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PAST IN-SITU BURNING POSSIBILITIES

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16. Abstract (MAXIMUM 200 WORDS)

This study evaluated the feasibility of conducting in-situ burning (ISB) using current technology on post 1967 major oil spills over 10,000 barrels in North America and over 50,000 barrels in South America and Europe. A diverse set of 141 spills representing various combinations of parameters affecting spill responses (e.g., spill size, oil type, weather conditions, sea temperature, and geographic location) were evaluated using four "Phase I" criteria: distance to populated area, oil weathering, logistics, and weather conditions. In Phase I, a spill that failed to meet one of the four criteria was considered an "unsuccessful" candidate for ISB. In total, 47 of the 141 spills passed the Phase I analysis. The potential effect of the plume on populated areas was the most significant of the four Phase I criteria; 59 of the 141 spills did not pass Phase I because the incident occurred near a sizable city. Spills that met all four criteria were further evaluated using a "Phase II" analysis that applied additional criteria and considered individual spill circumstances to determine if the spill should be rated a "successful," "marginal call," or "unsuccessful" ISB candidate. Fourteen spills were ultimately determined successful in the Phase II analysis, and 12 were designated marginal calls.

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EXECUTIVE SUMMARY

This study evaluated the degree to which in-situ burning (ISB) would have served as an effective response technique for past major oil spills. Through reviews of scientific and historical literature on oil spills and the collection of supplemental data, this study developed scenarios for 141 past oil spills that had a diverse set of parameters affecting spill response (e.g., spill size, oil type, weather conditions, sea temperature, and geographic location). Using criteria that could affect ISB, these scenarios were assessed and the feasibility of ISB as a response technique was determined.

The technical feasibility of ISB depends on the particular spill scenario, including the type of oil spilled, the location of the spill, the condition of the oil (both initially and over time), and weather and sea conditions on scene. These factors dictate a "window of opportunity" for executing an ISB operation. This study established criteria to assess whether a burn would have been successful based on the factors that most influence the feasibility of ISB. The criteria are based on the technology available in 1997 and address four primary factors: (1) oil weathering; (2) response logistics; (3) weather; and (4) distance to populated areas. Each spill was reviewed on the basis of the established criteria and assigned a pass or fail rating. These four criteria were applied to all 141 spills in the first phase of the evaluation. Spills that successfully met all criteria were subjected to a second analysis. This analysis provided an opportunity to consider more site-specific conditions for each spill. Instead of establishing any specific criteria, a number of factors were conjoined to assess the feasibility of ISB. Additional information was used to refine the initial assessment when it was available.

Of the 67 percent of the 141 spills that failed Phase I, 5 percent failed the weather criterion, 25 percent failed the oil weathering criterion, 30 percent failed the logistics criterion, and 42 percent failed the distance to populated area criterion. In total, 47 of the 141 spills passed the Phase I analysis. Fourteen of these (30 percent) were ultimately determined successful in the Phase II analysis, twelve (26 percent) spills were designated marginal calls, and 21 (45 percent) spills were designated unsuccessful candidates for ISB.

In general, the successful ISB candidate tended to occur in the coastal or offshore waters of the Gulf of Mexico or Caribbean Sea. The larger spills that occurred off the Atlantic coast of North America also tended to be successful. There were 7 successful ISB candidates out of the 38 spills that occurred in the Gulf of Mexico and Caribbean, and 4 successful candidates out of the eight spills of 50,000 barrels or more that occurred off the Atlantic coast of North America. None of the candidates were from inland waterways or from ocean waters off South America.

The results of the analysis show that, although there is growing interest in ISB for use on large volume oil spills, there are constraints to the widespread use of the technique. Considering the effectiveness of ISB, however, and the fact that constraints such as spill location, expected weather, and oil type are likely to be well known prior to undertaking a response, the results are encouraging. If the locations, oil types, and weather conditions of future oil spill incidents are similar to those of past incidents, then ISB may be a possible response option for a small but significant fraction of future incidents. Decision-makers must compare ISB to other response options knowing the respective limitations and effectiveness of each technique.

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1. Introduction

In-situ burning (ISB) has been envisioned as a promising countermeasure for dealing with large spills at sea, where the volume of oil and logistics of operating offshore decrease the effectiveness of other options, such as mechanical recovery and dispersants. ISB is the controlled burning of spilled oil while the oil is still on the water's surface. This technique, as opposed to others, has the potential to rapidly convert large quantities of oil into its primary combustion products — water and carbon dioxide, with a smaller percentage of other unburned or residual byproducts. Some studies have shown ISB can be less expensive than other techniques, and require less labor and equipment. However, the residue remaining after ISB is much more viscous than the original product and may be more difficult to remove or recover. The first major oil spill in which ISB was attempted was the 1967 *Torrey Canyon* spill in Great Britain. Although the results were unsuccessful because of emulsification of the oil, there have since been ISB studies and tests on spills in many regions of the world.

1.1 Objective and Scope of Study

The objective of this study is to evaluate the degree to which ISB would have served as an effective response technique for past major oil spills. Through reviews of scientific and historical literature on oil spills and the collection of supplemental data, this study develops scenarios for 141 past oil spills that reflect a diverse set of parameters affecting spill responses (e.g., spill size, oil type, weather conditions, sea temperature, and geographic location). Considering a number of factors that could affect ISB, these scenarios provided the necessary information to assess the feasibility of ISB as a response technique. This study establishes criteria to assess whether a burn would have been successful and applies these criteria to the analysis of each of the past major oil spills. The criteria are based on the technology available in 1997 and address four primary factors: (1) oil weathering; (2) response logistics; (3) weather; and (4) distance to populated areas. Each criterion is discussed in detail in Section 2. Each spill was reviewed on the basis of the established criteria and assigned a successful, unsuccessful, or marginal rating.

This study examined spills over 10,000 barrels that occurred in North America, and spills over 50,000 barrels that occurred in Europe and South America. In addition, only those spills occurring between March 18, 1967 (the date of the *Torrey Canyon* spill) and December 1997 were considered for analysis. The set of spills was established through a review of the historical and scientific literature on past oil spills. Initially, 154 spills were identified as spills within the scope of the study. However, thirteen were eliminated because very little information was available (e.g., missing oil type and location). Appendix A is a chronological list of all spills initially identified for the study. A detailed description of the methodology and data sources used to select the spills is included in Section 3.

1.2 Factors Affecting the Feasibility of ISB

The technical feasibility of ISB depends on the particular spill scenario, including the general nature of the spill, the location of the spill, the condition of the oil (both initially and over time), and weather and sea conditions on scene. These controlling and limiting factors dictate a "window of opportunity" for executing an ISB operation.

The variations in the nature of the spill include moving or stationary sources, an instantaneous or continuous spill, and large or small flow rates. Ideally, ISB operations are best suited to a stationary source, where the oil is spilling at a continuous rate that can be handled by the equipment available. Responders include other variables in contingency plans suited for conducting ISB. In addition to the safety protocols, such as operational safety for boom-towing vessels, required for conventional cleanup, the potential hazards of ISB require safety protocols for fire, such as on-board fire-protective equipment and emergency fire procedures. The National Response Team's Science and Technology Committee has been involved with developing a site safety plan for marine ISB operations.

Each location can affect the feasibility of ISB in different ways. For example, an offshore spill may pose minimum health and safety concerns, but would require containment of the slick and generally would involve more severe wind and wave conditions. ISB is most easily and effectively implemented during the early stages of a spill. Distance from logistic support, including major equipment such as igniters, vessels, and fire booms, greatly influences the possibility of a successful in-situ burn. This is particularly evident in spills occurring in remote areas. Holding all other factors constant, as deployment time increases, combustion efficiency decreases.

Nearshore wind and wave conditions may be more favorable than offshore conditions, but burning may be prohibited because of nearby populations. Existing Regional Response Team (RRT) and state policies, which delineate zones where burning is pre-authorized, subject to RRT approval also affect the possibility and the timeliness of an ISB operation.

Weather conditions play a critical role in determining the feasibility of ISB. Sea state has a profound effect on response capabilities and the extent to which oil will disperse. Wind speed and wave height, two of the most influential factors that can affect the feasibility of ISB, are positively correlated with sea state. For example, wind speed directly affects current speed, which affects the oil's spreading rate. Spreading, which enhances the evaporation and dissolution of oil by creating a large active surface area, decreases the effectiveness of ISB. High wind speeds and rough sea states also can decrease the effectiveness of ISB by increasing the weathering and emulsification of oil. Weathering is the process that occurs as oil is exposed to the elements and loses its more volatile components. Emulsification is the process in which water gets incorporated into the oil or oil into the water. High wind speeds and rough sea state also pose logistical complications such as creating difficulty in igniting a spill, deploying fireproof booms, or containing oil within a boom. Mechanical containment, which is usually required in ISB operations to maintain combustion/slick thickness, loses its effectiveness at winds greater than 20 knots. If weather and sea conditions are calm, the window of opportunity for conducting ISB may be extended.

Wave height, currents, and tides also affect the logistics for conducting an ISB operation and influence oil weathering. For instance, elevated wave heights and strong currents cause oil to emulsify. Additionally, most existing equipment have decreased effectiveness at wave heights greater than six feet and in currents over one knot. Oil usually escapes the boom in those conditions. The rate at which droplets of oil enter the water and flow beneath a boom's barrier depends on the current speed (or the relative velocity between the barrier and the water if the barrier is being towed), boom design, and properties of the oil. Weather conditions favorable to ISB include winds less than 20 knots, waves less than two to three feet, and currents less than ¾ knot relative velocity between the boom and the water.

Wind direction is particularly important if the spill occurs close to a populated area. Wind direction determines the direction that the smoke plume moves. If the wind is blowing towards a populated area, reasonable assurances must be made that people will not be exposed to excessive concentrations of pollutants. Wind direction also affects the direction the oil moves after an incident, and movement towards a shoreline may increase the environmental damage caused by the incident.

Local air and water temperature can affect the evaporation of oil and the competency of spill responders. Colder temperatures decrease the rate of evaporation, thus potentially increasing the feasibility of a successful ISB. Extreme temperatures can pose constraints for response personnel. Extreme temperatures increase the tendency to attempt shortcuts and also may impair one's judgment. The presence of ice can provide for natural containment of the oil; however, ice can also hamper access to the spill and complicate logistics.

Precipitation, in general, does not affect the feasibility of an ISB operation. However, rain or snow may slow the speed of the response. Further, heavy precipitation or thundershowers may present hazardous conditions, thus precluding responders from conducting ISB.

The type of oil spilled is one of the most important considerations for response and cleanup strategies. Important oil properties include the following:

- *Flash point:* The flash point is the lowest temperature at which vapors are formed which are capable of flaring up from an outside ignition source. Highly volatile oils, such as gasoline products that have flash points near 100°F/40°C, evaporate rapidly. Heavy crude oils and residual products (e.g., Venezuela crude, San Joaquin Valley crude, Bunker C, No. 6 fuel oil) are only slightly volatile, with flash points greater than 150°F/65°C, and thus, very little product is lost by evaporation. Because the more volatile components of spilled oil immediately begin to evaporate, there is less potential for successful ISB as the slick ages.

- *Specific gravity/API gravity:* Specific gravity is the ratio of the density of a substance to that of fresh water. The American Petroleum Institute (API) scale is used for hydrometers. Oil with a specific gravity greater than 1.00 (API gravity of less than 10) will sink in fresh water. Those with a specific gravity of 0.95 or higher (API gravity less than 17.5) are also at risk of sinking once they become mixed with suspended sediments. Gasoline products have a specific gravity of less than 0.80, whereas heavy crude oils and residual products have a specific gravity of 0.95 to 1.00 or an API gravity of 10 to 17.5.

- *Viscosity:* Viscosity is the resistance of a fluid to motion and it controls the rate that oil spreads on water. Low-viscosity oils spread rapidly into thin sheens, increasing the surface area and making recovery difficult. Gasoline products are an example of low viscosity oils. Viscous oils, heavy crude oils, and residual products can be so thick that they do not spread, particularly when spilled on cold water. Highly viscous oils do not readily emulsify, and it is difficult for water to be added to such oil.

- *Emulsification formation:* Under certain conditions, some oil slicks will form a water-in-oil emulsion often called "chocolate mousse." This material can contain up to 80 percent water and can be many orders of magnitude more viscous than the spilled oil. There is no simple qualitative measure of the tendency to form emulsions. When an emulsion is formed, the oil changes in appearance and viscosity, becoming much more difficult to address from a spill-response perspective; the fluid is more viscous and harder to pump, and the volume increases by a factor of four to five. Gasoline products do not emulsify. Diesel-like products and light crude oils, medium-grade crude oils and intermediate products, and heavy crude oils and residual products can form stable emulsions (API and NOAA, 1998).

The relationship of oil type to water density is an important element. It is a factor in the calculation of dissipated wave energy, which in turn is a factor in the calculation of oil-in-water dispersion, and it also affects the density of emulsion and emulsion viscosity.

Most, if not all, oils will burn if of sufficient thickness. The thickness of the oil must be maintained to avoid a heat sink effect that transfers the heat from the oil layer to the water and extinguishes the fire. Minimum thicknesses include two to three millimeters for fresh crude oil, three to five millimeters for diesel and weathered crude, and five to 10 millimeters for emulsions and Bunker C. In addition, for most crude oils, evaporation losses must be less than 30 percent to burn successfully.

Daylight factors into the safety of an ISB operation. ISB on large oil spills often involves several vessels working in relatively close proximity to one another. Further, it is difficult to see the oil in the absence of daylight. Although high intensity lighting systems are available, absence of daylight will impair visibility and may pose hazardous conditions.

2. Criteria

This study employed a bi-level methodology in determining the potential success of ISB technology in responding to a spill. Each spill included in the scope of the study was first evaluated by considering the most significant factors described in Section 1.2. The four part Phase I screening analysis incorporated the following elements: (1) oil weathering model analysis, which considered evaporation of oil from the surface of the water, dispersion of oil into the water column, and emulsification of oil and water; (2) logistics analysis, which related to the length of time necessary to arrive at the spill site and conduct ISB; (3) weather conditions (i.e., high winds that could impede response, generate rough seas, cause greater emulsification of oil, and make slick ignition difficult); and (4) distance to populated areas. These criteria were selected as important factors influencing the feasibility of ISB. A spill that failed in any one of these four categories was considered to have failed the initial analysis, and therefore, to have been an "unsuccessful" candidate for ISB. Such a spill was assigned an "unsuccessful" rating, and was not further analyzed. Spills that passed all four categories were evaluated a second time and were assigned a "successful," "marginal call," or "unsuccessful" rating. This was based on more detailed and stringent consideration of the criteria applied in Phase I, as well as site-specific limitations or conditions that would affect the success of ISB.

2.1 Phase I Criteria

Each spill included in the study was initially evaluated for four criteria: oil weathering, logistics, weather conditions, and distance to populated area. A spill that failed to meet one of the four criteria was considered an unsuccessful candidate for ISB. Spills that met all four criteria were further evaluated by examining additional criteria and individual spill circumstances to determine if the spill should receive a successful burn, marginal call, or unsuccessful burn rating as an ISB candidate. The four criteria are defined below.

- *Oil Weathering Model Analysis:* Oil was considered unburnable once the summed percentages of evaporated and dispersed oil reached 100 percent or the water content of the oil reached 75 percent, as both of these conditions prevent ignition. The "window of opportunity" for each spill is the elapsed time between the initial spill incident and the point at which the oil is no longer considered burnable. The analysis assumed that a window of opportunity of at least six hours was necessary in order for a response effort to be mobilized.

- *Logistics Analysis:* Response time includes locating and preparing appropriate equipment and transporting equipment and personnel to the spill site. As an initial screening, a spill was considered an unsuccessful candidate for ISB if the response time exceeded 1.5 times the window of opportunity. Since the weathering model only provided an approximate time for the oil to become unburnable, allowing the response time to exceed 1.5 times the window of opportunity results in a conservative measure for the potential success of ISB.

- *Weather:* Weather conditions at the time of each spill and in some cases, during the days following the spill, were assessed to determine if the weather would impede the ability to ignite the oil or respond to a spill. A spill was considered unburnable if there was no twenty-four hour period in which the average wind speed was below 20 knots (10.3 meters per second) during the first five days after a spill.

- *Distance to Populated Areas:* A "populated area" was defined as a city with 10,000 or more inhabitants, and a distance of six miles was established as the radius in which ISB could not be conducted. The six miles figure was derived from the practices of some RRTs (RRT IV, 1993).

2.2 Phase II Analysis

In the Phase I analysis, strict cutoffs were used to arrive at an initial assessment of the potential success of ISB for a given spill. For the spills that met these initial requirements, the second phase of the analysis provided an opportunity to consider more site-specific conditions for each spill. Instead of establishing any specific criteria, a number of factors were conjoined to assess the practical feasibility of ISB. Phase I criteria was reexamined to determine if the spill had only marginally passed in one or more criterion. For instance, if there were high winds at the time of a spill, and the oil was highly emulsified, this spill might fail in Phase II. Where additional information was available, we considered other factors, such as weather conditions (e.g., fog), distance to shoreline, historical occurrence and response scenarios, or historical use of ISB. For example, if a case study of a spill revealed that vessels had difficulty in responding to a spill, that spill would likely be an unsuccessful candidate in Phase II. If an offshore spill actually caught fire, that spill may be considered a successful candidate for ISB. However, if a spill in a harbor or near a populated area caught fire, and an effort was made to extinguish the fire, the spill was considered an unsuccessful candidate for ISB. The surrounding population would likely not support ISB if an extensive effort had been expended to extinguish the fire.

For several spills, information was not available beyond that used to analyze the spill in Phase I. In these cases, the spill passed Phase II, but it was noted in the spill summary report in the “Results Summary and Phase II Evaluation” section for that spill that it passed in Phase II because no further information was available. (See Appendix C for the individual spill summary reports.)

3. Methodology

3.1 Establishing a Study Set of Historical Oil Spills

To establish a set of historical oil spills that reflected a variety of conditions and locations, a broad range of historical literature and databases containing information on oil spills were used. Before reviewing these sources, factors were established that determined whether a spill would be included in the study set. The set was to include only those spills that occurred between March 1967 and December 1997, and those over 10,000 barrels in North America and 50,000 barrels in Europe and South America. The geographical limits on spills were set at 200 miles off the coasts of Europe, North America and South America. No limits were placed on spills in the Gulf of Mexico and the Caribbean Sea . Data sources were reviewed and compiled into a database of information on spills within the scope of the analysis criteria, as shown in Appendices A and C.

3.2 Sources of Information on Oil Spills

A total of eleven separate sources were used in generating the list of spills. Because these sources sometimes contained conflicting information on spills, such as the amount of oil spilled or the location of the spill, an order of priority was established with which the information contained in a data source would be accepted. The primary data source was the 1991 NOAA report, and secondary sources were the 1995 Marine Spill Response Corporation report, the 1990 Office of Technology Assessment list from “Coping with an Oiled Sea,” and the Oil Spill Intelligence Report newsletters. Spills were included that were not listed in these sources if they were listed in two or more data sources such as the Oil Spill Intelligence Report annual reports, the Minerals Management Service (MMS) Worldwide Tanker spills online database, and the NOAA Hazmat Response Reports. A detailed description of each data source consulted is presented below.

NOAA Report: Summaries of Significant U.S. and International Spills, 1961- 1991

The spills included in this source meet the following criteria:

- Exceeded 100,000 barrels internationally;
- Exceeded 10,000 barrels in U.S. waters;

- Involved the use of dispersants;
- Involved bioremediation; or
- Involved severe environmental impacts (e.g., more than 500 birds killed, more than 100 mammals killed, smothering of over a mile of intertidal zone, and closure of fisheries).

Each listing in this source contains a brief summary of the spill, including information on the location and size of the spill, the product spilled, the mitigation methods or countermeasures employed, and the types of shoreline affected. Each spill summary contains a list of references (NOAA, 1992).

NOAA Oil and Hazardous Materials Response Reports: 1990-1996

The NOAA Hazmat Response Reports were used as additional sources because the NOAA report did not cover all the years of our study. These Hazmat Response Reports detail spill incidents in the U.S. coastal zone to which NOAA provided technical or operational assistance. Each report provides an incident summary, details of the NOAA response, a summary of the resources at risk, and the cleanup countermeasures. Each report is referenced.

Marine Spill Response Corporation (MSRC) report: An Analysis of Historical Opportunities for Dispersant and In-Situ Burning Use in the Coastal Waters of the United States, Except Alaska

This report contains information on historical marine oil spills of 1,000 barrels or more that occurred in U.S. coastal and offshore waters between 1973 and the first half of 1994. Sources used in preparation of this report included U.S. Coast Guard spill databases, the Minerals Management Services database, and the Environmental Protection Agency's (EPA's) Emergency Response Notification System (ERNS). The following information is included for each spill in the MSRC report:

- Date and time of the spill;
- Name and type of the vessel;
- Cause of the spill;
- Latitude, longitude, and geographical location of the spill, including the distance from shore;
- Water body impacted by the spill and the depth of water at the spill location;
- Type and volume of oil spilled;
- Countermeasures employed; and
- List of references (Kucklick, 1995).

Oil Spill Intelligence Report: International Summary and Review

These reports were published annually from 1978 to the present. Each contains a chronologically ordered list of spills that occurred in a given year. Information on each spill is limited to the location of the spill and its source, size, composition, and cause. Reports from 1989 and later include damages caused by the spill, which were useful in determining if oil had entered navigable waters.

Department of Interior's Mineral Management Service (MMS) Database of Worldwide Tanker Spills

The MMS database includes spills from 1974 to June 15, 1990. All spills are from vessels on which a petroleum product was a cargo. The spill must be at least 1,000 barrels in size, must have been accidental, and acts of war are not included. (The MMS database is available on the Internet at http://www.etcentre.org/spills/index.htm.) The information listed for each spill includes the following parameters:

- Spill date;
- Vessel type, flag, size, and age;
- Volume of the spill, as well as lowest and highest reported volumes;
- Type of oil spilled; and
- Latitude, longitude, and location of the spill.

U.S. Coast Guard: Marine Safety Information System (MSIS) Database

The U.S. Coast Guard MSIS database provides data on spills from 1973 through 1996. The reports include all accidents or casualties involving vessels in U.S. waters. (The MSIS database is available via CD-ROM.) For each report, the following information is presented:

- Date, time, and location of the spill;
- Material spilled including the CHRIS code;
- Source of the spill; and
- Response information, including agency and cost of clean-up.

Office of Technology Assessment (OTA): Coping with an Oiled Sea

"Coping with an Oiled Sea" is a background paper, which was prepared by OTA in 1990. It contains a list of 66 oil spills greater than two million gallons (48,000 barrels), compiled from various reference sources. The spills on the list occurred between 1967 and 1989, and the information about each spill includes the year of the spill, the name of the vessel or facility, the general location, and the volume of the spill. Most of the spills were included in one or more of the other data sources, but a few were not found elsewhere (OTA, 1990).

Lloyd's Modern Shipping Disasters: 1963-1987

"Lloyd's Modern Shipping Disasters," published in 1987, contains brief narrative summaries of a number of maritime disasters involving vessels. This source was not used to identify any additional spills, but provided information describing the specific location of oil spills, as well as details of the incident (Hooke, 1987).

International Oil Spill Conference Proceedings: 1969-1997

The proceedings of the biennial International Oil Spill Conference (IOSC) provided additional detailed information on certain oil spills. These articles were particularly useful in identifying weather information at the time of a spill.

Information Sources for Recent Spills: Oil Spill Intelligence Report and Oil Pollution Bulletin

Two additional sources used for information on recent spills were the Oil Spill Intelligence Report and Golob's Oil Pollution Bulletin. Both are biweekly publications featuring information on oil spills in the U.S. and abroad as well as other oil-related news.

3.3 Distance to Populated Area

The distance between the spill location and a city with a population of 10,000 or more was estimated by using atlases and descriptions of the incident. If the distance was within six miles, then the spill failed the Phase I criterion for distance to a populated area. In some cases, the distance to a city was greater than six miles, but if the spill occurred very close to shore, that factor was considered in Phase II.

For many incidents, particularly those that occurred prior to the 1990s, the exact latitude and longitude of the spill were not reported, but a brief description of the location may have been provided. Even when a precise location was known, the location was usually the site of a collision or grounding and not an indication of the boundaries of the oil slick. In other words, some of the large spills with a reported location beyond six miles are likely to have spread out over time so that some part of the slick was within six miles of a populated area. Local policies and regulations differ, however, with respect to where ISB is allowed, and some areas may allow burning within six miles.

For these reasons, the six-mile distance is an imprecise and arbitrary cutoff. If a smaller distance had been selected, such as three miles, the number of successful ISB candidates would have been somewhat higher, but the vast majority of incidents within six miles were also within three miles of a populated area. The distance to a populated area was meant to reflect the fact that ISB of a large spill may not be feasible because of the large quantities of highly visible smoke generated and the resulting adverse public perception.

3.4 Weather Data Collection

In addition to information on spill size and location, data was obtained on oil type, wind speed, water temperature, and other factors. Inputs for the oil weathering model included the volume of oil spilled, the type of oil spilled, wind speed, and water temperature data. Information on spill size was available for most spills, but information from different sources often conflicted. When conflicts existed, more weight was given to information giving the amount of oil lost rather than the amount cleaned up. For many early spills, a specific oil type was not available. In some cases where crude oil was the only type specified, an assumption was made on the specific type of crude oil based on the port of origin of the vessel. Wind speed and water temperature data were available for all spills in either of the following sources:

The NOAA Marine Environmental Buoy Database

These data are collected from moored buoys and Coastal-Marine Automated Network (C-MAN) stations located on piers, offshore towers, lighthouses, and beaches operated by the NOAA National Data Buoy Center (NDBC). Data are provided for the Atlantic Ocean, Gulf of Mexico, Great Lakes, central and western Pacific Ocean, North Pacific Ocean above 50°N, and Eastern Pacific Ocean. The NDBC buoys began reporting in the early 1970s and the NDBC archive holds data from February 1970. The first C-MAN stations became operational in March 1983, and the NDBC archive of C-MAN data began in 1985.

Parameters reported by both buoys and C-MAN stations include: air temperature and pressure, wind speed and direction, wind gust, and sea surface temperature. The buoys and a few C-MAN stations located on offshore towers also report wave data, usually including wave height, wave period, and wave spectra. In general, the hourly readings use an eight-minute acquisition period for data collection by sensors on board moored buoys and a two-minute acquisition period for data collected by sensors at C-MAN sites. A limited number of spills occurred in proximity to these buoys or stations during periods of operation. (The C-MAN database is available on the Internet at http://www.nodc.noaa.gov/CDR-detdesc/buoy.html.)

The Comprehensive Ocean-Atmosphere Data Set (COADS)

The information in COADS includes data sets of atmospheric variables such as sea surface temperature, wind speed, and air temperature. The data have been compiled from ship reports over the global ocean. The data set is a joint effort between NOAA's Climate Diagnostics Center (CDC), the Cooperative Institute for Research in Environmental Sciences (CIRES), the National Center for Atmospheric Research (NCAR), and NOAA's National Climactic Data Center (NCDC).

The data sets we used to obtain sea surface temperature and wind speed were:

- *COADS Monthly Time Series Set:* This data set covers a time period from 1854 to 1993 and has average daily sea surface temperature and wind speed values for every month and year.

- *COADS Monthly Climatology:* This data set has average daily sea surface temperature values for every month of the year.

Data from these sets were extrapolated to provide approximate sea surface temperatures where more exact data were unavailable. For most spills, this was the only source of data for sea surface temperature and wind speed. (The COADS database is available on the Internet at http://ferret.wrc.noaa.gov/fbin/climate_server.)

3.5 Oil Weathering Modeling

Requirements for this study included correlating weather data with oil type spilled in each incident, predicting the window of opportunity that would allow the oil to be ignited or burned, and accounting for evaporative loss and emulsification. To perform this analysis in a cost-effective manner on over a hundred spill scenarios, it was necessary to utilize existing computer-based models for predicting the properties of oil spilled on water over time. Two models for predicting the properties of oil spilled on water were used for this purpose: the Automated Data Inquiry for Oil Spills (ADIOS) model prepared by the United States National Oceanic and Atmospheric Administration and the Oil Weathering Model developed by SINTEF. The SINTEF model was used as the primary analysis tool. The ADIOS model was used for oils that were unavailable in the SINTEF database (primarily certain refined products). The most recent versions of both models were used for the analyses. These were ADIOS Version 1.1 for Windows and the SINTEF Oil Weathering Model Version 1.5a for Windows >95. Details of the two models can be found in Daling et al., 1997 and Lehr et al., 1997.

The inputs for both models were essentially the same. The first step for use of either model was the selection of the oil to be modeled. The name of the oil, type, and in some cases, the API gravity were used to ensure the correct oil was selected. Where more than one oil type was spilled, the oil with the greater spilled volume was modeled. The water temperature at the time of the spill was used as a constant temperature.

Both models allow the user to enter either constant or time-dependent winds input from a text file. Time-dependent wind files were available for three of the first five spills analyzed. The models were run using both the time-dependent wind files and the initial speed reported at the time of the spill as a constant wind speed. The resulting analyses showed little difference in the results, and the extra time involved in trying to locate and input the time-dependent wind speeds was determined not to be worth the effort. Thereafter the wind speed reported at the time of the spill was used as a constant wind speed for spill modeling.

Both models allow the density of the water to be changed from the default for salt water. This input was varied for known freshwater spills. The SINTEF model also allows changes to the water depth and fetch for limiting the calculation of wave heights. Both of these features were used, for example, in modeling the *Amazon Venture* spill in the Savannah River.

In evaluating the window of opportunity, it was important to model the changes in oil properties over time and to know whether fresh oil was released continuously or intermittently. These factors determine whether a successful burn can occur some time after the initial incident. Oil is modeled as a series of individual instantaneous releases (called slugs) so that the results of the model can be used to obtain the change in properties over time.

3.6 Determining Logistics Response Time

The determination of response times for the mobilization and deployment of equipment sufficient to conduct ISB at the spill sites took into account several factors. The latitude and longitude of each spill location, or a name associated with the location, was obtained during the historical data review. The spill site was then located on an atlas. The nearest airport and nearest port for equipment mobilization and tow out were identified so that distances from the nearest equipment source could be measured. The potential problems related to local and international political jurisdictions delaying or preventing entry of oil spill response equipment were largely ignored except for some differences in initial mobilization time. It was also assumed that the nearest large airport could be used for international responses.

A worldwide survey of equipment necessary to complete ISB was conducted. Organizations in England, France, Norway, and the U.S. were contacted to determine the availability of equipment. It was determined that available ISB equipment suites are presently all located in the U.S. The owners, locations, and a description of these equipment suites are given below:

- *Alaska Clean Seas (ACS):* ACS maintains the following ISB burn equipment in its inventory: A helitorch airborne ignition system (with extra drums and gel mixers), 1,400 hand igniters, 17,500 feet of 3M fire boom, and 2,082 feet of old Shell fire boom. Most of their equipment is located in Anchorage, Alaska (Majors, 1997).

- *Alyeska Pipeline's Ship Escort Response Vessel System (SERVS):* SERVS has 3,600 feet of 3M fire boom and two helitorches stored in Valdez, Alaska. (The SERVS Website is located at at http:www.alyeska-pipe.com/servs/.)

- *Clean Caribbean Cooperative (CCC):* CCC has three complete systems located at their Ft. Lauderdale, Florida warehouse. One has 750 feet of 3M fire boom with 2- to 200-foot guide booms, packaged to be air transportable. The other two systems are 450 feet of Oil Stop Inflatable Fire Boom on reels, with 200 feet of guide boom at each end. All systems have support systems (e.g., blowers, power packs). They have 12 helitorches and 12 hand-held igniters in inventory. Oil Stop personnel have been identified to conduct equipment operations. CCC guidelines require that a firefighting vessel be present during ISB operations (Schuler, 1997).

- *Cook Inlet Spill Prevention and Response, Inc. (CISPRI):* CISPRI has 6,150 feet of 3M fire boom, 1,000 feet of Kepner fire boom, and a helitorch kit in inventory. All equipment is located in Kenai, Alaska (Majors, 1997).

- *Exxon Corporation:* Exxon has one system consisting of Oil Stop Inflatable Fire Boom and igniters located in Pradis, Louisiana.

- *Marine Spill Response Corporation:* Each system contains 500 feet of Oil Stop Inflatable Fire Boom on a reel, guide boom, and hand-held flare-type igniters which float. Personnel protection and fire fighting equipment standards were under development (O'Donovan, 1997). Systems are located in:

  ⇒ Edison, New Jersey (two systems);
  ⇒ Everett, Washington;
  ⇒ Galveston, Texas;

⇒ Honolulu, Hawaii;
⇒ Miami, Florida (four systems);
⇒ Pascagoula, Mississippi; and
⇒ St. Croix, U.S. Virgin Islands.

Outside of the U.S., in most of the areas in our study, ISB has not been accepted as a response option. However, Oil Spill Response Limited (OSRL), headquartered in Southampton, UK, has acquired a section of fire boom which it expended in at-sea ISB tests. Although they do not presently have ISB equipment in inventory, for the purposes of this study, it was assumed that OSRL will acquire the equipment necessary to conduct ISB, and used OSRL as the source of equipment for the spills that occurred in Europe.

The logistics response time included a mobilization time between the reported spill time and the time the ISB response equipment was ready for transport. This time was generally assumed to be two hours for domestic spills and five hours for international spills. For spills within CCC's operating area, a two-hour mobilization time was used. Likewise, for spills within the European Union, a two-hour mobilization time was used.

Transit times were calculated using the transit speeds from the latest draft of the ASTM "Guide For Estimating Oil Spill Recovery System Effectiveness." These are five knots for water transport, 35 miles per hour for land transport, and 100 knots by air transport. When equipment is not co-located at an airport or pier from which it is departing, a minimum one-hour trucking time to the airport or pier was assumed. Similarly, a minimum one-hour transit time was used from an airport to the deployment site. After arrival at the deployment site, a time of two hours to unpack and deploy the equipment was assumed.

Where the spill site was offshore, a transit time of five knots was used to calculate the estimated time to tow the equipment to site. Where distances to the spill site were small or where the mobilization site was co-located at the spill site, a minimum time of one hour to tow the boom to the site and capture the oil was used. In rare cases where the equipment location was next to the spill location (occurring most frequently in Galveston, Texas), the one hour minimum was built into the four hour total mobilization and unpack/deploy time.

The total response time was then the sum of the mobilization time, the time to truck the equipment to the airport (if used), transit time to the deployment site, unpack and deployment time, and time to tow and capture the oil.

4. Results

This study examined 141 large oil spills with a broad geographic distribution that occurred over the past 30 years. Appendix B contains a list of the 141 spills and their Phase I and Phase II ratings, and Appendix C contains detailed two-page summaries for each of the spills in the study.

4.1 Geographic Description and Spill Size

Table 1 presents the 141 spills included in this study by geographic distribution and spill size. As indicated in the table, the majority of the spills included in the scope of this study that occurred in North America were smaller than 50,000 barrels. Further, the majority of the spills that occurred in North America occurred in inland waterways or the Gulf and Caribbean regions. There were relatively few large oil spills in the South American region that were within the scope of this study. A substantial portion of the large oil spills (i.e., spills above 50,000 barrels) included in this study, occurred in Europe.

Table 1. Geographic Distribution of Spills Included in Study by Spill Size (in Barrels)

Spill Size (Barrels)	North America Offshore			North America Inland Waterways	South America	Europe	Total
	Atlantic	Pacific	Gulf/ Caribbean				
10,000-49,999	9	6	23	34	X	X	72
50,000-199,999	5	3	9	4	6	12	39
200,000 or more	3	2	6	2	3	14	30
TOTAL	17	11	38	40	9	26	**141**

Table 2 adds information regarding the Phase I and Phase II analyses of the spills to the information presented in Table 1. The table shows that, of the 72 spills of less than 50,000 barrels that occurred in North America, 15 passed Phase I and three were determined successful or passed Phase II.

Table 2. ISB Determination of Spills by Geographic Distribution and Spill Size (in Barrels)

Area	10,000-49,999		50,000-199,999		200,000 or more		Total	
	No. of Spills	Pass Phase I/ Phase II	No. of Spills	Pass Phase I/ Phase II	No. of Spills	Pass Phase I/ Phase II	No. of Spills	Pass Phase I/ Phase II
North America Total	72	15/3	21	11/5	13	5/4	106	31/12
Atlantic	9	2/0	5	5/3	3	1/1	17	8/4
Pacific	6	0/0	3	0/0	2	1/1	11	1/1
Gulf/Caribbean	23	9/3	9	6/2	6	3/2	38	18/7
Inland Waters	34	4/0	4	0/0	2	0/0	40	4/0
South America	X	X	6	2/0	3	1/0	9	3/0
Europe	X	X	12	8/1	14	5/1	26	13/2
OVERALL TOTAL	72	15/3	39	21/6	30	11/5	141	47/14

In total, 47 of the 141 spills passed the Phase I analysis. Fourteen of these (30 percent) were ultimately determined successful in the Phase II analysis, twelve (26 percent) spills were designated marginal calls, and 21 (45 percent) spills were designated unsuccessful candidates for ISB. Spills between 10,000 and 49,999 barrels had the greatest probability of being assigned an unsuccessful rating in the Phase I analysis. Only 21 percent of these spills passed the Phase I analysis and only four percent of the 72 spills were determined successful in the Phase II analysis. Forty-seven percent of the spills above 50,000 barrels that occurred in North America passed Phase I and 26 percent were determined successful in the Phase II analysis. Although an average of 33 percent of the spills that occurred in South America passed Phase I, none of the spills were determined successful in the Phase II analysis. Fifty percent of the spills that occurred in Europe passed the Phase I analysis (i.e., 13 of the 26 spills). Only eight percent of the 26 spills that occurred in Europe were determined successful in the Phase II analysis.

4.2 Phase I Results by Each of the Criteria

Table 3 below summarizes the number and percentage that failed only one criterion and the number and percentage of spills that failed multiple criteria (i.e., weather, oil weathering, logistics, and populated area).

Table 3. Phase I Results: Number and Percentage of Spills Failed by Criteria

Criteria Evaluated in PHASE I	Weather Results	Oil Weathering Results	Logistics Results	Populated Area Results
Failed This Criterion Only	4/141 (3%)	1/141 (0.7)	12/141 (9%)	41/141 (29%)
Failed Multiple Criterion	7/141 (5%)	35/141 (25%)	42/141 (30%)	59/141 (42%)

Proximity to populated areas was the most significant of the four criteria used to identify good candidates for ISB. Fifty-nine of the 141 spills did not pass the initial screening because the incident occurred near a sizable city. Nearby population can be important, in spite of the fact that some studies have shown that ISB does not necessarily produce an increased air pollution hazard. The public may perceive the highly visible smoke plume from a large ISB operation as an unacceptable health threat. Depending on spill response decision-making for a particular incident, however, at least some part of these spills may have been successfully burned. If, for example, local requirements allowed ISB between three and six miles, or if response vessels were used to tow oil farther out to sea, then many of these spills could have been successful candidates.

Two of the screening criteria considered were oil weathering characteristics and the logistics of the response. An oil weathering model estimated the amount of evaporation, dispersion, and emulsification of the spilled oil in a given incident. The type of oil spilled was an important factor, and most of the spills that did not pass the initial screening for weathering were light crude oils or light refined products that evaporated quickly. The amount of weathering must be low enough so that ISB is still feasible when the appropriate response equipment arrives at the scene. Of the 141 spills, 48 did not pass the initial screening for oil weathering or logistics, including 17 of the spills that did not pass the screening for proximity to a populated area. Those spills that did not pass tended to occur in remote locations or to involve oil types that evaporated or emulsified quickly.

The fourth screening criterion was for weather, and this factor eliminated incidents with persistently high winds following the spill. The persistence of such winds, with speeds of over 20 knots (or 10.3 m/sec), would preclude an effective ISB response. Only seven incidents did not pass the initial screening for weather, including four that did not pass on the basis of weather alone.

4.3 Phase II Results

The 47 spills that passed all the initial screening criteria in Phase I were examined more closely in Phase II to make a determination about which ones would be successful as ISB candidates. The data was reviewed for each screening criterion in conjunction with the other criteria, as well as narrative descriptions of each spill when available. This analysis led to the conclusion that many of the spills would be classified as unsuccessful or marginal calls. For example, some spills that passed the Phase I screening criteria for distance to populated areas failed the Phase II analysis because additional information indicated proximity to tourist beaches, significant populations within three miles of the incident, or other limiting factors. Some incidents that passed the screening criteria for weather and oil weathering nonetheless, were characterized by rough seas and relatively high water content (in the spilled oil), making ISB unfeasible.

Table 4 presents the counts and percentages of the 47 spills with their Phase II results. Forty-five percent (21 out of 47) of the spills analyzed in Phase II were unsuccessful.

Table 4. Phase II Results

Classification	Number/Percentage
Unsuccessful	21/47 (45%)
Marginal Call	12/47 (26%)
Successful	14/47 (30%)
TOTAL ANALYZED	47

4.4 Combined Results

Table 5 presents the combined Phase I and II determinations for all 141 spills. Eighty-two percent (115 out of 141) of the spills analyzed in the study were determined unsuccessful candidates for ISB.

Table 5. Summary of Phase I and Phase II Results

Classification	Number/Percentage
Unsuccessful	115/141 (82%)
Marginal Call	12/141 (9%)
Successful	14/141 (10%)
TOTAL ANALYZED	141

The final results identified 14 of the 141 spills as good candidates for ISB. Included among these candidates are well-known incidents, such as the 1989 *Exxon Valdez* spill, where an ISB test was in fact conducted, and the 1979 *Atlantic Empress* spill, where the vessel and spilled oil burned for several days following a collision. Several of these spills, such as the 1977 *Claude Conway* and the 1980 *Princess Anne-Marie*, are somewhat uncertain because very little information is available about the spill itself or the nature of the response. For various reasons related to the specific circumstances of the incidents, several well-documented spills, such as the 1967 *Torrey Canyon*, the 1976 *Argo Merchant,* and the 1984 *Alvenus*, were among the 12 considered to be marginal calls for ISB feasibility.

5. Conclusions

In general, the good candidates for ISB tended to occur in the coastal or offshore waters of the Gulf of Mexico or Caribbean Sea. The larger spills that occurred off the Atlantic coast of North America also tended to be successful. (There were seven successful ISB candidates out of the 38 spills that occurred in the Gulf of Mexico and Caribbean and four successful candidates out of the eight spills of 50,000 barrels or more that occurred off the Atlantic coast of North America.) None of the candidates were from inland waterways or from ocean waters off South America.

The results of the analysis show that, although there is growing interest in ISB for use on large volume oil spills, there are constraints to the widespread use of the technique. Considering the effectiveness of ISB, however, and the fact that constraints such as spill location, expected weather, and oil type are likely to be well known prior to undertaking a response, the results are encouraging. If the locations, oil types, and weather conditions of future oil spill incidents are similar to those of past incidents, then ISB may be a possible response option for a small but significant fraction of future incidents, perhaps 10 percent. Decision-makers must compare ISB to other response options knowing the respective limitations and effectiveness of each technique.

The results of this study can be significant in three ways. First, the identification of patterns and trends of past spills can help the USCG develop simulation studies for forecasting the likelihood of future oil spill disasters. The USCG can predict future oil shipments, weather conditions, major spill probabilities, and spill response time for various locations, and these predictions can be used as modeling tools to compare different prevention and response strategies. Second, this study's identification of high-risk coastal areas should be incorporated into regional preparedness planning. The USCG should help ensure that adequate response resources are available at locations where they are needed and should work with Regional Response Teams to develop appropriate response policies that include consideration of ISB. Third, as more experience is gained and more fire boom equipment is positioned, the criteria could change. The impacts on the logistics and distance to populated areas criteria would be affected the greatest. The result could be a significant increase in the number of potential spills that could use ISB. Data collected here should be reviewed as conditions and attitudes change.

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APPENDIX A

Oil Spills Considered For Analysis By Date

No.	Spill Name	Date	Latitude	Longitude	City/State/Country	Continent	Size (bbls)	Oil Type	Data Source Discrepancies
1	Torrey Canyon	3/18/67	50 03 N	004 44 W	Lands End, England	Europe	860,000	Kuwait crude oil	
2	Humble Oil Pipeline	10/15/67	29 00 N	89 40 W	Offshore, LA	North America	200,000	Grand Isle	
3	Ocean Eagle	3/3/68	18 29 N	066 10 W	San Juan, PR	North America	83,400	Leona	
4	General Colocotronis	3/7/68	25 20 N	076 20 W	Eleuthera, Bahamas	North America	37,700	Lago treco	
5	Witwater	12/13/68	09 35 N	080 40 W	Galeta Island, Canal Zone, Panama	North America	14,000	Marine diesel (API 31.3) and Bunker C (API 7-14)	
6	Santa Barbara Well Blowout	1/28/69	34 10 N	119 45 W	Santa Barbara, CA	North America	100,000	Willmington crude oil	
7	Keo	11/5/69	39 00 N	68 00 W	120 miles South of Nantucket		209,523	No. 6 fuel oil	
8	Arrow	2/4/70	45 28 N	061 06 W	Nova Scotia, Canada	North America	77,000	Bunker C (No. 6 fuel) oil	
9	Chevron Main Pass Block 41	2/10/70	29 23 N	088 59 W	Nr. Mississippi River Delta, LA	North America	65,000	Crude oil (API 34)	
10	Othello*	3/20/70	59 20 N	018 20 E	Sweden	Europe	400,000	Fuel oil No. 6	
11	Polycommander	5/5/70	42 15 N	008 50 W	Spain	Europe	400,000	Souedie	
12	Mariena*	11/11/70			Sicily, Italy	Europe	100,000		
13	Shell Platform 26	12/1/70	28 46 N	090 10 W	Gulf of Mexico, off Louisiana	North America	58,640	Grand Isle	
14	Oregon Standard	1/18/71	37 40 N	122 20 W	San Francisco, CA	North America	20,400	Bunker C	
15	Texaco Oklahoma	3/27/71	36 00 N	073 00 W	Off the coast of North Carolina	North America	250,000	West Texas Sour	
16	Trader	6/11/72	36 20 N	019 43 E	Greece	Europe	260,000	Soviet export blend	
17	Schuylkill River	6/22/72	40 15 N	075 38 W	Douglassville, PA	North America	170,000	No. 6 cargo residue	
18	Bellingham Bay	1/10/73	48 45 N	122 30 W	Bellingham Bay, WA	North America	10,476	Alaskan North Slope	
19	Bayou Lafousche	3/9/73	29 38 N	094 58 W	Upper Galveston Bay, TX	North America	10,000	Louisiana crude, Bunker C	
20	Zoe Colocotronis	3/18/73	18 00 N	067 15 W	Cabo Rojo, PR	North America	37,579	Tia Juana light	
21	Oil Recovery	5/19/73	33 44 N	118 16 W	California	North America	142,857	Wilmington	
22	Esso Brussels	6/2/73	40 40 N	75 50 W	New York Harbor, NY	North America	36,650	Forcados crude	
23	Petrola	6/3/73	41 00 N	72 00 W	Off NY	North America	20,000	No. 6 fuel	
24	Napier	6/10/73	44 45 S	75 05 W	Off west of Chile	South America	270,000	Loreto Peruvian export grade	
25	Jawacta*	12/21/73							
26	Keytrader	1/18/74	29 15 N	089 25 W	Mississippi River, LA	North America	17,592	Kerosene	
27	Elias	4/9/74	40 00 N	075 00 W	Delaware River, Ft. Mifflin, Philadelphia, PA	North America	22,000	Bachaquero heavy	
28	Sea Spirit	4/15/74	34 00 N	118 15 W	Los Angeles Harbor, CA	North America	50,028	Heavy fuel oil	Exact spill date unknown; the only date found in text was 4/74.
29	Eugene Island 317	4/17/74	28 16 N	91 35 W	Gulf of Mexico, TX	North America	19,833	South Louisiana crude	
30	Barge No. 15*	8/1/74	29 30 N	90 15 W	Mississippi River (Mile 16), LA	North America	46,454	Unknown	
31	Jos Simard	8/4/74	58 43 N	062 54 W	Newfoundland, Canada	North America	10,714	No. 4 diesel fuel	
32	Metula	8/9/74	52 34 S	069 41 W	First Narrows, Straits of Magellan, Chile	South America	398,019	Light Arabian crude, Bunker C	
33	Bouchard 65	10/9/74	42 30 N	69 30 W	Atlantic Ocean, MA	North America	36,650	Fuel	
34	Ercole	10/22/74	30 10 N	091 15 W	Mississippi River (Mile 174.2), LA	North America	14,660	East Texas crude	
35	Athenian Star	1/20/75	43 00 N	59 30 W	Off of New Hampshire	North America	17,000	Arab medium crude	MMS Database: 11,905 bbls spilled.
36	Jakob Maersk	1/29/75	41 11 N	008 44W	Leixoes, N. Portugal	Europe	637,500	Iranian heavy crude	
37	Corinthos	1/31/75	39 49 N	075 25 W	Delaware River, Marcus Hook, PA	North America	266,000	Algerian crude oil	

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No.	Spill Name	Date	Latitude	Longitude	City/State/Country	Continent	Size (bbls)	Oil Type	Data Source Discrepancies
38	Panglobal Friendship	2/11/75	11 04 N	061 34 W	Caribbean Zone, 20 Mi. off Trinidad	North America	14,660	Fuel oil	
39	IOT-105	3/3/75	32 20 N	090 50 W	Lower Mississippi River, MS	North America	20,000	Automotive gasoline	
40	B-421/Barge 13	3/5/75	31 40 N	091 25 W	Lower Mississippi River (Mile 435.8), MS	North America	24,715	East Texas crude	MMS Database: 20,395 bbls spilled.
41	Tarik Ibn Ziyad	3/26/75	22 54 S	043 10 W	Rio de Janeiro, Brazil	South America	109,950	Iranian light crude	
42	Spartan Lady	4/4/75	39 02 N	0'71 00 W	Off NJ	North America	142,857	No. 6 fuel	
43	No Name*	10/16/75			Gulf of Mexico, LA	North America	60,000		
44	Olympic Alliance	11/12/75	50 59 N	001 35 W	Dover Strait, Pas de Calais, English Channel, England	Europe	87,000	Iranian light crude oil	NOAA Case Histories: 14,000 bbls entered water at time of impact; reported to have spilled 73,000 additional bbls between site of collision and Wilhelmshaven, GDR.
45	St. Peter	2/5/76	01 30 N	079 30 W	Cabo Manglares, Colombia	South America	279,000	Oriente crude	
46	Urquiola	5/12/76	43 22 N	008 23 W	La Coruna, Spain	Europe	733,000	Light Arabian crude oil, Bunker fuel	NOAA Case Histories: 513,000 bbls burned in initial fire, 180,000-200,000 bbls polluted the coast.
47	Hackensack Estuary	5/26/76	40 44 N	074 11 W	Hackensack, NJ	North America	47,619	No. 6 fuel oil	
48	Al-Damman	6/30/76	37 50 N	021 10 E	Mediterranean, Agioi Theodoroi, Greece	Europe	110,000	Arab medium crude	
49	LSCO Petrochem*	10/4/76	29 00 N	89 00 W	Gulf of Mexico, LA	North America	109,950	Fuel oil No. 6	
50	N30*	12/3/76	21 45 N	080 00 W	American Atlantic, Trinidad, Cuba	North America	10,000	Crude	
51	Argo Merchant	12/15/76	41 02 N	069 27 W	Nantucket, MA	North America	183,330	No. 6 fuel oil, Cutter stock	
52	Sansinena	12/17/76	33 43 N	118 16 W	Los Angeles Harbor, CA	North America	30,000	Bunker C (Group V) fuel oil, Indonesian light crude	
53	Ethel H (II)	2/4/77	41 21 N	073 57 W	Hudson River, NY	North America	10,000	No. 6 fuel oil	
54	Claude Conway	3/20/77	32 45 N	75 25 W	150 Mi. SE of Cape Fear	North America	146,600	Bunker C	
55	Ekofisk Bravo Oil Field	4/22/77	56 34 N	003 12 E	Off Norway	Europe	202,381	Ekofisk crude oil	
56	Caribbean Sea	5/27/77	11 34 N	089 51 W	S. of El Salvador, Central America	North America	181,672	Bachaquero	
57	Dauntless Colocotronis	7/22/77	29 30 N	89 30 W	Mississippi River (Mile 89), Breton Sound, LA	North America	15,000	Arabian light crude	
58	Oswego Tarmac	7/29/77	12 00 N	069 00 W	Caribbean, Netherlands Antilles	North America	73,300	No. 6 fuel oil	
59	URSS 1	8/10/77	41 02 N	28 57 E	River near Black Sea, Bosporus	Europe	146,000	Soviet export blend crude	The lat/long for the URSS 1 was based on the lat/long for the Independenta, since they both took place along the Bosphorus, and lat/long information for URSS 1 was otherwise unavailable.
60	Brazilian Marina	1/9/78	23 48 S	045 43 W	San Sebastiao, Brazil	South America	73,600	Kuwait, Mina-al-Ahmadi crude (API 31.4)	OSIR 1978-81: 87,142 bbls spilled.

APPENDIX A

Oil Spills Considered For Analysis By Date

No.	Spill Name	Date	Latitude	Longitude	City/State/Country	Continent	Size (bbls)	Oil Type	Data Source Discrepancies
61	Union Oil Co. of California	2/8/78	42 24 N	071 01 W	Revere, MA	North America	35,714	Automotive gasoline	MSRC Tech. Rept.: 32,040 bbls spilled.
62	Amoco Cadiz	3/16/78	48 35 N	004 43 W	Brittany, France	Europe	1,634,952	Light Arabian crude, Iranian light crude, Bunker C	
63	Ocean 250	3/16/78	41 17 N	071 51 W	Block Island Sound, RI	North America	16,249	Aviation gasoline	
64	Interstate 19	3/20/78	39 35 N	075 35 W	Delaware City, DE	North America	15,000	JP-4 Aviation fuel, Kerosene	
65	Eleni V	5/6/78	52 49 N	001 48 E	Off Norfolk, England	Europe	52,500	Heavy fuel oil	
66	Aminona	5/26/78	02 18 S	044 13 W	Atlantic Ocean, Banco do Meio, Brazi	South America	146,600	No. 2 fuel oil	
67	Cabo Tamar	7/7/78	36 40 S	073 10 W	Talcahuano, Chile	South America	50,833	Oriente crude	
68	U.S. Strategic Petroleum Reserve	9/21/78	29 59 N	093 22 W	West Hackberry, LA	North America	32,520	Light Arabian crude	OSIR 1978-81: 67,500 bbls spilled.
69	Mara	11/12/78	12 00 N	068 00 W	Caribbean, 8 Mi. off Curacao, Netherlands	North America	73,300	Fuel oil No. 6	
70	Peck Slip	12/19/78	18 15 N	065 34 W	Cape San Juan, PR	North America	11,000	Bunker C	
71	Kosmas M	12/25/78	40 05 N	027 00 E	Akbas Nr. Canakkale, Dardanelles, Turkey	Europe	73,300	Fuel oil No. 6	
72	Andros Patria	12/31/78	43 31 N	009 37 W	Off Cape Villano, Spain	Europe	347,619	Iranian heavy crude	
73	F.W. Bekman	1/4/79	51 26 N	006 45 E	Duisberg, West Germany	Europe	61,904	Heavy fuel	
74	Messiniaki Frontis	3/2/79	34 55 N	024 48 E	Kaloi Limenes, Crete	Europe	116,214	Sirir crude	
75	Kurdistan	3/15/79	46 00 N	060 00 W	Cabot Strait, Nova Scotia, Canada	North America	43,900	Bunker C (Naptha)	
76	Simonburn	3/15/79	46 56 N	059 40 W	65 Km NE of Sydney, Nova Scotia	North America	79,990	No. 6 fuel	Exact spill date unknown; the only date found in text was 3/79.
77	Gino/Team Castor	4/28/79	48 14 N	005 50 W	Ile d' Ouessant, France	Europe	307,860	Fuel oil No. 6	
78	Ixtoc I, Petroleos Mexicanos	6/3/79		092 20 W	Bahia de Campeche, Gulf of Mexico, Mexico	North America	3,202,000	IXTOC 1 crude oil	NOAA Case Histories: 352,400 bbls spilled; OSIR 1978-81: 3,202,000 bbls spilled during 1979 and 131,333 bbls during 1980. Oil entered water from 6/3/79 to 3/23/80.
79	Aegean Captain	7/19/79	11 19 N	060 33 W	32 km North of Tobago	North America	145,261	Tia Juana medium 24	
80	Atlantic Empress	8/2/79	13 05 N	55 28 W	450 km East of Barbados	North America	987,714	Arabian medium crude	
81	Chevron Hawaii	9/1/79	29 42 N	095 08 W	Deer Park, TX	North America	20,000	Santa Maria crude, Catalytic cracker feedstock	OSIR 1978-81: 17,857 bbls spilled.
82	Titipor	10/15/79	03 06 S	060 00 W	Tomanaus Rds, Brazil	South America	158,004	Diesel fuel	Exact spill date unknown; the only date found in text was 10/79.
83	Gunvor Maersk	10/27/79	03 00 S	060 00 W	Amazon River, Manaus Rds., Brazil	South America	109,950	Fuel oil No. 6	
84	Burmah Agate	11/1/79	29 17 N	094 27 W	Galveston Bay, TX	North America	254,761	Forcados crude	
85	Independenta	11/15/79	41 02 N	028 57 E	Istanbul, Turkey	Europe	687,785	Es Sider crude oil	
86	Princess Anne-Marie	1/28/80	21 50 N	084 40 W	Cabo San Antonio, Cuba	North America	28,571	Bachaquero heavy crude	

APPENDIX A

Oil Spills Considered For Analysis By Date

No.	Spill Name	Date	Latitude	Longitude	City/State/Country	Continent	Size (bbls)	Oil Type	Data Source Discrepancies
87	Irenes Serenade	2/23/80	36 56 N	021 42 E	Pilos, Greece	Europe	871,428	Sirir crude	Explosion and fire; sinking. Two-hundred and eighty thousand barrels burned during a 14-hour fire.
88	Tanio	3/7/80	49 10 N	004 16 W	Brittany, France	Europe	98,955	No. 6 fuel oil	OSIR 1978-81: 45,714 bbls lost and 75,476 bbls sunken.
89	Texaco North Dakota	8/21/80	28 04 N	091 39 W	100 m. S of Morgan City,Gulf of Mexico, LA	North America	18,000	Raffinate	
90	Georgia	11/22/80	29 10 N	089 15 W	Gulf of Mexico, LA	North America	32,000	Louisiana light sweet crude	
91	Hannah 4001	1/4/81	29 30 N	93 30 W	Near Galveston, TX	North America	29,320	Gasoline	
92	Concho	1/19/81	40 35 N	074 01 W	Kill Van Kull, NY	North America	18,149	No. 6 fuel oil	OSIR 1978-81: Only 1,758 bbls spilled; NOAA Case Histories: 2,381 bbls spilled into water.
93	Olympic Glory	1/28/81	29 41 N	095 00 W	Houston Ship Channel, TX	North America	23,809	Galeota crude	NOAA Case Histories: 20,000 bbls spilled.
94	Apex Houston	3/19/81	29 07 N	89 20 W	Lower Mississippi River (Mile 13), Near Pilottown	North America	25,042	No. 6 fuel	
95	Cavo Cambanos	3/29/81	41 11 N	007 09 E	Tarragona Rds, Off Corsica, Spain	Europe	148,976	Naptha	
96	Golden Dolphin	3/6/82	30 09 N	046 23 W	700 Mi. E. of Bermuda, Atlantic Ocean	North America	21,990	Fuel oil No. 6	
97	Arkas	3/31/82	30 00 N	090 28 W	Lower Mississippi River (Mile 130), Montz, LA	North America	35,000	Louisiana light sweet crude	
98	BU 42	6/29/82	34 20 N	092 00 W	Arkansas River (Mile 66), Near Pine Bluff, Arkansas	North America	28,144	No. 6 fuel	
99	Marin Mist*	1/12/83			Port, CA	North America	14,660	Fuel oil	
100	V882/V883/V884/V885	4/2/83	38 40 N	090 15 W	Mississippi River, St. Louis, MO	North America	13,212	Rainbow crude	
101	SF1 71/SF1 72	6/9/83	32 21 N	090 51 W	Vicksburg, MS	North America	14,047	No. 6 fuel	
102	Conoco	8/22/83	30 14 N	93 16 W	Calcasieu River, LA	North America	15,000	Heavy gasoil	
103	US 218	12/25/83	30 05 N	091 00 W	Lower Mississippi River (Mile 180.8), Donaldson, LA	North America	25,000	Light diesel No. 1-D	
104	Barge	1/24/84	33 40 N	091 10 W	Lower Mississippi River (Mile 694.5), AR	North America	26,119	No. 6 fuel	
105	Hoegh Mascot	2/16/84	43 20 N	124 20 W	Coos Bay, OR	North America	16,667	Clarified	
106	Chem 102*	2/26/84	30 00 N	090 20 W	Lower Mississippi River (Mile 123), LA	North America	13,830	Crude, Mineral seal	
107	Alvenus	7/30/84	29 35 N	093 15 W	11 nm S-SE of Cameron, LA	North America	65,000	Venezuelan Merey and Pilon crude	OSIR 1982-85: 66,452 bbls spilled.
108	Puerto Rican	10/31/84	37 30 N	123 02 W	San Francisco Bay, CA	North America	38,500	Bunker fuel, Lubricating	OSIR 1982-85: 8,000 bbls sunk and 40,000 burned and spilled.
109	Cape Fear River	11/21/84	33 59 N	77 58 W	Cape Fear River, NC	North America	17,000	No. 6 fuel	
110	Almar	11/26/84	12 10 N	069 00 W	Curacao, West Indies	North America	25,000	Bachaquero crude	
111	Passenger Vessel	11/26/84	40 54 N	73 26 W	Huntingdon Harbor, NY	North America	142,857	No. 1 diesel	
112	Neches River*	2/15/85	29 59 N	93 53 W	Neches River, TX	North America	30,000	Range of petroleum products	
113	Galveston Bay	7/13/85	29 17 N	94 54 W	Galveston Bay, TX	North America	25,000	Mineral seal	

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Oil Spills Considered For Analysis By Date

No.	Spill Name	Date	Latitude	Longitude	City/State/Country	Continent	Size (bbls)	Oil Type	Data Source Discrepancies
114	Exxon No. 32	8/18/85	37 06 N	076 38 W	Off Norfolk, VA	North America	30,000	No. 2 fuel	
115	Grand Eagle	9/28/85	39 50 N	075 25 W	Marcus Hook, PA	North America	10,357	Ninian crude	
116	SFI 41	11/24/85	37 20 N	089 30 W	Mississippi River, MO	North America	16,300	No. 6 fuel oil	OSIR 1982-85: 7,142 bbls spilled.
117	Texas	3/7/86	37 10 N	089 30 W	Mississippi River, MO	North America	17,055	East Texas crude	
118	Texaco Storage Tank	4/27/86	09 40 N	079 05 W	Bahia Las Minas, Panama	North America	240,000	Venezuelan crude, Mexican Isthmanian crude, Medium	Approx. 140,000 bbls. not retained and entered Bahia Cativa; 1987 Oil Spill Conference Proceedings: 60,000 bbls spilled.
119	TTT-103 Chevron USA	7/31/86	30 26 N	088 33 W	Intercoastal Waterway, Pascagoula, MS	North America	14,000	Auto Gas, LPG, No. 2 fuel, Resin	
120	PEMEX	10/23/86	18 48 N	092 35 W	Bahia de Campeche, 40 Mi. NW of Cuidad del Carmen, Mexico	North America	247,000	Isthmus	
121	Amazon Venture	12/4/86	32 04 N	81 50 W	Savannah, Savannah River, GA	North America	11,900	No. 6 fuel	
122	Stuyvesant (I)	1/6/87	51 29 N	136 16 W	Valdez, Gulf of Alaska, AK	North America	14,285	North Slope crude	
123	Fuyoh Maru/Vitoria	6/23/87	49 30 N	000 30 E	Le Havre, Seine River, France	Europe	80,880	Kerosene	
124	Stuyvesant (II)	10/4/87	54 05 N	138 00 W	Gulf of Alaska, AK (100 to 200 Mi. off B.C.)	North America	14,285	North Slope crude	
125	PEMEX/YUM II	10/10/87	18 48 N	092 35 W	Gulf of Mexico, 40 Mi. NW of Ciudad de Carmen, Mexico	North America	56,000	Light crude oil	NOAA Case Histories: 58,640 bbls and referred to as "YUM II/Zapoteca."
126	Ashland Petroleum Co.	1/2/88	40 33 N	080 00 W	Floreffe, PA	North America	70,523	No. 2 diesel	NOAA Case Histories: 23,810 bbls spilled. Tank spilled 90,476 bbls; only 23810 bbls entered water.
127	Amoco Oil Co.	2/7/88	29 41 N	94 80 W	Galveston, Gulf of Mexico, TX	North America	15,576	South Louisiana light crude	OSIR 1986-88: 14,000 bbls spilled.
128	Athenian Venture	4/22/88	42 30 N	49 30 W	350-400 Mi. SE of Cape Race, Newfoundland, Canada	North America	252,429	Unleaded gasoline, Bunker	MMS Database: 4/21/88.
129	Nord Pacific	7/13/88	27 49 N	097 25 W	South side of inner harbor, Corpus Christi, TX	North America	15,350	Beatrice (North Sea) crude oil	
130	Esso (Exxon) Puerto Rico	9/3/88	29 55 N	090 15 W	Mississippi River, Baton Rouge, New Orleans, LA	North America	23,000	Fuel oil No. 6	
131	Exxon Pipeline	1/13/89	29 02 N	091 27 W	Eugene Island Block, LA	North America	14,000	Grand Isle	
132	UMTB 283	1/15/89	54 46 N	158 18 W	South of Semidi Islands, AK	North America	48,619	Diesel	NOAA Case Histories: 47,620; MMS Databse: Spill began on 12/26/88.
133	Gran Tor	2/15/89	18 35 N	069 35 W	800 yards E of Punta Nisbon, Dominican Republic	North America	16,119	Bunker C	
134	Exxon Valdez	3/24/89	61 02 N	146 05 W	Prince William Sound, AK	North America	257,142	North Slope crude	NOAA Case Histories: 240,500 bbls spilled.
135	TWE 23 De Agosto*	6/27/89			Caribbean Sea, Port in Cuba	North America	14,660	Gasoline	
136	Hess Oil Tanks*	9/20/89	17 40 N	62 90 W	Port Alucroix, Limetree Bay, St Croix, U.S.V.I.	North America	10,000	Heavy crude oil	NOAA Case Histories: 10,000 bbls spilled; only 1,000 bbls entered water.

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Oil Spills Considered For Analysis By Date

No.	Spill Name	Date	Latitude	Longitude	City/State/Country	Continent	Size (bbls)	Oil Type	Data Source Discrepancies
137	Aragon	12/29/89	33 34 N	015 34 W	NE of Madeira, Portugal	Europe	175,000	Mexican Maya crude oil (Type 3)	
138	Exxon Bayway Refinery	1/2/90	40 38 N	074 14 W	Arthur Kill, NY	North America	13,500	No. 2 home heating oil	
139	Ship Shoals Block 281	1/24/90	28 18 N	90 52 W	Gulf of Mexico, TX	North America	14,423	South Louisiana crude	
140	Mega Borg	6/8/90	28 33 N	094 08 W	Gulf of Mexico, 57 Mi. SE of Galveston, TX	North America	100,000	Angolan Palanca crude oil	OSIR 1989-90: 119,047 bbls spilled. MMS Database: 6/9/90.
141	Apex Oil Co.	7/28/90	29 29 N	094 52 W	Houston Shipping Channel, Galveston Bay, TX	North America	16,476	No. 5 oil, Catalytic feedstock oil	
142	Jupiter	9/16/90	43 30 N	084 00 W	Saginaw River, Bay City, MI	North America	20,000	Unleaded gasoline	
143	Lakehead Pipeline Company*	3/3/91	47 14 N	093 38 W	Grand Rapids, MN	North America	40,476	Crude	
144	Vesta Bella	3/6/91	17 17 N	062 18 W	Nevis Isle. (U.K.), Caribbean Sea	North America	13,300	No. 6 fuel oil	OSIR 1978-81: 47,619 bbls spilled.
145	Haven	4/11/91	44 20 N	009 00 E	Genoa, Italy	Europe	142,857	Heavy Iranian crude	NOAA Case Histories: 142,857 bbls entered water; 450,000 bbls burned. Oil Spill Conference Proceedings: 179,663 bbls spilled.
146	Greenhill Petroleum	9/29/92	29 00 N	091 00 W	Gulf of Mexico, off Timbalier Bay, LA	North America	11,500	Light Crude	USCG estimated that 2,381 bbls.entered the Gulf of Mexico.
147	Aegean Sea	12/3/92	43 20 N	008 20 W	La Coruna Harbor, Spain	Europe	521,428	Brent Light Crude (North Sea Fields crude)	
148	Braer	1/5/93	59 00 N	001 30 W	Garth Ness, Shetland Islands, U.K.	Europe	595,238	Norwegian (Gullfaks) Crude	
149	Morris J. Berman	1/7/94	18 28 N	066 05 W	Off San Juan, PR	North America	17,857	Blended No. 6 fuel oil, Heavy No. 6 heating	OSIR 1994: 14,809 bbls spilled; Oil and Haz. Mat. Response Reports, FY 1994: 17,700 bbls removed from the water and leaking barge; 1995 Oil Spill Conference Proceedings: Oil Type-Low API Gravity (LAPIO) or Group V Fuel Oil.
150	San Jacinto River	10/20/94	29 48 N	095 04 W	San Jacinto River, Channelview, TX	North America	406,000	Gasoline, Arabian crude, Diesel, Natural gas	Oil and Haz. Mat. Response Reports, FY 1995: 64,000 bbls gasoline, 196,000 bbls crude oil, and 146,000 bbls fuel oil spilled; OSIR 1994: 28,571 bbls spilled.
151	North Cape	1/19/96	42 21 N	071 35 W	Narragansett, RI	North America	19,643	No. 2 fuel oil, Home heating oil	

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No.	Spill Name	Date	Latitude	Longitude	City/State/Country	Continent	Size (bbls)	Oil Type	Data Source Discrepancies
152	Sea Empress	2/15/96	51 40 N	005 10 W	Milford Haven Harbor, Wales, U.K.	Europe	547,619	Forties Blend crude	OSIR Oil Spill Reporter 1996: 452, 300 bbls spilled.
153	Bay of Campeche Tanker	3/7/96	21 00 N	97 20 W	Bay of Campeche, Mexico	North America	250,000	Bunker C	
154	Houston	2/3/97	24 31 N	081 34 W	Maryland Shoal, Florida Keys NMS	North America	19,048	IF-30 Bunker crude oil	

*These spills were not included in the analysis because not enough information was available on oil type and/or latitude and longitude.

APPENDIX B

Phases I and II Analyses Results

No.	Spill Name	Date	Weather Results	Oil Weathering Results	Logistics Results	Populated Area Results	Phase I Evaluation	Phase II Evaluation
1	Torrey Canyon	3/18/67	Pass	Pass	Pass	Pass	Pass	Marginal Call
2	Arrow	2/4/70	Pass	Pass	Pass	Pass	Pass	Marginal Call
3	Argo Merchant	12/15/76	Pass	Pass	Pass	Pass	Pass	Marginal Call
4	Brazilian Marina	1/9/78	Pass	Pass	Pass	Pass	Pass	Marginal Call
5	Eleni V	5/6/78	Pass	Pass	Pass	Pass	Pass	Marginal Call
6	Mara	11/12/78	Pass	Pass	Pass	Pass	Pass	Marginal Call
7	Kosmas M	12/25/78	Pass	Pass	Pass	Pass	Pass	Marginal Call
8	Aegean Captain	7/19/79	Pass	Pass	Pass	Pass	Pass	Marginal Call
9	Tanio	3/7/80	Pass	Pass	Pass	Pass	Pass	Marginal Call
10	Alvenus	7/30/84	Pass	Pass	Pass	Pass	Pass	Marginal Call
11	Vesta Bella	3/6/91	Pass	Pass	Pass	Pass	Pass	Marginal Call
12	Haven	4/11/91	Pass	Pass	Pass	Pass	Pass	Marginal Call
13	Witwater	12/13/68	Pass	Pass	Pass	Pass	Pass	Successful
14	Keo	11/5/69	Pass	Pass	Pass	Pass	Pass	Successful
15	Spartan Lady	4/4/75	Pass	Pass	Pass	Pass	Pass	Successful
16	Claude Conway	3/20/77	Pass	Pass	Pass	Pass	Pass	Successful
17	Caribbean Sea	5/27/77	Pass	Pass	Pass	Pass	Pass	Successful
18	Simonburn	3/15/79	Pass	Pass	Pass	Pass	Pass	Successful
19	Gino	4/28/79	Pass	Pass	Pass	Pass	Pass	Successful
20	Atlantic Empress	8/2/79	Pass	Pass	Pass	Pass	Pass	Successful
21	Princess Anne-Marie	1/28/80	Pass	Pass	Pass	Pass	Pass	Successful
22	Cavo Cambanos	3/29/81	Pass	Pass	Pass	Pass	Pass	Successful
23	Almar	11/26/84	Pass	Pass	Pass	Pass	Pass	Successful
24	PEMEX	10/23/86	Pass	Pass	Pass	Pass	Pass	Successful
25	PEMEX/YUM II	10/10/87	Pass	Pass	Pass	Pass	Pass	Successful
26	Exxon Valdez	3/24/89	Pass	Pass	Pass	Pass	Pass	Successful
27	General Colocotronis	3/7/68	Pass	Pass	Pass	Pass	Pass	Unsuccessful
28	Polycommander	5/5/70	Pass	Pass	Pass	Pass	Pass	Unsuccessful
29	Shell Platform 26	12/1/70	Pass	Pass	Pass	Pass	Pass	Unsuccessful
30	Trader	6/11/72	Pass	Pass	Pass	Pass	Pass	Unsuccessful
31	Zoe Colocotronis	3/18/73	Pass	Pass	Pass	Pass	Pass	Unsuccessful
32	Keytrader	1/18/74	Pass	Pass	Pass	Pass	Pass	Unsuccessful

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Phases I and II Analyses Results

No.	Spill Name	Date	Weather Results	Oil Weathering Results	Logistics Results	Populated Area Results	Phase I Evaluation	Phase II Evaluation
33	Jakob Maersk	1/29/75	Pass	Pass	Pass	Pass	Pass	Unsuccessful
34	Olympic Alliance	11/12/75	Pass	Pass	Pass	Pass	Pass	Unsuccessful
35	St. Peter	2/5/76	Pass	Pass	Pass	Pass	Pass	Unsuccessful
36	Al-Damman	6/30/76	Pass	Pass	Pass	Pass	Pass	Unsuccessful
37	Dauntless Colocotronis	7/22/77	Pass	Pass	Pass	Pass	Pass	Unsuccessful
38	Kurdistan	3/15/79	Pass	Pass	Pass	Pass	Pass	Unsuccessful
39	Gunvor Maersk	10/27/79	Pass	Pass	Pass	Pass	Pass	Unsuccessful
40	Hannah 4001	1/4/81	Pass	Pass	Pass	Pass	Pass	Unsuccessful
41	Barge	1/24/84	Pass	Pass	Pass	Pass	Pass	Unsuccessful
42	Exxon No. 32	8/18/85	Pass	Pass	Pass	Pass	Pass	Unsuccessful
43	SFI 41	11/24/85	Pass	Pass	Pass	Pass	Pass	Unsuccessful
44	Texaco Storage Tank	4/27/86	Pass	Pass	Pass	Pass	Pass	Unsuccessful
45	Stuyvesant (II)	10/4/87	Pass	Pass	Pass	Pass	Pass	Unsuccessful
46	Aragon	12/29/89	Pass	Pass	Pass	Pass	Pass	Unsuccessful
47	Houston	2/3/97	Pass	Pass	Pass	Pass	Pass	Unsuccessful
48	Humble Oil Pipeline	10/15/67	Pass	Fail	Fail	Pass	Unsuccessful	N/A
49	Ocean Eagle	3/3/68	Pass	Pass	Pass	Fail	Unsuccessful	N/A
50	Santa Barbara Well Blowout	1/28/69	Pass	Pass	Pass	Fail	Unsuccessful	N/A
51	Chevron Main Pass Block 41	2/10/70	Pass	Fail	Fail	Pass	Unsuccessful	N/A
52	Oregon Standard	1/18/71	Pass	Pass	Pass	Fail	Unsuccessful	N/A
53	Texaco Oklahoma	3/27/71	Pass	Pass	Fail	Pass	Unsuccessful	N/A
54	Schuylkill River	6/22/72	Pass	Pass	Pass	Fail	Unsuccessful	N/A
55	Bellingham Bay	1/10/73	Fail	Pass	Pass	Fail	Unsuccessful	N/A
56	Bayou Lafousche	3/9/73	Pass	Fail	Fail	Fail	Unsuccessful	N/A
57	Oil Recovery	5/19/73	Pass	Pass	Pass	Fail	Unsuccessful	N/A
58	Esso Brussels	6/2/73	Pass	Fail	Pass	Fail	Unsuccessful	N/A
59	Petrola	6/3/73	Pass	Pass	Pass	Fail	Unsuccessful	N/A
60	Napier	6/10/73	Pass	Pass	Fail	Pass	Unsuccessful	N/A
61	Elias	4/9/74	Pass	Pass	Pass	Fail	Unsuccessful	N/A
62	Sea Spirit	4/15/74	Pass	Pass	Pass	Fail	Unsuccessful	N/A
63	Eugene Island 317	4/17/74	Pass	Fail	Fail	Pass	Unsuccessful	N/A
64	Jos Simard	8/4/74	Pass	Pass	Fail	Pass	Unsuccessful	N/A

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Phases I and II Analyses Results

No.	Spill Name	Date	Weather Results	Oil Weathering Results	Logistics Results	Populated Area Results	Phase I Evaluation	Phase II Evaluation
65	Metula	8/9/74	Pass	Fail	Fail	Pass	Unsuccessful	N/A
66	Bouchard 65	10/9/74	Pass	Pass	Fail	Pass	Unsuccessful	N/A
67	Ercole	10/22/74	Pass	Fail	Pass	Fail	Unsuccessful	N/A
68	Athenian Star	1/20/75	Pass	Pass	Fail	Pass	Unsuccessful	N/A
69	Corinthos	1/31/75	Pass	Pass	Pass	Fail	Unsuccessful	N/A
70	Panglobal Friendship	2/11/75	Pass	Fail	Fail	Pass	Unsuccessful	N/A
71	IOT-105	3/3/75	Pass	Pass	Pass	Fail	Unsuccessful	N/A
72	B-421/Barge 13	3/5/75	Pass	Fail	Fail	Pass	Unsuccessful	N/A
73	Tarik Ibn Ziyad	3/26/75	Pass	Pass	Pass	Fail	Unsuccessful	N/A
74	Urquiola	5/12/76	Pass	Fail	Fail	Pass	Unsuccessful	N/A
75	Hackensack Estuary	5/26/76	Pass	Pass	Pass	Fail	Unsuccessful	N/A
76	Sansinena	12/17/76	Pass	Pass	Pass	Fail	Unsuccessful	N/A
77	Ethel H (II)	2/4/77	Pass	Pass	Pass	Fail	Unsuccessful	N/A
78	Ekofisk Bravo Oil Field	4/22/77	Pass	Fail	Fail	Pass	Unsuccessful	N/A
79	Oswego Tarmac	7/29/77	Fail	Pass	Pass	Pass	Unsuccessful	N/A
80	URSS 1	8/10/77	Pass	Pass	Pass	Fail	Unsuccessful	N/A
81	Union Oil Co. of California	2/8/78	Pass	Pass	Pass	Fail	Unsuccessful	N/A
82	Amoco Cadiz	3/16/78	Fail	Fail	Fail	Pass	Unsuccessful	N/A
83	Ocean 250	3/16/78	Pass	Fail	Fail	Pass	Unsuccessful	N/A
84	Interstate 19	3/20/78	Pass	Pass	Pass	Fail	Unsuccessful	N/A
85	Aminona	5/26/78	Pass	Pass	Fail	Pass	Unsuccessful	N/A
86	Cabo Tamar	7/7/78	Pass	Fail	Fail	Fail	Unsuccessful	N/A
87	U.S. Strategic Petroleum Reserve	9/21/78	Pass	Fail	Pass	Fail	Unsuccessful	N/A
88	Peck Slip	12/19/78	Pass	Pass	Pass	Fail	Unsuccessful	N/A
89	Andros Patria	12/31/78	Fail	Pass	Pass	Pass	Unsuccessful	N/A
90	F.W. Bekman	1/4/79	Pass	Pass	Pass	Fail	Unsuccessful	N/A
91	Messiniaki Frontis	3/2/79	Pass	Fail	Fail	Pass	Unsuccessful	N/A
92	Ixtoc I, Petroleos Mexicanos	6/3/79	Pass	Fail	Fail	Pass	Unsuccessful	N/A
93	Chevron Hawaii	9/1/79	Pass	Fail	Fail	Fail	Unsuccessful	N/A
94	Titipor	10/15/79	Pass	Pass	Fail	Pass	Unsuccessful	N/A
95	Burmah Agate	11/1/79	Pass	Pass	Pass	Fail	Unsuccessful	N/A
96	Independenta	11/15/79	Pass	Fail	Fail	Fail	Unsuccessful	N/A

APPENDIX B

Phases I and II Analyses Results

No.	Spill Name	Date	Weather Results	Oil Weathering Results	Logistics Results	Populated Area Results	Phase I Evaluation	Phase II Evaluation
97	Irenes Serenade	2/23/80	Pass	Fail	Fail	Pass	Unsuccessful	N/A
98	Texaco North Dakota	8/21/80	Pass	Pass	Fail	Pass	Unsuccessful	N/A
99	Georgia	11/22/80	Pass	Fail	Fail	Pass	Unsuccessful	N/A
100	Concho	1/19/81	Pass	Pass	Pass	Fail	Unsuccessful	N/A
101	Olympic Glory	1/28/81	Pass	Fail	Fail	Fail	Unsuccessful	N/A
102	Apex Houston	3/19/81	Pass	Pass	Pass	Fail	Unsuccessful	N/A
103	Golden Dolphin	3/6/82	Pass	Pass	Fail	Pass	Unsuccessful	N/A
104	Arkas	3/31/82	Pass	Pass	Pass	Fail	Unsuccessful	N/A
105	BU 42	6/29/82	Pass	Pass	Pass	Fail	Unsuccessful	N/A
106	V882/V883/V884/V885	4/2/83	Pass	Fail	Fail	Fail	Unsuccessful	N/A
107	SF1 71/SF1 72	6/9/83	Pass	Pass	Pass	Fail	Unsuccessful	N/A
108	Conoco	8/22/83	Pass	Pass	Pass	Fail	Unsuccessful	N/A
109	US 218	12/25/83	Pass	Pass	Pass	Fail	Unsuccessful	N/A
110	Hoegh Mascot	2/16/84	Pass	Pass	Pass	Fail	Unsuccessful	N/A
111	Puerto Rican	10/31/84	Pass	Fail	Fail	Fail	Unsuccessful	N/A
112	Cape Fear River	11/21/84	Pass	Pass	Pass	Fail	Unsuccessful	N/A
113	Passenger Vessel	11/26/84	Pass	Pass	Pass	Fail	Unsuccessful	N/A
114	Galveston Bay	7/13/85	Pass	Pass	Pass	Fail	Unsuccessful	N/A
115	Grand Eagle	9/28/85	Pass	Fail	Fail	Fail	Unsuccessful	N/A
116	Texas	3/7/86	Pass	Fail	Fail	Fail	Unsuccessful	N/A
117	TTT-103 Chevron USA	7/31/86	Pass	Pass	Pass	Fail	Unsuccessful	N/A
118	Amazon Venture	12/4/86	Pass	Pass	Pass	Fail	Unsuccessful	N/A
119	Fuyoh Maru/Vitoria	6/23/87	Pass	Pass	Pass	Fail	Unsuccessful	N/A
120	Stuyvesant (I)	1/6/87	Fail	Pass	Pass	Pass	Unsuccessful	N/A
121	Ashland Petroleum Co.	1/2/88	Pass	Fail	Pass	Fail	Unsuccessful	N/A
122	Amoco Oil Co.	2/7/88	Pass	Fail	Pass	Pass	Unsuccessful	N/A
123	Athenian Venture	4/22/88	Pass	Pass	Fail	Pass	Unsuccessful	N/A
124	Nord Pacific	7/13/88	Pass	Pass	Pass	Fail	Unsuccessful	N/A
125	Esso (Exxon) Puerto Rico	9/3/88	Pass	Pass	Pass	Fail	Unsuccessful	N/A
126	Exxon Pipeline	1/13/89	Pass	Fail	Fail	Pass	Unsuccessful	N/A
127	UMTB 283	1/15/89	Fail	Pass	Pass	Pass	Unsuccessful	N/A
128	Gran Tor	2/15/89	Pass	Pass	Pass	Fail	Unsuccessful	N/A

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Phases I and II Analyses Results

No.	Spill Name	Date	Weather Results	Oil Weathering Results	Logistics Results	Populated Area Results	Phase I Evaluation	Phase II Evaluation
129	Exxon Bayway Refinery	1/2/90	Pass	Fail	Pass	Fail	Unsuccessful	N/A
130	Ship Shoals Block 281	1/24/90	Pass	Pass	Fail	Pass	Unsuccessful	N/A
131	Mega Borg	6/8/90	Pass	Fail	Fail	Pass	Unsuccessful	N/A
132	Apex Oil Co.	7/28/90	Pass	Pass	Pass	Fail	Unsuccessful	N/A
133	Jupiter	9/16/90	Pass	Pass	Fail	Fail	Unsuccessful	N/A
134	Greenhill Petroleum	9/29/92	Pass	Pass	Fail	Pass	Unsuccessful	N/A
135	Aegean Sea	12/3/92	Pass	Fail	Fail	Fail	Unsuccessful	N/A
136	Braer	1/5/93	Fail	Fail	Fail	Pass	Unsuccessful	N/A
137	Morris J. Berman	1/7/94	Pass	Pass	Pass	Fail	Unsuccessful	N/A
138	San Jacinto River	10/20/94	Pass	Pass	Pass	Fail	Unsuccessful	N/A
139	North Cape	1/19/96	Pass	Fail	Fail	Pass	Unsuccessful	N/A
140	Sea Empress	2/15/96	Pass	Fail	Fail	Fail	Unsuccessful	N/A
141	Bay of Campeche Tanker	3/7/96	Pass	Pass	Pass	Fail	Unsuccessful	N/A
Total Failed			**7/141**	**35/141**	**42/141**	**59/141**	**94/141**	**21/47**[1]
Total Failed (Percentage)			**5%**	**25%**	**30%**	**42%**	**67%**	**45%**

[1]The number of spills that passed Phase I that was 47. Therefore, 47 spills were analyzed in Phase II.