Oil Spill Response Preparedness in the Alaska Beaufort Sea

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ABSTRACT

Following the wake of legislation and regulation promulgated in response to the 1989 Exxon Valdez oil spill in pristine Prince William Sound, Alaska, the oil spill response industry worldwide experienced exponential growth. To fulfill compliance obligations many oil exploration, production and transportation companies purchased large stores of additional equipment without full consideration for the suitability of the equipment for the types of oils to be encountered, the environment in which the equipment would operate, or the tactics that would be utilized in a response. These reactive measures were not the result of poor judgement or mismanagement but rather the enforcement of regulatory compliance without the benefit of sufficient relative data and experience. However, the outcome of increased regulatory pressure and the enhanced environmental awareness within the oil and gas industry was a business environment that demanded change.

The evolution of oil spill response preparedness on the North Slope of Alaska represents a model of change based on almost thirty years of practical experience with offshore and onshore drilling and production operations in all types of challenging sea and ice conditions. The current North Slope response action plans are founded in this experience, intense field training, and the investigation and ground truthing of related research and development projects.

1.0 INTRODUCTION

The first Alaska North Slope oil spill response organization was originally established in Prudhoe Bay in 1979 under the name of ABSORB, an acronym for Alaskan Beaufort Sea Oilspill Response Body, to support offshore exploration ventures in the Alaskan Beaufort Sea. In 1983 ABSORB as reorganized into Alaska Clean Seas (ACS) and was defined by the following organizational objectives (Shafer, 1990):

1) to develop spill response technology for the area,
2) to acquire an appropriate inventory of the best available countermeasure equipment and materials,
3) to maintain the equipment and materials in a high state of readiness, and

4) to provide spill response training for personnel of member companies and their contractors.

Hindsight would prove that the organization was active in some of the initial arctic oil spill research and development projects but the primary purpose of the organization was to inventory and maintain response equipment to support the offshore exploration program. In 1989, ACS provided no direct spill response manpower to the offshore operators and provide no assistance whatsoever to the onshore exploration and production operations that were growing rapidly. It was not until 1990 that the North Slope oil spill cooperative, ACS, expanded it's mission to include the provision of response manpower and incident management for both offshore and onshore operations. The operational role of ACS combined with the intense state and federal scrutiny of Alaska's oil spill contingency plans provided the catalyst for an evolution of response preparedness on the North Slope of Alaska..

The primary purpose of this paper is to summarize the arctic arctic effects on oil fate and behavior and to describe response preparedness the spill response strategies, tactics and equipment that are utilized effectively across the range of Arctic environmental conditions.

2.0 OIL FATE AND BEHAVIOR IN ICE COVERED WATERS

The comprehensive understanding of oil fate and behavior in arctic condition is of paramount importance to developing effective oil spill response strategies and tactics. This knowledge was also key to the creation of a practical, fit-for-purpose, inventory of oil spill response equipment on the North Slope. The physical distribution and condition of spilled oil under, within, or on top of the ice plays a major role in determining the most effective response strategies at any time of the year and the most appropriate inventory to bring into combat operations.

Strategies and techniques for dealing with oil in ice have been studied intensively in the United States, Canada and Norway for many years. The most significant scientific knowledge was gained through a number of Canadian field studies aimed at gaining approvals for offshore Beaufort Sea exploration beginning in 1976. These field studies and others in Alaska and most recently in Norway have looked at the behavior of fresh and emulsified crude oil, with and without gas, in a variety of ice conditions including landfast and broken pack ice (e.g., McMinn, 1972; Norcor, 1975; Buist and Dickins, 1981; Nelson and Allen, 1982; S. L. Ross, 1987; Vefsnmo and Johannessen, 1994). Dickins and Fleet (1992) contains a comprehensive summary of all known references on the subject of oil-in-ice fate and behavior, including analytical studies, tank and basin tests, spills of opportunity, and experimental spills at sea.

The fate and behavior of oil in ice covered waters is governed by a number of important processes, several of which are illustrated in Figure 2-1 (after Bobra and Fingas, 1986) and discussed below.

- ***Spreading.*** In Arctic waters during early and late summer, oil spills tend to spread less and remain slightly thicker than in temperate waters (such as the Gulf of Mexico) partly because oil is more viscous in cooler waters, but mostly due to the presence of broken ice and brash ice, respectively. In high concentrations (greater than 5/10), oil spreading tends to be limited to the spaces between the floes. There are a number of models that predict the spreading of oil as a function of ice concentration. These are based largely on the results of a field trial off the east coast of Canada (Ross and Dickins, 1987). In general, oil spilled under stable landfast ice will not spread beyond hundreds of feet from the spill source, based on currents and projected under-ice storage capacity (see ice storage below). The maximum expected under-ice currents in the Beaufort Sea nearshore are extremely low. In a March 1996 study inside the barrier islands, no currents were detected under the ice over a period of five days (Intec, 1996a). In the extreme case, any tidal currents present are expected to be much lower than the minimum threshold of 0.5 feet per second (ft/sec) necessary to initiate and maintain any transport of oil under solid ice (Cox and Schultz, 1980).

- ***Evaporation*** of volatile components occurs with any oil resting on the water or ice surface. Evaporation rates of oil slicks are influenced by wind speed, slick thickness and environmental temperatures. Laboratory testing of oils from the North Slope indicates that the initial evaporative loss, by volume, within the first 48 hours can be expected to range between 16 and 30% depending on the oil tested. (Buist, 1994)
- ***Dispersion*** is a process by which small oil droplets are driven under the surface by waves and turbulence and remain suspended in the water column. Dispersion rates depend largely on sea state, oil viscosity, interfacial tensions, and the tendency of the oil to emulsify. The formation of stable water in oil emulsion generally stops the natural dispersion of a slick.
- ***Entrainment and rapid immobilization*** of oil spilled beneath growing ice essentially stops all weathering processes (Buist and Dickins, 1981; Norcor, 1975; Allen and Nelson, 1981). The implications of this are significant. When response crews pump or burn oil brought to the surface from a trapped layer under or within the ice, they will be dealing with almost fresh crude, even months after the spill occurred.
- ***Ice Storage.*** Natural variations in first-year ice thickness provide huge natural “reservoirs” to effectively contain oil spilled underneath the ice within a small area. Under-ice storage capacities have been estimated to be as high as one million barrels per square mile from surveys in late winter near West Dock (Kovacs et al., 1981). The implication here is that any mid-winter spill that may for whatever reason occur beneath the ice would be naturally contained within a relatively small area when compared to an identical volume spill on open water
- ***Vertical migration*** of oil through the melting ice starts in the spring (Norcor, 1975; Buist and Dickins, 1981). Beginning as early as the last week in May and continuing through breakup, oil will naturally rise to the surface from wherever it is trapped within or beneath the ice. The timing of this process will dictate appropriate response strategies to deal with any accidental spill that may have become trapped within the ice during the previous winter months.

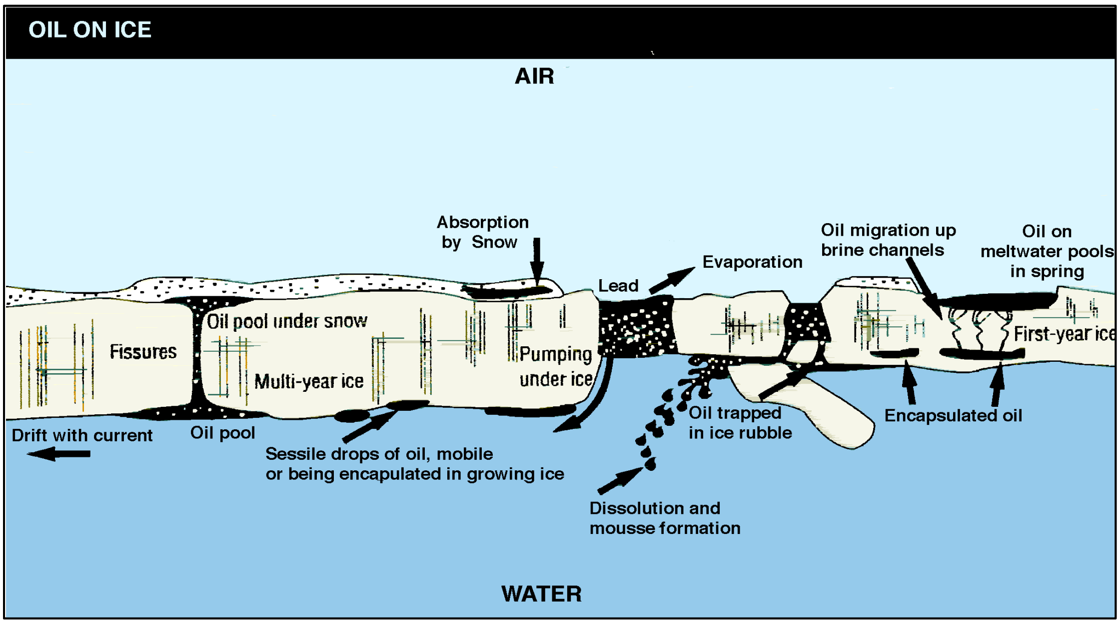

Figure 2-1
Illustration of Oil and Ice Processes

3.0 SEASONAL EFFECTS ON OIL BEHAVIOR

In addition to understanding the fate and behavior process, arctic oil spill responders must also have a comprehensive understanding of how oil will behave during any of the seasonal ice and snow conditions present in their area of operations. The following section describes the anticipated oil behavior impacts attributed to the Alaskan North Slope ice seasons.

3.1 Winter, Oil Spills Beneath Solid Floating Ice

A solid ice surface is present in the nearshore area of the Alaskan North Slope for over 7 continouous months every year. The behavior of oil spilled under solid ice covers has been the subject of numerous field, laboratory and analytical studies. The two largest field experiments took place in the Canadian Beaufort Sea in 1974-75 and 1980 (Norcor 1975; Dickins and Buist, 1981). The Norcor project involved eight spills of two different crude oils totaling 330 barrels under ice ranging in thickness from 17 to 70 inches. An experiment sponsored by Dome Petroleum and supported by ABSORB (Dickins and Buist, 1981) simulated a subsea blowout by injecting compressed air and Prudhoe Bay crude oil under landfast ice. One of the Dome releases was predominantly oil alone and can be used in conjunction with the Norcor results to accurately describe the interaction of oil with the ice during winter and spring conditions right up to breakup. It is convenient to separate the discussion seasonally into:

- Winter ice contamination and oil encapsulation (October to April), and
- Spring oil migration and surface appearance (April to July).

3.1.1 Winter Ice Contamination And Oil Incorporation

Oil released into the water column under a floating solid ice cover will rise and gather in pools or lenses at the bottom of the ice sheet. Based on Stokes Law, the terminal rise velocity of a 0.4-inch diameter oil particle, with a density of 0.850 g/ml, is about 0.75 ft/sec in seawater. Typical under-ice currents within the North Slope barrier islands are unlikely to exceed 0.5 ft/sec. As a result, almost all of the oil will contact the ice under surface within a few feet of the vertical center of a release.

Winter under-ice currents, in the coastal area of the Beaufort Sea, will not spread spilled oil beyond the initial point of contact with the ice under surface. Several studies have provide empirical data to indicate that the roughness values typical of undeformed first-year sea ice will trap oil in place. The threshold current speed needed to initiate and sustain movement of an oil lens or pool along the ice under surface is approximately 0.7 ft/sec, well above the highest currents measured in the near coastal areas associated with Alaskan North Slope oil exploration and development (Cammaert, 1980; Norcor 1975; Rosenegger, 1975).

Two physical factors that act to naturally limit the area contaminated by oil under ice are natural depressions related to variability in snow depth, and rapid incorporation of the oil by new ice growth around and beneath the oil layer. Ice naturally develops an undulating bottom surface in response to snow drift patterns on the surface. Researchers have investigated the holding capacity of ice covers by mapping the under-ice topography and calculating the potential for oil containment (e.g., Kovacs et al., 1981). Results indicate that typical under-ice containment capacities for first-year landfast ice representative of the Prudhoe Bay area within the barrier islands, range from 0.012 barrels per square foot (bbls/ft^2) for 25-inch thick ice in December to 0.026 bbls/ft^2 for 60-inch thick ice in April (equivalent to about one million barrels per square mile). As the natural containment increases with ice thickness, the area needed to contain a given spill volume decreases steadily throughout the winter, as shown in Figure 3-1.

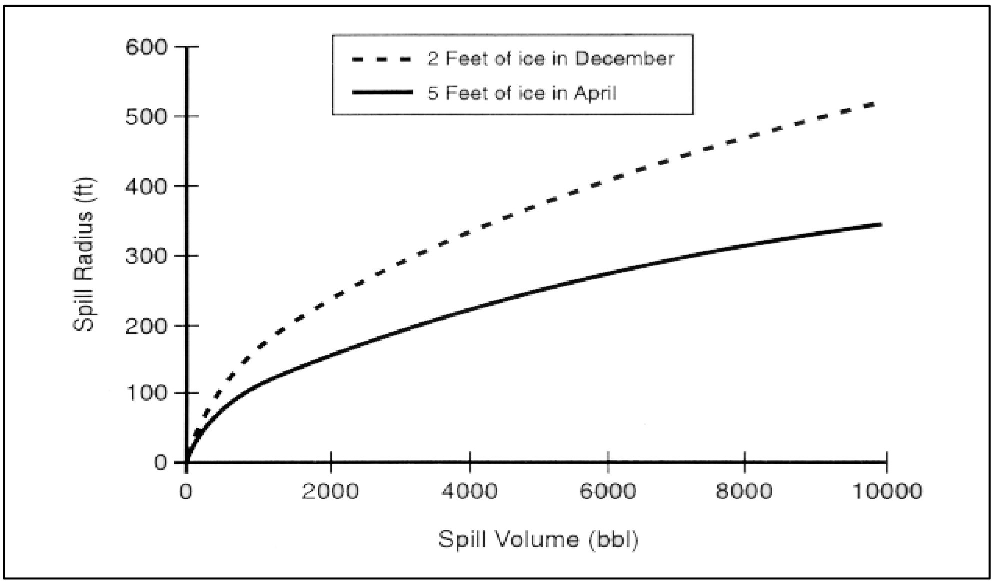

Figure 3-1
Predicted Radii of Spills of a Given Volume Spilled Under Landfast Ice

(Dickins, 1985)

Based on these containment capacities, a 10,000 barrel spill from the Northstar sub-sea pipeline source beneath the ice surface in April would be naturally contained within a diameter of approximately 320 feet. Natural variations in ice thickness comprise the most important physical characteristic limiting the spreading of oil from a sub-surface release. In the case of a small leak, the formation of a lip of new ice at the outer perimeter of the spilled oil will also act to further limit spreading in the case of unusually smooth ice.

In a batch release, new ice will completely encapsulate the oil layer within 18 to 72 hours, depending on the time of year from December to late April (Dickins and Buist, 1981). Oil spilled under the ice after May 1 may not become encapsulated due to the seasonal warming of the ice layer.

With a chronic leak that occurs over a long period of time, new ice is prevented from immediately growing directly as a hard layer beneath the oil pocket due to the continuing arrival of fresh oil. Ice crystals present in the water at the oil/ice interface will probably be incorporated to provide a slush/oil mixture that gradually thickens the longer the spill source remains undetected. At the same time, new ice growing around the perimeter of the contaminated area will progressively contain the oil. The end result for most of the winter will be a cylinder of liquid oil and slush deepening as the surrounding ice grows. In the case of a chronic leak spanning the April to June period, the contaminated area will increase as the ice growth rate slows down. The final trapped oil geometry in this situation would be similar to chronic leaks in mid-winter, except that the oil pocket will assume the shape of an inverted truncated cone, with the largest diameter at the deepest depth and the angle of the cone increasing as new ice growth diminishes. Once the spill source is detected and the flow stopped, new ice will begin to form beneath the oil within several days (December to April).

3.1.2 Spring Oil Migration And Surface Appearance

Oil that has released under on within the ice during the early to mid-winter season will become encapsulated and remain trapped until late-winter, at which time a process of vertical migration will begin due to the gradual warming of the ice sheet.

The rate of vertical migration depends on the degree of brine drainage within the ice (a function of internal temperature), oil pool thickness, and oil viscosity. During the period from November to February when the sheet is cooling and growing rapidly, there are very few passages for the oil to penetrate. Vertical migration of the oil in this period is limited to several inches of initial penetration through the porous skeletal layer of individual ice crystals at the ice/water interface.

The internal ice temperature reaches it's minimum typically in late February. As ice temperatures gradually increase in April and May the brine trapped between the columnar ice crystals will drain out of the ice, leaving vertical channels for the oil to eventually rise to the surface. The first evidence of natural oil appearance on the surface can be observed in mid to late May or may be delayed until the first week in June, depending on air temperatures. Oil released under six feet of ice in one experiment on May 21 reached the ice surface within one hour (Norcor, 1975).

The rate of oil migration increases rapidly once daily air temperatures remain consistently above freezing. During the same experiment mentioned above, up to 50 percent of the oil originally trapped within the ice became exposed on the ice surface between June 10 and June 20. Oil slick thickness in the melt pools on the surface increased from 0.04 inches to over 0.4 inches during a one-week period.

Natural melt of the ice from the surface down acts as a competing process to expose encapsulated oil When this melt reaches the level where the ice was growing at the time of the spill, the oil is exposed. In most situations of a concentrated thick oil layer encapsulated in the ice, natural migration will bring most of the oil to the surface before the surface melts down to meet it.

When oil reaches the ice surface, it lies in melt pools or remains in patches on the melting ice surface after the surface waters have drained. The heat absorbed by the dark oil on the surface further serves to enhance surface melting into pools where the oil is present. Winds act to herd the oil into thicker layers against the edges of individual pools. This concentrated presence of oil can be effectively recovered or burned *in-situ* if seasonal conditions pose a safety risk to responders attempting to conduct mechanical recovery operations (refer to *In-Situ* Burning discussion in Section 4.3).

Any oil remaining in or on the ice at final breakup and disintegration of the ice cover will be released slowly into the water as thin slicks and sheens.

3.2 Winter, Spreading Oil on Top of Ice and Snow

The resulting area of contamination from a release of oil on top of ice will be influenced by a number of site specific factors, such as, wind speed, surface roughness and the amount of snow cover in the area of the release. Other factors associated with an individual release may have an even greater potential to influence the total area of contamination. For instance, a release from a high pressure pipeline versus a tank rupture has a greater potential to spread the contamination to a larger area. Likewise, if a breach of a high pressure pipeline directed the escaping oil toward the ground the overall impacted area would be less than if the breach directed the escaping oil high into the air where wind conditions could potentially spread the contamination for miles.

A number of process equations are available to predict the spreading behavior of oil in snow (Belore and Buist, 1988). Key behavioral factors associated with oil spilled on snow can be summarized as follows (after Wotherspoon, 1992):

- Oil evaporation rates in snow are substantially reduced compared with oil slicks on open water;
- Oil mixed with snow does not readily form emulsions; and
- Once ignited, there are no appreciable differences between burning oil in snow or oil in water.

Demonstrations conducted during the 2000 International Oil & Ice Conference effectively illustrated how oil absorbed into the surface snow layer or lying on the surface ice could be effectively recovered through mechanical means or even stockpiled and burned. Oil contaminated snow can be piled into a volcano like shape with a strong indentation in the denter of the pile. Utilizing ignitors to create an intense heate source in the center of the contaminated snow pile will cause impregnated oil to be released toware the water pool in the center where it is consumed and serves to sustain the burn until oil quantities are no longer sufficient to support combustion.

3.3 Late Spring/Early Fall, Oil Spills in Broken Ice conditions

Oil spilled beneath broken ice would rise to the surface and either collect in the interstices or openings between individual floes or be trapped underneath the floes themselves. Oil spilled on the surface would likewise adhere to the ice surface or become wind herded against the ice edges and would eventually be frozen in place on the surface of the ice unless disturbed by extreme wind conditions causing the ice to break up and become rafted. During the primary period of broken ice in the spring, oil released beneath the floes will naturally migrate through the rotting ice and appear on the ice surface within a matter of hours (refer to the above discussion of the spring oil migration process). Oil released into spring broken ice conditions would be contained in the openings between floes and coat the surrounding ice edges and float in surface pools. As spring melt continues the area of contamination would increase. For the case of oil trapped within or under newly forming pancakes or sheet ice in the fall, the likely fate will be rapid entrapment, with new ice quickly growing beneath the oil as already discussed. The fate of oil trapped between floes will depend largely on the ice concentration, air temperatures and local wind effects.

During freezeup, the oil will most likely be entrained in the solidifying grease ice and slush present on the water surface prior to forming sheet ice. Storm winds at this time often break up and disperse the newly forming ice, leaving the oil to spread temporarily in an open water condition until incorporated in the next freezing cycle (within hours or days depending on the air and water temperatures at the time). Ice drift rates at this time of year are highly variable, but a daily average of five nautical miles per day can be expected in October, decreasing as the ice thickens and stabilizes in a landfast condition through November.

At breakup, ice concentrations are highly variable from hour to hour and over short distances. In high ice concentrations (greater than 5/10), the oil is effectively prevented from spreading and is contained by the ice. As the ice cover loosens, more oil is able to escape into larger openisngs as the floes move apart. Eventually, as the ice concentration decreases to less than 3/10, the oil on the water surface behaves essentially as an open water spill, with localized oil patches being temporarily trapped by wind against individual floes. Any oil present on the surface of individual floes will move with the ice as it responds to winds and nearshore currents.

4.0 PLANNING AND RESPONSE STRATEGIES

Response planning and strategies for oil spills in ice have been developed over twenty years of actual experience with North Slope drilling and production operations. The techniques discussed in this document have been demonstrated and applied in real spill situations. The following sections describe:

- methods and applicability of surveilling and monitoring oil spills in various ice and open water conditions,
- the influence of various ice conditions on the logistics of mounting an effective response operation and determining the best cleanup strategies,
- the effective use of in-situ burning as a response option in various oil and ice conditions, and

- a summary of seasonal response strategies based on ice conditions.

4.1 SURVEILLANCE AND MONITORING

Surveillance and monitoring involves the techniques and systems available to detect, map, and track oil spilled into the Beaufort Sea from any source connected with the current North Slope production facilities and pipelines.

4.1.1 Surveillance and Monitoring Systems

One of the initial actions that must be implemented for any oil spill is to determine the initial extent of contamination and in the case of spills on water or in moving ice to continually locate and track oil as it migrates. Numerous systems and specific equipment have been developed to detect and track oil spills on open water and ice through experience in southern areas, arctic field trials, and laboratory research (summarized in Wotherspoon, 1992). Common techniques and equipment available to ACS include a combination of the following:

- ***Satellite tracking buoys*** are designed to follow the movement of the oil slick in response to winds, surface currents, and ice movements. Using the new Global Positioning System (GPS), these "Slicktrackers" are capable of delivering real-time positions to computers in the command center with accuracy of better than 150 ft. (Costanzo, 1994). ACS maintains an inventory both the Trimble Sliktrak buoys and Metocean satellite ice beacons in their existing inventory. The Metocean beacons are capable of being deployed under virtually all ice conditions and providing a location signal for months after their initial release.
- ***Radio tracking buoys*** are similar in design and use to the satellite tracking systems but utilize a small radio transmitter built into the buoys to emit burst signals. These signals are then tracked by the receiving equipment which can be placed onboard vessels of opportunity, fixed wing or rotary wing aircraft. An inventory of Orion radio tracking buoys are maintained by ACS on the North Slope.
- ***Airborne reconnaissance*** is conducted with visual observers, still and video cameras, infrared and ultraviolet sensors, laser fluorosensors, and radar. Trained visual observers are used, together with more sophisticated remote-sensing equipment to enhance the information (helping to differentiate between natural "slick-like" targets such as silt on the ice, cloud shadows on water, and wind patches, and to map both the thick and thin parts of the slick).

  Optical methods (still and video cameras) are useful for recording overall spill location and slick boundaries in reasonable light conditions. They do not provide a good indication of slick thickness and can cause confusion in low light conditions.

  Infrared (IR) systems are highly effective in documenting offshore slicks through temperature differences between the oil and water. UV systems are more expensive and used primarily in conjunction with IR to differentiate between thick and thin sections of the slick.

ACS has immediate access to a variety of helicopters and fixed wing aircraft to map any slicks observed on the water in the project area. The ARCO Twin Otter, located on the North Slope, is equipped with a Forward Looking InfraRed (FLIR) thermal imaging system. The system is a gyro-stabilized, microprocessor-based system that provides state-of-the-art digital image processing. An onboard computer system is capable of processing the digital information and combining these images with environmental data and GPS information simultaneously collected by other shipboard instruments. The images shown below, in Figure 4-1, depict two (2) crude oil storage tanks on the North Slope. The image on the left shows two tanks of which the tank on the right is full and thus give a brighter image. The image on the right is a close up of the other tank in the left hand image and clearly indicates the tank is approximately 25% full. In addition, the U.S. Coast Guard operates specialized UV/IR and Side Looking Airborne Radar-equipped aircraft for surveillance of large spills over wide ocean areas (known as the "Aireye").

Figure 4-1
Infrared Photography of Crude Oil Storage Tanks
(Source: ARCO Aviation, 1995)

- ***Handheld GPS*** units are used extensively on the North Slope to document locations and extent of spill sites. ACS maintains an inventory of Garmin 45 handheld GPS units at each of the operating oilfields on the North Slope. Responders are trained in the use of these units and as such they are used frequently to support daily work activities. During previous spill events GPS data has been used in conjunction with survey crews to delineate areas of contamination under extreme winter conditions.
- ***Portable Current Meters*** are available and have been used to determine both current speed and direction under both summer and winter conditions. Information gathered by current meters is extremely important to produce accurate computer modeling.

- ***Underwater Lights*** have been researched, field tested and found to be very effective in locating oil under ice. The systems utilized by the NSSRT consist of a high intensity quartz halogen light fixture attached to a long handle. The assembly is lowered through a hole augered through the ice and illuminated once it is placed in the water. Once the snow cover is removed the lighting clearly indicated areas of oil accumulation.

4.1.2 Surveillance During Arctic Ice Season

When drifting ice concentrations are less than 5/10 the process of detection and mapping is basically the same as open water. As ice concentrations increase to greater than 6/10, visual detection of oil in small openings and leads becomes more difficult. These problems are magnified in October and November by conditions of frazil ice, thin moving ice and decreasing daylight. There are a number of possible approaches to tracking and mapping oil under these conditions. Experimental airborne systems such as the laser fluorosensor and IR sensors have shown potential for detecting oil on or amongst ice floes. Satellite beacons are available for airborne deployment and do not require aircraft to land on the ice. As of April 1996, daily satellite coverage is now available for offshore ice conditions independent of daylight, cloud cover, or fog (Canadian Radarsat). The satellite lacks the resolution to detect small oil slicks directly, but it can provide a clear picture of the ice conditions in the vicinity of the oil when used in combination with tracking buoys.

As the ice sheet stabilizes and thickens a number of resources may be utilized to approach an offshore spill site. Small one and two man All Terrain Vehicles (ATV's) (i.e., snowmachines, 4 wheelers, ARGO tracked vehicles) are available across the North Slope to support reconnaissance and survey teams. In December, as thicker ice forms, it is possible to land by helicopter and confirm any sightings of oil. Once the ice is stabilized and landfast out to the barrier islands, any oil spilled will either lie trapped within, under, or, in the case of a coastal blowout incident, lie mixed with snow on top of the ice surrounding the island.

The primary techniques for detecting oil on top of the ice are visual observation or optical cameras. During the winter, oil on the ice surface may be covered by drifting snow, and it may become necessary to map any suspected contaminated area with radial trenches or a grid pattern shoveling down to the bare ice. This process will clearly reveal the extent of snow contamination through visual inspection of the trench walls.

In May and early June, optical and visual methods work well in mapping oil on the surface. Oiled snow will melt faster than the surrounding snow due to the increased heat absorption in late May. As the melt progresses, sediment on the ice (particularly in the river overflood area) and the light and dark patterns characteristic of a deteriorated ice surface appearance can easily be confused with weathered oil. Oiled ice tends to melt slightly faster than the surrounding ice, and these differences can still provide visual clues to the location and extent of oiling (Norcor, 1975; Dickins and Buist, 1981).

Oil remaining trapped beneath or within the ice at the end of the growth cycle becomes mobile as the ice sheet warms in April. For a known area of trapped oil, the rate of vertical migration of the oil within the ice can be monitored by regular core samples (starting weekly in April and progressing to daily by mid-May). At the same time, the degree of weathering of the surfaced oil can be monitored by collecting samples for lab analysis.

4.2 Influence of Ice Conditions on Cleanup Strategies

Ice in one form or another can be encountered in the vicinity of the North Slope oilfields at any time of the year. Of all the factors affecting the choice of response actions to deal with a marine spill originating from coastal facilities or pipeline river crossings, ice and weather conditions largely determine workable strategies and control the eventual outcome. Examples of important ice conditions include thickness, stability, bearing capacity and concentration.

Ice thickness dictates the available site access and load-bearing capacity for staging equipment and surface travel to and from the spill site. Depending on location and time of year, sea ice will support heavy equipment, such as trenchers, end-dumps, backhoes, ditch witches, and bladders for temporary storage and/or transport of liquid oil pumped from within the ice. Figure 4-2 illustrates the correlation between ice thickness and loading capacity.

During a typical winter, ice roads will be available or can be constructed to support oil spill recovery operations from late December to late April. By early May the ice surface is normally too deteriorated to maintain the ice road in a usable state. The ice sheet itself usually retains enough stability and thickness until early June to support heavy loads at the spill site itself; the problem during this period becomes one of access to and from shore. On-ice operations from early June to breakup will depend on day to day conditions and may require continuous helicopter or Air Cushion Vehicle (ACV) support to ensure the safety of work crews.

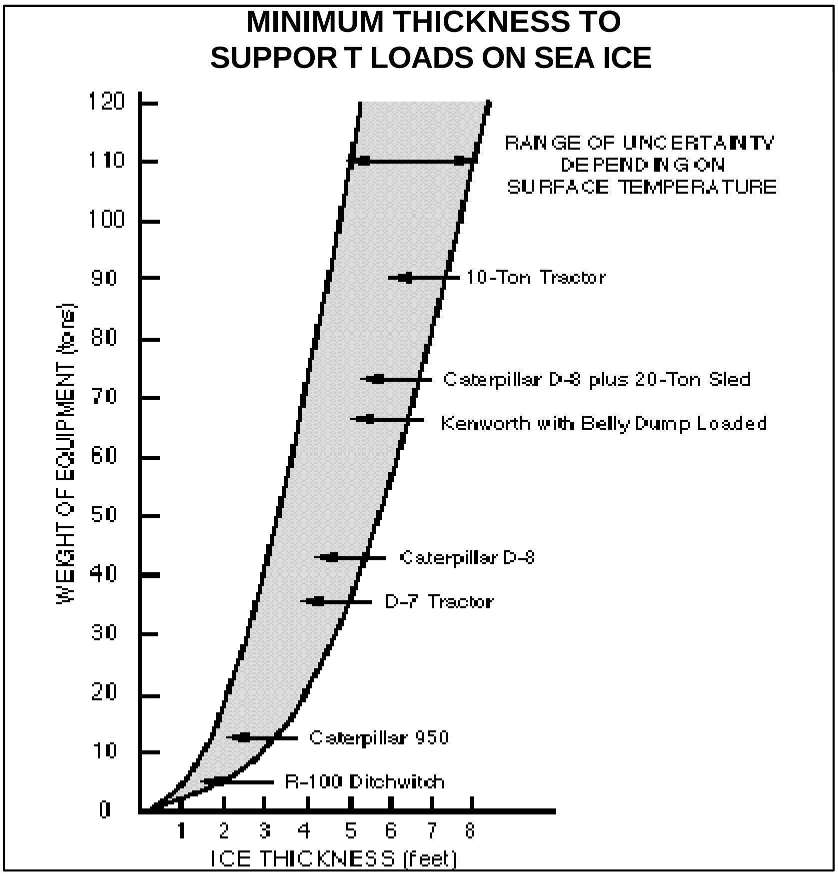

Figure 4-2
Load Bearing Capacities of Sea Ice (Source: ACS Techincal Manual)

Helicopters, ACV's and airboats can be used during the shoulder seasons of freezeup or breakup to transport limited payloads of personnel and equipment to an offshore spill site. ACS has a contract in place to utilize a high speed, turbine powered ACV currently located at West Dock in Prudhoe Bay. The unit has a cargo payload of 30 tons and can be operational within four (4) hours of crew arrival in Prudhoe Bay.

Bottom founded ice refers to the condition where a portion of the fast ice becomes thick enough to rest on the bottom in shallow water. This condition is commonly encountered between the shore and the barrier islands after mid-February. Winds have a great effect on water levels throughout the study area, even in the winter; westerly storms can create a one to two foot increase in water levels and lift the ice sheet off the bottom temporarily during mid-winter (Coastal Frontiers in Intec, 1996a). After March, much of the ice in Simpson Lagoon rests firmly on the seabed with an attached layer of frozen sediment at the ice/bottom interface. Figure 4-3 shows a typical transitional cross-section for arctic sea ice. It is important to note that in the nearshore area of Prudhoe Bay the bottom founded condition could extend for 2 - 5 miles offshore to contact the barrier islands. The implications of this "bottom-founded" condition are that crews may have to trench completely through the ice and recover oiled sediments encapsulated within or lying under the ice. The capability to perform this operation was demonstrated by BPXA during a trenching test in April 1996.

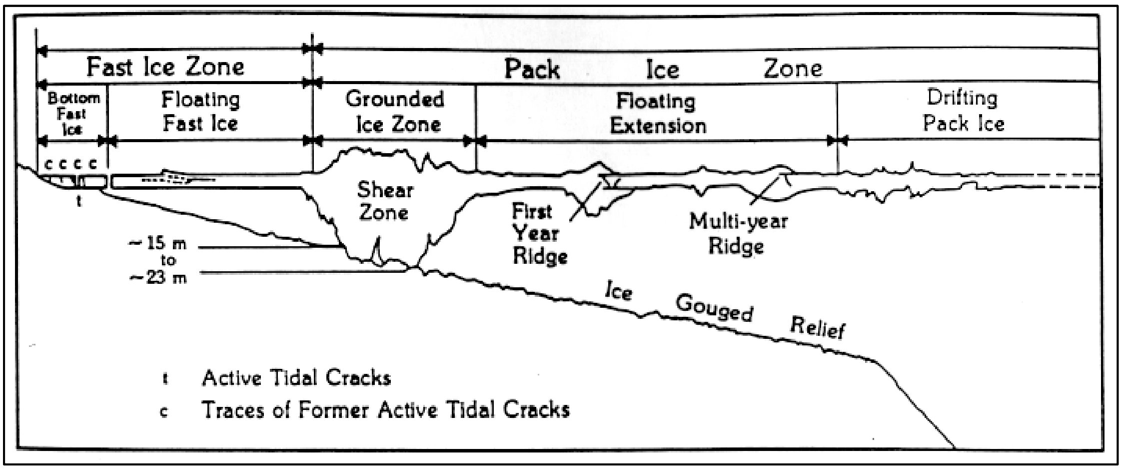

Figure 4-3
Typical Arctic Sea Ice Cross Section

Ice Stability is closely linked to thickness and refers to the potential for large ice movements in response to storm winds. Periods of most concern for oil spill response are freezeup from October through December, and breakup in June and July. During October and November, the ice is less than two feet thick and easily broken up by sustained storm winds predominantly from the east-northeast (Vaudrey - internal project memorandum, May 1996) . By late December, once the first-year ice has reached approximately three feet in thickness, ice becomes relatively stable and remains so until late June. There are exceptions, such as February 1989 when 90- to 100-knot southwesterly winds drove most of the landfast ice from inside the barrier islands 20 to 30 nautical miles offshore (Vaudrey , 1996).

Once the ice has deteriorated during spring melt, another short period of instability occurs during the transition from a continuous ice cover to predominantly open water. The ice normally melts in-situ in the shallow waters near the coastline by mid- to late June. Further offshore the fast ice becomes unstable and susceptible to wind-induced breakup in early July (Vaudrey, 1996).

During these "unstable" months, response operations may encounter the possibility of oil trapped in, or on top of the ice, moving 10 miles or more in a 24-hour period of sustained storm winds. The oil location can be tracked accurately on an almost real-time basis by deploying Global Positioning System (GPS) beacons reporting to satellites. During dynamic broken ice conditions following freezeup and preceding breakup, helicopter-supported burning operations with the Heli will likely be the most effective response strategy.

Ice concentration refers to the area of surface water covered by ice, and is described by an ice-to-water ratio expressed in tenths. Ice concentrations dictate not only the extent to which conventional open water oil recovery systems can be used in deeper water, but also the extent to which the natural containment offered by the ice will limit spreading and allow direct in-situ burning (S. L. Ross and D. F. Dickins, 1987). The period when the choice of cleanup strategy will be most affected by drifting ice stretches from approximately July 4 (±2 weeks), the average dates when breakup occurs in the vicinity of the barrier islands, to July 22 (±7 days), the average dates when ice concentrations fall to less than or equal to 3/10. The value of 3/10 is significant in that it represents a generally accepted upper limit for deploying conventional booms and skimmers without unacceptable interruption from drifting ice (S. L. Ross, 1983; Shell et al., 1983).

The period from first breakup in early July to approximately mid-July provides a two-week window when the ice cover is likely to remain in concentrations of 7/10 to 9/10, high enough to support natural burning with aerial ignition from helicopters. Ice concentrations between 3/10 and 6/10 represent the greatest problem for oil spill cleanup. Conventional booms may be collapsed, overrun, or damaged by drifting ice. At the same time there is insufficient ice to naturally contain the oil into sufficiently thick patches to burn in-situ without firebooms. Fortunately this troublesome range of concentrations is short lived; concentrations normally fall from 5/10 to 3/10 in less than one week during breakup (Vaudrey, 1996).

The period of ***ice overflood*** introduces a special set of circumstances in modifying the oil behavior and complicating cleanup efforts for a period of 10 days to two weeks. From late May to mid-June, a large proportion of coastal waters within the ACS area of operation is incorporated within the spring overflood from the Sagavanirktok, Putuligayuk, and Kuparuk Rivers (Vaudrey, 1996). Figure 4-4 represents the areas of spring overflood. Not only is surface access difficult at this time, but any oil surfacing through the ice is potentially free to spread on the surface waters. After a short period of five to 10 days, the overflood waters drain through natural holes in the ice (in some cases creating pits called ***strudel scours*** in the seabed). Some surface oil, if not contained or recovered, may be redistributed under the ice during the process of surface drainage. As the overflood drains, the sea ice lifts off the bottom and quickly melts to provide open water nearshore a month or more ahead of the offshore areas.

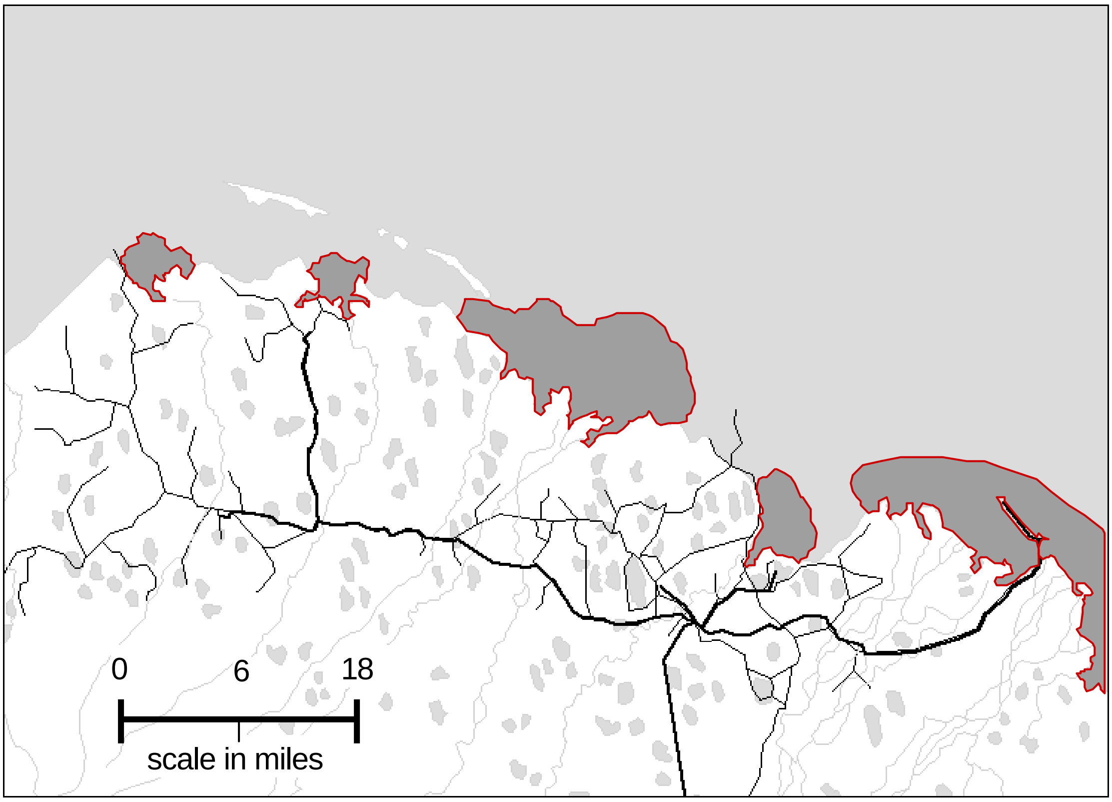

Figure 4-4
Areas of Spring Overflood Near North Slope Oilfields

4.3 In-situ Burning, A Response Option

Mechanical recovery is considered a primary means of response for both fresh crude and emulsified oil in calm to moderate seas with ice concentrations of less than 3/10. For spills over solid ice, response actions are very similar to terrestrial spills and therefore mechanical recovery is also considered the primary response option. The actual efficiencies of mechanical recovery are highly variable, depending on skimmer design, oil viscosity, pour point, and degree of emulsification. Environmental conditions also play an important role in determining efficiencies of mechanical recovery operations. In some cases, such as the periods of freezeup and breakup, the environmental conditions limit the use of mechanical containment and recovery. Recent developments and greater understanding of the residual effects of in-situ burning have increased the window of opportunity for in-situ burning and gained acceptance within the State of Alaska as a viable response option.

In-situ burning in open water, using fireproof booms, offers the potential of achieving almost complete oil removal from the water under a wide range of conditions (fresh to lightly-emulsified oil, seas less than three to five feet, and winds less than 20 knots). Burning is considered as a proven response technique that, depending on circumstances, would be used together with mechanical recovery to substantially increase the overall oil removal rate. Comprehensive guidelines are available to establish procedures for requesting, evaluating, and authorizing the use of in-situ burning during an actual response (Alaska Regional Response Team, May 1994).

In-situ burn efficiencies in the range of 95 to 98 percent have been demonstrated in a wide variety of tests and field trials in Alaska, Alabama, Norway, and the Canadian East Coast, and have involved test basins, experimental crude oil spills in ice, and open ocean trials with actual oil (summarized in Buist et al., 1994). High removal rates of 60 to 80 percent have also been achieved in more extreme conditions with up to 50 percent oil/water emulsions, stronger winds and oil on slush ice in leads. A fire boom was used successfully during the *Exxon Valdez* response to remove an estimated 360 barrels of crude in 75 minutes (Allen, 1991). Two successful burns were recently carried out in the United Kingdom using harbor fire boom under adverse conditions of five-foot seas and 15-knot winds (Allen pers. comm. June 1996).

Extensive scientific measurements of large scale burns at sea by U.S. and Canadian scientists in 1993 have conclusively demonstrated that with appropriate guidelines and safe distances, in-situ burning poses no significant human health or other environmental risk, either from smoke inhalation, or toxic compounds associated with the smoke (Fingas et al., 1995). There are three emissions of possible concern to regulatory agencies and local residents:

- ***Respirable particulates in the smoke.*** Measurements have found that the ground level concentrations fall below human health limits within a thousand feet downwind of the burn. Concentrations in the plume fall below ambient air quality standards within several miles (Buist, per. comm. September 1996)
- ***Volatile organic compounds.*** Levels have been found above normal background as far as 1,500 feet from the fire, but even those slightly elevated levels were still lower when burning than when the oil slick was left on the water.
- ***Polycyclic aromatic hydrocarbons (PAH).*** Extensive monitoring of large scale oil burns has shown that in-situ burning actually removes PAHs and that the soot contains PAHs at lower levels than the original oil. Results from water analyses similarly showed that in-situ burning did not adversely affect the underlying water column beyond those effects already associated with the unburned oil slick in the Newfoundland trials (Daykin et al., 1994).

In addition to removing almost all oil present from the water surface, burning eliminates the need for storage and disposal. The taffy-like residue survives in small volumes (typically one to ten percent of the original oil volume). The residue can be manually recovered from the ice surface and deposited in open top barrels or portable tanks with shovels and pitchforks (Norcor, 1975; Dickins and Buist, 1981). Concerns have been expressed about residues sinking after the burn, and this subject is being studied. It is not likely that residues from naturally contained slicks, such as in melt pools or win-herded against ice edges, will sink (Buist et. al., 1995: Trudel et. al., 1996). A comprehensive summary and evaluation of the state of knowledge surrounding the burning of oil spills at sea is provided by Buist et al. (1994).

The Alaska North Slope Operators currently maintain in excess of 14,000 feet of fire boom, and six Heli-torches (Figure 4-5) for airborne ignition of oil either within a boom, trapped in broken ice, or lying in melt pools on the ice surface.

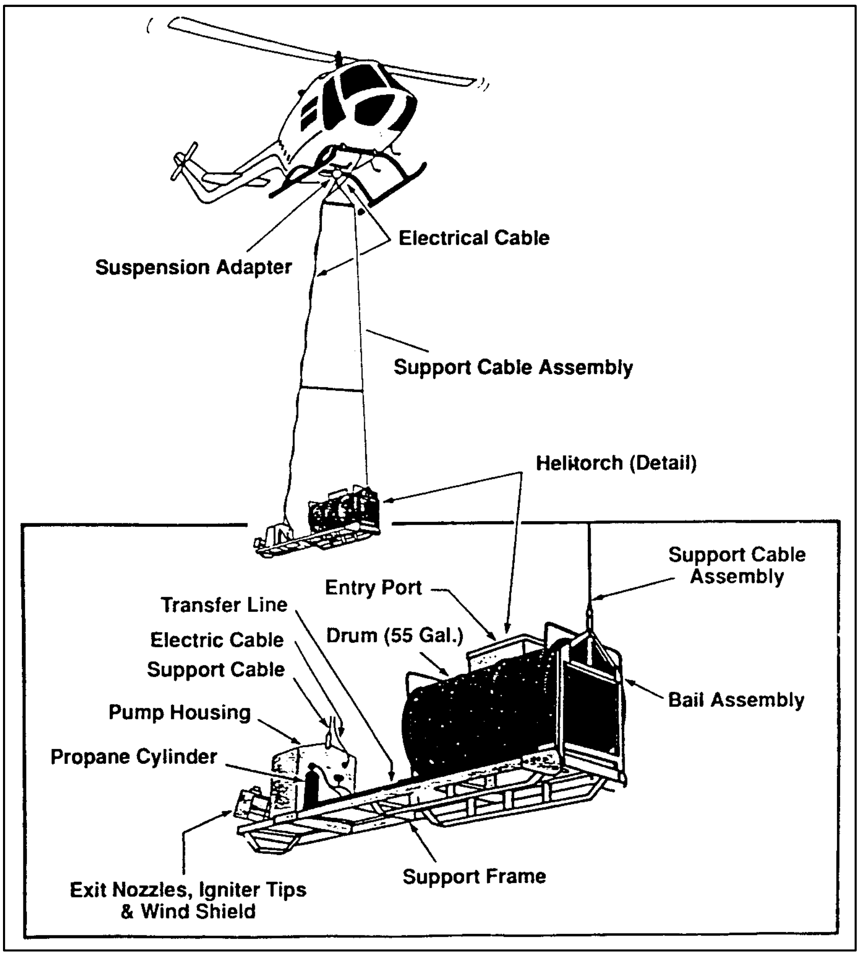

Figure 4-5
Heli-torch Ignition System

In summary, he expected removal effectiveness for an offshore open water or broken ice response is highly variable and depends on a large number of factors including timing, weather and sea conditions, degree of emulsification, and slick conditions. Very few historical response operations have achieved better than five to 15 percent using mechanical systems (excluding natural processes). Increased levels of preparedness and equipment resources can improve on these numbers.

Using a combination of mechanical recovery and burning downwind of a surface blowout, Gulf Canada (1990) calculated removal rates of up to 80 percent of the oil present under ideal conditions. When environmental factors (visibility, waves, ice, and response times) were included in the final analysis, the expected effectiveness fell to between 30 and 40 percent. Given the high level of readiness on the North Slope, it is possible that crews can achieve equivalent or even better, especially with the growing acceptance of in-situ burning as a response option.

4.4 Seasonal Response Techniques

The following sections describe strategies and techniques for dealing with oil spilled in different combinations of ice and open water, drawing on experience with past spills (both accidental and experimental) and knowledge of the expected fate and behavior of oil in ice.

4.4.1 Fall and Early Winter Response (October to December)

There are limited mechanical options for recovering large volumes of oil spilled under or among new and young ice in the fall months of October and November. A "Foxtail" rope mop style skimmer can be deployed by crane over the side of a response barge or vessel to recover localized oil patches trapped in water and slush between floes. This is one of the few skimmers able to recover oil from leads and openings in heavy ice conditions (Counterspil, 1992). Additionally there are 37 portable rope mop skimming systems within the North Slope response equipment inventories could be placed into service as required. In areas of heavy oil concentration near the coastline or in available open water leads other portable skimming systems could be utilized. These would include vacuum, drum and disc type skimmers. It is possible to utilize weir type skimmers under building ice conditions as long as the skimmers are equipped with mechanical systems to handle debris and ice. Any skimming operations will likely be curtailed by thicker, more concentrated ice within one to two weeks of initial freezeup.

In the beginning of the ice growing season many of the spill response vessels would remain operational. The jet powered vessels will become inoperative as the brash ice and slush thickens and begins to interfere with the exposed mechanical parts of the jet systems. Outboard powered vessels will also be taken out of service when the thickness of the forming ice begins to clog the water intake ports on the lower units. Screw driven vessels along with the tug and barge systems will have the longest sustainable operational period.

The most effective sustainable strategy during freezeup conditions will likely utilize in-situ burning, with the ice providing natural containment and Heli-torches providing a remote ignition source. A number of tests have shown the feasibility of burning oil trapped in leads with and without the presence of brash ice and slush (Brown and Goodman, 1987; SL Ross and D. F. Dickins, 1987). Depending on conditions, removal efficiencies over 90 percent are readily achievable. Weathering the oil up to 20 percent had no significant effect on the results. As the ice growth continues, oil spreading and conveyance processes will decelerate and eventually cease. Ultimately the oil will be incorporated into the new ice formation.

The oiled ice may move short distances (thousands of feet) in October before becoming landfast. Oil, during this time, is effectively trapped within the ice and contained from spreading until response teams can gain access. During the early stages of freezeup, the fringe of new landfast ice protects the shoreline from oiling.

Satellite tracking beacons will be deployed at the spill source to monitor the drift of any oiled ice away from the spill site. If this ice subsequently becomes incorporated as part of the landfast zone some distance from the original spill location, conventional winter response procedures can be followed by using helicopters, ATV's, and ACV's to ferry personnel and equipment to the site. Due to the temperatures, remote locations and darkness involved in these type of operations, personnel safety considerations will require additional attention. Resources such as personnel shelters, portable lighting, portable heaters and restroom facilities will be required along with the initial response resources.

The contaminated area will be located through visual observation of surface oiling and boring holes in the ice on a grid pattern to locate sub-surface accumulations of oil. Using underwater lighting the extent of contamination will be marked and recorded. It may become necessary to auger additional holes, in a radial pattern, from a known contaminated location to complete the delineation process. Handheld GPS units will be used to record the exact locations of both surface and sub-surface pools.

Recovery operations on early season, but landfast, ice are very similar to remote terrestrial spill response actions once the oil is brought to the surface. Teams would be set up to trench, slot and bore into sub-surface oil pools to gain access to the oil. Surface oil would be bladed into bermed recovery trenches. Skimmers will recover oil into portable tanks or into small, 500 gallon, airliftable bladders for helicopter transport to shore. Ice blocks cut from the landfast sheet could also be used to build containment reservoirs until surface transportation becomes feasible. Figure 4-6 represents a typical recovery operation on solid ice. Logistics constraints may demand that in-situ burning be utilized as the primary recovery option. If there were concerns over the ability to muster adequate resources to the site or if recovered product could not be transported back to shore within acceptable timeframes, burning operations would be the most effective option. In all recovery operations, mechanical or in-situ burning, the site would be thoroughly cleaned during the demobilization operations.

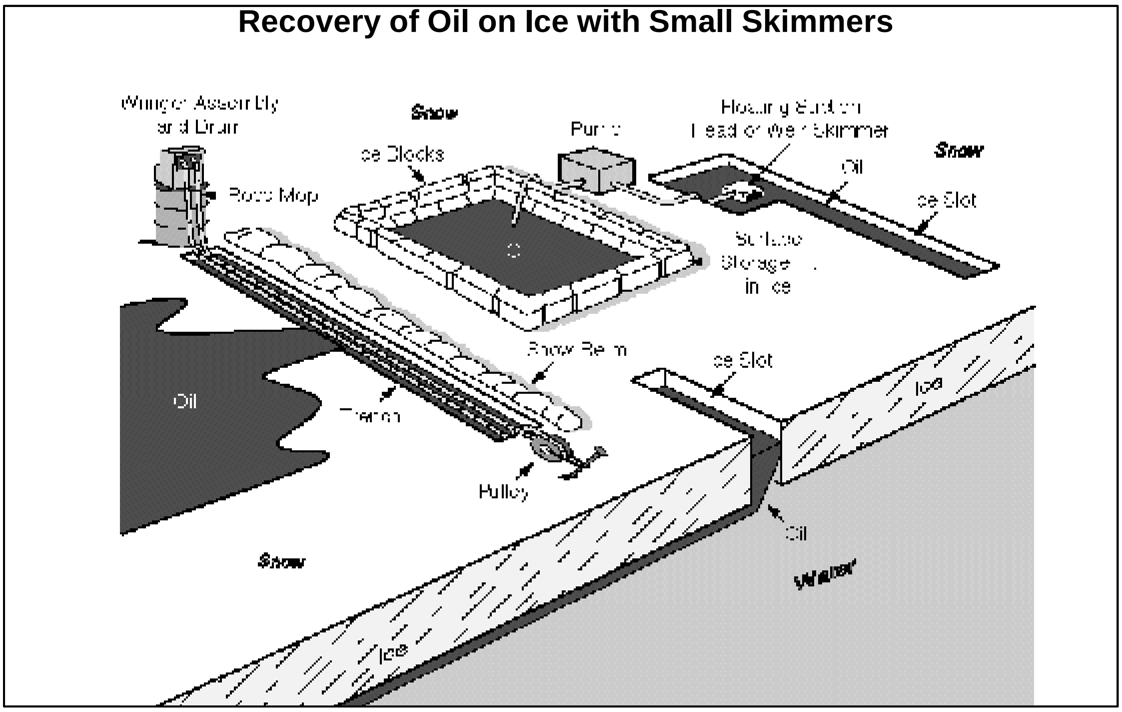

Figure 4-6
Typical Solid Ice Recovery Operations

4.4.2 Mid-winter Response (January to April)

Current technology is considered capable of successfully cleaning up oil spilled onto solid ice. Although more difficulties are expected in terms of initial detection, a similar successful outcome is expected for oil spilled under the ice from offshore winter exploration projects (MMS, 1996).

By late December, the landfast ice is normally stable along the entire length of the pipeline out to the barrier islands (Vaudrey, 1996). From this time until late May, cleanup operations dealing with spills originating from either offshore exploration or a shoreline production facility can utilize the ice cover as an secure operating platform for support equipment, including trucks, bladders and portable trenching equipment. Depending on location, this period of on-ice operation can be extended in some years. For example, the ice cover in the near shore areas can often support lightweight vehicles by November, and in many years the ice near the barrier islands (although deteriorated) can still support substantial loads and work crews into late June. While stable winter ice allows for greater access winter arctic conditions may control feasibility of cleanup operations. Extreme low temperatures present a hazard to operating heavy equipment and other hydraulic systems. In order to maintain personnel safety and reduce the risk of further contamination through hydraulic failure the North Slope operators have set a temperature limit of -45°F for all heavy equipment operations.

In the case of a known reservoir of oil trapped within the ice sheet in mid-winter, direct pumping and ice road haul operations will result in almost complete removal of the spilled oil. Larger equipment would be utilized to gain access to sub-surface pools. In order to eliminate the volume of contaminated ice the upper layer of ice can be removed prior to exposing the oil pool. Ice roads and pads can be built to allow heavy equipment and vacuum trucks direct access to the oil pools. These trucks would recover oil directly into attached 300 barrel insulated tankers for transportation to waste disposal facilities. During extremely cold periods it may be necessary to use steam wands on the oil pools to facilitate recovery. Additionally, it may become necessary to load 200 to 300 gallons of hot water into the vacuum tanks from shoreside facilities to maintain internal tank temperatures during recovery and transport periods.

The logistics are also quite feasible, even without the benefit of an ice road. For example, four Rollagons hauling bladders for 20 hours per day could transport 20,000 barrels in 15 days from a site 10 miles from shore. This sample calculation assumes a five mph average vehicle speed and a one-hour turnaround. Larger trucks operating on an improved ice road or high speed ACV's could achieve over five times as much productivity through greater speeds and loads. Even greater volumes could be dealt with by adding more equipment over a longer period, or by burning at the site. Final cleanup in June will use selective burning of oil on melt pools followed by manual recovery of any residue. It is estimated that the remaining oil available to enter the marine environment (after all mechanical recovery and evaporation) be less than 10 percent of the original spill volume.

The choice and application of the two primary winter waste handling options of burning in-situ or removal to shore (Figure 4-7) depend on both time of year and water depth. Once an encapsulated oil layer is delineated drilling or trenching would be conducted to expose the oil layer for recovery. Snow melters can be placed on site or at shoreside positions to melt contaminated snow and ice. Recovered oil can then be trucked to designated disposal wells for reinjection or to a designated production facility for reprocessing. Burning on-site could become the preferred option late in winter when there may be insufficient time to transport the recovered oil to shore prior to breakup.

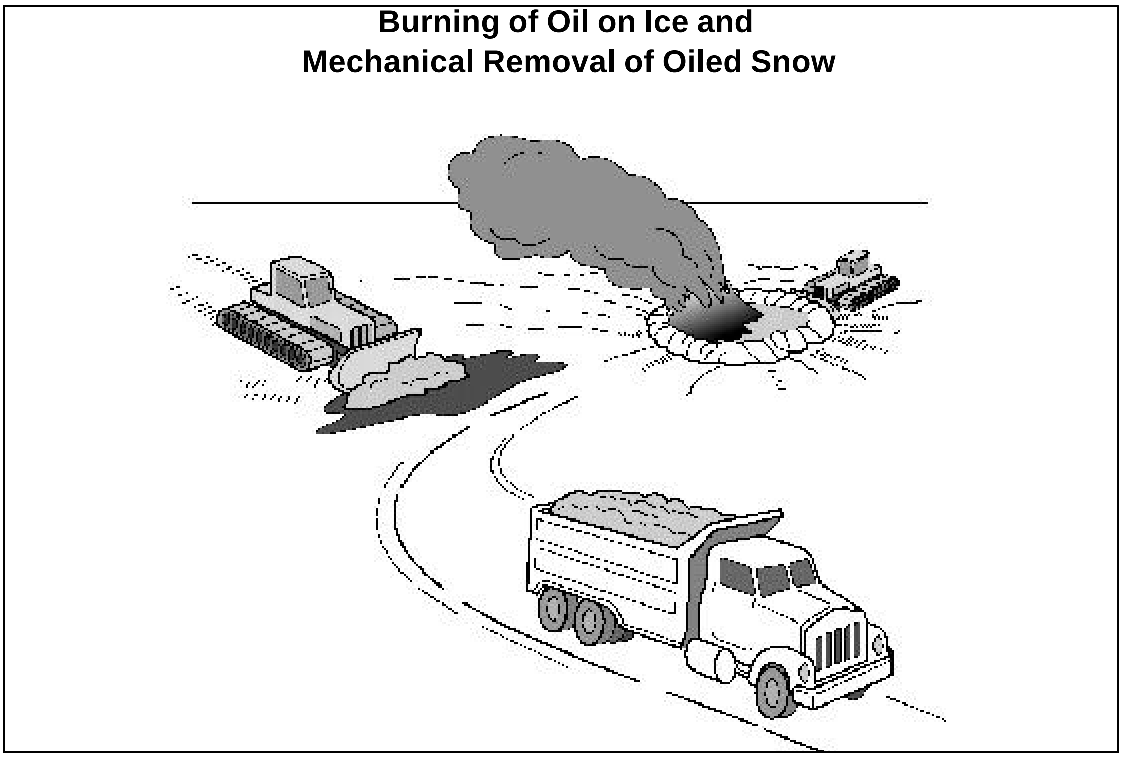

Figure 4-7
Winter Oilspill Waste Handling Operations

In the case of bottom founded ice encapsulating an oil pool, responders could trench and remove all of the ice blocks and cuttings in very shallow water (zero to four feet). After March it may be possible to operate within a dry trench in many areas. There may still be a thin layer of frozen soil at the ice/seabed interface. It may be necessary to penetrate this icy soil layer to release any oil accumulated within the sediment. Recovered oiled seabed or trench material can be trucked to shore for interim storage and final disposal.

A mid-winter blowout or pipeline rupture from either a coastline production facility or an offshore winter exploration project could produce significant areas of surface contamination. Given the predicted oil plume height and droplet size, the oil concentration on much of the surface area may be insufficient for successful burning. Exceptions would be: (1) where surface procedures did not achieve well control and the flow continued for more than a number of days; and (2) within a few thousand feet of the island where up to 4 mm of oil could accumulate over 10 days during periods of light winds. In order to limit the spreading of thicker oil accumulations close to the well site, a snow berm will need to be constructed as close as safely possible (Figure 4-8), with the priority being the east-northeast and west-southwest quadrants (matching the predominant winds).

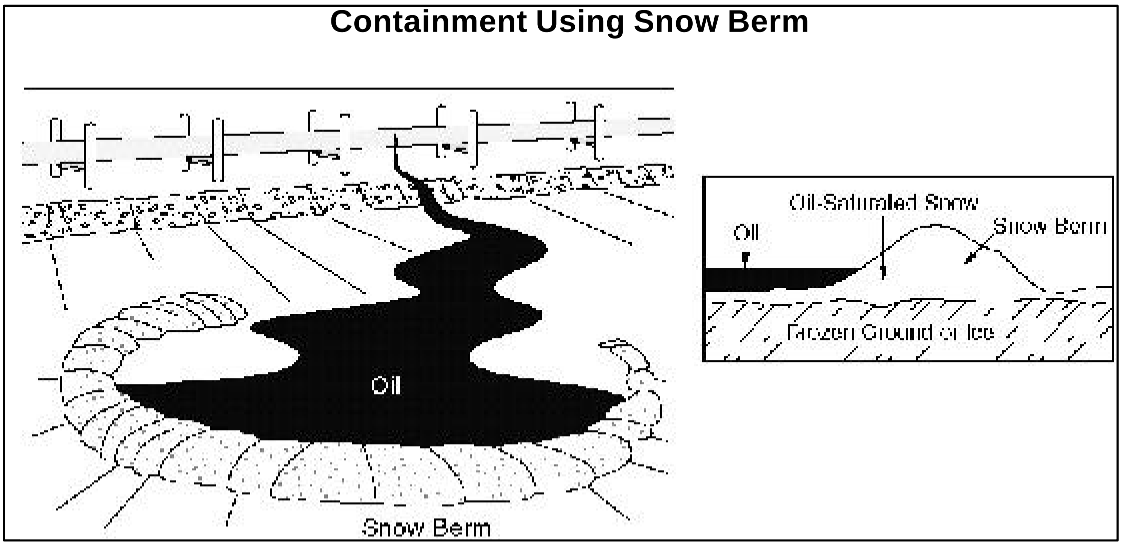

Figure 4-8
Snow Berm Construction for Winter Oilspill Containment

Plowing surface materials and removing the uppermost ice layer (2 - 4 inches) in the areas of gross contamination would be conducted utilizing heavy equipment. In areas of lighter contamination hand recovery operations would be conducted to reduce the total volume of solids recovered. Previous winter responses on the North Slope have proven this method to be very effective in recovering all visible traces of crude oil.

As long as the ice remains stable and strong enough to support heavy equipment, the cleanup operation becomes an exercise in materials handling. In order to recover the oil, it is necessary to plow and recover the contaminated snow from the ice surface. If the oil is not too weathered, it can be recovered for reprocessing at onshore facilities. Otherwise, contaminated snow and ice can be melted and reinjected through approved disposal wells.

In rougher ice ridging and rubble, oil cleanup is still feasible, although more labor intensive. Experiences in Canada with flare burner malfunctions offshore have resulted in minor spills in rough ice close to the drilling structure. In those cases, a combination of local melting with torches and manual chipping and removal of the oiled ice was used to achieve a high percentage of overall recovery.

6.4.3 Spring Response (May to June)

The period between the first onset of surface snow melt and final deterioration of the landfast ice provides the best opportunity for in-situ burning of oil that naturally appears on the surface, or remains on the surface following a winter cleanup operation. However, this period also marks the end of easy site access with any heavy equipment.

In-situ burning is an efficient and effective method of removing oil from a solid ice cover in late May and June, after ice roads have been closed to traffic. Tests have demonstrated that the oil on the surface of the ice can be successfully ignited and burned even after weathering for several weeks. Wind herding of the oil in small pools enables much thinner oil films to be burned than would otherwise be possible (Dickins and Buist, 1981). Fresh crude must be approximately 0.04 inches thick for ignition to take place, and weathered crudes in the range of 0.1 to 0.2 inches are readily ignitable. Weathering of the oil is not as critical as once thought. Ongoing work by SINTEF in Norway has demonstrated that it is possible to effectively burn fresh crudes with up to 40 percent emulsification (water in oil), albeit at a reduced efficiency (Guenette and Sveum, 1995). ACS has conducted similar studies in the last few years concentrating on emulsions made of Alaskan risk oils and seawater. During these studies bench testing was conducted utilizing various emulsion breakers and gelled fuel mixtures to enhance ignition of emulsions. Promising techniques from the laboratory were then re-evaluated during both small scale and meso-scale testing, producing similar results to the SINTEF studies (Buist et. al., 1994)

Work in Alaska and elsewhere has proven that the Heli-torch is a highly effective tool in igniting multiple oil pools over large areas (Allen, 1987). Slung beneath a helicopter, the Heli-torch is safe and efficient. Approved hand-held igniters can still be used by helicopter-transported field crews to ignite isolated pools of oil. Burning efficiencies of approximately 97 percent have been achieved in numerous large scale and meso-scale experiments.

In practical applications, values tend to be lower because a proportion of the oil is contained in pools too small and numerous to burn (refer to pool sizes shown in Table 5-1), and not all of the oil is available in sufficiently thick films. As a general rule it is considered practical to burn 80 percent of all oil present in pools greater than 50 square feet, amounting to 68 percent of the total oil exposed on the surface (Norcor, 1975; Buist and Dickins, 1981, Gulf Canada, 1990). Manual recovery of any burn residue or thin unburned oil films on the ice may increase the overall recovery effectiveness by up to 10 percent. In addition, natural evaporation will remove an additional 30 percent of any oil lying on surface melt pools prior to burning. Realistic estimates for the amount of residual oil remaining after all cleanup and natural processes up to the point of final ice breakup range from 10 to 20 percent. With appropriate safety precautions and a helicopter or amphibious vehicle in attendance, surface operations on the ice can continue until within a few days of breakup.

The small amount of residue left after burning (typically a few percent of the oil available for burning) can be recovered manually with crews on the ice and transported to shore with helicopter buckets.

As the ice begins to break up in mid-June nearshore, and in early July near the barrier islands, the response options will depend on the ice concentration as discussed earlier. There will be a period of several weeks when response operations will need to apply a mix of strategies over short periods as conditions allow: booms and skimmers operated from shallow draft barges in light to moderate ice, in-situ burning of thick oil trapped between the floes in heavier ice, and manual cleanup and pumping from any ice rubble remaining attached to the island, as well as cleanup of any shoreline or gravel pad surfaces that may have been affected.

As ice concentrations diminish to less than 3/10 by mid-July offshore and by mid-June in the nearshore areas, response operations will become increasingly less restricted by ice more able to rely on traditional open water mechanical containment and recovery techniques (Figure 4-9).

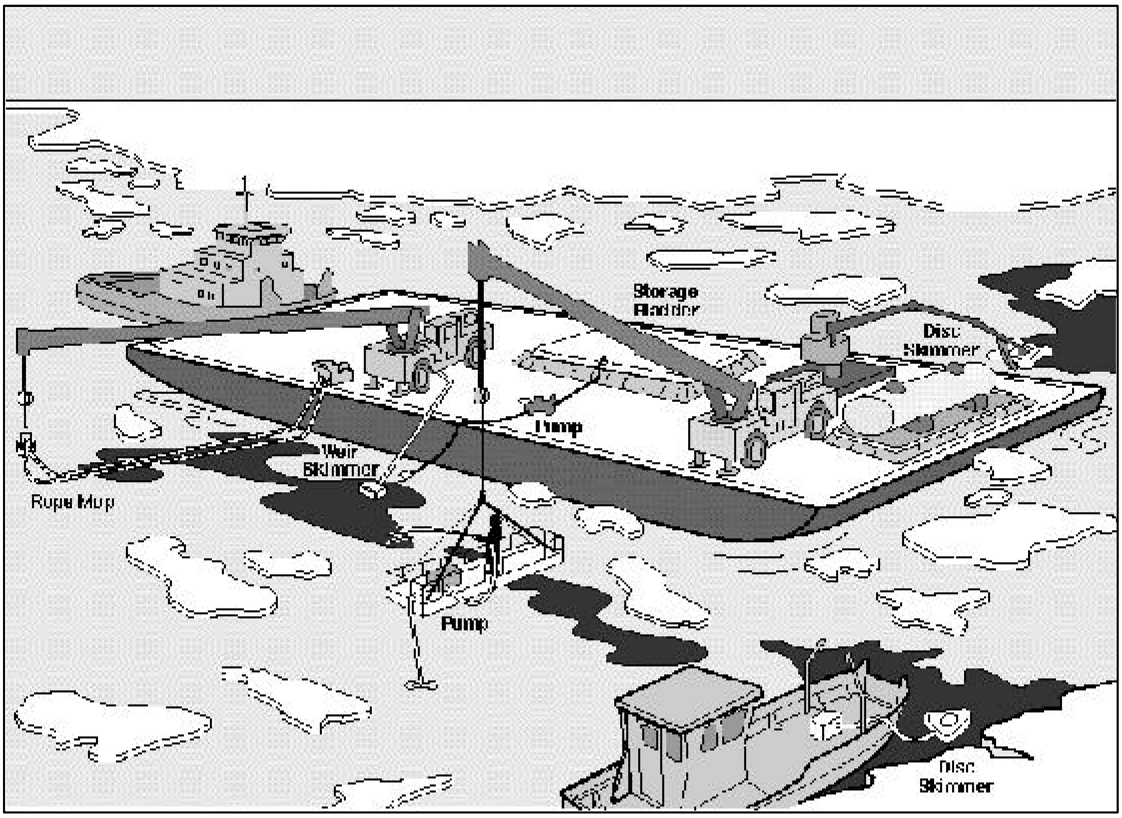

Figure 4-9
Broken Ice Mechanical Containment and Recovery Operations

5.0 SYNOPSIS: OIL AND ICE SPILL RESPONSE IN THE BEAUFORT SEA

In summary, the knowledge gained through actual spills, drills, experimental field spills, tank tests, and analytical studies has led to the evolution of a number of practical response strategies and options to deal with a wide range of nearshore and offshore conditions expected in the Beaufort Sea adjacent to the North Slope oilfields. Today's arctic spill contingency plans focus on multiple countermeasure options to cope with different spill situations. In-situ burning in ice and with fireresistant booms in open water are proven techniques, as is mechanical recovery with the latest generation of containment and recovery equipment.

Each season presents different drawbacks and advantages for spill response. During freezeup and breakup, drifting ice and limited site access tend to restrict the possible response options and significantly reduce recovery effectiveness. Mid-winter involves long periods of darkness and cold temperatures but provides a stable ice cover that not only naturally contains the oil within a relatively small area but also provides a safe working platform for oil recovery and transport. The summer open water period provides the advantage of familiar response techniques but introduces the variability of wind and waves and the challenge of containing an extremely mobile target.

For seven to eight months of the year, ice aids oil spill response in the Beaufort Sea. Solid ice naturally contains and immobilizes oil for an extended period of time in the winter (up to 230 days corresponding to the period of stable ice cover nearshore). The presence of solid landfast ice allows response teams to mobilize the necessary resources and plan a coordinated winter response effort with a high probability of recovering a large percentage of the spilled oil. At the same time, the environmental conditions present during the summer months are also much more favorable to offshore cleanup when compared with many southern areas. For example, broken ice during breakup tends to limit oil spreading and maintain the oil in thick patches amenable to burning in-situ with a Heli-torch. The generally low to moderate sea states during the open water period increases the effectiveness of booms and mechanical recovery systems.

Response planning supported by detailed sensitivity assessments, coastal classifications, computer tracking models, and regular training for the response team members provides the foundation for an organized and timely response at any time of the year. This foundation is augmented through continuous development of working relationships with other spill response organizations and response contractors within the State of Alaska. Further improvements are achievable as the North Slope Operating Companies continue to support and participate in ongoing research and development of new or enhanced response methodologies, systems and equipment dedicated to mitigating the effects of oilspills in the arctic environment.

Recently, a great deal has been learned about Arctic offshore oil spill response through practical experience and research. In many respects, the Arctic offshore is a more favorable environment to carry out an effective oil spill cleanup than many ice-free waters. This is not to say that spill cleanup in an Arctic environment will ever be a simple operation, or that the impacts of spills in ice covered waters can be dismissed. There are, however, many aspects of the natural ice environment that, if properly understood, can be made to work in favor of a successful offshore cleanup.

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