PAST *IN SITU* BURNING POSSIBILITIES

Gary Yoshioka, Eva Wong, Beverly Grossman, and Wendy Drake
ICF Incorporated
9300 Lee Highway
Fairfax, Virginia 22031

Robert W. Urban and Tom Hudon
PCCI, Inc.
300 North Lee Street, Suite 201
Alexandria, Virginia 22314

Robert R. Hiltabrand
U.S. Coast Guard Research and Development Center
1082 Shennecossett Road
Groton, Connecticut 06340-6096

ABSTRACT: *This study evaluates the feasibility of conducting* in situ *burning (ISB) on past major oil spills (i.e., spills since 1967 over 10,000 barrels in North America and over 50,000 barrels in South America and Europe) using current technology. A diverse set of 141 spills representing various combinations of parameters affecting spill response (e.g., spill size, oil type, weather conditions, sea temperature, and geographic location) initially 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. 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.*

In total, 47 of the 141 spills passed the Phase I analysis. Fourteen spills were ultimately determined successful in the Phase II analysis, and 12 were designated marginal calls. Proximity to 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.

Discussion

Objective and scope. This study's objective 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, scenarios for 141 past oil spills were developed. The spills reflect a diverse set of possible combinations of parameters affecting spill response (e.g., spill size, oil type, weather conditions, sea temperature, and geographic location). Considering a number of factors that could affect ISB, these scenarios provide the necessary information to assess the feasibility of ISB as a response technique. Criteria were established and applied to each of the past major oil spills to assess whether a burn would have been successful. The criteria are based on the technology available in 1997 and address four primary factors: (1) oil weathering; (2) response logistics; (3) weather conditions; and (4) distance to populated areas.

Spills over 10,000 barrels in North America and over 50,000 barrels in Europe and South America that occurred between March 18, 1967 (the date of the *Torrey Canyon* spill) and December 1997 were examined. Initially, 154 spills were identified as spills within the scope of the study. Thirteen were eliminated, however, because very little information was available (e.g., oil type and location) making it difficult to analyze the feasibility of ISB.

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

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.* 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 (flash point greater 150°F/65°C) and 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.* Oils 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 controls the rate that oil spreads on water. Low-viscosity oils (e.g., gasoline products) spread rapidly into thin sheens, increasing the surface area and making recovery difficult. 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 emulsify as readily; it is difficult for water to be added to oil with this property.
- *Emulsification formation.* Under certain conditions, some oil slicks will form a water-in-oil emulsion, often referred to as "chocolate mousse." This material can contain up to 80% water and can be many orders of magnitude more

viscous than the spilled oil. 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 hard to pump, and the volume is increased 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, NOAA, 1998).

Most, if not all, oils will burn if of sufficient thickness. Minimum thickness ranges from 2 to 3 mm for fresh crude oil; 3 to 5 mm for diesel and weathered crude; and 5 to 10 mm for emulsions and Bunker C. Further, for most crude oils, evaporation losses must be less than 30%.

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. Distance from logistic support (e.g., major equipment such as igniters, vessels, and fire booms), particularly for spills that occur in remote areas, greatly influences the possibility of a successful ISB. Holding all other factors constant, as deployment time increases, combustion efficiency decreases. Near-shore wind and wave conditions may be more favorable than offshore conditions, but burning may be prohibited because of nearby populations. Wind direction is particularly important if the spill occurs close to a populated area. Wind direction determines the direction 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 (e.g., movement towards a shoreline may increase the environmental damage caused by the incident).

The weather at sea has a profound effect on response capabilities and the extent to which oil will disperse. High wind speeds and rough seas can decrease the effectiveness of ISB by increasing the weathering and emulsification of oil and can pose logistical complications, such as difficulty igniting a spill, deploying fireproof booms, or containing oil within a boom. Mechanical containment, which is usually required in ISB operations to maintain combustion and thick slickness, 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.

Phase I and Phase II analysis. 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 evaluated in a four part "Phase I" screening analysis that incorporated the following elements: (1) oil weathering model analysis; (2) logistics analysis; (3) weather conditions (i.e., wind speed); and (4) distance to populated areas. In Phase I, 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. Unsuccessful spills were not subjected to further analysis. Spills that passed all four categories were assigned a "pass" Phase I rating and were evaluated a second time in a "Phase II" analysis. Phase II assigned a "successful," "marginal call," or "unsuccessful" rating to each spill, 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 an ISB. The four Phase I criteria are defined below.

- *Oil weathering model analysis.* The oil weathering criterion considers evaporation of oil from the surface of the water, dispersion of oil into the water column, and emulsification of oil and water. The authors considered oil unburnable once the summed percentages of evaporated and dispersed oil reached 100%, or the water content of the oil reached 75%, as both of these conditions would prevent the ignition of the oil. 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 authors' analysis assumed that a window of opportunity of at least 6 hours was necessary in order for a response effort to be mobilized. Therefore, a spill in which a window of opportunity was less than six hours was considered an unsuccessful candidate for ISB.
- *Logistics analysis.* The logistics criterion relates to the length of time necessary to arrive at the spill site and conduct ISB. This time includes locating and preparing appropriate equipment and transporting equipment and personnel to the spill site. As an initial screening, the authors considered a spill an unsuccessful candidate for ISB if the response time exceeded 1.5 times the window of opportunity. Because the oil weathering modeling only provides an approximation, allowing the response time to slightly exceed the predicted window of opportunity provided a conservative measure of the potential success of ISB.
- *Weather.* The 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. High winds would impede response, cause greater emulsification of oil, and make ignition difficult. The authors considered a spill unburnable if there was no 24-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.* The authors defined a "populated area" to be a city with 10,000 or more inhabitants, and established a distance of 6 miles as the radius in which ISB could not be conducted. The 6-mile figure was derived from the practices of some Regional Response Teams (RRTs) (RRT IV, 1993). They considered a spill to be an unsuccessful candidate for ISB if it occurred within 6 miles of a populated area.

The Phase II analysis provided an opportunity to consider more site-specific conditions for each spill. Instead of establishing any specific criteria, a number of factors were considered in conjunction to assess the practical feasibility of ISB. The authors reexamined Phase I criteria to determine if more than one criterion had passed Phase I only marginally. For instance, if there were high winds at the time of a spill, and the oil was highly emulsified, this spill may fail Phase II. Where additional information was available, the authors considered other factors, such as weather conditions (e.g., fog), distance to shoreline, historical occurrence and response scenarios, or historical use of ISB.

Methodology

The authors utilized a total of 11 separate sources in generating their 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, the authors established an order of priority with which the authors would accept the information contained in a data source. The primary data source was the 1991 United States National Oceanic and Atmospheric Administration (NOAA) report, (NOAA, 1992) and secondary sources were the 1995 Marine Spill Response Corporation (MSRC) report (Kucklick and Aurand, 1995), the 1990 Office of Technology Assessment list from "Coping with an Oiled Sea," (OTA, 1990) and the Oil Spill Intelligence Reporter newsletters.

The authors obtained data necessary to completely analyze each spill (e.g., spill size, oil type, wind speed, water temperature, location) according to their Phase I and II criteria. Wind speed and water temperature data were available for all spills in either of the following sources: the NOAA Marine Environmental Buoy Database, or the Comprehensive Ocean-Atmosphere Data Set (COADS), both accessible via the Internet.

Two models for predicting the properties of oil spilled on water were used to model oil weathering: the Automated Data Inquiry for Oil Spills (ADIOS) model prepared by NOAA in 1994 and the Oil Weathering Model developed by SINTEF (Aamo and Reed, 1993). The SINTEF model was used as the primary analysis tool. The inputs for both models were essentially the same (i.e., name of the oil, type, water temperature, wind speed.) 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.

Determining response times for the mobilization and deployment of equipment sufficient to conduct an ISB at the spill sites took into account the latitude and longitude, the nearest airport, and the nearest port for equipment mobilization and tow out. 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. The authors also assumed that they could fly into the nearest large airport for international responses.

The authors determined that available ISB equipment sites are presently all located in the United States. 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.

Results

The majority of the 141 spills included in this study occurred in North America and were smaller than 50,000 barrels. Table 1 summarizes spill size, location, and results of the Phase I and Phase II analyses. 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.

In total, 47 of the 141 spills passed the Phase I analysis; 14 were ultimately determined successful in the Phase II analysis; and 12 were designated marginal calls. Spills between 10,000 and 49,999 barrels had the greatest probability of being assigned an unsuccessful evaluation in the Phase I analysis. Only 21% of these spills passed the Phase I analysis and only 4% of the 72 spills were determined successful in the Phase II analysis. Forty-7% of the spills above 50,000 barrels (i.e., 11 of 34 spills) that occurred in North America passed Phase I and 26% (i.e., 9 of 34 spills) were determined successful in the Phase II analysis. Although an average of 33% 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 8% of the 26 spills that occurred in Europe were determined successful in the Phase II analysis.

Of the 67% of the 141 spills failed Phase I, 5% failed the weather criterion; 25% failed the oil weathering criterion; 30% failed the logistics criterion; and 42% failed the distance to populated area criterion.

The Phase II analysis led to the conclusion that many of the spills would be considered unsuccessful or marginal call ISB candidates. 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 the proximity of tourist beaches, a significant population within 3 miles of the incident, and other 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, which would make ISB infeasible. Of the 47 spills analyzed in Phase II, 45% were determined unsuccessful; 26% were determined marginal calls; and 30% were determined successful.

Conclusions

Thus, of the 141 spills analyzed, 115 were ultimately determined to be unsuccessful candidates; 12 were determined to be marginal calls; and 14 were ultimately determined successful. Proximity to populated areas was the most significant of these criteria; 59 of the 141 spills did not pass the initial screening in Phase I 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.

Table 1. ISB determination of spills by geographic distribution and spill size (in barrels).

	10,000–49,999		50,000–199,999		200,000 or more		Total	
Area	**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	—	—	6	2/0	3	1/0	9	3/0
Europe	—	—	12	8/1	14	5/1	26	13/2
Overall Total	72	15/3	39	21/6	30	11/5	141	47/14

Two of the screening criteria consider analysis of oil weathering and logistics. First, an oil weathering model estimated the amount of evaporation, dispersion, and emulsification of the spilled oil in a given incident. 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, 47 did not pass the initial screening for oil weathering or logistics, including 16 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 meters per second), would preclude an effective ISB response. Only seven incidents did not pass the initial screening due to weather conditions, including four that did not pass on the basis of weather alone.

After further analysis beyond the screening criteria, 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. The analyses of 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.

In general, the best candidates for ISB tended to be from the coastal or offshore waters of the Gulf of Mexico or Caribbean Sea (7 of 38 spills in this area were good candidates) and from larger spills off the Atlantic Coast of North America (with four candidates out of eight spills of 50,000 barrels or more). None of the strong 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%. Decision-makers must compare ISB to other response options, taking into consideration the respective limitations and effectiveness of each technique.

Biography

Gary Yoshioka has a Ph.D. in Geography and Environmental Engineering from the Johns Hopkins University and a J.D. from the University of Maryland School of Law. For the past 14 years, he has researched and analyzed oil spills and response techniques and has investigated environmental policy issues for ICF Incorporated.

References

1. Aamo, O., and M. Reed, 1993. User's Manual for the IKU Oil Weathering Model, Version 1.0. IKU Petroleum Research, N–7034: Trondheim, Norway.
2. American Petroleum Institute, and National Oceanic and Atmospheric Administration, 1998. Inland Oil Spills: Options for Minimizing Environmental Impacts of Freshwater Spill Response Actions (Appendix 6).
3. Kucklick, Janet H. and Don V. Aurand, 1995. *An Analysis of Historical Opportunities for Dispersant and In situ Burning Use in the Coastal Water of the United States, Except Alaska.* Washington, DC: Marine Spill Response Corporation, MSRC Technical Report Series 95-005.
4. NOAA, Hazardous Materials Response and Assessment Division, 1992. *Oil Spill Case Histories: 1967-1991, Summaries of Significant U.S. and International Spills*. Springfield, VA: National Technical Information Service.
5. U.S. Congress, Office of Technology Assessment, 1990. *Coping With an Oiled Sea: An Analysis of Oil Spill Response Technologies*. Washington, DC: U.S. Government Printing Office. OTA-BP-O-63.
6. RRT IV, 1993. "Use of *In situ* Burning in RRT Region IV," *In situ* Burn Workgroup of the Region IV RRT.
7. The NOAA Marine Environmental Buoy Database is available on the Internet at *http://www.nodc.noaa.gov/CDR-detdesc/buoy.html*
8. COADS is available on the Internet at *http://ferret.wrc.noaa.gov/fbin/climate_server*.