The Spreading, Retention and
Clean-up of Oil Spills

Final Report

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May 1976

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Prepared for
The U.S. Energy Research and Development Administration
Under Contract No. E(11-1)2756

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Abstract

This study reviews and assesses the technological state of the art of oil spill spreading, retention and clean-up and proposes research needs in these areas. Sources of oil spills are analyzed and the difficulty of gathering meaningful statistics is discussed. Barrier technology is reviewed and problem areas analyzed. Natural and forced biodegradation and natural and chemical dispersion of oil spills are presented. Research recommendations are categorized under the following two headings (1) Preventive techniques and (2) Containment, Clean-up and Dispersion.

Foreword

In accordance with P.L.-93-577, The Federal Nonnuclear Energy Research and Development Act of 1974 authorizes the Energy Research and Development Administration under Section 6(b)(3)(Q) "to improve methods for prevention and clean-up of Marine spills". This report is in response to this directive and is the result of a contract awarded to the University of Rhode Island under the direction of Dr. Mason P. Wilson, Jr. The study was to analyze the current state-of-the-art of oil spills in the categories of spreading, retention and clean-up and to make recommendations on areas where more research is needed.

The contract was administered by Dr. William E. Mott, Assistant Director for Nonnuclear Programs, Division of Environmental Control Technology. He has made substantial contributions to the project.

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Chapter I

Introduction

Information used for evaluating and analyzing the current state-of-the-art for the spreading-retention and clean-up of oil spills have come from many sources. Most of these are in the open literature. Some of these are summary reports that should be read before embarking on any intense study of a particular area of oil spill technology. Suggested readings include a report prepared for The Ford Foundation (1) by Boesch, Hershner and Milgram, a report prepared by the National Academy of Sciences (2) and a host of others listed at the end of this chapter.

Naturally, in any study of this kind there will be an overlap with some of the other existing studies especially with respect to some of the recommendations contained in this report. The primary objective of this study was to analyze what has been done and to concentrate on the areas where it was felt more in-depth analysis was needed especially in the areas of retention, spreading and clean-up of oil spills. Some of the conclusions and recommendations are in variance to others in the reported literature. The authors make no apologies for these for this should be expected in a complex field such as oil pollution. Nor should it be a reflection on the expertise of these sources, since the analysis of incomplete data will invariably lead to a variety of different conclusions. What is of prime importance is to define the areas which lack sufficient research and attempt to point out the possible consequences of the proposed research in terms of minimizing the occurrence and the effects of oil spills on the marine environment.

This report is summary in nature, and in-depth analysis was conducted only in specific areas in which an in-depth analysis were lacking in the literature. Some chapters are included for the purpose of general information and to provide some degree of reference to establish the relative importance of certain areas investigated. References and partial bibliographies are listed at the end of each chapter. Much more complete bibliographies are available in the open literature.

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Chapter II

Oil Spill Statistics

2.1 Introduction

There are several major reasons for carefully compiling detailed statistics on oil spills. In order to set up a worthy program management system it is helpful to know where and how oil is entering the environment. Statistics can also be used as an indicator of how successful the oil spill prevention program is, both on the legislative and surveillance levels and how successful the clean-up program is. The information can also be used as baseline data for interpretation of environmental effects. If a consistent program of collecting and compiling data exists over a period of years, the data can be used as an approximation of whether or not the oil entering the environment is actually increasing or decreasing. This too, can add to the evaluation of an oil spill program.

The Water Quality Improvement Act of 1970, an amendment of the Federal Water Pollution Control Act, designated the United States Coast Guard as the appropriate agency for responsibility and enforcement authority for the protection of the environment from oil and other hazardous substances. This increased responsibility and authority led to the establishment in 1971 of the Marine Environmental Protection Division (MEP). The MEP then established the Pollution Incident Reporting System (PIRS) to facilitate the need for properly organizing the oil spill statistics. Since the United States Coast Guard (USCG) is the only designated authority given the specific responsibility for data collection, their statistics are heavily relied upon when any study, such as this one, is undertaken.

When beginning a statistical study of oil spills, one realizes all of the available data falls into one of two categories. The first grouping of data covers a relatively short period of time and is collected in a restricted geographic area (like a country, state, or region) and records a large number of spills, the majority being small. The U.S. Coast Guard's information is of this type. (3) Table 2-2 illustrates one of the USCG's methods of classifying information, in this case it covers the period from 1971 to 1973 and lists spills with respect to type of location. This classification can aid in the determination of the major areas where an oil spill is likely to occur. However, the data cannot be taken solely at face value, because, as will be discussed in further detail later, there

Table 2-1

Some General Oil Spill Statistics

	<u>1971</u>	<u>1972</u>	<u>1973</u>
World oil produced (Mta)*	2725.8 ⁴	3062.4 ⁵	3340.7 ⁵
Volume Spilled into the oceans world wide (Mta) ⁴	-	-	6.113
Volume Spilled in USA(Mta) ⁷	.029	.061	.056
No. of Accidents in USA ⁷	8,622	9,832	12,822
No. of Ships involved in spillage accidents in USA ⁷	2,134	2,474	3,550

*Mta - million metric tons annually

Table 2-2

Type of Location of US Spills⁷

	<u>No. of incidents</u>		
<u>INLAND WATERS</u>	'71	'72	'73
1. Roadsteads	99	16	76
2. Ports	63	37	463
3. Terminals and docks	141	164	
4. Beaches	7	3	112
5. River areas	252	340	777
6. Non-navigable areas	69	122	294
Total	631	682	1,722
<u>COASTAL WATERS (INCLUDING GREAT LAKES)</u>			
1. Bays, estuaries, sounds	2,933	2,237	1,511
2. Ports	1,452	1,504	4,590
3. Terminals and docks	869	1,622	-
4. Beaches	93	98	288
5. Channels, canals, inlets	869	656	-
6. River areas	938	1,260	3,279
7. Non-navigable areas	47	65	203
8. Open waters (Great Lakes or Territorial Sea)	315	423	571
Total	7,516	7,864	10,442
<u>CONTIGUOUS ZONE</u>	396	801	483
<u>HIGH SEAS</u>	193	583	581
Total	8,736	9,931	13,328

are many inaccuracies which must be taken into account when evaluating these statistics.

The second group is a selective sample of only large spills and covers a longer period of time than the restricted group. Such an example of this type of grouping is found in Table 2-3, which lists some of the major spills occurring between 1967 and 1972 and gives some pertinent facts about each.

2.2 World Statistics

There is, at the best estimate, 6.13 million metric tons per annum (mta) of oil and other hazardous substances entering the ocean, as shown in Table 2-4. Of this, approximately 10%, or .6 mta, can be attributed to the 190 known significant worldwide marine seeps. This estimate is based on geological and geochemical data; however, there is very little literature concerning the nature and magnitude of these seeps. It has been estimated, though, that 50 to 100 times as much oil has been lost to the environment through seepage as now exists in reservoirs. (4)

Offshore production contributes about 0.08 mta. This number includes drilling and production operations, of which 0.02 mta is estimated to be lost through minor spills (50 barrels or less) with the remaining 0.06 mta lost in major accidents of 50 barrels or more. The major accidents include such occurrences as blowouts, rupture of gathering lines, and similar unpredictable occurrences. (4)

In 1971, total world oil production was about 2,400 million tons. One thousand three hundred and fifty-five million tons were transported by sea. Generally, at the end of the journey, tankers which have carried crude oil, wash the cargo tanks with seawater and discharge the waste overboard. Due to industry's improved technology, this practice has been reduced but transportation spills continue to occur due to accidents in ship/shore transfers, tankers and non-tanker accidents, and the flushing out of tanks when going to dry-dock for inspection. All together, transportation losses account for 2.13 mta of the total oil lost into the environment. (4)

Dispersed oil entering the oceans from seaboard refineries is estimated to be about 0.2 mta. This quantity is expected to decrease further within the next few years due to more stringent regulations on the amount of oil discharge permitted.

Petroleum-derived hydrocarbons (PHC) are estimated to enter the atmosphere at 68 mta on a worldwide basis. (4) The majority of this

Table 2.3.

A List of Major Oil Spills (2,8)

Event	Date	Location	Circumstances	Quality & Type Oil Spilled	Extent of Beach Contamin- ation	Beach Cleanup Procedures	Adverse Effects
1. Chryssi P. Gou- landro spill	1/17/67	Milford Haven, England	Tanker spilled oil in harbor	1700-3500 barrels crude	-	-	-
2. Torrey Canyon	3/18/67	Seven Stones Reef, England	grounded tanker broke in two	700,000 barrels Kuwait crude	242 mi. of shoreline in England & France	detergents, manual	severe destruction to marine life
3. R.C. Stoner Spill	9/16/67	Wake Island	Ground Tanker broke in two	143,300 mixed aviation & general fuels	-	-	-
4. West Delta area Block 73 Field Spill	10/15 - 27/67	Gulf of Mexico	Dragging Anchor caused pipeline leak	160,639 barrels crude	-	-	-
5. Pegasus Spill	2/8/68	Off Cape Hatteras, N.C.	tanker hull during storm	undetermined amount Bunker C fuel	-	-	-
6. Tim Spill	2/18/68	Philadelphia, Pa.	Tank barge sank	up to 7,000 barrels No. 6 fuel	-	-	-
7. Ocean Eagle	3/3/68	San Juan, P.R.	tanker grounded & broke in two	83,400 crude oil, leona	16 mi. of recreation & commercial beaches & entire harbor	manual, mech. equip., dispersants, sorbents	dispersant turned beach to quicksand
8. General Colo- cotronis Spill	3/7/68	Elenthera Island, Bahamas	grounded tanker	37,700 barrels Venezuelan crude	-	-	-
9. South Timbalier area Block 131 Field Spill	3/12/68	Gulf of Mexico	dragging anchor caused pipe- line leak	6000 barrels crude	-	-	-
10. Moron Refinery Spill	3/29/68	Venezuela	Oil from refinery spilled through sewers to sea	16,000 barrels crude	-	-	-
11. Esso Essen Spill	4/29/68	Off South Africa	Tanker struck underwater object ruptur- ing hull	30,000 barrels Arabian crude	-	-	-

12. Andron Spill	5/68	Off West Africa	Tanker sank, hull leaking oil	117,000 barrels Kuwait crude	-	-	-
13. World Glory Spill	6/14/68	Off South Africa	Tanker broke in two & sank	322,000 barrels Kuwait crude	-	-	-
14. Witwater Spill	12/13/68	Cristobol, C.Z.	Tanker broke in two	115,000 barrels mixed bunker & diesel fuel	-	-	-
15. Waterford Beach Spill	1/18/69	Waterford Beach, Ct.	Grounded oil barge	unknown quantity No. 6 fuel	-	-	-
16. Santa Barbara Spill	1/28/69	Santa Barbara Channel	Oil well blowout	100,000 barrels	40 miles residential & recreational coastline	straw, sand-blast, mech. equip.	when burning straw heavy smoke developed
17. Algol Spill	2/9/69	Long Island Sound, N.Y.	grounded tanker	up to 4,000 barrels No. 6 fuel	-	-	-
18. Main Pass Area Block 299 Field Spill	2/11-16/69	Gulf of Mexico	Pipeline leak	7,532 barrels	-	-	-
19. Dutch Coast Spill	2/16/69	North Sea	Source unknown	1,000 or more barrels	-	-	-
20. Cook Inlet Spill	3/4/69	Alaska	Tanker struck underwater object, rupturing hull	unknown quantity of Alaskan crude	-	-	-
21. Ship Shoal Spill	3/16/69	Gulf of Mexico	Floating rig shifted in heavy seas, breaking control valve on recently completed well	2,400 barrels 40 gravity crude	-	-	-
22. Hamilton Troder Spill	4/30/69	Irish Sea	Tanker collided with another vessel	5,000 barrels heavy fuel oil	-	-	-
23. Robert L. Polling Spill	5/10/69	Portsmouth, N.H.	Tank barge struck bridge abutment	4,700 barrels fuel oil	-	-	-
24. Benedicte Spill	5/31/69	Baltic Sea	Tanker collided with another vessel	14,000 barrels crude	-	-	-
25. Weymouth Spill	6/7/69	Weymouth, Mass.	Fuel barge leaked	2,500 barrels No. 2 fuel	-	-	-

26. Alma Spill	6/16/69	Alma, Wis.	Mississippi River fuel barge ran aground and sprang a leak	950 to 9,500 barrels No. 2 fuel	-	-	-
27. West Palmouth Spill	9/16/69	West Palmouth, MA	Barge Florida ran aground	4,100 barrels No. 2 fuel	-	-	-
28. Keo Spill	11/3/69	Off New Jersey	Tanker broke in two	210,000 barrels No. 2 fuel	-	-	-
29. Seewarren Spill	11/19/69	Seewarren, N.J.	Storage tank collapsed	200,000 barrels crude	-	-	-
30. British Isles Seabird Mortality	12/69 - 2/70	Northwest Coast of England	Oil from North Sea	unknown amount Fuel & lubricating oil	-	-	-
31. Martha's Vineyard Bird Mortality	2/70	Martha's Vineyard, MA	undetermined	amount and type unknown	-	-	-
32. Arrow Spill	2/4/70	Chedabucto Bay, Nova Scotia	Tanker ran aground	36,430 barrels Bunker C	150 mi. shoreline contaminated, 30 mi. of beach were cleaned	Mechanical equipment	when bulldozing, clean sand mixed with oily sand
33. Main Pass Block 4's OCS0374, Chevron Oil Co. Spill	2/2 - 3/3/70	Gulf of Mexico	Offshore platform fire, loss of well control	30,500 barrels crude	-	-	-
34. Delean Apollon Spill	2/13/70	Tampa Bay Fla.	Tanker ran aground	240 barrels fuel oil	10 mi. shoreline	sorted, manual, corexit 7664	contaminated oil caused recontamination
35. Kodiak Island Oil Pollution	2/3/70	Alaska	deliberate discharge from tank ships	unknown amount of oil ballast	-	-	-
36. Oceanic Grandeur Spill	3/3/70	Torres Strait, Australia	tanker struck underwater object, rupturing hull	unknown amount of Indonesian crude	-	-	-
37. Othello Spill	3/20/70	Sweden	tankships collided	between 420,000 & 700,000 barrels Bunker C	-	-	-
38. Tarut Bay Spill	4/20/70	Saudi Arabia	Pipeline ruptured during storm	100,000 barrels lightweight crude	-	-	-
39. Oregon Standard	1/18/71	San Francisco, CA	tankers collided	20,000 barrels Bunker C	50 miles of beaches	manual, Mech. equip.	oily straw washed up on shore causing contamination

40. Polycommander Spill	5/5/70	Western Spain	Tanker ran aground	70,000 barrels lightweight crude	25 miles of shoreline	Mech. equip., sand blasting	-
41. Kasamatsu Maru Spill	10/16/70	Cape Irozaki Japan	Tanker exploded & sank	8,700 barrels gasoline	-	-	-
42. Pacific Glory Spill	10/23/70	Isle of Wight, England	Tankships collided	unknown amount of crude	-	-	-
43. Schuylkill Spill	11/13/70	Douglasville, Pa.	retaining wall of pump failed	71,400 barrels crankcase oil	30 miles of shore	front-end loaders	-
44. Florida Keys Oil Slick	12/1/70	Key Largo, Florida	Tanker discharge	unknown amount of Bunker C	-	-	-
45. Jacksonville Oil Slick	12/1/70	Jacksonville, Florida	US Navy offshore disposal program for residual oil	12,000 - 16,000 barrels diesel oil	-	-	-
46. South-Timbalier Block 26, OCS-G1870, Shell Oil Co. Spill	12/1/70 4/16/71	Gulf of Mexico	Offshore platform explosion & fire, crude wells blowing out of control	53,00 barrels crude	-	-	-
47. USNS Towle Oil Spill	7/14/71	New York Harbor	Accidental discharge while fueling due to incorrect connection of valves	900 barrels Bunker C	3.5 mi. beach	front-end loaders	oil flowed into berm and into ditch
48. USS Mantee Spill	8/20/71	San Clemente, CA	Operational Oil spill	5,463 barrels Navy Special Fuel	75 miles	front-end loaders	-
49. Tamano Spill	7/22/72	Portland, ME	Tanker struck submerged ledge	2,400 barrels No. 6 fuel oil	several miles	Mechanical equipment, flame-thrower	discolored rocks

Table 2-4

Budget of Petroleum Hydrocarbons Introduced into the Oceans⁴

<u>Source</u>	<u>Input Rate (Mta)</u>	
	<u>Best estimate</u>	<u>Probable range</u>
Natural Seeps	0.6	0.2 - 1.0
Offshore Production	0.08	0.08 - 0.15
Transportation		
LOT Tankers	0.31	0.15 - 0.4
Non-LOT Tankers	0.77	0.65 - 1.0
Dry Docking	0.25	0.2 - 0.3
Terminal Operations	0.003	0.0015 - 0.005
Bilges Bunkering	0.5	0.4 - 0.7
Tanker Accidents	0.2	0.12 - 0.25
Nontanker Accidents	0.1	0.02 - 0.15
Coastal Refineries	0.2	0.2 - 0.3
Atmosphere	0.6	0.4 - 0.8
Coastal Municipal Wastes	0.3	-
Coastal, Non-refining Industrial Wastes	0.3	-
Urban Runoff	0.3	0.1 - 0.5
River Runoff	<u>1.6</u>	-
Total	6.113	

influx, about 45 mta, emanate from transportation sources. Fuel combustion in stationary sources, solvent and gasoline evaporation, and industrial processes constitute the other 23 mta. Automobile emissions have been categorized as reactive and non-reactive, depending on their relative rates of photochemical oxidation. About 1/2, or 22 mta, of PHC coming from transportation sources are reactive. Due to long periods of time in the atmosphere, it is assumed that 90% of the non-reactive PHC and 100% of the reactive ones never reach the earth's surface as PHC. This leaves only 4 mta affecting the earth. However, what actually enters the ocean through rainfall or dry fallout is only 10-20% of the 4 mta, which leaves only 0.4-0.8 mta entering the seas yearly. The estimation is made recognizing the fact that "the major source of error arises from the paucity of the data regarding the reaction kinetics of the PHC, their resulting end products, and the PHC content of the aerial particulate matter," (4).

It is certainly worth noting that together the natural seepage and atmospheric fallout account for approximately 1.2 mta, or 20%, of the PHC entering the oceans. In attacking the oil pollution problem, these are the two areas where we have very little direct control. So, even the most effective preventive and cleanup program on the oceans could never solve the problem completely.

The data on coastal, municipal and non-refining industrial wastes has been derived from studies on major coastal cities. It was found that the majority of the oil and grease coming from this source was entering the oceans through municipal sewers, and the municipal wastewaters contained PHC from such sources as gas stations, garages, commercial operations, etc. These sources account for approximately 0.3 of the PHC entering the oceans. (4)

River runoff contributes approximately 1.6 mta and this estimate is based on information supplied by the Federal Water Quality Administration (FWQA). They tested the silt in the Mississippi River to determine the oil content. The Mississippi is considered to have a representative value for all rivers, .085 mg/liter, and this number is multiplied by the ratio of the total river flow to that of the Mississippi, or 2.7. This results in approximately .53 mta of PHC being dumped into the oceans from U.S. waters. This number is then multiplied by the ratio of the total world petroleum production to U.S. production for a final result of 1.6 mta. (4)

2.3 U.S. Statistics and Problems Encountered

The data for oil input from the United States is available only through the USCG's PIRS. It divides the information on sources

into similar, though not identical, categories. Table 2-5 shows their breakdown pattern and, as is easily noticed, there is no information on natural seeps or atmospheric contribution, both very difficult to measure on a national basis, and the divisions are broader. However, the data is there in an alternate form for use in U.S. investigations of oil pollution.

Table 2-6 shows some of the problems this study encountered while attempting to evaluate the USCG's oil spill statistics. To begin with, the first 6 categories were changed between 1972 and 1973. It is quite possible that in 1973 the USCG merely combined collision, grounding, capsizing, fire explosion, other casualty, and tank rupture into the tank rupture category, since all of the above generally lead to a rupture or leak. Also, there has been a large variance in the amount of oil spilled and the number of incidents from year to year. The Coast Guard attributes this to several causes. The major ones are attributed to an improvement in reporting capabilities and an increasing public awareness of the need to report polluting incidents. Also, the MEP program activities are motivating the reporting of small, recurring discharges of oil. In the case of a loaded tanker sinking, the oil outflow is always equal to the vessel's deadweight but according to Leotta and Wallace in their recent article on the PIRS (6) it is "not uncommon for the oil to remain intact." When reports are received by the USCG, there is generally no indication of how the outflow from an accident was estimated. Sometimes the data is miscoded or misread and some accidents are not reported or are missed in the collection process. Another discrepancy occurs when a vessel collides or is grounded. Sometimes a fire breaks out and some oil is burned and does not enter the environment, nevertheless all of the oil is included in the outflow estimation. (1)

On a worldwide basis estimates are even less accurate. This is because in many places there is no definite reporting system. The figures in Table 2-4 are based on the assumption that losses due to minor spills may average 10 times greater than those occurring in U.S. waters. Also, assumptions are made based on a nation's economic self-interest, such as proportions of oil lost via offshore field brine discharges. These discharges consist of brine, which is produced along with oil and gas, containing traces of oil not removed when the mixture is passed through an oil-water separator. U.S. federal regulation forbids the oil concentration to exceed 50 parts per million of produced brine. Since it is assumed that it would be uneconomical for operations to exceed these proportions set by U.S. Federal regulation, estimations can be made. However, both of the above mentioned estimates are made using the United States' statistics as the standard. As previously pointed out, the U.S. system has a

Table 2-5

USCG PIRS - Sources ⁷ (1972 Statistics)

	No. Incidents	% of Total	Volume in Gallons	% Total
Vessels				
1. Dry Cargo Vessels	271	3.1	418,206	4.7
2. Tank Ships	386	4.4	1,665,264	18.8
3. Tank Barges	828	9.5	1,197,819	13.6
4. Combatant Vessels	261	3.0	440,849	5.0
5. Other Vessels	<u>388</u>	<u>4.4</u>	<u>180,127</u>	<u>2.0</u>
Total	2,134	24.4	3,902,265	44.1
Land Vehicles	77	.9	101,225	1.2
Onshore Facilities				
1. Refineries	188	2.2	2,206,781	25.0
2. Bulk Storage Fac.	296	3.4	446,567	5.1
3. Waterfront Transportation Fac.	382	4.4	613,970	6.9
4. Non-Transportation Fac.	450	5.1	435,978	4.9
5. Other Land Transportation Fac.	<u>22</u>	<u>.3</u>	<u>159,961</u>	<u>1.8</u>
Total	1,338	15.4	3,863,257	43.7
Offshore Facilities	2,595	29.7	662,203	7.5
Miscellaneous	239	2.7	61,038	.7
Unknown	<u>2,353</u>	<u>26.9</u>	<u>249,535</u>	<u>2.8</u>
Total	8,736	100.0	8,839,523	100.0

Table 2-6

Distribution of Oil Spill Incidents and the Percentage of Oil Spill⁷

						<div> <div>8614 ('71)</div> <div>8,821,844</div> </div> <div> <div>9832 ('72)</div> <div>18,786,927</div> </div> <div> <div>12,715 ('73)</div> <div>17,166,332</div> </div>
						<div> <div>Total No. Incidents</div> <div>Total Volume (gals.)</div> </div>
Cause	'71 % I % V	'72 % I % V	'73 % I % V			
Collision	.7 - 16.5	1.1 - 7.7				
Grounding	.6 - 10.1	.5 - 4.0				
Capsizing/overturning	.2 - .4	.4 - .5				
Fire explosion	.1 - 4.5	.3 - .2				
Other casualty	.8 - 2.9	1.3 - 9.2				
Tank rupture/hull rupture/leak	.8 - 23.5	1.4 - 3.2	6.3 - 22.2			
Transportation pipeline rupture			3.0 - 5.3			
Structural failure	.3 - .1	1.1 - .8	1.5 - 8.7			
Storage tank rupture/leak	1.4 - 1.7	1.3 - .6				
Hose rupture	1.2 - .6	1.5 - .2	2.1 - .4			
Line leak	17.5 - 6.4	10.1 - .6				
Pipe rupture/leak	6.7 - 7.6	3.7 - 8.7	8.0 - 29.6			
Other rupture/leak	3.6 - 2.2	3.1 - 11.6	.4 - .1			
Valve failure	5.3 - 1.6	5.9 - .3	3.5 - 1.5			
Pump failure	2.4 - .2	3.0 - .1	1.9 - .2			
Other equipment handling	3.2 - 1.3	6.6 - 1.2	8.3 - 1.5			
Tank overflow	2.9 - 1.1	6.5 - 2.2	7.6 - 3.1			
Improper valve handling		2.0 - 2.2	1.1 - .3			
Improper hose handling	.8 - .1	.8 - .3	1.1 - 0.0			
Other personal error	5.8 - 10.5	3.7 - .3	4.3 - .6			
Other improper equipment handling			2.5 - .6			
Bilge pumping			1.9 - 1.0			
Ballast pumping			.2 - 6.2			
Other intentional discharge	4.1 - .6	4.6 - .4	2.4 - 1.8			
Natural or Chronic phenomena	1.1 - .1	2.6 - 42.8	2.7 - 8.4			
Unknown	40.5 - 8.0	38.5 - 2.9	41.3 - 8.6			
%I - Percentage of Incidents	100.0 - 100.0	100.0 - 100.0	100.0 - 100.0			
%V - Percentage of Volume						

way to go before it approaches reasonable accuracy, therefore, although the worldwide statistics serve as an indicator of the amount of oil entering the environment, they leave much to be desired.

2.4 Conclusion

Despite all the problems and inaccuracies found in dealing with oil spill statistics, there is certain valuable information to be gained from them. For example, Table 2-1 gives a few general statistics, they can give one an overview of the amount of oil spilled over a period of three years. This gives an indication of whether our current oil spill legislation, surveillance, and prevention systems are being enforced or used effectively. In this case, the volume spilled in the U.S. has a very large increase between 1971 and 1972. This could have been caused by the inaccuracies stated above or due to some major spills. There was a decrease in volume spilled between 1972 and 1973. Again, this may be due to more strictly enforced legislation and better preventive techniques, or it could be a difference in the number of spills reported. Clearly, more information is necessary to draw any substantial conclusions. Unfortunately, at the time of this writing, the USCG data for 1974 was unavailable.

The type of location of U.S. spills (Table 2-2) gives important logistical information. By determining where the majority of the spills occur, one can determine such things as where the cleanup equipment should be located for prompt cleanup, where preventive measures should be more closely adhered to, and where more work should be done in the areas of research and development. For example, the majority of spills occur in coastal waters, almost 9 times as many as in inland waters for the period 1971-1973. The majority of coastal water spills occur around ports, terminals, and docks. This indicates a need for development of preventive measures and cleanup techniques in these areas. There has been an increasing awareness in regard to port, terminal, and dock oil pollution, as well as an improvement in the enforcement of legislation; therefore, the 1974 and 1975 statistics would be able to show more clearly if these types of pollution sources are decreasing, leveling off, or steadily rising so as to better evaluate the present program. The USCG statistics point to another important source of oil pollution - the river areas. A large increase was present between 1972 and 1973, possibly due to the increasing use of sewers draining into rivers as dumping areas for oil and grease from gas stations and garages. This amount corresponds to the large contribution by river runoff on a worldwide basis, as Table 2-4 indicates. As mentioned earlier, however, this world input is based on U.S. statistics.

Table 2-3 gives valuable information in dealing with the oil spill problems of major accidents. It gives major causes of accidents; grounding is a common one, and in some cases where the information was available, the table gives various cleanup techniques on the beaches. It also shows the large amount of oil spilled per large accident in comparison with the total yearly outflow. For example, according to Devanney and Steward (3) the "Torrey Canyon" spilled twice as much oil as the total oil spilled in the U.S. in 1970. Two-thirds of the oil spilled in the U.S. entered through three spills while 17 spills accounted for 70% of the total U.S. outflow in 1972 and 18 spills were responsible for 85% of U.S. outflow in 1972. This is why it is difficult to predict the amount of oil which could be spilled in any one accident or predict how much oil will be spilled in one year since large accidents will invariably throw one's calculations off.

Table 2-4 has already been discussed in some detail. Since it is an overview of the worldwide problem, this table provides some information on where our world resources should be placed for cleanup and prevention. The river areas are a point of concentration, also converting tankers to the LOT type (Load-on-Top, to be explained in detail in Chapter 3).

The statistics on causes of oil pollution can yield valuable information. Finding the major causes of accidents could necessarily help reduce and control oil pollution. The largest number of incidents are of unknown cause, but that accounts for only 3-8% of volume spilled. In 1973, pipelines accounted for 29.6% of the volume spilled, indicating the need for work in that area. The U.S. outflow from tanker accidents has progressively decreased, but they still contribute about 20% of the volume spilled.

This table is a good example of the difficulties encountered in this statistical study. As previously mentioned, the data for 1974 was unavailable in June 1975. This made a more recent comparison of data impossible. Apparently, the USCG revised its system in order to improve their reporting mechanism. Unfortunately, there was no explanation given as to the changes.

In evaluating cleanup equipment and retention measures, it would certainly be helpful to know what percentage of the oil spilled was cleaned up. In all of the statistics found for this study, this information was unavailable. This would admittedly be a difficult estimate to make, but it could lead to a better evaluation of our present program.

In conclusion, there is a limited amount of knowledge to be obtained from statistics. There is great difficulty in arriving at reasonable estimations and interpretations can be obscured by these

difficulties. But information exists for those seriously concerned about our present program, and by upgrading and improving our present statistical program, we can continue to evaluate our oil spill program accurately and effectively.

2.5 Bibliography

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Chapter 3

Ship Generated Pollution, Tanker and Non Tanker

3.1 Present Estimates and Projections

The National Academy of Science Report (4) gives the estimated budget of PHC introduced into the ocean from ships for the year 1973 as follows:

Input rate in mta (million of metric tons per annum)

Source	Best Estimate	Probable Range
LOT Tankers	0.31	0.15 - 0.4
Non LOT Tankers	0.77	0.65 - 1.0
Dry Docking	0.25	0.2 - 0.3
Terminal Operations	0.003	0.0015 - 0.005
Bilges, Bunkering	0.5	0.4 - 0.7
Tanker Accidents	0.2	0.12 - 0.25
Non Tanker Accidents	<u>0.1</u>	0.02 - 0.15
Total	2.133	

Other estimates give totals as:

- a. 1970 MIT SCEP Report 1.13 (4)
- b. 1973 USCG Impact Statement 1.72 (4)

Reference (10) presents a table projecting the oil discharged from tankers only as follows:

Quantity of oil discharged from tank washings
and deballasting (mta)

	<u>1970</u>	<u>1980</u>	<u>1990</u>	<u>2000</u>
Non LOT (Uncontrolled Discharges)	0.53	1.35	1.86	2.20
LOT	0.11	0.27	0.37	0.44
Total Pre '73 IMCO Standards	0.64	1.62	2.23	2.64
Post '73 IMCO CONV.	0.01	0.04	0.04	0.04

These two estimates agree but a third estimate by Theobald (10) is much lower. He estimates that 89,000 tons will be discharged in 1980 if the IMCO*standards are not met. He also projects an average cost of \$1830/ton as the cost of preventing this pollution in 1980 by meeting the IMCO 1973 standards.

3.2 Present and Proposed Legislation on Ship Discharges (1)

A. International (present)

The only international agreement on discharge from ships which is now in force is the 1954 International Convention for the Prevention of Pollution of the Sea by Oil, as amended in 1962. This permits:

- a. Unlimited discharge of oil outside the prohibited zone (within 50 miles from land).
- b. 100 ppm discharge within the prohibited zone.
- c. No limit on total quantity of oil discharged per voyage.

The 1969 and 1971 amendments to the 1954 Convention rectified many faults with the above and has been ratified by 21 nations controlling over 80% of the world's tanker tonnage, however, they have not yet come into force since they require ratification of 32 nations. Included among the 21 nations is the U.S.A. who ratified the Convention by the Oil Pollution Act Amendments of 1973.

*Intergovernmental Maritime Consultative Organization

B. International (proposed)

The 1973 IMCO International Convention for the Prevention of Pollution from Ships discharge standards are basically those proposed in the 1969 Amendments to the 1954 Oil Pollution Convention with a major exception that new tankers may discharge no more than a total of 1/30,000 of the cargo carried rather than the 1/15,000 for existing tankers. These standards permit:

- a. Maximum discharge rate of 60 liters per nautical mile outside the 50 mile limit.
- b. Maximum total discharge of 1/15,000 of the cargo for existing tankers and 1/30,000 for new tankers, and less than 100 ppm of effluent for non-tankers.
- c. Complete prohibition of all oily discharges within 50 miles from land, except for clean ballast effluent, i.e., not exceeding 15 ppm PHC.
- d. All tankers will be required to be capable of operating with the LOT system and Retention on Board (ROB) for retaining and decanting oily ballast.
- e. All new and existing oil tankers designed to operate on the LOT system will be required to be fitted with automatically operated oil discharge monitor and control systems, oily water separating systems, slop tanks, sludge tanks, and piping and pumping arrangements for discharge to reception facilities.

These standards will require all tankers, 70,000 DWT and over, contracted after January 1, 1976 or delivered after January 1, 1981 to be provided with segregated ballast tanks. This requirement will probably not be fully effective until the year 2000 due to the tanker construction program. However, this requirement will be optional for tankers of less than 70,000 DWT.

A complete summary of these standards (3) is given in Table 1.

Enforcement of the 1973 IMCO Convention standards will be initiated 12 months after ratification by only 15 nations who, when combined, control 50% of the gross tonnage in the world's merchant fleet.

The 1973 IMCO Convention standards have not yet been ratified by the U.S.A.

Table 3.1. Comparisons of 1973 convention with 1954 convention

Topic	1954 Convention (as amended in 1962)	1973 Convention
Applicability as regards carriage of oil.	<ol style="list-style-type: none"> 1. Seagoing tankers over 150 gross tons.. 2. Other seagoing ships over 500 gross tons. 	<ol style="list-style-type: none"> 1. All tankers over 150 gross tons. 2. All other ships over 400 gross tons including novel craft and fixed and floating platforms.
Dispute settlement.....	<ol style="list-style-type: none"> 1. Referred to International Court of Justice unless all parties agree to arbitration. 	<ol style="list-style-type: none"> 1. Compulsory arbitration by specially formed tribunals upon application of any party to dispute.
Amendment procedure.....	<ol style="list-style-type: none"> 1. Effective only upon specific acceptance via IMCO assembly and contracting States. 	<ol style="list-style-type: none"> 1. Speedier method for annexes and appendices via IMCO Committee and tacit acceptance procedures.
Survey and certification.....	<ol style="list-style-type: none"> 1. No comparable provision..... 	<ol style="list-style-type: none"> 1. Survey at 5-year intervals and at intermediate (mid period) intervals. 2. Equipment must be approved by Administration (monitors, filters, separators, interface detectors). 3. Administration issues certificate attesting to compliance by its ships, which certificate shall be accepted except when there are clear grounds to believe the ship is not in compliance.
Definition of oil.....	<ol style="list-style-type: none"> 1. Limited to crude, fuel, heavy diesel and lubricating oils..... 2. Does not include bilge slops and fuel and lube oil purification residues. 	<ol style="list-style-type: none"> 1. Includes all petroleum oils except petrochemicals (which are regulated by annex 11).
Discharge criteria in prohibited zones (this term does not appear in the 1973 Convention which uses a distance from land criterion).	<ol style="list-style-type: none"> 1. Prohibits discharges by all ships in concentrations in excess of 100 parts per million within the prohibited zones. 2. Prohibited zone generally 50 miles or greater from nearest land for tankers. Prohibited zone applies to other ships unless proceeding to a port not provided with adequate reception facilities. 	<ol style="list-style-type: none"> 1. Prohibits discharges which leave visible traces unless it can be established by installed instruments that the concentration discharged was less than 15 parts per million. 2. For tanker cargo slops, discharge is prohibited within 50 miles from nearest land. For other ships slops, and other tanker slops, discharge is prohibited within 12 miles from the nearest land.
Discharge criteria outside of the prohibited zones.	<ol style="list-style-type: none"> 1. No restriction on discharges from a ship less than 20,000 gross tons. Vessels over 20,000 gross tons are limited to discharges whose concentrations are 100 parts per million or less, unless when in the opinion of the master, circumstances make it unreasonable or impractical to retain the higher concentrated slops on board. 	<ol style="list-style-type: none"> 1. Tankers must meet all the following conditions: <ol style="list-style-type: none"> a. Ship is proceeding enroute. b. Discharge is limited to 60 liters per mile instantaneous rate. c. Total quantity discharges is limited to 1/15,000 of cargo last carried for existing tankers and 1/30,000 of cargo last carried for new tankers. d. Tanker bilges, except pump rooms, shall be treated same as other ships. 2. Other ships must meet all of the following conditions: <ol style="list-style-type: none"> a. Ship is proceeding enroute. b. Oil content of the effluent must not exceed 100 parts per million.

Table 3.1 con'd.

Enforcement mechanism.....	1. No comparable provision.....	1. Requires that the monitoring and control system be in operation and a permanent record made anytime oily effluent is being discharged, except for clean or segregated ballast.
Construction and equipment requirements to control operational discharges of oily mixtures.	1. No comparable provision.....	1. Segregated ballast is mandatory for new tankers of 70,000 deadweight tons and greater, and is optional for tankers of less than 70,000 deadweight tons. Note that "new" tankers are defined by calendar dates and are therefore not dependent upon entry into force of this Convention. 2. Retention of oil on board (LOT) is mandatory for all tankers. 3. Mandatory installation of effluent monitor and control system, provision of slop tanks, and provision of oil/water interface detectors. Effluent must comply with discharge criteria or be transferred to reception facility. 4. Other ships require sludge tank installations, oil water separator and/or filters dependent upon ship size.
Reception facilities.....	1. Provision to promote according to need of ships using ports.	1. Expanded provision to undertake to insure availability and adequacy at oil loading ports, repair ports and at other ports according to the needs of ships.
Oil record book.....	1. Establishes basic requirement to provide oil record book and requires entries for specific operations. 1. No comparable provision.....	1. Expands requirements to provide entries for more specific operations and in greater detail to aid in enforcement. 1. Establishes damage assumptions and methods of calculation of the amount of hypothetical oil outflow for tankers. 2. Establishes tank arrangement and size limitations for the cargo tanks of tankers. 3. Establishes subdivision and damage stability criteria to be applied to tankers to increase survivability in the event of accident.
Construction requirements to limit the amount of oil discharge in case of accidents.		1. Annex II details mandatory requirements for construction of chemical tankers and discharge criteria for liquid noxious substances in bulk. 2. Annex III contains regulations for the prevention of pollution by harmful substances carried at sea in packaged form, or in freight containers, portable tanks of road and rail tank cars. 3. Annex IV contains regulations for the prevention of pollution by sewage from ships. 4. Annex V contains regulations for the prevention of pollution by garbage from ships.
Additional annexes for substances other than oil. Annex II is mandatory and annexes III, IV and V may be adopted at the motion of contracting States.	1. No comparable provision.....	

C. National

Three pieces of legislation now regulate the oil shipping industry in the U.S.A. The Port and Waterways Act of 1972, the Oil Pollution Act as amended in 1973 and the FWQIA, a 1972 amendment to the FWPCA*.

- a. The Port and Waterways Act specifies requirements for structural and navigational considerations of U.S. tankers.
- b. The 1973 Oil Pollution Act, a piece of legislation that ratified the 1969 and 1971 amendments to the 1954 IMCO Convention, sets the national standards for discharge. It must be realized that these standards can be enforced by the U.S. only against U.S. ships. These requirements specify less than 100 ppm between 12 miles and 50 miles for ships other than tankers, and no visible sheen (less than 15 ppm of PHC) for tankers.
- c. A no visible sheen is a requirement enforced under the FWQIA for the contiguous zone (0 to 12 miles) and all inland waters. This piece of legislation is the only one of the three that pertains to all ships, tanker and non tanker, regardless of their flag state.

The enforcement of these standards lies mainly with the U.S. Coast Guard. Enforcement of high seas violations is left up to the flag state administrations.

3.3 Present Activities With Respect to Ship Discharges

At least four groups have programs to reduce the PHC introduced into the ocean. These are:

- U.S. Coast Guard
- U.S. Maritime Administration (MarAd)
- U.S. Navy
- Industry involved in marine transportation.

Some of the programs are joint programs and others independent. These involve studies of:

- a. Segregated ballast for new tankers
- b. Double bottom hulls for tankers
- c. Load on top (LOT) and retention on board (ROB) procedures
- d. Slop tank design with associated pumps and discharge piping
- e. Onshore facilities for oily discharges

*Federal Water Pollution Control Administration

- f. Oil discharge monitoring and control equipment
- g. Deep water ports and offshore terminals
- h. Inert gas systems
- i. Improved navigational procedures and equipment
- j. Improved training for shipboard personnel
- k. Improved ship maneuverability
- l. Harbour traffic control
- m. Support of international activities associated with technical, legal, policing, and enforcement activities related to ship operation

3.4 Proposed R & D Required to Minimize PHC Entering the Ocean Environment from Ships

A. Load on top and retention on board

The greatest reduction to the PHC entering the ocean environment by intentional means will come about through more effective use of load on top and retention on board procedures. It is presently believed that about 80% of the world tanker fleet use LOT with an efficiency of 75%. It has been shown to be capable of recovering 98% to 99% of oil remaining in tanker after discharge of its cargo (4). These procedures should also be applied to cargo ships and Naval vessels.

The 1973 IMCO standards are weak from the enforcement point of view. They provide for in port inspection of retained slops to determine whether or not LOT operations had been practiced. This does not prove compliance with the convention provisions.

More effective use of these procedures will come about only when monitoring and surveillance methods are developed to insure that all ships are obeying the discharge requirements. This will require the design of automated systems with the proper monitoring instrumentation and records. This instrumentation is not now available on a commercial scale, and its development is believed to represent the best return on investment in the form of a reduction in PHC entering the marine environment.

Effective monitoring will require instrumentation to determine the

- a. Location of the oil water interface in slop tanks
- b. Thickness of oil above water in tanks
- c. Concentration of oil in effluent
- d. Flow rate of effluent

In addition, a tamper proof, continuous recorder must be used to monitor the total quantity of oil discharged as well as the instantaneous rate of oil discharge in the effluent. This would be similar to the flight recorder now required on commercial aircraft.

Personnel in the Ocean Engineering Department of U.R.I. have developed an acoustic sensor to determine the thickness of an oil slick in the ocean. This appears to be quite successful and is currently undergoing tests by the U.S. Coast Guard. It appears that this device could be adapted to the first two items mentioned above.

A sensor to determine the concentration of oil in the effluent in the range of 10 to 100 ppm is a more difficult development problem. Attempts have been made to utilize the dielectric properties of an oil water mixture to determine the quantity of oil present but this method has, in general, been unsuccessful. It appears dielectric characteristics change with the type of oil present and with the size of oil droplets present in the mixture. Other physical principles have been tried but always without much success.

The selection of a flow measuring device and the recorder should present no difficulty since they are readily available from existing instrumentation.

It appears then, that the most formidable development problem involved with the monitoring equipment is in a sensor that will be able to determine 10 to 100 ppm of PHC in sea water at various temperatures with a reasonable accuracy.

A second required area of research and development is the optimization of an automated control system for tank cleaning and ballasting, as well as loading and discharging cargo. This must be designed so that it is impossible for an operator to accidentally discharge oil or oily ballast water by opening the wrong valve or pressing the wrong button. This becomes a question of system design once the sensors mentioned previously have been developed.

We have reference to a joint U.S. Coast Guard/MarAd project at the Maritime Research Center, Galveston, Texas on oil discharge monitoring and control equipment. The

Oil Companies International Marine Forum (OCIMF) has reported to IMCO on several occasions the status of oil-in-water monitor development progress (3).

An assessment of these programs should be undertaken before funding any instrumentation developments.

B. Shore discharge and processing equipment

A second major requirement for the reduction of intentional pollution and a necessity for LOT procedures is the availability of onshore discharge and processing equipment for the treatment of oily wastes.

Both the Navy and MarAd have been working on this project but at this date there appear to be only two such facilities for processing bilge and tank cleaning water from ships in the U.S. One is in Indiana and the other is in Seattle. Presently there is a joint program at the Cheatham Annex Fuel Farm near Yorktown, Virginia to build an additional facility. MarAd is also studying the feasibility of converting reserve fleet ships into floating oily waste processing plants.

MarAd has funded a study known as the "Frederic R. Harris Study" to determine the volume of oily waste which would arrive at U.S. ports under different pollution criteria. The conclusion was that port reception facilities for oily wastes can be economically viable operations, provided that regulations are enforced to assure sufficient waste volumes, and government assisted programs are instituted in cases where projected volumes do not warrant large capital expenditures.

The 1973 IMCO standards require the construction of loading terminal reception facilities at the major tanker loading ports throughout the world. Some must be ready by January 1, 1977 and others do not have specific dates.

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Chapter 4

The Spreading And Drifting Of Oil Slicks

4.1 Introduction

In order to establish a logical structure for the presentation of a critical review of the spreading and drifting of oil slicks, the flow diagram shown in Fig. 1 will be used. This figure represents the steps in a process by which methods for the prediction of the drifting and spreading of oil slicks are usually employed in a decision-making process.

Starting in the upper left-hand corner of Fig. 4.1, an oil spill is postulated at a particular site in a body of water. Information is provided on the type of oil, rate of leakage and total volume. The spill occurs at a site at which the current, wind and wave conditions are specified either in terms of steady values or in terms of spatial and temporal distributions. It is an over simplification to state that the current, wind and wave conditions are specified since this is in fact one of the most difficult specifications to make at most oil spill sites. Although one can use historical data, a specific spill occurs at a specific time. Figure 1 should show another box from which, for example, surface current predictions originate based on such inputs as wind levels, wind duration, fetch, tidal data, etc.

In postulating the development of an oil spill, one must immediately answer the question of whether a continuous oil slick will be produced. One desires the ability to predict, either based on analytical and/or experimental data, the existence of the continuous slick. If a continuous slick is not formed, then one must determine if discrete patches of oil will be formed. Presumably one would use continuous-slick prediction techniques for discrete patches. If discrete patches are not formed then, in all probability, the oil will be mixed in the water and one desires predictive techniques for determining the dispersion of oil in the water and its effects.

Assuming either the formation of a continuous slick or a group of patches, then the spill history is predicted. This prediction is shown as a single box in Fig.4.1 and will be discussed more fully in Fig. 4.1. The spill history produces information on the trajectory of the spill, its dimensions due to spreading, its composition due to evaporation and dissolution processes, and information on the

Fig. 4.1 - USE OF OIL SPILL HISTORY PREDICTOR FOR RESPONSE DECISIONS

Fig. 4.2 - DETAILS OF OIL SPILL HISTORY PREDICTOR.

concentration of products beneath the oil slick. The information from the predicted spill history is combined with some of the existing techniques for estimating environmental effects of the spill. Obviously the location of land masses are combined with the spill history data in order to predict arrival times at beaches, etc. The process summarized in Fig. 4.1 has a variety of applications. It can be used for the development of environmental impact statements for refineries, mono-buoys, deepwater ports and Outer Continental Shelf (OCS) drilling platforms, etc. It can be used in the development of oil spill contingency plans and it could be available for the use of Strike Teams of the National Strike Force under the National Oil Spill Contingency Plan. The technique can be used in the design of new facilities to reduce the impacts of oil spills and to improve the response to possible spills. As will be seen later in this report, many of these applications have already been considered using the available data.

Figure 4.2 expands the spill history box from Fig. 4.1. A detailed prediction of a spill history involves inputs of current, wind and wave data so that a step-by-step prediction can be made using some selected time step. In general, knowing the type of oil, the oil temperature, the water temperature, etc., the trajectory and size of the spill can be calculated. Superimposed on this calculation should be several rate processes. The more volatile components in the oil spill will evaporate into the atmosphere and the more soluble components will dissolve in the water beneath the slick. There are other "weathering" phenomena which occur which would change the oil slick properties. As the three rate processes continue, the properties of the slick may change. Properties such as the viscosity and surface tension are important parameters in the prediction of the slick spreading. Simultaneously with the surface behavior of the slick, vertical dispersion into the water should be calculated so that concentrations of various hydrocarbon components can be determined for estimates of environmental impacts. A continuous determination of whether the slick has broken into discrete patches or has become mixed into the water should be made after every time step with modifications of the spill history calculation required if either phenomena has become important.

Tables 4.1 and 4.2 indicate the range of water bodies in which oil spreading and drifting predictions must be made and the large number of sources from which oil spills may originate. The remainder of this report contains discussions of the state-of-the-art information on many of the categories shown in Figs. 4.1 and 4.2.

TABLE 4.1

AFFECTED BODIES OF WATER IN VARIOUS OIL SPILL REGIONSIN-LAND REGIONS

LAKES

PONDS

RESERVOIRS

RIVERS

COASTAL ZONE REGIONS

BAYS

GULF AREAS

HARBORS

RIVERS

SALT MARSHES

SALT PONDS

OUTER CONTINENTAL SHELF REGIONSOPEN-OCEAN REGIONS

TABLE 4.2

SOURCES OF OIL IN VARIOUS OIL SPILL REGIONS

<u>OIL SOURCE</u>	<u>IN-LAND REGIONS</u>	<u>COASTAL ZONE REGIONS</u>	<u>OUTER CONTINENTAL SHELF REGIONS</u>	<u>OPEN OCEAN REGIONS</u>
TANKS	X	X		
TRUCKS	X	X		
BARGES	X	X		
PIPELINES	X	X	X	
DRAINS	X	X		
DOCKS	X	X		
STORAGE TERMINALS	X	X		
REFINERIES	X	X		
SHIP-TO-SHIP TRANSFER POINTS		X		
SHIPS	X	X	X	X
MONOBUOYS		X		
DRILLING PLATFORMS			X	
SUPERPORTS		X	X	

4.2 Continuous Oil Slick Behavior

Oil may enter water over a range of water temperatures from about 32°F to about 100°F. Oil spilled on ice may encounter temperatures well below 0°F. Since certain transport properties of oil are strongly temperature dependent, significant variations can be produced. In addition, oils may exhibit Newtonian or non-Newtonian flow characteristics. Finally, the phase or thermodynamic state of the oil may be strongly temperature dependent. For the range of oils and temperatures to be encountered, the above data are important prior to any concern about continuous oil slick behavior, etc. Mikolaj et al (11) have examined some of the natural oil seepage at Santa Barbara and have made observations of the behavior and motions of such natural oil seeps. McLean (15) and McLean and Odedra (32) have examined the behavior of oil in cold water with special examination of the behavior of Sable Island crude oil due to the OCS potential for Canada and the United States.

Assuming knowledge of the thermodynamic state of the oil upon water entry, the questions of continuous-slick, patch formation and dispersion must be considered. Leibovich (162) has given a preliminary analysis of the patch formation problem and an examination of the vertical mixing problem. Reference (162) indicates a forthcoming publication by the author on this subject.

4.3 Oil Slick Spreading Theory

Figure 4.3 (28) will serve as background to a discussion of oil spreading theory. Shown in Fig. 4.3 for the spill radius for an ax-symmetric spill in calm water as a function of time after the spill has started. The spill involves a 2,000 barrel spill of Bunker C oil. The required property data for this calculation are shown in Table 3 and the calculations are based on the method of Fay (2). Initially the spill spreading is controlled by gravity and inertia forces. In this example the first 3000 seconds of the spill are in the gravity-inertia regime. Then there is a period of time during which the gravity viscous forces control the spreading. Finally, a long period of time is encountered during which viscous and surface tension forces dominate the spreading process. The final spill radius is based on empirical data as is the spreading constant σ . As has been noted these calculations correspond to a calm water situation.

Prior to the work of Fay, the major references on oil slick spreading theory, were those of Blokker (161) and Berridge et al

Table 4.3

SUMMARY OF SOME DATA FOR SPILL
SPREADING CALCULATIONS

Oil Spill Volume, V	2000 BARRELS
	⁴ ³
	1.123 X 10 FT
	³
Oil Spill Volume, V _m	318 M
Water Kinematic Viscosity, ν_w	1.3 X 10 ⁵ FT/SEC
Spreading Coefficient, σ	5.7 to 30.0 DYNE/CM (SEE FIG. 3)
Water Density, ρ_w	1.0 GM/CM ³
Oil Density, ρ_o	0.977 GM/CM ³

FIGURE 4.3: SPREADING REGIMES FOR A 2,000 BARREL OIL SPILL.

(160). The analytical basis for the spreading process in these references was not detailed. During the late 60's and early 70's the analytical and experimental works of Fay and Hoult advanced the analytical base for the prediction of oil slick spreading. The results of this work are contained in References (2, 41, 61, 62, 72, 98, 112). Fanelop and Waldman (163) and Waldman (114) made several improvements on the Fay and Hoult results. A recent paper by Buckmaster (73) represents another important addition to the spreading theory literature. A report by James and Hann (134) illustrates the application of the spreading theory to predict the motion of an oil spill.

Most of the analytical predictions for oil slick spreading have been developed for the calm water case. Schwartzberg (5) conducted some early laboratory experiments on spreading and drifting. Hellmann (93, 94) also has conducted spreading experiments and the use of mineral oil as a simulant. Kennedy and Wermund (3) is typical of airborne observation of oil slick spreading. Most of the early oil slick spreading theory as developed by Fay and Hoult was based on laboratory observation of the spreading process coupled with the use of quantitative data such as were available from the Torrey Canyon and other spills.

4.4 Oil Slick Drifting Theory

4.4.1 Introduction

As background to the drifting theory, Fig. 4.4 will be useful. A surface wind vector, V_{10} , is shown which indicates the wind magnitude and direction. A wind or leeway factor, WF, is defined as:

$$WF \equiv V_o / V_{10} \quad (1)$$

The vector, V_o , is called the surface wind drift vector and indicates the actual drift direction of an oil slick due to the wind. The surface wind drift vector is drawn relative to the wind vector through the use of the drift angle shown in Fig. 4.4. Various data are available for selecting both the wind factor and the drift angle. The wind factor is also sometimes called the leeway of the spill. To the surface wind drift vector, a surface current vector is added as indicated in Fig. 4.4 to produce the resulting slick motion drift vector. Even with this simple discussion, one can see a group of parameters which are required to predict the actual slick motion drift vector. These quantities are the wind magnitude and direction, the wind drift factor or

FIGURE 4.4: CONSTRUCTION OF THE SLICK MOTION DRIFT VECTOR.

leeway, the drift angle and the surface current magnitude and direction. Obviously, if any or all these factors are changing with time, then they must be known so that displacement of the oil slick can be calculated using the current slick motion drift vector.

4.5 Drift Factor (Leeway)

The early work of Edman (164) can be used to relate the drift angle to wind duration and latitude. James (165) suggested an angle of 20° to the right for mid-latitudes in the northern hemisphere. This result was supported by more recent work of Teeson (70). Teeson's work was performed in the West Passage of Narragansett Bay using thin polyethelene sheets. Teeson suggests an empirical equation for the wind factor which yields values in the range from 1% to 5%. Munday (166) developed the concept of a relative wind factor which was defined as the ratio of the slick velocity, relative to the local surface current, to the local surface current. The values were about 0.25% to 1.75%. Additional studies were made by Webb et al (167), Schwartzberg (5, 128) and O'Brien (168). The following publications are concerned with the influences of wind, current and waves on the oil slick drift motion with some of them specifically concerned with the wind factor or leeway. These are References (33, 48, 52, 53, 57, 60, 68, 107, 159). A study by Warner et al (10) is typical of decisions which are made when one actually develops an oil slick spreading and drift motion analysis. These authors studied two cases. In one, the velocity of the oil slick drift was taken as 3% of the wind speed and the direction corresponded to the wind speed. This is equivalent to taking the wind factor as 0.03 and the drift angle as zero.

4.6 Surface Current

It is clear that a knowledge of the surface current is required. There are two situations involving an estimate of the surface current. First, if one is observing and using the motion of an actual oil spill to check existing analytical techniques, one must have a knowledge of the surface currents. A second major situation involves the preparation of environmental impact statements or oil spill contingency plans. One must predict the current at a projected refinery or deepwater port site. In this situation, one must either use historical data or numerical predictive techniques. In some cases, the numerical predictions may be well developed and well verified or may be based on more statistical data. It should be

recognized that the prediction of slick drifting motion is critically influenced by the accuracy of the current data, wind factor, etc. The following references contain considerations of current effects. They are References (33, 75, 52, 59, 74, 101, 106).

4.7 Wave Effects

Comments on wave effects on oil slick drifting are similar to those just made on surface current effects. First of all, it is necessary to know the actual effects of the waves on controlling the drift motion and second, to generate the necessary wave data at specific sites. The entire theory of wave effects on drifting of oil slicks is significantly less-developed than effects due to wind and current. The following References contain information on wave effects on oil slick drifting and a discussion of typical methods for forecasting conditions. These are References (16, 18, 40, 48, 85, 86, 106).

4.8 Effects of Rate Processes

Although the title of this section is somewhat of a misnomer since the oil spill drifting and spreading processes obviously involve "momentum" rate processes, it has been used specifically for the evaporation, dissolution and weathering-and-aging processes for oil slicks.

4.9 Evaporation Processes

A limited amount of data exists on the evaporation process for spilled oil. The early work by Blokker (161) is available. More recent studies associated directly with the evaporation process are to be found in References (26, 50, 143, 127, 124). Gibbs (121) has investigated the oxidation process of crude oil and seawater, Garrett (120) has studied the changes in the air-sea interface properties and Cousens (119) has measured the vapor-liquid equilibrium of hydrocarbons and seawater. Work by Cousens is typical of basic data which are required to establish the proper energy and mass balances involved in modeling evaporation processes.

4.10 Dissolution Processes

At the major interface with the oil slick, a mass transfer occurs with the water column. This dissolution process, plus the

vertical mixing process, controls water quality beneath the oil spill. The dissolution process is actually a two-fold problem of mass transfer at the water-oil interface followed by vertical mixing in the water column. Lysyj and Russell (122) studied the overall dissolution process, while Loucks (99) and Murray (100) have investigated the dispersion and turbulent diffusion processes. Devanney (67) outlined an excellent study of surface fractionation and vertical dispersion in an unsuccessful proposal to NOAA. The vertical dispersion problem was also considered in several reports on the Georges Bank oil study, and a refinery and deepwater port in Maine. Both studies which will be identified later. References (117, 118, 123, 151) report the solubility of various hydrocarbons in seawater. Work by Frankenfeld (27) and Cox et al (37) contain measurements on the dissolution and dispersion processes.

4.11 Weathering and Aging Processes

This is a catch-all category to which rate processes other than the dissolution and evaporation processes are assigned. It includes various biological and chemical processes which act over various time periods to change the thermodynamic, transport and other properties of the oil slick. References (1, 19, 51, 116, 144, 145) all contain information on such processes. It is not obvious that state-of-the-art knowledge on a variety of weathering and aging effects can be incorporated into computer simulations for the prediction of oil slick spreading and drifting. Some of the knowledge of these processes is such that basic information is not available so that even order of magnitude estimates can be made on the importance of these processes.

4.12 Instrumentation

The instrumentation discussion of this session is concerned with measurements for in-situ oil spill experiments. The instrumentation for laboratory experiments is available although the range of instruments and support equipment is quite formidable. Devanney (67) documents the instrumentation problems in his proposal to NOAA. In-situ experiments consist of either planned spills for the purpose of examination of spreading and drifting predictions and actual spill behavior or spill-of-opportunity in which preplanning of instrumentation, etc. can produce accurate quantitative data. For either type of in-situ experiment, measurements will be made either by aerial observation or using ships, divers or small underwater research vessels. Regardless of aerial or ship support systems in-situ measurements are difficult.

4.13 Aerial Observations

Aerial measurements obviously involve photographic methods which permit definition of the area extent of the spill. More recently the use of the ERTS Satellite is being investigated at the University of Delaware.

Aerial observations have involved the use of infra red detectors, microwave imaging and lasers. The U.S. Coast Guard has developed its own prototype aerial surveillance system. In addition to defining the overall dimensions of the spill as a function of time, these aerial systems have been used to measure the slick thickness and other compositional aspects of the oil through various signatures which the systems can data process. Attempts to use lasers are discussed in References (22, 43). An infra red system is discussed by Kennedy and et al (3). Microwave systems are discussed in References (3, 43). The U.S. Coast Guard airborne surveillance system is discussed in References (24, 44).

4.14 Other Instrumentation Developments

Overfield (13) discusses the problems in a simulated oil spill experiment, Estes et al (23) discuss volume determinations by airborne surveillance and surface sampling techniques. Chang and Saner (31) had discussed problems of sampling from boats and boat samplers. Reference (54) discusses surface current measuring problems while Sauer and Klemas (108) discusses an oil thickness monitoring gauge. Most recently Lamb (63) has developed an acoustic oil thickness measuring system. The work by Lamb was sponsored by the U.S. Coast Guard and is being evaluated and used as part of the OHMSETT test facility.

4.15 Estimate of Environmental Effects

If one is using oil spill spreading and drifting techniques to predict only the size and location of a spill, then environmental effects do not enter the picture. However if one is developing an overall predictive technique, then the environmental implications are necessary subsystem components. If a complete predicted system were available, the slick size, thickness and composition would be predicted as a function of time as well as its location. In addition, information would be available as to the water quality in the water below the slick. If knowledge is available of the biological species which are present in the slick locations and if

mortalities and other damage estimates can be assigned to various concentration of chemicals, then these data can be coupled to the predictive analysis in such a way as to estimate potential damage to biological species in the water column. There will be situations in which the water quality will be affected all the way to the bottom and begin to interact with plants, animals and sediments. Although one can state casually that the bottom phenomena could be investigated, this is undoubtedly stretching one's imagination in terms of our basic knowledge of these processes and our ability to model them. Although such problems can be studied, it is not obvious that we have the ability to model the vertical structure of the pollutants in the water column. Before that problem is under control an analysis of bottom interaction remains remote. The predictive technique will also identify when the spill reaches land masses and presumably this could be inputted into an analysis of water fowl mortality, etc.

A significant amount of modeling with environmental affects has already been attempted. These studies have been concerned with super tanker moorings in the Gulf of Mexico and off the Delaware and New England coasts, the Georges Bank petroleum development and a terminal in Maine. It is reasonable to state that a significant portion of an overall systems analysis structure already exist. Much of the definition of such a system is lacking in the areas of prediction of concentration of chemicals in the water column and, as usual, the inclusion of biological damage.

4.16 Experimental Verification of Predictive Models

Since predictive models for oil spill spreading and drifting are used regularly in environmental impact analysis, etc., one must be concerned with the accuracy of the predictions. The following publications involve attempts to analyze the accuracy of the predictions.

Mikolaj et al (11) have evaluated data on the oil movements in the Santa Barbara oil spill. Additional discussion of these data have been presented by Fischer and Stevenson (21). The work by Mikolaj et al does not contain an analysis of the observed oil movements. Waldman et al (12) has made predictions of the oil spill motion that occurred in the Chevron Oil spill. Additional data on the Chevron spill is available from overflights and the data are presented in References (38, 45, 46). Although Waldman et al made a series of predictions on spill motion, their analyses suffer from a lack of actual current and wind data. It has been stated repeatedly that inputs of current and wind data are critical

for the evaluation of the predictions. Warner et al (10) analyzed the Arrow spill and their predictive techniques also suffer from a lack of accurate data during the spill. Premack and Brown (28) analyzed a spill from the P.W. Thirtle which occurred in the Narragansett Bay. An available numerical model to predict the tidal currents was used in addition to the wind factor of James. A very simplified analysis was used to combine the spreading theory of Fay with the current data from the numerical model. The predicted arrival times at various land masses from the model were compared with data from a series of newspaper articles and the agreement was acceptable. Jeffery (25) described a really excellent control experiment where oil was released in its movement followed the better part of a week. However in spite of the beautiful detail of the extent of the spreading and its motion no measurements of current or wind were made. A Southern California spill experiment (77) was conducted with remote sensing involved.

4.17 Application of Predicted Models

The use of predicted models of oil spill spreading and drifting is in fact quite impressive. In 1971 the U.S. Coast Guard issued a preliminary forecast guide for estimating oil spill motion. This was published in Reference (39). Similar estimates have been made for oil spills motions in New York Harbor (55), for San Francisco Bay (90) for the Straits of Georgia (29) for the Bahama Islands (91, 92) and for the Atlantic Coast and the Gulf of Alaska in Reference (111).

Three significant studies were conducted of super tanker mono buoy installations in the Gulf of Mexico off the Delaware Coast and Machias, Maine. These results are summarized in References (88, 134, 140). Studies have also been conducted involving oil spill motion prediction for the Georges Bank Petroleum study by MIT and these results are presented in References (137-139). Additional studies of this type have been described in references.

Additional studies are given in References (149, 115, 148).

Oil spill predictive motions have also been used in planning offshore oil spill cleanup operations (135, 136) and for cleanup response teams (142).

4.18 Arctic Oil Spills

This section has been included in the oil spill spreading and drifting section since many of the references contain information on oil which is spilled over and under ice and the behavior was observed including the spreading characteristics. This type of

experiments in some cases have been analyzed by the available spreading theory or with some modifications. The Alaskan Oil Spill potential has been discussed by Glaeser (4) and in Reference (75). Some of the aspects of combatting Alaska Oil Spills have been discussed by McLeod and McLeod (14). Barber (6), Glaeser (9), McMinn (20), and Keevil and Ramseiner (234) have all studied experimental spills on ice. Helles Hist et al (35) investigated oil spill on Arctic Lake. The following References also contain information on oil spill on ice. They are References (42, 74, 76, 87, 89).

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Chapter 5

Oil Containment Devices

5.1 Introduction

In order to establish a logic to the presentation of a critical review of oil containment devices, the flow diagram shown in Fig. will be used. This figure presents the steps which are involved if an oil containment device is to be used effectively in an oil spill situation. The figure also contains a list of questions which should be considered in the decision to employ an oil containment device. After a discussion of the elements in Fig. 4.3, sections of the report will be devoted to major categories identified by Fig. 4.3. Each major section contains a discussion of the important characteristics of the category, a review of the available analytical and experimental data on the category and recommendations for future research in the category. Throughout this report the words "containment device" and "barrier" will be equivalent.

The use of an oil barrier in a specific oil spill situation involves the following steps. In Fig. 4.3 the National Oil Spill Contingency Plan issues an alert on the oil spill. Ideally, the alert should contain an initial estimate of the oil type and the amount of oil, or the type of oil and the rate of leakage along with the maximum amount of oil which could be involved in the spill. The alert should also include the geographical location of the spill, the actual meteorological and sea state data, and the amount of debris in the vicinity of the oil spill site. The use of these various data will be identified shortly. Regardless of whether or not the oil barrier will be used, at the storage site preparations should be made for packaging the device for possible shipment to the spill site. However, before transportation of the device to the site occurs, there are a series of questions which must be considered in the use of the barrier. First, it is desirable to know whether an oil slick has been formed which is containable. An oil spill which has covered many square miles and has reached an extremely thin film probably would not be handled by a containment device. The cost of such a containment attempt would probably be prohibitive. Spill site conditions may be such that the oil has been dispersed into the water column with containment not being an option. Specific types of oil at certain temperature conditions may coagulate and be easily containable. For conditions where the slick cannot be contained, the barrier will not be shipped.

The second question to be considered is the estimate of the total amount of oil involved in the spill. There is a physical limit to the amount of oil which a barrier with a given draft and freeboard can support in calm water, on a windless day and in the absence of waves. Although the barrier may be transported to the spill for oil volumes which are many times larger than the maximum containable volume, a comparison of these two oil volumes is useful for the On-Scene Coordinator (OSC). Decisions can be made on multiple requests for containment devices, the likely success of the containment device and possible future actions which must be taken due to the volume of the oil spilled.

A third and extremely important question is related to the ability of the barrier to contain the oil within its surfaces. For the device to function efficiently the surface currents must be below a certain range or the oil will be carried under the barrier. Oil flow under the barrier is affected by the oil properties which in turn are dependent on water temperature. The barrier's dynamic response to wind, wave and current actions must be such that the barrier can follow the movement of the water surface while maintaining its design draft and freeboard. If the device does not follow the water's surface then oil will flow over or under the barrier and the device will not perform efficiently. The mooring system for the device is a major element in the determination of the dynamic behavior of the barrier. The mooring system must be consistent with the elastic and inertial characteristics of the containment device and must compensate for water depth changes if such changes are important. If, over the time period for which the containment device must function, there will be significant changes in current or wind direction, then the mooring system must be designed to accept these directional shifts. It can be seen that some of the initial alert information becomes important in the considerations just described.

The fourth question is related to whether the structural integrity of the barrier can be maintained and, hence, whether the barrier functions efficiently, if at all. At many spill sites, the amount of debris in the water may be such that barrier damage will occur which will permit oil leakage. This is especially true in navigable waters with heavy river traffic and fast currents. It may also be a problem in major harbors of the United States. Such information on debris levels, provided in the initial oil spill alert, permits evaluation of the probable success of the containment device.

Although the answers to the previous four questions may be satisfactory, a judgement must be made on whether an oil barrier can actually be deployed and moored. This could be a problem in high sea states and many fast current situations. If an extremely low probability of successful deployment and mooring exists, it may be senseless to use the

containment device. The question of deployment and mooring can sometimes be by-passed if the containment system is already in place. Such deployments are sometimes a standard procedure at oil transfer terminals, ship-to-ship transfer points, etc. At least one major oil barrier is manufactured which can be placed at the bottom of an estuary, lake, etc. and, if an oil spill occurs, a pneumatic pressurization system permits the oil barrier to rise to the surface. Therefore, one element in this fifth question is to ask if the barrier is already deployed.

The sixth question indicates that consideration must be given to potential hazards from the use of an oil containment device. There may be situations at ships, piers, drilling platforms, etc. where there is a potential fire hazard. This judgement could be made either by the OSC or the owners of the property in the absence of the OSC. In the existence of some hazards and in the absence of the OSC, it is possible that property owners from whose equipment the oil is flowing, might decide that it is a more economical decision to pay for clean up of the oil spill away from the property rather than risk a more severe economic penalty associated with the destruction of the property.

The final question is related to transportation of the containment device to the oil spill site. Depending on the oil spill site, one or more means of transportation may be possible. Difficulties in transportation of the equipment could arise from at least two major considerations. First, the meteorological and sea state conditions may prohibit all means of transportation; second, the equipment may be only compatible with one of the possible shipment means and not others. As will be indicated later, such limitations already exist in terms of the present status of certain oil spill response systems.

Assuming that the answer to these seven questions is acceptable to the spiller or the OCS, then transportation of the containment device will be made to the spill site. The barrier will be deployed and moored, and the recovery operation of the oil within the barrier will proceed as part of the overall clean-up operation. After the recovery phase is completed, the containment device will be removed and transported to its point of origin where it will be cleaned and necessary repairs made. It is possible that, under certain conditions, the transportation and cleaning operation may be one operation. For example, at the spill site the barrier may be loaded onto a specially designed ship with suitable cleaning and storage systems so that the cleaning operation is completed by the time the ship returns to its home port. Once the cleaning and repair operations are completed, the barrier will be packaged and stored for the next oil spill alert.

Tables 4.1 and 4.2 indicate that oil containment devices must function in a variety of water bodies and must contend with a large number of potential spill sources. Spill sites indicated in Table 4.1 range all the way from ponds and lakes in which relatively easy containment

situations exist to the open ocean in which very severe and adverse conditions exist. From Table 4.2 it will be seen that over a dozen different oil spill sources exist with which oil containment devices must contend.

The remainder of this report has been prepared to cover a group of categories related to many of the elements shown in Fig. 4.3. Although the categories may not be arranged in exactly the order shown, they will summarize our present ability to answer many of the questions indicated in Fig. 4.3 in terms of available analytical and experimental techniques.

For this report, the term "barrier" is defined in terms of a physical barrier having a vertical member to retain the oil and sufficient floatation members and stabilizing members to maintain the design freeboard and draft of the vertical member. Special barriers, such as air or pneumatic barriers will be discussed separately. Table 5.1 summarizes present barrier manufacturers and distributors. The major portion of this table was constructed from a table provided by the Exxon Co. whose assistance is gratefully acknowledged. Additional entries for Appendix A were obtained from Reference (63)*. Additional descriptions for barriers will be found in a 1973 EPA report (3) and a recent A.D. Little, Inc. report (120).

5.1.1 Oil Slick Containability

5.1.2 Fluid Dynamic Aspects

The problem of oil slick containability will arise as conditions change from calm water, windless and waveless conditions to less favorable conditions. For some combination of parameters, a large slick will divide into discrete slicks or patches, with a second transition for which the oil will become dispersed vertically in the water column. Under either of these conditions, containment by oil barriers will become difficult, if not impossible. Leibovich (137) suggests that he has at least developed an analysis of both of these phenomena, the results of which will be published in a forthcoming paper in Ocean Engineering. Reference (137) contains some analysis of the problem. The thickening-thinning response of oil riding wave crests and troughs may be the initial mechanism by which the oil slick is broken into patches. Some experimental observations of this phenomena were reported by Lindenmuth (11). The analytical efforts by Leibovich are the first published attempts to analyze the containability problem.

*

Entries in parentheses using a format of B followed by 4 digits are presented in the Bibliography of this report.

Table 5.1

OIL BARRIER MANUFACTURER/DISTRIBUTOR INFORMATION*

NO.	NAME	MANUFACTURER(S)	DISTRIBUTOR(S)
1.	Acme	Acme Products Co. P.O. Box 51388 Tulsa, OK 74151 (918) 836-7184	The Bovaird Supply Co. P.O. Box 2590 Tulsa, OK 74102 (918) 587-7271
2.	Acorn/Adsol	UK Agents: Hardmans, 57 Oldham Rd. Manchester, England	
3.	American Marine	American Marine Inc. 401 Shearer Blvd. Cocoa, FL 32922 (305) 636-5783	
4.	American Rubber	American Rubber Manufactur- ing Company 1145 Park Avenue Oakland, CA 94608 (415) 652-0800	
5.	Anchor	Anchor Canvas 247 W. 6th Street San Pedro, CA 90731 (213) 833-1307	
6.	Aquaboom	Merchandman Trading Agency 45 Russell St. Vaucluse, NSW, Australia	
7.	Barracudaverken	Barracudaverken AB Box 25-S-18251 Djursholm 1 Sweden 08/755 2600 (phone) 17268 Barcents (Telex)	Barracudaverken (Great Britain) Ltd. Circle House South 65-67 Wembley Hill Road Wembley, Middlesex HA9 IBM England 01-903 3251-4 (phone)

* The information in this Table was obtained from two sources. The basic structure of table is that of a table provided by the Exxon Co., and this is gratefully acknowledged. Into that structure have been introduced a data summary from B0063.

NO.	NAME	MANUFACTURER(S)	DISTRIBUTOR(S)
8.	Bennett	Bennett Pollution Controls, Ltd. 119 Charles St. North Vancouver, British Columbia Canada V7H 1S1 (604) 929-5451 (phone) 043-52686 (Telex)	MacMillan Bloedel, Ltd. Powell River-Alberni Sales Corp. 1700 Russ Bldg. San Francisco, CA 94104 (415) 421-6470 International Underwater Contractors, Inc. 264 Fordham Place City Island, NY 10464 (212) 885-0600 Alaska Pollution Control P.O. Box 224 Anchorage, AD 99510 (907) 344-5036 Ergon, Inc. Drawer 1639 Jackson, MS 39205 (601) 948-3472
9.	Bridgestone	Bridgestone Tire Co., Ltd. Industrial Rubber Products Export Section 1, 1-chome Kyobashi Japan 567-0111 (phone) J22217 (Telex)	Lord Kinematics 2400 West Loop South, Suite 310 Houston, TX 77027 (713) 627-2751 The Darcoid Co. of Calif. 450 Townsend St. San Francisco, Calif. 94107 (415) 861-6984
10.	Clean Water	Clean Water, Inc. Courthouse Square P.O. Box 1002 Toms River, NJ 08753 (210) 341-3600	
11.	Coastal Services	Coastal Services, Inc. 22 River St. Braintree, MA 02184 (617) 848-4820	
12.	Colloid	Colloid Spilldam, Inc. P.O. Box 861 Brockton, MA 02450 (617) 583-7850	

<u>NO.</u>	<u>NAME</u>	<u>MANUFACTURER(S)</u>	<u>DISTRIBUTOR(S)</u>
13.	Dube	Dube Scele Via San Sebastiano 18/3 Genova Italy	
14.	Effle. Mgmt.	Effluent Management Company 250 Earls Court Rd. London, SW 5 U.K.	
15.	Environetics	Environmatics, Inc. 9824 Industrial Dr. Bridgeview, IL 60455 (312) 264-6600 (312) 585-6000	
16.	Expandi	Sanera Projecting AB Nordmaling, Sweden S910 01	
17.	Fabri	Firestone Coated Fabrics Div. 2525 Firestone Blvd. P.O. Box 1592 Southgate, CA 90280	
18.	Gamlen	Gamlen Maitre S.A. 2, rue Huntziger 92112 - Clichy France 737.67.95) 270.13.53) (phone) 270.77.59) 62 889 F (Telex)	Gamlen Chemical Co. 11 Broadway New York, N.Y. 10004 (212) 944-5823 (phone) 12-7737 (Telex)
19.	Goodrich	B.F. Goodrich Engineered Systems Co. 430 South Main Street Cohasset, MA 02025 (617) 383-6000	
20.	Goodyear	The Goodyear Tire & Rubber Co. 1144 East Market Akron, OH 44316 (216) 794-2121	
21.	Headrick	Headrick Industries 3508 Ocean View Blvd. Glendale, CA 91208	

<u>NO.</u>	<u>NAME</u>	<u>MANUFACTURER(S)</u>	<u>DISTRIBUTOR(S)</u>
22.	Hoyle	Hoyle Marine Ltd. 24 Elm Park Road Wallasey, Cheshire, England 051-639 9757 (phone) Hoyle Chamcon 627110 (Telex)	
23.	Humble/Bottom Tension	Exxon Co.	
24.	Hurum	Hurum Enterprises 87 Main St. Champlain, NY 12919 (518) 298-3905	Hurum Shipping & Trading Co., Ltd. 300 St. Sacrement St. Montreal, Quebec H2Y 1X5 (514) 842-5211 (phone) 05-25365
		Smith Anderson Co., Ltd. 3181 St. James St. West Montreal, Quebec H4C 1G7 Canada	Sorbent Sciences Inc. 1269 East Edna Place Covina, CA 91723 (213) 339-1259
25.	Imodco	Imodco, Inc. 10960 Wilshire Blvd. Los Angeles, CA 90024 (213) 477-1441 (phone) 06-74787 (Telex)	
26.	INCO	International Engineering, Inc. 14929 Clark Avenue City of Industry, CA 91745 (213) 330-7439	
27.	JPS	JPS Equipment, Inc. P.O. Box 13095 Port Everglades, FL 33316 (305) 584-8387	
28.	Kepkam	Kepkam Company 5406 Distributor Drive Richmond, VA 23225 (703) 231-4307	
29.	Kepner	Kepner Plastics Fabricators, Inc. 4221 Spencer Street Torrance, CA 90503 (213) 371-2003	Seaward International, Inc. 6269 Leesburg Pike Falls Church, VA 22044

<u>NO.</u>	<u>NAME</u>	<u>MANUFACTURER(S)</u>	<u>DISTRIBUTOR(S)</u>
30.	Kleber	Kleber-Colombes 6, Avenue Kleber, B.P. 9-16 75784 Paris, Cedex 16 France 553-01-00 (phone) 26.811 F (Telex)	
31.	Logan	Logan Engineering and Contract- ing Co. 5731 St. Augustine Rd. Jacksonville, FL 32207 (904) 731-0000	
32.	Marsan	Marsan Corp. Rt. 1, Box 83 Elgin, IL 60120 (312) 741-9047	
33.	Megator	Megator Pumps & Compressors, Ltd. 87A Newington Causeway (01) 407-5616 (phone) 886847 (Telex)	Megator Corp. 136 Gamma Drive Pittsburgh, PA 15238 Other agents worldwide
34.	Metropolitan	Metropolitan Petroleum Petro- chemicals Co., Inc. 25 Caven Point Road Jersey City, NJ 07305 (201) 434-4451	
35.	Mitsubishi	Mitsubishi Denki K.K. 57-1-1, Miyashita, Sagami-hara City Kanagawa Pref. Japan	
36.	Morris	Morris Productions (Sales) Pty. Ltd. 2-12 Harp Street Campsie, NSW, 2194 Australia	
37.	Muletex	Muehleisen Company El Cajon Industrial Park 1100 North Johnson Avenue El Cajon, CA 92020	
38.	Nasko	Nakamura Sengu Kogyo Co., Ltd. No. 104, Aioi-Cho, 6-chome Naka-ku, Yokohama 231 Japan 681-0941 or 641-3567 J47804 (Goldena) (Telex)	

<u>NO.</u>	<u>NAME</u>	<u>MANUFACTURER(S)</u>	<u>DISTRIBUTOR(S)</u>
39.	Natl.Mar.Plastic	National Marine Plastic K.K. 1-22-1, Omori Kita, Ota-ku Tokyo, Japan	
40.	Offshore Devices	Offshore Devices, Inc. 106 Sanderson Avenue Lynn, MA 01902 (617) 581-6404	
41.	Oil Spill Serv.	Oil Spill Services P.O. Box 548 Kirkland, WA 98033 (206) 454-2514	
42.	Pacific Poll.	Pacific Pollution Control 800 Grayson Berkley, CA 94710 (415) 843-5602	A.L. Somers, Inc. 5719 Kirby Drive Houston, TX 77005 (715) 524-5300
43.	PSI	Parker Systems, Inc. Box 1652 Norfolk, VA 23501 (804) 543-0647	
44.	Pirelli Type R1	Industrie Pirelli Azienda Seregno Via Milano 8 20038 SEREGNO (MI)	
45.	PBI	Pollution Booms, Inc. 491 West Main Street Avon, MA 02322 (617) 471-2760	
46.	Quincy Adams	Quincy Adams Marine Basin, Inc. 47 Palmer Street Quincy, MA 02619 (617) 471-2760	
47.	RFD/GQ	RFD/GQ Ltd. Godalming, Surrey, U.K. Godalming 4122 (phone) 85233 (Telex)	
48.	SOS	Scandinavian Oil Service Stora Badhusgatan 20 S-411 21 Gothenburg Sweden (031) 17 85 30 (phone) 21067-Stuart (Telex)	Scandinavian Oil Service Laan Copes van Cattenburch 131 Holland (070) 07 (phone) 33374 :)

NO.	NAME	MANUFACTURER(S)	DISTRIBUTOR(S)	NO.	NAME	MANUFACTURER(S)	DISTRIBUTOR(S)
19.	Seaboom	Submarine Engineering Assoc. 430 South Main Street Cohasset, MA 02025		53.	Spillguard	Johns Manville 22 East 20th Street New York, N.Y.	
10.	Seaclean	Seaclean International, Ltd. Industrial Estate, Holmbush Way Midhurst, Sussex GU 29 9HX England Midhurst 2406 (phone) MINSTRUC via Westcham London 268312 (Telex)	Com. te Andrea de Angelis Via A. Carrara 253 16147 Genoa Italy Pains-Wessex (Canada), Ltd. 100 Leiblin Drive Leiblin Park Halifax, Nova Scotia BR3 1N5 Canada P. Burden, Esq. 2 Wybalena Road Hunters Hill Sydney 2110, NSW, Australia Ramsey International 271 Abbas Abad Suite 5 P.O. Box 12/1614 Teheran, Iran Marco Pollution Control Corp.	54.	Stamford	Stamford Industries 18 Smith Street Chatswood, 2067, NSW, Australia 407-3112 407-1751 406-4454	
				55.	Steltner	Steltner Development and Manufacturing Co., Ltd. 5 Sparkes Street St. Catharines, Ontario Canada L2N 4E1 (416) 934-3302 (phone) 021-5216 (Telex)	
				56.	Suzuei	Suzuei Marine Co. Fukushima Bldg. 10-15, 1-chome Uchi-Kanda, Chiyoda-ku Tokyo, 101 Japan (03) 295-1616 (phone) 222-3138 Suzuei J (Telex)	Sumitomo Shoji America, Inc. 1100 Milam Bldg. Suite 3434 Houston, TX 77002 (713) 224-2713 (phone) (713) 224-1933 775-475 (Telex)
1.	Skuteng	Skuteng A/S Marstrandt 6 P.O. Box 6559 Rodeløkka Oslo 5 Norway (21 35 12) 35 00 20 (phone) 11784 (Telex)		57.	Tampella	Oy Tampella Ab 33100 Tampere 10 Finland 931-32400 (phone) 22-236 (Telex)	
2.	Slickbar	Slickbar, Inc. P.O. Box 295 Saugatuck Station Westport, CT 06880 (203) 226-6343 Industrial Plastics Canada, Ltd. P.O. Box 93 Fort Erie, Ontario Canada (416) 871-0412	D.A. Comstock & Co., Inc. P.O. Box 428 South Norwalk, CT 06856 Export sales handled by above Sunshine Chemical Corp. P.O. Box 5534 Jacksonville, FL 32207 (904) 356-1733	58.	Trelleborgs	Trellegorgs Gummifabrics AB S-231 01 Trelleborg 1 Sweden 0410-15000 (phone) 329 29) 329 50) (Telex)	Trelleborg Rubber Co., Inc. 30700 Solon Industrial Pkwy Solon, OH 44139 (216) 248-8600 (phone) 980282 (Telex)
				59.	Trygve Thune	Trygve Thune A/S Munchsgate 5 Oslo 1 Norway (02) 20 45 04 (phone)	East Coast Services 343 Washington Braintree, MA 02184

<u>NO.</u>	<u>NAME</u>	<u>MANUFACTURER(S)</u>	<u>DISTRIBUTOR(S)</u>
60.	Underwater Tech.	Underwater Technics, Inc. N. 7th St. & Delaware River Camden, NJ 08102 (609) 963-4460	
61.	Uniroyal	Uniroyal, Inc. 312 N. Hill Street Mishawaka, IN 46544 (219) 255-2181	
62.	Warne	William Warne & Co., Ltd. Industrial Division Barking, Essex (England) Rippleway 3800 (phone) 23979 (Telex)	Surface Separator Systems, Inc. 103 Mellor Ave. Baltimore, MD 21228 (301) 747-4744
63.	Whittaker	Whittaker Corp. Survival Systems Division 5845 River Road New Orleans, LA 70183 (504) 733-7050 (phone) 58-7343 (Telex)	
		Sanera Projecting AB 5910 01 Nordmaling Sweden 0930-11030 (phone)	
64.	Yamamizu	Yamamizu Trading Co., Ltd. 3-18, Nihonbashi, 2-chome, Chuo-ku Toyko 103 Japan (03) 271-5751 (phone) 222-3649 (Telex)	

5.1.3 Surface Active Chemical Agents

Under conditions for which an oil slick might be broken into patches or dispersed, surface active chemical agents might be used to contract the slick into one which can be contained and removed by skimmers. Although one might be tempted to call these chemical agents "herders" such a term is already used by Shell Oil Co. as a commercial product name, the Shell Herder. Due to the surface tension effects produced by these chemical agents, there will only be a limited range of water conditions for which they will function. The use of such agents may be of considerable importance in terms of deepwater port and Outer Continental Shelf (OCS) developments. For such sites sea conditions may exist for a significant part of the year for which the oil slick would be broken and dispersed. Initial studies of these chemical agents were presented in 1969 by Garrett (24) and Frank (20). Reports from research at Shell were made in 1971 by Milz and Fraser (121). The U.S. Coast Guard (USCG) has been actively pursuing this concept since 1971 (92) with reports published in References (119, 93, 95, 117). In general, the results of this research effort still support the use of the surface active chemical agents as a method for producing a containable slick.

5.2 Fundamental Aspects of Barriers

5.2.1 Contained Oil Fluid Dynamics

This section of the report discusses the fluid dynamics results concerned with the behavior of the oil once it is located in the barrier and against the vertical retaining member. To summarize briefly, it has been found that present generation oil barriers only function efficiently to retain collected oil over a range of surface current velocities up to about one knot. The formation of a head wave at the leading edge of the collected oil, and entrainment processes from the lower surface of the head wave and oil produce a situation in which the collected oil is carried under the barrier even in calm water and in the absence of winds. Wicks (19) identified this problem in a paper in 1969. However, based on prior fluid dynamics research, the existence of these phenomena would have to have been expected. The problem of predicting the shape, and hence volume, of the collected oil, the head wave formation and stability, and the entrainment processes have been pursued actively since 1969. At M.I.T., Hoult and his co-workers have produced a significant literature on the subject contained in References (114, 103, 104, 105, 106, 108). Additional studies were performed by Cross and Hoult (68). Table 5.2 summarizes model tests on contained-oil fluid dynamics. Most of the data were obtained from experiments on single panels in flow channels or towing tanks. Lindenmuth et al (11, 13) did some significant

TABLE 5.2

SUMMARY OF MODEL TESTS ON CONTAINED-OIL FLUID DYNAMICS

REFERENCE	AUTHOR	TEST SITE/ FACILITY	MODEL TESTED	CONDITIONS			COMMENTS
				CURRENT	WAVES	WIND	
11	LINDENMUTH ET AL	HYDRONAUTICS TOWING TANK	PLATES CYLINDERS	X	X		STUDIES OF HEAD WAVE, SLICK
41	SORENSEN & SPENCER	TEXAS A & M WIND-WAVE TANK	PLATE			X	STUDY OF WIND SET-UP OR SET- DOWN OF CONTAINED OIL
108	ROBBINS	M.I.T. PARSONS LAB FLUME	PLATE	X			STUDY OF SLICK THICKNESS
110	HOULT ET AL	FLUME	PLATE	X	X		STUDY OF CONTAINED OIL SHAPE
		CEDAR KEY, FLORIDA	MODEL BARRIER	X	X	X	STUDY OF CONTAINED-OIL VOLUME, LEAK RATE. UNDER- WATER PHOTOGRAPHY. DE- PLOYMENT & RETRIEVAL STUDIES.
39	AGRAWAL	TEXAS A & M	PLATE	X			STUDY OF HEAD WAVE INSTABILITY
135	AGRAWAL & HALE	FLUME					

studies of the problem with single panels in a towing tank. Some of the studies indicated in this section and Table 5.2 were conducted with funds from the USCG's Lightweight Oil Containment System Program and with funds from the Environmental Protection Agency (EPA). Additional studies were conducted by Wilkinson (33, 62) with discussions of his work contained in References (60, 61). Agrawal at Texas A&M has continued the study of these problems and published results in Reference (39, 135). As already mentioned, Leibovich (137, 148) has considered the oil slick instability and entrainment failure problems while contributing additional analysis to wave effects inside the barrier, slick breakup and slick dispersion in the water column. Finally, in order to obtain a better analytical prediction for the drop entrainment phenomena under the oil slick, the USCG has funded additional work described in Reference (18). Sorensen and Spencer have studied the wind set-up problem (41).

The experimental data contained in the above references were obtained in laboratory test facilities. Additional data on contained-oil fluid dynamics are found in References (7, 12, 145).

5.2.2 Fast Current Barrier Studies

The need for barriers to contain oil in regions of fast currents has been recognized for some time. However, based on the fluid dynamics phenomena described in the previous section, the design of a fast-current barrier will be difficult. These phenomena have really only been under extensive study since the late 1960's. Also, within the budget limitations of sponsoring R & D organizations, other barrier studies have had a higher priority. However, within the last three years, the USCG initiated an identifiable fast-current oil barrier development program. One of the major problems in the development of a fast-current barrier is the dissipation of the initial kinetic energy of the oil-water stream in such a manner as to permit the barrier to retain the contained oil without its physical removal from within the barrier. Presently, energy dissipation mechanisms are being investigated and the results of this program are described in References (15, 38, 49, 94, 136, 140, 141).

5.2.3 Barrier Dynamics, Loads and Shapes

To a great extent the fluid dynamics discussed in the previous two sections correspond to a barrier which is able to maintain its design draft and freeboard relative to the water surface. The assumption is also made that the contained oil has practically zero relative velocity with respect to the barrier. The barrier dynamics could significantly change the results of these fluid dynamics analyses if the barrier does

not retain approximately a fixed position relative to the water surface and oil. Obviously, a barrier which moves a great deal with respect to the oil is a poorly designed barrier. Therefore, no research has been devoted to the case where the contained-oil slick fluid dynamics must be coupled with the barrier dynamics. The motion of the barrier is also important in determining the loads in the structural members and the dynamics of the barrier must involve its response to currents, winds and wave actions.

The analytical basis for the prediction of barrier dynamics has been developed mostly under the sponsorship of the USCG. The results of efforts by Hydronautics, inc. are described in References (2, 13, 15). Milgram at M.I.T., produced an initial analytical model in 1971 (107) and has recently published an up-dated version of this analysis (43). Finally, the third significant dynamic analysis was developed by Fowler at Texas A&M in Reference (40) and published by Fowler and Bailey (31).

Table 5.3 summarizes model tests which have been performed to study barrier dynamics, loads and shapes. The experimental portions of the work by Lehr and Scherer (2) and Lindenmuth et al (13) indicate agreement for the calculated model barrier shapes and barrier motions, and provided data on drag coefficients. Robbins (108) did some of the early work on measurements of drag coefficient and location of drag force. The work by Hoult et al (110) on model barriers turned out to be preliminary work on the USCG's Lightweight Oil Containment System (LWOCS). Some of the tension and drag coefficient data are generally useful. The observations of barrier motions were not quantitative but did permit them to study rapidly the effects of changes of the model barrier structure. The data presented by Milgram and O'Dea (43) are, with the exception of a table on measured sway data, also quantitative. Milgram (129) and Miller (115) have proposed equations for the calculation of wave effects on the drag coefficient. Neither correlation is well-supported by careful documentation.

Additional data on full-size barriers are summarized in Table 5.4 and will be discussed later.

5.3 Applied Barrier Technology

5.3.1 Debris Impacts

There are certainly many pictures in the literature which show that many harbor and river areas have large concentrations of water-borne debris which is a threat to the structural integrity of oil barriers and skimmers, and present problems for certain types of oil skimmers. However, the only reference found on the subject is a USCG report in Reference (96).

TABLE 5.3

SUMMARY OF MODEL TESTS ON BARRIER DYNAMICS, LOADS AND SHAPE

REFERENCE	AUTHOR	TEST SITE/ FACILITY	MODEL TESTED	CONDITIONS		COMMENTS
				CURRENT	WAVES	
2	LEHR & SCHERER	HYDRONAUTICS SHIP MODEL BASIN	MODEL BARRIER	X	X	MEASURED SHAPE, LOADS, YAW, PITCH & ROLL
13	LINDENMUTH ET AL	----	--			SAME AS ABOVE WITH MORE DE- TAILED DATA
43	MILGRAM & O'DEA	M.I.T. SWIMMING POOL	MODEL USCG LWOCs*	X	X	SOME DATA ON SWAY AMPLITUDE. SOME OBSERVATIONS ON HEAVE RESPONSE
		TOWING TANK(?)				NO DATA GIVEN
79	KIRKMAN	----	--			-----
108	ROBBINS	M.I.T. PARSONS LAB FLUME	PLATE	X		DRAG COEFFICIENT, LOCATION OF DRAG FORCE
110	HOULT ET AL	FLUME (?)	PLATE	X	X	DRAG COEFFICIENT, FORCE PROPORTIONAL TO WAVE AMPLI- TITUDE AND BARRIER MOTION AMPLITUDE
		M.I.T. SHIP TOWING BASIN	MODEL BARRIER	X	X	OBSERVATIONS OF BARRIER DYNAMICS AS INFLUENCED BY CHANGES IN MODEL
		BARNEGAT BAY, N.J.	MODEL BARRIER	X	X	LOAD MEASUREMENTS. OBSERVA- TIONS OF BARRIER DYNAMICS.

TABLE 5.4

SUMMARY OF FULL-SIZE BARRIER TESTS

REFERENCE	AUTHOR	BARRIER	TEST SITE	DATES	COMMENTS
54	ANON.-EPA	VARIOUS BARRIERS & SKIMMERS	GULF OF MEXICO	1970	10 KNOT WINDS, 8 FT. WAVES
---	---	USCG LWOCS*	NORTH CAROLINA FLORIDA	1971	-----
12	MILLER ET AL	USCG LWOCS	POINT CONCEPTION, CALIFORNIA	1972	DISCUSSION OF OIL LOSS RATE, MEAN SLICK THICKNESS, RECOVERY FRACTION, TENSION, MOTION PICTURES, WATER QUALITY. NO WAVE DATA SHOWN.
07	ESTES ET AL	---	---	--	OIL LOSS RATES
37	KOWALSKI	---	---	--	-----
43	MILGRAM & O'DEA	USCG LWOCS	POINT CONCEPTION	1972	SHAPE PLOT, COMMENTS ON ROLL AND HEAVE MOTION. PLOTS OF SWAY MOTION.
55	CAMPBELL	KEPNER BARRIER & NAVY CONNECTORS	HARBOR (?) OPEN SEA (?)	1973-1974(?) 1973-1974(?)	LOADS, CONNECTOR FAILURE LOADS SWELLS 3-4 FT., WIND 5 KNOTS
112	BARTLETT	SLICKBAR	NARRAGAN- SETT BAY, R.I.	1973	MEASURED TENSION, SHAPE AND DRAG- COEFFICIENTS
145	WIDAWSKY	SEA CURTAIN SLICKBAR FLEXY BOOM AQUA FENCE SEALBOOM INSHORE OIL BOOM	COLUMBIA RIVER SEQUIM BAY BATTELLE WAVE TANK		DEPLOYMENT & TOWING TESTS SOAK TESTS OIL CONTAINMENT TESTS WITH CURRENT & WAVES
150	LARRABEE & BROWN	SLICKBAR	NARRAGAN- SETT BAY, R.I.	1974	MEASURED SHAPE, TENSION, DRAG COEFFI- CIENTS AND WAVE EFFECTS

*LWOCS-LIGHTWEIGHT OIL CONTAINMENT SYSTEM

5.3.2 Deployment and Mooring Considerations

The literature on the problems of deployment and mooring of barriers is rather limited. Some consideration to the shore terminations for oil barriers was presented by Roberts (5) and in a document from the U.S. Naval Facilities Engineering Command (NAVFAC) in Reference (149). Milgram (129) and Milgram and O'Dea (43) have considered the deployment problem. Milgram and O'Dea in an attempt to produce a systems analysis of the barrier contend that the forces on the barrier may be in fact largest in the deployment process. References (29, 55, 58, 61, 144, 145) contain additional references. It is known that other documentation on deployment and mooring aspects of oil barriers exist in the manuals of oil companies and barrier manufacturers. It is also felt that there exist U.S. Navy and U.S. Coast Guard documents directed to the same problem. Unfortunately, this type of information is not generally published in the open literature.

5.3.3 Potential Hazards From The Use Of Barriers

No publications were found which document the problems of potential hazards arising from the use of oil containment devices.

5.3.4 Transportation Considerations for Barriers

Transportation considerations are controlled by the delivery mode. The USCG's equipment can be delivered by air or water shipment. The Air Deliverable Anti-Pollution Transfer System (ADAPTS) is air deliverable (130) as is its barrier system HSOCS (44). These components and the skimmer will also be deliverable by a helicopter or ship towed sled as a result of the Fast Surface Delivery System program (78). Wilson et al (144) describes some U.S. Navy systems, while Berry and Wolfe (156) describe the systems of the Clean Gulf Associates. Reference (44) contains general comments.

5.3.5 Cleaning and Repair Tests

Widawsky (145) describes some tests on time requirements, manpower requirements, etc. for cleaning and repairing barriers. Reference (63) presents general considerations of these subjects.

5.3.6 Full-Size Oil Barrier Tests

During the last decade, a significant number of tests have been made on full-size oil barriers and sections thereof with and without

oil present. Testing programs have been performed in laboratory facilities and under in-situ conditions. Some of the major towing tanks in the United States have been used in these test programs and, in many cases, companies have constructed new, small towing tanks for test purposes. Oil companies have developed basins in which tests are made, private barrier manufacturers have tested their devices without oil present at available open water sites. The U.S. Coast Guard, U.S. Navy and Environmental Protection Agency have conducted a few open-sea tests with oil present.

The laboratory testing situation has changed significantly with the opening of the EPA's Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) (139) in New Jersey. This facility, over 600 feet long and some 65 feet wide, can take segments of full-size barriers and full-size skimmers under a variety of regular wave and "chop" conditions. It should be noted that the introduction of the OHMSETT facility still only provides capability at the present for waves with approximately a two foot wave height. This comment is noted since interest in deepwater ports involves the operation of these ports under Sea State 5 or 6 conditions which requires equipment to operate in seas with a 12 foot wave height. Although the opening of the OHMSETT facility is a major advance, it still does not offer the capability of full-size equipment testing over the entire range of water conditions which are of practical importance.

In-situ testing, especially in the presence of any type of hydrocarbon oil or oil simulant, is extremely expensive. Complete control of water, wind and wave conditions is no longer possible and instrumentation difficulties increase significantly. In spite of the expense of in-situ testing, one of the recommendations of this report will be to encourage funding levels which permit such testing.

Although a firm analytically based model testing program is an important element in the development of new equipment, actual data on devices through in-situ testing is the only way by which certain phenomena can be tested. Certainly operating experience with real barriers or any real device often controls acceptable performance. Table 5 summarizes available full-size barrier tests. It must be emphasized that many more full-size barrier tests have been performed by and for private industry, oil companies and various governments. Results of such tests are not available in the open literature.

A major test was conducted by EPA in the Gulf of Mexico in 1970 of mechanical and air barriers and oil skimmers (54). The USCG's LWOCs test program represents the largest documented full-size barrier test program, being described in References (7, 12, 37, 43). U.S. Navy test programs are described by Campbell (55) and Widawsky (145). Additional full-size tests have been conducted by Brown and Bartlett (112, 127) and Brown and Larrabee (150).

These programs have produced data on oil loss rates, contained-oil profiles, entrainment loss mechanisms, barrier shapes, tensions and drag coefficients, deployment-mooring-and-handling problems and limited data on barrier motions.

5.3.7 General Barrier Experience

Although many experimental programs are conducted in which careful instrumentation are used and measurements are made, there is another group of what one might term "experimental data" which, although not so quantitative, is generally useful in evaluating barrier performance. These qualitative data are the general experiences of people who use the equipment during actual spill incidents. It should be clearly understood that although such general experience is useful, it is no substitute for careful experiments. The danger of extrapolating general experience, with rather poorly specified conditions, to other situations represents the greatest misuse of general experience data. However, experience such as reported in References (20, 75) and by Betts (126), Betts et al (152), Bernard and Jacobson (122), Berry and Wolfe (156, 138), Widawsky (145) and Wilson et al (144) are useful in the overall system evaluation of barriers. Careful summaries such as the report on the Santa Barbara oil spill (88) and the oil pollution incident at Platform Charlie in Louisiana (147) are useful as general barrier experience data.

5.3.8 Barrier System Analysis

It is clear from Fig 4.3 that an oil barrier which performs all of the indicated functions could be evaluated as a system in itself. Marks (28) announced such an attempt in 1971. This study, conducted for the American Petroleum Institute, has not been referenced to the knowledge of the authors, since that time. Rodenbarger (76) attempted a systems evaluation for the solution of open-sea spills in general. Milgram (129) outlined his thoughts on systems evaluation of barriers in 1973 and followed this description by a technical report by himself and O'Dea (43). These four publications represent attempts to solve a formidable problem. None of these efforts have really solved the problem. At the present time, one would be happy to have a good summary of all available oil barriers with a description of the conditions under which they have been tested and comments on the oil containment efficiency, the dynamic response, structural integrity under debris impact, storage capability, deployment characteristics, etc. Such a summary itself would be useful as a guide to purchase of barriers and attempts to extrapolate their behavior to new situations. Unfortunately, such summaries do not readily exist. One of the few documents which attempts such a description is published by the Institute of Petroleum (63). Although this report is marked "Confidential", it apparently is

on sale by a London publishing company. Table 5.1 of this publication contains useful comments on over 47 barriers.

Wilson et al (144) and Widawsky (145) summarize some of their systems' experience with U.S. Navy programs.

Mainville (74) and Schneider (77) present their considerations on the very important problems of deepwater ports.

5.3.9 U.S. Coast Guard Programs

At the present time, the U.S. Coast Guard has in operation the Coast Guard Strike Teams of the National Strike Force. These Strike Teams operate as elements in the National Oil Spill Contingency Plan. Planning for equipment support for these teams has been under development since the late 1960's. At that time, planning for the equipment to combat large offshore oil spills included (130):

1. A high seas oil containment barrier;
2. The Air Deliverable Anti-Pollution Transfer System (ADAPTS);
3. An air transportable high seas oil harvester.

As in the development program of any new system, changes have been made in some of the original goals while other goals have already been achieved. The high seas oil containment barrier is presently labeled as the HSOCS system which consists of five sub-systems, namely, the barrier, container, mooring, handling and air delivery sub-systems. Characteristics of this system are described in Reference (143). Although the original objective of deploying the barrier from the air into the water has been modified, the HSOCS system can still be air-delivered into the water using C-130 aircraft. The ADAPTS system consists of a prime mover, pump, hose and rubber containers into which oil can be transferred. The prime mover and pump system is already operational and has been used by the U.S. Coast Guard; the system is also air-deliverable. The development program on the rubber storage bags is continuing. The air-deliverable oil harvester is still under study but an acceptable high seas oil skimmer is available to the U.S. Coast Guard. In order to obtain rapid delivery to the spill site of those components which cannot be delivered by air, a new system is being studied called the Fast Surface Delivery System (78, 98). This is a sled onto which various components can be loaded and towed to the spill site either by helicopter or by ship.

The U.S. Coast Guard's program to develop equipment to combat open-seas oil spills is an excellent example of a program which has used analysis and experiment to study basic problems associated with the eventual equipment design, to design the prototype system and to create

the final hardware. Briefly, early aerial delivery studies are described in Reference (80). The ADAPTS program is described in References (81, 85). Prior and during the design competition for the LWOCS basic research was conducted on barrier dynamics (2, 11) and contained-oil fluid dynamics. The USCG program certainly benefited from early EPA funded projects at M.I.T. The design competition results are described in References (8, 9, 10, 16, 89). Results of the final LWOCS design and its testing are summarized in Table 5.1.

5.4 Other Barrier Programs

5.4.1 Air Barriers

During a period in the late 1960's, many concepts for oil containment devices were investigated. Among the types investigated was the air or pneumatic barrier in which a rising stream of bubbles creates a surface current opposed to the water motion which is carrying the oil, thereby collecting the oil in front of a bubble barrier. The concept of an air bubble barrier is not new - studies were made at the Hydrodynamics Laboratory at the California Institute of Technology in 1949 (109) and in 1955 at the Waterways Research Station in England (101). Reference to research activities in the late 1960's are found in References (71, 113, 51, 27). Experience with an actual installation in the Buffalo River has been described by Frank (20). The EPA tested a barrier in the Gulf of Mexico in 1970 (54). Although the air barrier is an interesting concept, to date, it has not received wide acceptance. A commercially available barrier is described in Reference (3).

5.4.2 The Bottom Tension Barrier

The Bottom Tension Barrier, as the concept implies, is a barrier in which the main tension member is placed below the surface at the lower edge of the barrier. In most physical barriers, the tension member is located near the water line as either an integral member of the barrier or as a member to which the barrier skirt is attached at some stand-off distance. This barrier is a development of the oil industry and is another excellent example of the orderly development of a new barrier system by combined analytical and experimental study. Details and progress reports on the bottom barrier concept are presented by Chung et al (133), Cunningham et al (123), Glaeser (125) and Fowler (40).

5.4.3 The U.S. Navy Program

A program for barrier development for U.S. Navy needs must handle

both open sea salvage problems and oil spill problems such as one encountered in harbors, bays, etc. References (144, 145) summarize some developments from this program. The program has been concerned with evaluation of commercially available equipment which would meet defined U.S. Navy standards.

5.4.4 Other Boom Concepts

Several barriers have attempted to use geometry or streamlining effects to produce desired barrier performance. The "dynamic keel" barrier as indicated by its title, uses a keel to increase stability (26). A concept proposed by Wilcox (142) employs several booms placed in series with a porous material or net underwater between the two booms. Flow, passing beneath the first boom tends to be directed into the space between the barriers, with the oil being trapped, and then the flow proceeds underneath the second boom through the porous material with, hopefully, a reduced entrainment loss. Wooten (128) has also investigated streamlined boom effects. In an EPA study (118) the concept of a chemically jellied boom was investigated. The study by Mazewski and Kroop (116) was typical of those in which an absorbent material is incorporated into the boom structure. Several investigations have been performed of the use of water streams to control floating oil (73, 151). Several emergency booms which can be rapidly deployed are discussed in References (4, 67, 69). Larsen (32) has examined alternate methods for employing booms especially in relation to Navy harbor problems.

5.5 An Overview of Oil Containment Barrier Research and Development Efforts

One's overview of any research and development program is influenced by several factors. First, the senior member of this report as a member of the academic community, has been trained to evaluate information in terms of the precision in which the experiments are described, the care with which the measurements are made and the detailed information which is presented in the report. Such a data set obviously makes it relatively easy to evaluate a particular research effort. Research paid for by public funds should be published in the detail just described, unless national security requires classification. Research published by private organizations may involve proprietary information or information which might be used adversely in court actions. Although the principal author of this report would like to see more private information published in sufficient detail to evaluate its quality, he does not expect that to happen. The second factor in judging any research and development program involves an estimate of the original program specifications and how many times they were changed during the program. Generally, this information is not available either to the casual reader or to the professionally concerned reader. A third factor which should

be considered, and usually is not, is related to the budget levels involved in the research and development program. Seldom does a reviewer have detailed knowledge of funding levels, which is an unfortunate situation.

With these opening remarks as background, the following observations are offered. At least three major government agencies have been involved in research and development of oil containment systems. These organizations are the U.S. Coast Guard, the Environmental Protection Agency and the U.S. Navy. It would appear that from a jurisdictional viewpoint, under the National Oil Spill Contingency Plan, the U.S. Coast Guard has responsibility for responding to oil spills in the open sea, coastal zone waters and other navigable bodies of water. The Environmental Protection Agency has jurisdiction for inland bodies of water where, in general, less adverse conditions are encountered. This jurisdictional decision explains the fact that the U.S. Coast Guard has had the major responsibility for the development of oil containment devices. It has already been stated that the program on the development of high seas oil containment systems accomplishment. The program is solidly based on critical decisions on fundamental aspects of the oil containment system which have been investigated analytically and experimentally. This procedure has been an excellent complement to the preliminary and final design studies on the barrier systems. The in-situ experimental program is also well-planned and executed and has led to the present distribution of the high seas oil containment systems to the U.S. Coast Guard Strike Teams.

The U.S. Environmental Protection Agency funded several critical projects related to oil barriers in the late 60's and early 70's, conducted the 1970 equipment evaluation and has produced the OHMSETT test facilities.

Activities of the U.S. Navy in the oil containment area have been well thought out and executed. The only observation that seems relevant is that technical accomplishment from U.S. Navy programs should receive more publicity. The total bibliography of this report contains very few references from Navy laboratories although published results on oil containment systems exist. Within the time limitations of this study, it is not possible to locate all these sources, but this will be done during the coming year. The main problem seems to be one of Navy policy which does not prohibit nor encourage the publication of results. Too many Navy in-house laboratory reports end up as in-house reports in the libraries of the existing laboratories or centers and remain unknown to the technical community since they are not listed as DDC or NTIS documents. It is a valid observation that more publicity should be given to U.S. Navy technical contributions in the oil containment device and other areas.

5.6 Conclusions and Recommendations

5.6.1 Fluid Dynamics of Oil Slick Containability

Analytical methods for predicting when an oil spill will undergo transition to discrete patches or become dispersed in the water column do not exist. These methods should predict the transition points between the continuous slick, the "patchy" slick and dispersion into the water column. The prediction methods should apply to combinations of current, wind and wave conditions and be generally applicable to a range of oils over the complete temperature range of interest.

It is recommended that basic fluid dynamics research be supported to develop the analyses to predict the breakdown of continuous oil slick into patches and the dispersion into the water column. The research should also include experimental laboratory phases. At a later stage in the research, the developed prediction techniques should be tested by planned in-situ experiments and by using spills of opportunity.

5.6.2 Surface Active Chemical Agents

The ability of surface active chemical agents to contain spilled oil in a continuous configuration is still attractive. This is especially true for deepwater and Outer Continental Shelf sites which are being considered. These types of sites are more susceptible to oil slick breakdown into patches and dispersion in the water column than many other sites.

It is recommended that basic research in the surface active chemical agents be continued with the specific objective of qualitative definition of the size of the spills and Sea State conditions under which the chemical agents will function. It is important to define whether these chemical agents can be used in the case of rather large spills at deepwater ports or Outer Continental Shelf drilling sites in the presence of large spills, or whether they are more limited to the case of thin films under calm water conditions. The environmental impacts of the use of surface active chemical agents must also be studied as part of this research program.

5.6.3 Contained-Oil Fluid Dynamics

Contained-oil fluid dynamics is a term which applied to the behavior of oil once it has been contained by an oil barrier. At the present time, analytical techniques to predict the presence of the head wave, its instability and the shape of the contained oil are very good. The prediction of the entrainment loss from under the barrier is not as satisfactory. Since this is a mechanism by

2

which oil is lost under the barrier, predictions of this type of flow are important.

Basic analytical and experimental studies of the entrainment process should be continued using both laboratory facilities and the OHMSETT test facility. Barrier concepts by which the entrainment loss can be reduced, but which do not lead to impossible barrier configurations and deployment problems, should be considered.

5.6.4 Fast Current Barrier Studies

A practical solution to barriers which can operate in fast current areas is still not available. The present results suggest that the obvious idea of locating multiple barriers in series along the flow path does not significantly increase the capture efficiency of the barriers. Only one innovative technique for dissipating the kinetic energy for the in-coming oil-water stream has been given publicity in the open literature.(49)

Studies of the entrainment problem previously noted may produce a better understanding of the mechanisms and details by which contained oil is carried downstream of the barrier. The fast current barrier problem is one of the reasons for sponsoring additional research on the entrainment problem. The only recommendation that can be made for a solution to the fast current barrier problem is to encourage a design competition for such a barrier. Although detailed fluid mechanics knowledge is required, creative design engineering is a prerequisite for the solution of this problem. As mentioned many times in this report, the design must be one by which the oil is retained by the barrier in the presence of strong currents, and which produces a barrier which can be packaged, transported, deployed, etc.

5.6.5 Barrier Dynamics, Loads and Shapes

Analytical techniques have been developed to calculate the steady state shape of a deployed oil barrier and a reasonable base exists for evaluation of the drag coefficients for such barriers when located in calm water. The existing experimental correlations by which wave effects on barrier loading is estimated are not well-documented in the open literature. A well-documented base does not exist for predicting barrier motions under a wide range of current, wave and wind conditions. The only two sources of experimental data are from model tests and from the U.S. Coast Guard's Lightweight Oil Containment Systems Test program. Since the latter program was conducted on in-situ condition, a wide range of wind, wave and current conditions were not studied and although some of the predictions from the available

barrier dynamics analyses seem to support the observed barrier behavior, these data are not extensive. It is also concluded that instrumentation required for such barrier dynamics studies needs development.

The major problem of documentation of the acceptability of analytical techniques for barrier dynamics is the experimental difficulty of obtaining data. The ability to predict any barrier dynamic behavior is an important technical, political and environmental question. One would like assurance that the analytical predictions are accurate and can be used, for example, to evaluate existing commercial barriers or to design new barriers especially suited for Outer Continental Shelf application. Because of the continuing concern for the environment and the obvious political nature of this struggle between resource developers and environmentalists, analytical techniques of this type must rest on firm experimental data. It is recommended that the existing analytical techniques for the prediction of barrier dynamics be given an exhaustive evaluation using a range of model barriers and employing the OHMSETT test facility. As part of this program instrumentation must be developed for measurements of barrier displacement, barrier angular changes, barrier velocities and barrier accelerations. The development of this instrumentation should be keyed to the eventual use of the instruments on in-situ type testing. If the evaluation of these analytical techniques is acceptable, then a full-scale in-situ program involving oil also should be conducted in the open ocean over a range of conditions to verify that the analytical techniques do in fact work. If the OHMSETT evaluation does not support the analytical techniques, then additional analytical research should be supported until such time as the analysis-experiment cycle produces a verified technique for barrier motion prediction.

5.6.6 Potential Hazards From The Use Of Barriers

It is an interesting conclusion that little has been published in the open literature on potential hazards from the use of containment devices at specific drilling platforms, etc. It is recommended that a conference be sponsored to discuss the problem of potential hazards from the use of containment devices at drilling platforms, etc. This conference, or a series of conferences, should discuss the problem and make recommendations for future research programs.

5.6.7 Full-Size Oil Barrier Tests

It is obvious that the number of tests of full-size oil barriers has been very small. In terms of results which are reported in the open literature and therefore available for public evaluation. The availability of OHMSETT should permit testing of full-size barrier segments with length up to about 200 foot. This number is based on the present width of the OHMSETT facility of 65 feet and the use of a gap ratio of about 0.3. The gap ratio is the opening at the mouth of the barrier divided by the length of the barrier. Instrumentation

for eventual open-seas operation and testing should be developed during the OHMSETT test program. The instrumentation of particular concern is that for the measurement of barrier motions, including displacements velocities and acceleration. This instrumentation needs a thorough evaluation at facilities such as OHMSETT prior to open-sea testing.

A systematic program has already been outlined and recommended under the section on barrier dynamics, loads and shapes. An additional recommendation which should be mentioned is that barriers should be conceived that are improperly designed. The reason for this requirement is that any analytical predictive techniques for barrier motion, must be able to predict the entire range of barrier behavior from poor to acceptable behavior. In the planning of any systematic experiment, a complete range of independent variable should be investigated. Due to the number of independent variable in the design of a barrier, this is clearly not possible. But there are certain dimensionless groups and major independent variables which should be systematically investigated in a full-size barrier test program.

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Chapter 6

Natural and Forced Biodegradation

6.1 Introduction

Over the past four decades, vast quantities of PHC have found their way into the world's oceans and seas. It may seem surprising that the seas, estuaries, coastlines and beaches aren't completely covered with oil. The reason for this comparatively slight amount of pollution is due to the fact that natural processes take place which break down the oils into different compounds already abundant in the environment, such as carbon dioxide and water. Microbial oxidation is a primary mode of this transformation. During this process, various forms of marine microorganisms feed on the PHC in the oils and form CO_2 , H_2O , and cell biomass. Various byproducts may be formed and individual species may excrete partially degraded products. The actual processes depend upon the types of PHC and the species of microorganism. They usually begin by the addition of oxygen to form a hydroxy derivation of the hydrocarbon and then with further oxygen lead to the formation of CO_2 and H_2O . This type of process has been observed in a wide variety of both terrestrial and marine microorganisms including many species of bacteria and several species of yeast and fungi (7).

Several processes take place which reduce the amount of PHC in the marine environment. These are (a) evaporation and decomposition in the atmosphere, (b) dispersal in the water column, (c) incorporation into sediments, (d) oxidation by chemical or biological means to CO_2 and H_2O , (7).

Reference (9) points out that the standing crop of petroleum-like material in the world's oceans is of the order of one year's input. This means that the above processes taken together are keeping up with the rate at which the PHC's are entering the ocean. However, the effectiveness of the individual processes are not known. It is known that they are interdependent in that the rate of microbial degradation is highly dependent on the amount of dispersal in the water column and on the composition of the PHC which in turn is determined by the original composition of the spill and the weathering effects due to evaporation and decomposition.

6.2 Rate of Hydrocarbon Biodegradation

When specifying rates of oil degradation it is very important to include the conditions under which these rates were obtained. Included must be temperature, whether reported rate occurred in an open or closed

system, and whether conditions were quiescent, or what kind of agitation occurred. Also important is whether the rates were obtained from field or lab tests. Rates of hydrocarbon biodegradation measured in laboratory experiments are one to two orders of magnitudes higher than in situ rates (13).

It might be hoped that the many investigations already carried out would provide an estimate of the rate at which oil might be degraded at sea. Unfortunately, the field and laboratory conditions that have been used, the concentrations and types of oil employed, the multiplicity of ways of measuring activity, and the differing methods of evaluation of the data make generalization difficult and probably misleading. Published estimates of rates based on laboratory studies are probably much higher than would be expected to be found in most of the marine environment (9).

Because of the diverse conditions occurring in the environment there are many factors that may limit the rate of PHC biodegradation. Included among these are:

- a. Organism availability: Hydrocarbon degrading microorganisms are not a naturally occurring phenomena in all bodies of water. They are normally found in coastal areas or along tanker routes but rarely in the open seas. Some sort of seeding technique might be employed to compensate for this lack.
- b. Dispersion of oil: The spreading of oil by natural factors, i.e., viscosity, density, wind speed, current velocity, etc., makes it more vulnerable to autoxidation and microbial degradation.
- c. Temperature: It has been found that there are PHC degrading organisms with the ability to survive in relatively extreme temperatures, for example, the Arctic Ocean. However, the temperature range that they are most active in is approximately 20 to 35°C.
- d. Nutrient availability: If the supply of oxygen failed, then a resulting anaerobic condition halting any further oil oxidation would occur. In reality, with the constant re-aeration of the surface layers of the ocean by wind and waves, oxygen would be a limiting factor only in extreme cases. The lack of nitrogen and phosphorous are the real limiting elements in an oil spill. These elements, in some form which would adhere to the oil, would have to be supplied in order to attain rapid degradation of significant quantities of oil.

6.3 Artificial Seeding

Since PHC consuming microorganisms are such a rarity in the open seas, some sort of seeding technique of a suitable mixture of organisms might be employed to insure that proper degradation occurs. At the present time microbial seeding of oil slicks might be realistically viewed (8):

- a. As a useful cleanup method to be used on relatively thin oil films covering large areas where physical removal is not possible or practical.
- b. In conjunction with other cleanup operations such as mechanical removal, chemical dispersion, absorption, or burning - perhaps as a final treatment to cleaning up residual oil.

It does seem advisable, though, to remove as much of the oil as possible by mechanical means prior to seeding. This will minimize the amount of seed culture required.

Biodegradation of all fractions of spilled oil will require a mixed population of microorganisms since no single organism can degrade all of the diverse compounds present (7); therefore, any seed culture must contain several different types of microorganisms.

One of the unanswered questions of biodegradation is -- once accumulated in sufficient concentrations, will biodegradation products be injurious to aquatic organisms and eventually to man or will the products of carcinogenic hydrocarbons be more potent than that of parent compounds under field conditions? What has not been thoroughly investigated is the possibility of upsetting the delicate balance of microorganisms in a certain area by introducing a large number of alien species. Virtually untouched is the problem of the ultimate fate and biological effects of intermediate oxidation products.

Once these problems have been investigated, artificially seeded biodegradation should find its proper place in an integrated oil spill control program by helping to eliminate oil that has escaped containment and collection and has spread out too thinly to be eliminated by these measures.

6.4 PHC in Food Chains

A highly speculative effect of oil biodegradation is the problem of how biodegrading microorganisms affect the food chain. Those microorganisms that feed on oil are used for food by higher level

organisms. It might be possible that toxic hydrocarbons may be absorbed but not degraded by microorganisms and therefore enter the marine food chain (7).

Other sources of possible PHC products in the food chain occur when animals living in oil polluted environments swallow oil droplets along with their normal food or breathe dissolved or dispersed petroleum through their gills.

Studies have shown that part of the oil or its oxidation products may be incorporated in the cells, tissues, or organs of aquatic or soil organisms (14). It is very possible that harmful hydrocarbons from crude and fuel oils may be absorbed from the gut and either stored in cells or tissues or degraded in the liver or other organs. These organisms that digest oil may be pathogenic to or completely exclude other marine organisms. Some oil degrading organisms could produce toxins. These effects would be most obvious when the numbers of organisms increase suddenly and considerably as a result of an oil spill, but they are difficult to separate from the toxicity of the oil itself, or from stress that lowers resistance to infection.

6.5 Natural and Forced Biodegradation Bibliography

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Chapter 7

Natural and Chemical Dispersion of Oil Into The Marine Environment

7.1 Introduction and Background

An authoritative documentation of the present state of knowledge of oil spills can be found in the 1975 report by The National Academy of Science (1). Since this is a widely distributed report there is little need to repeat the details herein. Only a brief description of the natural dispersion process will be given to afford the reader who is unfamiliar with the above document, some background in which to follow this portion of the report. This chapter is devoted primarily to the question of what to do with the unconstrained, uncontrolled spill, should it be allowed to disperse by natural means, or should the dispersion process be aided by the use of chemical dispersants?

The Office of Technology Assessment recently presented an interim report on the coastal effects of offshore oil and gas development. (2) One of the factors, stated in this report, of concern to coastal states, involves basic uncertainties about environmental and economic impacts. Studies estimate that the total probable oil spills from OCS operations ranges from a low of 85,000 barrels to a high of 1 million barrels and that one out of ten spills from a drilling or production platform would reach a beach in New Jersey or Delaware. Present U.S. policy for combating oil spills is concentrated on physical containment with mechanical or sorbent removal techniques. When these means fail, the uncontrolled, untreated spill can cause considerable damage to the marine environment, especially to birds, salt water marshes and beaches. The use of treating agents for final clean-up and for preventing the spills from reaching the shore and mitigating the environmental impact, when mechanical means fail, has been minimal because of the lack of information concerning the use of these agents and their effect on the environment. Since the Torrey Canyon spill off the coast of England, there has been considerable development of treating agents that are far less toxic than those available in 1969.

The debate over whether to use dispersants to treat oil spills has been long and controversial. The truth about dispersants and their use and effectiveness has often been obscured by undocumented and, at times, emotional opinion. Certainly, the excessive use and unfortunate experience with dispersants on the Torrey Canyon spill serves to form the basis for most of the criticism. On closer examination, however, it was found that much of the damage of the spill did not come directly as a result of the dispersants themselves, but rather, from the very toxic solvents that were used to dissolve the dispersant material. Additional criticism concerning the use of dispersants is grounded in the belief that even if the dispersants themselves were not toxic, the use of these agents make the oil more toxic by its' increased dispersion within the environment. (3) There is an element.

of truth in this statement since it would be expected that the use of dispersants will increase the acute toxicity zone in the immediate vicinity of the spill. However, studies to determine the extent of this zone and how long it remains toxic are virtually non-existent; furthermore, will dispersing of an oil spill cause less environmental losses than an untreated spill? This is an extremely difficult question to answer, however, the counter argument for the use of dispersants is based on the premise that most of the damage caused by oil spills occurs in the inter-tidal zone and in saltwater marshes where there is a concentration of marine life. (4) The greatest impact also appears to be caused by the loss of recreational uses of the beaches. (5) Waterfowl, in particular, are highly vulnerable to the spilt oil and the longer the spill remains, generally, the higher the total bird kill.

It is well known that marine life is concentrated in three major areas: (a) The surface, (b) The benthic zone and (c) The inter-tidal zone. It is these three major areas that the uncontained poorly dispersed oil spill is concentrated, whereas, the majority of oil in the chemically treated spill is concentrated in the water column where it is more easily diluted by tidal flushes and where there is less concentration of marine life.

Dispersants are almost exclusively used to treat oil spills in the U.K. and their use, does not appear to cause any appreciable damage to the environment. This is not sufficient reason to promulgate the use of dispersants in this country. Throughout the U.K. tides are substantially higher than found in most continental U.S. waters. Tides at Milford Haven in Wales run as high as twenty-six feet as compared to two to three feet for much of the eastern U.S. seaboard. The high tides in the U.K. produce an effective means for flushing bays and river basins of spilt and dispersed oil and could be the most important factor in their successful use of dispersants.

Despite improvements in oil spill prevention over recent years, oil spills continue to occur. In fact, natural seepage alone accounts for some 10% of the oil input into the oceans annually (see Table 2-4). Oil enters the environment through a variety of different types of spills and unless a spill is contained and subsequently recovered through mechanical means, the spilt oil is dispersed into the environment through a number of mechanisms including evaporation, chemical and biological degradation, and settling to the ocean floor. The efficiency and effectiveness of oil containment and recovery techniques to prevent the oil from dispersing into the environment depends on many factors. The first and most important of these is the size of the spill. If the spill is relatively small, containment presents few problems if the equipment can be deployed before the spill spreads into an unmanageable size and if the current is below 1 knot and wave heights less than three feet. Once contained, a high percentage of this spilt oil is recoverable. Unfortunately, most spills that have occurred have not been contained and the oil continues to wash up on beaches and into marshes. A very recent spill during the summer of 1975 (6) inundated hundreds of miles of beaches along the Florida Keyes. This spill was 100 miles long and much too large to be physically contained. This particular

spill illustrates some of the practical limitations of containment and recovery techniques which constitutes the major U.S. effort for combatting oil spills. The spilt oil is then free to advance to the coastal areas, where beaches and inter-tidal life can be severely damaged.

Unfortunately, the story does not end there. Long-term studies on the effects of oil spills are now being carried out in several areas, one of which is at West Falmouth, Massachusetts. (7) This study evaluates the status of the benthic fauna through the fourth and fifth years after a small spill of No. 2 fuel oil that occurred near the entrance to West Falmouth Harbor in September 1969. The documentation of the immediate effects of the spill indicated a persistence of the oil and indeed the study found this to be the case. The No. 2 fuel oil is still detectable in the offshore sediment as well as that of the marshes and the boat basin. The number of species was found to be significantly lower in some spill areas than in the control areas. There were also significantly fewer individuals in spill areas, however, both the number of species and number of individuals were found to increase notably over the test period, indicating some sort of recovery taking place.

There are other documented studies on the long term effects that specific oil spills have had on the environment. Notable among these are the Torrey Canyon and the Santa Barbara spills. With the exception of the expensive use of toxic dispersants, it appears that neither one of these spills has had disastrous long term effects on the environment. It should be noted, however, that the amount of damage that an oil spill has on the environment is very much a function of the toxicity level of the oil, the location and weather conditions that exist at the time of the spill and thirdly, the toxicity sensitivity of the various species in the vicinity of the spill. It is well known that, in general, chronic pollution of an area can have much more long range effects than a single large spill in the same area. But our knowledge of long term effects in some areas, such as under either polar ice caps, is still severely limited.

The effects of oil on the marine environment has long been of concern to the environmentalists and oil companies alike. The severity of biological damage depends on many factors, some of the major ones are: the type of oil spilled, the dose of oil, the physiography of the area, weather conditions, type of local biota, season, previous exposure of the area to oil and other pollutants, and the treatment of the spill. (4) Three conditions are especially critical, and some researchers claim all three must exist simultaneously for a spill to have significant environmental damage. The conditions are:

1. The volume of oil spilled must be large with respect to the body of water being impacted.
2. The oil should be a refined oil, such as No. 2 fuel oil.

3. Storms or heavy surf must cause the spilled oil to be churned into bottom sediments. (9)

Whether or not these conditions occur, some portion of marine life is likely to be affected by an oil spill. Studies from more than a hundred major spills over a twelve year period indicate that birds are the type of marine life most often significantly affected. (10) But oil pollution remains a major concern of those in the fishing industry. Controversy has existed for some time over whether or not organisms taking up oil will cleanse themselves or continue to be contaminated. However, The Energy Policy Project of The Ford Foundation (11), The National Academy of Sciences, (1) and The Marine Technological Society (12) all share the conclusion that once a spill episode has passed, organisms cleanse themselves quickly of essentially all the oil contamination they may have incurred. (10). Indeed, the fishing industry seems to have suffered little as a result of the controversy, and apparently the fishermen have not found their catches significantly reduced as a result of an oil spill. Figure 7.1 indicates a relatively constant fish catch in the Gulf of Mexico during the past 40 years. During this time offshore drilling operations significantly increased and six spills in The Gulf ranging from 2000-160,000 barrels occurred since 1967. In the other three U.S. coastal regions, the total harvest has been declining. The number of fishermen, foreign competition, weather conditions, and a variety of other reasons have all contributed to the decline. (13)

The variability of sea conditions, as well as the size of a spill, are two of the major factors which often inhibit the containment and recovery of spilt oil. If about 2,000 barrels (84,000 gallons) of Bunker sea oil was spilt on a calm sea on a windless day, and if no action is taken for about 3 hours (many oil spills go undetected for at least that long), the circumference of the spill would be approximately 6300 ft. (See Figure 4.3). Obviously, since barriers cost an average of \$50 per foot, the cost of containing such a spill would be very high. Furthermore, we assumed calm sea and wind conditions, and since these conditions often do not exist, clean-up operations are hampered by lack of suitable containment devices. Although there is ongoing research and effort being put into the improvement of containment devices, there are still many situations where the oil simply cannot be contained. Many oil spills occur in harbor areas, near water supply intakes, near recreational beaches, and/or near concentrations of bird and other wildlife where the presence of oil may be especially hazardous to human and marine dependent life.

When examining the dispersant usage controversy one realizes the large number of questions that are still simply unanswered and many problems remain unresolved. There have, however, been a number of investigations on the use of dispersants and dispersant effectiveness as well as dispersant toxicity studies. These studies were primarily designed to determine the effectiveness of the dispersant to disperse the oil in the water column and to determine its toxicity. These are laboratory type tests used to evaluate dispersants and were not designed to determine if

FIGURE 7.1 -- CATCH OF FISH AND SHELLFISH

1939-1973

MILLION
POUNDS

dispersants should be used under any particular set of circumstances. What needs to be determined is what type of circumstances and where and how should the oil be dispersed if it is impossible to mechanically contain and retrieve to minimize the environmental and economic impact of oil spills. The potential benefits that might be derived by the use of dispersants warrant such a thorough investigation.

7.2 Dispersants

Dispersants have been in existence for some time now. However, they have gone under various names - dispersants, emulsifiers, detergents, and degreasers are all names for the same thing. (14) By definition, "dispersing agents are those compounds which emulsify, disperse, or solubilize oil into the water column or act to further the surface spreading of oil slicks in order to facilitate dispersal of oil in the water column." (15) Whatever they are called, dispersants consist of three primary components - surfactants, solvents, and stabilizers. The surfactants alter the interaction between oil and water so the oil tends to spread and can thus be more easily dispersed into small globules. (14) Surfactants are either hydrophilic (water compatible) or lipophilic (oil compatible). They can be divided also according to atomic structure, being either anionic, cationic, or non-ionic. The anionic surfactants compose the largest group in use since the anion is quite surface active. Usually these dispersants are alkalai salts of sulphates or sulphonates. Cationic surfactants have a low surface activity as do the non-ionic ones. However, the non-ionic ones have been found to be the most effective in saline water oil spills, being composed of fatty alcohol condensates, ethylene oxide the most common. (16).

The second primary component of a dispersant, the solvent, comprises the bulk of the product. The solvents enable the active agent (surfactant) to mix and penetrate into the oil and form an emulsion. The solvents range in base from petroleum to water, petroleum solvents being the most toxic but the ones which dissipate most rapidly in a water environment. (14)

A certain amount of mechanical mixing energy is generally required in order to get the dispersant into the water. In the past, helicopters and tugboats or other large powerful boats were flown over or driven through the spill in an effort to cause dispersion. In the U.K. the use of batter boards towed behind boats have proved very effective. Obviously, in high sea conditions, the mixing energy is no problem. Under such high sea conditions, dispersants have found to be very effective.

Gerald P. Canevari, in an article in the proceedings from the 1975 Conference on The Prevention and Control of Oil Pollution (18) wrote about the feasibility of self-mixing dispersants which, if perfected, could reduce the problem of supplying mechanical energy. A self-mix dispersant

is oil compatible and is applied directly to the oil. It utilizes the diffusion energy of the surfactant, acting where the oil-water interface contacts the water. The self-mix formulation contains a particular surfactant component which enables the interfacial area, the most critical area in the dispersant process, to be more readily broken down. Thus, mechanical mixing energy is not needed. Canevari points to the formation of uniformly-sized droplets due to a constant energy source as another major advantage of the self-mix system. These small uniform droplets enhance the behavior, movement, and stability of dispersants as well as minimizing ecological and toxicological effects by getting the oil into the water column and dispersed more rapidly. Canevari concludes, "The ability of self-mixing has been well established and documented during the past two years." He admits, however, that the information is not yet complete and much controversy and many questions have yet to be resolved.

Another problem associated with dispersants involves bulk storage. Captain G. Dudley of Milford Haven, Wales recommends bulk storage and bulk handling if chemicals are to be used in significant quantities. (23) In the past, dispersants were supplied in 40-50 gallon steel drums loaded onto tugs and other sea-going vessels. These containers presented problems in loading, unloading, and usage in oil spill situation. Recently, in England especially, pillow tanks, which are flexible and can be easily loaded, have been used and they have proved easily transportable and loaded as well as being deflatable for compact storage. They have been a considerable improvement over the original methods. (24,25)

Dispersant effectiveness is greatly affected by the viscosity of the oil spill. Water base dispersant effectiveness becomes marginal over 1000 CS. However, 90% of the tanker cargoes have viscosities well below 1000 CS. Water temperature plays a role in dispersant effectiveness, too. Low water temperature implies less volatility of the lighter fractions and higher viscosity of oil and thus increases exposure time to the marine community. When an oil spill occurs in a confined area caution must be taken to prevent the dispersed oil from entering municipal water systems and contaminating a city's water. (26)

7.3 Dispersant Toxicity

One of the most contested issues in dispersant usage is toxicity and its resulting ecological effects. To begin with, oil has a certain toxicity of its own. Crude oil is the least toxic of the petroleum products, and when spilled evaporation and dissolution of the volatile parts occurs in about 3 days. The more refined petroleum products, such as diesel fuel and gasoline, have a much higher evaporation rates, however, the more refined and easily vaporized a product is, the more toxic it becomes.

There is an argument that the dispersed oil is available to a larger quantity of marine life and is therefore more harmful. (3) Others claim that the oil is much more easily biodegraded when formed into small droplets since the hydrocarbon is in better contact with the water and the only way

the microorganisms can use it is when the oil has good water contact. (27) Still others claim the toxicity decreases very rapidly once dispersion occurs, so that the high potency of the chemical exists, but only for a short while. (19) The diversity of opinion and misunderstanding of the issue is summed up by a quote from Arthur D. Little, Inc.'s study on oil pollution (19), "The adverse publicity regarding the use of chemical dispersants is frequently the result of misapplication: e.g. high concentration application in areas where rapid dilution could not be achieved." Indeed, this seems to be the case. Mr. J. Wardley Smith of The Warren Spring Laboratory recommends the use of dispersants in the open sea because dilution is very great and very rapid so even the most toxic dispersants are not harmful. He does not recommend, on the other hand, their usage in the intertidal zone since it is a very sensitive area. (24) These ideas, along with the knowledge that dispersants are made much less toxic now than in The Torrey Canyon days, gives increasing evidence to the favorability of dispersant usage, provided that the biologic sensitivity of the polluted area is known and taken into account.

It is the policy of the Federal Water Quality Administration (FWQA) of the U.S. Department of the Interior that the relative toxicity of all chemical dispersants, both alone and in combination with oil, will be determined prior to their usage for the dispersion of oil spills and used only with the approval of The Environmental Protection Agency (EPA) and/or The United States Coast Guard. This includes their use for cleaning shores and beaches. The responsibility for providing the toxicity information is given to the chemical manufacturer by The Department of The Interior. The manufacturers must use short term bioassays with designated test organisms. The tests do not include the effects of long-term toxicity of the dispersant on aquatic life, safe levels for marine life or for humans, nor do they constitute an endorsement by The FWQA. (20) As a result of the policy, however, several tests have been developed for the testing of oil spill dispersing agents. For example, the EPA has a standard test they recommend. The EPA Standard Dispersant Toxicity Test, as described by McCarthy, Wilder, and Dorrler (15), "involves exposing three species Pimphales promelas (fathead minnow), Fundulus heteroditus (mummichog), and Artemia salina (brine shrimp) to five different concentrations of each dispersant alone and in combination with oil, in a ratio of 1:10 (dispersant to oil). From these tests, a curve relating the survival of the organisms to the concentrations of the test material can be generated that allows the determination of median tolerance limits. To ensure consistency in the assays carried out by different workers and to detect any changes in the condition of the test organisms that might lead to different results, reference bioassays will be made with doceyl sulphate in addition to the usual control tests."

The EPA also has a test for determining dispersant effectiveness whereby "oil is applied to the surface of synthetic sea water contained in a cylindrical tank. The dispersant is applied in a fine stream to the oil and a 1.0 minute contact time is allowed for the dispersant to contact the oil. Energy is imparted to the oil/dispersant mixture by hosing and agitating the mixture with a pressurized water stream. The contents of the tank

are allowed to recirculate and samples are withdrawn from the tank after 10 minutes and after 2 hours of recirculation. Oil is extracted from the samples with chloroform and the quantity of oil is spectrophotometrically determined." The results are then analyzed, curves are drawn, and recommendations are made for the dispersant. (15) Many oil dispersant experts will agree that much of the confusion surrounding toxicity tests results because data is used to predict ecological damage and the data was not designed to provide such information. (22) For example, some petroleum industry critics maintain that oil accumulates in marine organisms after a spill and that the oil fractions accumulated become more and more concentrated as they move up the food chain. Thus, the oil fractions become a threat to human health as the contaminated organisms enter a person's diet. Max Blumer's tests and conclusions articulate well this hypothetical syndrome. "Following a spill of No. 2 fuel oil near West Falmouth, Massachusetts, in September 1969, Blumer analyzed oysters, scallops, and other marine organisms and found that they had taken up oil fractions. He kept three oysters in flowing sea water in his laboratory. He analyzed one oyster after it had been kept in this manner for 72 days, the other two after 180 days. According to his analyses, none of these three oysters had depurated; that is, purged themselves, of any of the oil they contained prior to the beginning of the experiment. He concludes, 'Thus, once contaminated, shellfish cannot cleanse themselves of oil pollution.'" (3) However, studies by Battelle-Northwest Laboratories and Texas A&M University involving large numbers of organisms and tightly structured experiments disprove Blumer's conclusion. Although both of the affirmative studies involved laboratory, as well as field experimentation, their ecological applications were much more cautious than those made by Blumer. We can learn much from toxicity tests on oil and dispersants, and the results of the tests can be used to predict within limitation the effects of a dispersant on marine life. But the data must be treated in the context of the experiment and any wider applications must be made carefully.

7.4 Summary and Conclusions

Dispersants are used to 1) remove oil from the water surface where it poses a hazard to marine life, 2) prevent the formation of water-in-oil emulsions, 3) enhance the microbial degradation by increasing the interfacial area between the oil and water, and 4) reduce the oil concentration to sublethal levels as rapidly as possible. Ideally, they should also be effective under all environmental conditions for the spectrum of oils, require minimal agitation, be non-toxic to important segments of the bio-environment, and have a low flash point. The "ideal" dispersant does not yet exist, however, significant progress has been made in the past two years in dispersant technology with respect to effectiveness and ease of application (e.g. self-mix dispersants and pillow tanks), there is a better understanding of the limitations of bioassays involving dispersants and dispersed oil, and there has been a reduction in dispersant toxicity to almost non-toxic levels in some cases (18). These facts lead one to conclude dispersants are not a tool to be overlooked by those concerned with oil spill cleanup. Dispersant's past history has been detrimental, but their past need not banish them from future consideration, rather, further work should be done to re-evaluate and improve where necessary.

dispersant technology. The advantages of dispersant usage - their simplicity of operation, the fact that they can be used without sophisticated mechanical devices or expensive hardware and are one of the cheaper methods of oil spill cleanup - should make them a primary target for future investigations. Although care and caution should be emphasized in where and how to apply dispersants, there are many cases where dispersants could be used successfully. Information on wind velocities, coastline type, presence or absence of recreation beaches and/or bird and wildlife refuges, etc. can be stockpiled in oil spill high-risk areas to prevent improper usage of dispersants. Also, better testing procedures and new chemicals could be developed. Chemical marketers have said they have not had much demand for dispersant chemicals, but an increase in the demand could lead to more innovative dispersant development by industry. The use of dispersants on beaches is still a somewhat confused issue; one expert claims beach use is advantageous B.L. Dudley (9) , most other, however, firmly disagree FWPCA (16) .

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Chapter 8

Research and Development Needed to Mitigate The Environmental Impact of Oil Pollution

8.1 Introduction

This chapter outlines a number of areas of needed research and development in the area of the technology of oil pollution, its prevention and control. Research on the fate and effects of oil pollution in the marine environment may be needed. However, this was not one of the objectives of this study. This type of information is readily available from a number of different sources; e.g. references 1 through 6. The research needs in this chapter are divided into two major categories: (1) Preventive techniques and (2) Containment, Cleanup and Dispersion.

8.2 Preventive Techniques

Several small spills each year are attributable to the failure of pipelines, fittings, etc. Increased awareness and the proper training of operating personnel can and has decreased the number of these types of accidents. Not all of these accidents, however, are caused or can be prevented by even the most cautious operators because of the difficulty of proper inspection of this type of hardware. Non-destructive testing and inspection techniques would greatly minimize this as a source of oil pollution.

The inspection of submerged pipelines for oil leaks and possible potential failures is a very difficult task often employing divers or small submersibles. One of the major difficulties is the detection of small quantities of oil from pin hole leaks which is generally the precursor to pipeline failure. Today, most inspection is visual; it would be greatly advantageous to have an instrument that could detect small quantities of oil. This would be especially useful for inspecting buried pipes.

In The North Sea and planned Atlantic offshore operations, buried pipe will be used. However, there is some question as to under what conditions the pipe will be remained buried or perhaps even undermined. Analysis of pipe surveying reports and the concomitant recording of pertinent oceanographic data will aide in forecasting, preventing and eliminating this type of hazard.

One of the most frequent causes of small spills from ships is the unfamiliarity of the crew with the ship's piping system. Itinerant crews, working on international carriers, very often speak a different language

than the officers of the ship, and oftentimes neither crew nor officer speak the same language of the country where they are operating. This can cause accidents to occur in the operation of the ships systems as well as in navigation and response to distress calls. Standardization, whether it be by color coding or by labelling, of fresh water, salt water or product piping and systems is almost non-existent and aggravates the situation. Possible solutions to these problems would be to develop standard labelling practices and techniques that would be amenable to backfitting of existing ships. Some countries are already looking into requiring at least one individual on board to speak the language of the country in which the ship is operating.

Although navigation equipment is quite adequate, especially aboard larger ships, there have been times when ships have gone aground or have collided with drilling rigs. An example of the latter type of accident is the collision of the 33,000 ton Globtik Sun with a Chevron drilling rig in The Gulf of Mexico on August 15, 1975 resulting in a 350,000 barrel oil spill. This type of problem should be thoroughly analyzed. Could a modification to the Loran system be used to sound an alarm aboard ship? Such a system might include a shipboard computer with programmed cards of the location of all the oil rigs in the vicinity and coded in such a way to be capable of automatically sounding an alarm when the ship is near a drilling rig. Although the number of these type of accidents have been relatively rare, they could increase in offshore drilling areas that have a preponderance of poor visibility conditions such as The Georges Bank area.

Reliable shipboard instrumentation for detecting oil in bilge water and more reliable liquid level measurement would be beneficial. Studies should be conducted of the control systems for offloading and transferring operations to ensure that they can safely start and stop and to respond to an emergency situation as required. Research is needed in the area of stress monitoring of mooring systems and offshore drilling platforms.

8.3 Containment, Clean-up and Dispersion

In the area of containment once a spill has occurred, we need to know much more about how these systems behave in the open sea. Limits of capabilities to contain and pick up spilt oil have to be ascertained along with logistic studies of present and future retention equipment so that methods can be developed as required. Mooring, drifting and deployment techniques can be developed for barrier systems as well as developing techniques and procedures to use these containment devices in conjunction with other oil spill clean-up and dispersion methods. For example there are some chemicals that exist, which are biodegradable, which might be used to protect the inter-tidal zone before a spill reaches a beach. It is conceivable that barrier techniques could be developed together with the use of this type of chemical to minimize the long range effects of an

oil spill. The use of these type of chemicals are not without problems, because some of them, although quite harmless when on the beach and in the water, can be harmful if inhaled.

In the area of oil spills drifting, spreading and dispersion we need to know more about its toxicity level as a function of the depth of penetration into the water column and its lateral transport as a function of time. The rate of degradation of oil as a function of its degree of dispersion has to be studied. It well may be that it is best to disperse the oil when first spilt, particularly in the open sea to prevent damage to the beaches and inlet areas should it come ashore and to mitigate long range effects. Real time analyses and prognostication of the movement and dispersion of oil spills as a function of weather and sea conditions and forecasts can greatly aide any advisory system for combating oil spills. The intermediate storage problem of containing the picked-up oil and transporting it to shore is still unresolved, also techniques of reclaiming the oil from absorbents etc. should be developed to preclude dumping or burying it as is the common practice. Onshore oil spills have to be studied to determine the common causes and to develop techniques for preventing them. For example, when an oil tank ruptured in New Jersey, its dike was unable to contain the oil and a million gallons of oil was swept into the Arthur Kill. Present specifications on the construction of dikes are based on a simple volumetric containment of the quantity of oil contained in the tank with little or no regard to the dynamic effects should catastrophic failure of the tank occur. Secondary sewage treatment techniques for removing oil need to be studied. Tertiary methods already exist, however, these place an unreasonable economic burden for most communities.

The whole question of the use of chemical dispersants should be thoroughly investigated. This should be done on a comparative basis with the untreated spill. The conditions under which dispersants should or should not be used must be formulated and delineated.

There are many national and international agencies that are involved in the various aspects of oil pollution, and in general each agency is concerned with only with a portion of the oil pollution problem. Although there has been productive cooperation among the agencies there appears to be no one agency which has been assigned the task of keeping abreast of the efforts. Perhaps a national or international group made up of people from government, industry and universities could be formed to serve as an advisory panel for assessment and direction of oil spill research and development. This committee should be properly funded and should issue an annual report on the assessment and recommendations and should be coordinated through one federal agency.

8.4 References

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