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PAST IN-SITU BURNING POSSIBILITIES

FINAL REPORT
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N O T I C E

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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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