduction in the spillage rate, is the increased exposure to accidents caused by having to schedule more voyages because double-hulled vessels have lower cargo capacity than an equivalent single-hulled vessel. Currently tankers operate 14.5 million miles a year in loaded condition. When adjustment is made of the reduction in the amount of oil shipped due to the price rise, and the smaller capacity of each vessel, the number of annual loaded vessel miles increases to 14.8 million miles a year in the most probable case.



#### 4.4 Valuing Oil Spillage

The costs of oil pollution are difficult to totally quantify. The shipping company has to bear the costs of the lost oil, salvage of the vessel, repairs, and chartering replacement vessels. However, these costs are relatively minor. In the "Exxon Valdez" case the cost of the lost oil was \$5 million and salvage and repair \$20 million, which is approximately \$2.50 per gallon spilled (17).

The shipping company may be faced with legal reparations to other parties whose property is damaged or livelihood affected. Temple, Barker and Sloan (18) in an analysis of 38 major persistent oil spills in U.S. waters calculates that the average legal settlements as \$28,000 per ton or \$91 a gallon spilled. Settlements in the "Exxon Valdez" incident were higher.

The next cost is clean-up. The International Maritime Organization (19) estimates that the costs of clean-up at \$4,000 a ton in 1985 prices, which converts to \$16 a gallon in 1990 prices. By comparison, Exxon Corporation spent approximately \$2 billion in clean-up or about \$200 per gallon spilled. The "Exxon Valdez" was clearly an exceptional case due to the confined nature of Prince William Sound, its remote location and pristine condition. The actions of waves and sun often break up smaller spills, and evaporate the oil, before the slick encounters land. Of course, double hulls are designed to mitigate collisions and groundings which most likely occur in in-shore areas. The "Exxon Valdez" is probably not a reliable guide to valuations used in this analysis as the magnitude of the damage to the vessel was such that a double-hull would not have mitigated the disaster. However, in our cost benefit analysis we will assume that the costs of clean up are \$16 a gallon in the most probable and unfavorable cases, and \$100 a gallon in the most favorable case.

It is clearly arguable whether these clean-up costs and legal claims accurately reflect all of the environmental damage caused by spills. While economist may discuss methods for estimating a value of denigrated natural beauty, scientists are unclear about the long term environmental impacts of oil spills. Cohen (5) discusses uncompensated environmental damage costs in the range of \$1,500 to \$10,500 a ton, or about \$5 to \$34 a gallon. In our most probable and unfavorable cases we will assume uncompensated environmental damage of \$10 a gallon, and \$35 a gallon in the most favorable case.

Therefore, we will value a gallon of oil spilled at \$228.50 in the most favorable case to double-hulled tankers. For the most probable and unfavorable cases we will value oil spilled at \$119.50 per gallon.

#### 4.5 Dollar Valuation of Benefits

Table 4 shows a comparison of the estimated number of gallons spilled for double- versus single-hulled tankers. We are estimating that 1.6 million gallons of spilled oil are avoided each year in the favorable case, 1.2 million in the most probable case, and 0.5 million in the unfavorable case. We therefore calculate the annual dollar values of reduced spills are \$361 million, \$143 million, and \$89 million respectively.

**Table 4: Comparison of Accident Rates of Double- and Single-Hull Tankers**

	Unfavorable	Most Probable	Favorable
<b>Current Situation - Single-Hull Tankers</b>			
Ton-Miles Shipped (millions)	1,012,866		
Loaded Vessel Miles	14,449,279		
Gallons Spilled per Vessel Mile	0.363		
Annual Gallons Spilled	5,242,879		
<b>Double-Hulled Tankers</b>			
Ton-Miles Shipped (millions)	1,010,264	1,010,340	1,010,417
Loaded Vessel Miles	14,799,741	14,800,857	14,801,974
Gallons Spilled per Vessel Mile	0.304	0.272	0.247
Annual Gallons Spilled	4,497,297	4,026,953	3,661,143
Annual Spillage Avoided (Gallons)	745,582	1,215,926	1,581,736
Cost per Gallon Spilled	\$119.50	\$119.50	\$228.50
<b>Annual Benefit</b>	<b>\$89.1m</b>	<b>\$145.3m</b>	<b>\$361.4m</b>

## 5. BENEFIT-COST ANALYSIS

A cost-benefit analysis was conducted based on a twenty-year vessel life. Construction costs for the fleet are assumed to all occur now. Changes in operating costs, deadweight loss and reduced spillage occur annually for each of twenty years. A 7% discount rate is used to calculate a present value for these streams of costs and benefits (20).

The cost-benefit analysis is shown in table 5, where costs and benefits are shown in present values. In the most probable case, the expected benefits are only 20% of the expected costs. The damage caused by the oil spillage avoided is a fraction of the cost imposed on the industry in terms of more expensive vessels which each carry less cargo.

Double-hulls do not even show a positive net present value in the most favorable assumptions. Even if double-hulls prevent all of the spillage that occurs due to collisions and groundings, and that the damage per gallon spilled is as extensive as in the "Exxon Valdez" incident, the benefits are under half of the costs.

**Table 5: Cost-Benefit Analysis**

	PRESENT VALUES (\$ Millions)		
	Unfavorable	Most Probable	Favorable
<b>Benefits</b>			
Oil Spills Avoided	1010.0	1647.1	4097.0
<b>Costs</b>			
Increased Construction Cost for Existing Fleet	5787.3	5511.7	5236.1
Increased Operating Cost for Existing Fleet	1994.8	1994.8	1994.8
Construction of Additional Vessels	979.8	936.1	893.1
Operation of Additional Vessels	802.0	804.6	807.1
Deadweight Loss due to Price Increase	9.6	9.1	8.5
Total Costs	9573.6	9256.3	8938.7
Net Present Value	-8563.6	-7609.2	-4841.8
<b>Benefit-Cost Ratio</b>	<b>0.11</b>	<b>0.18</b>	<b>0.46</b>

REFERENCES

1. NATIONAL RESEARCH COUNCIL, COMMITTEE ON TANK VESSEL DESIGN (1991), *Tanker Spills: Prevention by Design*. (Washington, D.C.: National Academy Press).
2. *MOTOR SHIP* (1991), Double-skinned designs are not the ideal solution. *Motor Ship*, 72(June), 32-35.
3. BURROWS, PAUL, CHARLES ROWLEY AND DAVID OWEN (1974), The economics of accidental oil pollution by tankers in coastal waters. *Journal of Public Economics*, 3(3), 251-168.
4. EPPLE, DENNIS AND MICHAEL VISSCHER (1984), Environmental pollution: Modelling occurrence, detection and deterrence. *Journal of Law and Economics*, 27(1), 29-60.

5. COHEN, MARK A. (1987), Optimal enforcement strategy to prevent oil spills: An application of a principal-agent model with moral hazard. *Journal of Law and Economics*, 30(1), 23-48.
6. PEDRICK, JOHN L. (1978), Tankership design regulation and its economic effect on oil consumers. *Journal of Maritime Law and Commerce*, 9(3), 377-395.
7. INTERNATIONAL CHAMBER OF SHIPPING, OIL COMPANY INTERNATIONAL MARINE FORUM, INTERNATIONAL ASSOCIATION OF INDEPENDENT TANKER OWNERS (1991), *Oil Tanker Design and Pollution Prevention*. (London: International Chamber of Shipping).
8. DREWRY SHIPPING CONSULTANTS (1991), *Tanker Regulations: Implications for the Market*. Seaborne Trade and Transport, Number 91/3. (London: Drewry Shipping Consultants).
9. HOFMANN, HANS, GEORGE KAPSILIS, ERIC SMITH AND ROBERT WASALASKI (1994), Implications of OPA 90 in general and its effect on the T-A0 187 class oilers in particular. *Marine Technology*, 31(3), 175-182.
10. U.S. DEPARTMENT OF ENERGY (1992), *Transporting U.S. Oil Imports: the Impact of Oil Spill Legislation on the Tanker Market*. (Washington, D.C.: U.S. Government Printing Office).
11. DREWRY SHIPPING CONSULTANTS (1991), *Forecast World Oil Trades*. Seaborne Trade and Transport, Number 91/7. (London: Drewry Shipping Consultants).
12. HAWDON, DAVID (1989), *Oil Prices in the 1990s*. (New York: St Martin's Press).
13. U.S. DEPARTMENT OF THE ARMY, CORP OF ENGINEERS (1990), *Waterborne Commerce of the United States*. (Washington D.C.: U.S. Government Printing Office).
14. NATIONAL RESEARCH COUNCIL (1985), *Oil in the Sea*. (Washington, D.C.: National Academy Press).
15. LLOYD'S REGISTER OF SHIPPING (1990), *Statistical Study of Oil Outflow from Oil and Chemical Tank Casualties*. Report STD R2-0590. (Washington, D.C.: American Petroleum Institute).
16. DET NORSKE VERITAS (1990), *Comparative Study on Potential Oil Spill in Collisions and/or Groundings: Different Tanker Designs*. Report 90-161. (Høvik, Norway: Det Norske Veritas). (Reprinted in reference 1.)
17. HARRALD, JOHN R., HENRY S. MARCUS AND WILLIAM A. WALLACE (1990), The Exxon Valdez: An assessment of crisis prevention and management systems. *Interfaces*, 20(5), 14-30.

18. TEMPLE, BARKER AND SLOAN (1990), *Analysis of a Sample of 38 Major Persistent Oil Spills*. (Lexington, MA: Temple, Barker and Sloan).
19. INTERNATIONAL MARITIME ORGANIZATION (1988), *Manual on Oil Pollution, Section IV Combating Oil Spills*. (London: International Maritime Organization).
20. U.S. OFFICE OF MANAGEMENT AND BUDGETS (1992), Circular A-94, Revised Transmittal memorandum No. 64. (Washington D.C.:U.S. Office of Management and Budgets).